International Research Journal of Architecture and Planning IRJAP
Vol. 5(1), pp. 102-110, January, 2020. © www.premierpublishers.org. ISSN: 1530-9931

Research Article

Use of Bamboo for Sustainable Housing Construction in Developing Countries

ATAMEWAN, Eugene Ehimatie
Department of Architecture, Cross River University of Technology, PMB, 1123, Calabar, Cross River State, Nigeria
E-mail: atamewaneugene@gmail.com; **Tel:** +234-8036602248

The study examined the use of bamboo as a sustainable building material combined with other material like mud to produce houses. Methodology of study was descriptive and qualitative which included review of literature on bamboo, participatory observation and in-depth interviews with local artisans and building owners. Structured questionnaires were administered to 50 respondents while purposive sampling method was used to select the respondents across the study area. Data collected was analyzed using SPSS version 22 statistical tool to obtain percentages, rankings and relative significance index (RSI). Findings reveal that most of the low-income group are able to build their houses through the use of bamboo at a reduced cost, while others not in support of the use of bamboos are yet to have their houses. Also, the use of modern method of building houses completely with bamboo and its by-products is missing due to lack of technological know-how. The study recommends advocacy enlightenment, training of professionals and artisans on the modern use of bamboo in all aspects of building; change of orientation/perception on the use of locally available materials for building construction.

Key words: Building material, bamboo, housing, sustainable, earth construction

INTRODUCTION

The use of bamboo for construction of houses is not new but dates back to centuries and served as one of the dominant building materials for the construction of traditional houses in the past. The recent fight against global warming arising from the depletion of the ozone layer has placed restrictions on timber felling around the world, hence the recent search for alternative to timber as a building material. Bamboo, a more versatile, economical and readily available material is now the world's alternative construction material to timber (Kumar *et al.*, 2017).

The use of bamboo as a building material has undergone some industrial revolution and modernization in recent times thereby increasing its applicability not just in building construction alone but in other areas such as light bulb manufacturing, toys, medicine, aircraft making and others. Thus, bamboo products can be grouped into several uses such as construction, structural, industrial, cottage, food products, and handicraft industry (Bohra, *et al.*, 2008).

Sustainable Housing provisions will require sustainable building materials like bamboo which is vastly available, fast growing, economical and renewable. Bamboo have been discovered to be environment friendly with its ability to act as carbon sequesters, restoring degraded land, and protection from soil erosion thereby mitigating the effect of climate change (Raj and Agarwal, 2014).

There are about 1200- 1575 species of bamboo which each particular species has different properties and qualities. Some of the popular bamboo species are Dendrocalamus Strictus (D. Strictus), D.Membranaceous, the Bambusa family species such as B. Balcooa, B. Nutans, B. Polymorpha, B. Vulgaris and others (Suprapti, 2010; Schmidt *et al.*, 2011). Bamboo is a versatile biological raw material that is easily workable and it is often economical especially in the tropics where it is in abundance. Its natural durability is however not to be compared with that of materials such as concrete or metal. However, all micro-organisms use bamboo and it content as their source of energy (food), thus resulting in bamboos being vulnerable to micro-organisms (e.g. decay fungi and boring insects like termite (Chavan and Altar, 2013; Nguyen, 2002).

Bamboo consists of 50-70% hemicelluloses, 30% pentosans and 20-25% lignin. The lignin present in bamboo is known to be rich in silica (0.5-4%) but the entire silica is located in the outer layer (1mm). Bamboo also have minor amount of waxes, resins and tannins but none of these have enough toxicity to improve durability (Wahab *et al.*, 2013). According to Chavan and Altar (2013), carbohydrate content of bamboo plays an important role in its durability and service life. This means that the variation in bamboo durability strongly depends on the length of the culms, thickness of the wall, time of harvesting and the bamboo species (Dhawan and Mishra, 2005). On the average, natural bamboo has a lifespan of only 2-5yrs. For instance, under natural conditions; Bambusa polymorpha has the highest durability of 84 months, while *D.* Membranaceous has a durability of 21 months respectively (Wei *et al.*, 2013; Schmidt *et al.*, 2011).

In most developing parts of the world, the use of bamboo for traditional housing construction was limited to walling and roofing elements. However, advancement in technology created improvements in preservation, protection and jointing properties of bamboo resulting in the diversified use of bamboo, thus, bamboo is now used in flooring, roofing, windows and doors in addition to walling (Jambal and Gambhir, 2011).

This study focussed on the use of bamboo mainly as a construction material in combination with other available materials for the construction of low-income housing in the study area which have helped in provision of affordable housing, thereby reducing homelessness in this part of the world and solving housing problems globally.

MATERIALS AND METHODS

Methodology of study was descriptive and qualitative which includes review of literature on the use, properties and preservation of bamboo, participatory observation and interviews with local artisans and building owners. In addition, structured questionnaires were administered to 50 respondents while purposive sampling method was used to select the respondents across the study area. Data collected was analyzed using SPSS version 22 statistical tools to obtain percentages, rankings and relative significance index (RSI) with results shown in Tables and pie charts. Also, pictures of stages of construction using bamboos were taken to enhance the output of the study.

LITERATURE REVIEW

The reviewed literature centred on the characteristics of bamboo as a building material, its advantages, preservation and uses in construction in general. Several authors (Raj and Agarwal, 2014; Baksy 2013; Chaowana 2013; Virdi and Rashkoff 2014; Kaur *et al.*, 2016; Kumar *et al.*, 2017; Bui *et al.*, 2017; Sulaeman *et al.*, 2018) have dealt extensively on the subject of bamboo in these areas and their findings are presented as follow:

Raj and Agarwal (2014) researched on 'Bamboo as a Building Material' stating that bamboo is a versatile material used for many purposes with both economic and cultural importance. The study discussed the reasons for using bamboo and how bamboo is used as a building material, the construction details, the properties as well as the disadvantages. The methodology employed by the authors was descriptive and review of literature. The paper concluded that the use of bamboo should be promoted with special interest in the preservation and processing for effective and durable use. This is due to its high valued use which in addition to promoting the economic development, also serves as forest resources to protect our ecological environment.

Similarly, Bui *et al.* (2017) did a study on 'A Bamboo Treatment Procedure: Effects on the Durability and Mechanical Performance'. The purpose of the study was to explore effect of oil treatment on the mechanical properties and durability of bamboo, thus different conditions of treatment were carried out at temperature of 100 _C or 180 _C; using sunflower oil and flax oil and also without oil at different duration period ranging from 1 to 3 hours respectively. Also, different cooling methods and durations ere used. The study was experimental in nature, with emphasis on mechanical and durability tests including other test such as humidity tests, 3-points bending tests, uni-axial compression tests and water immersion tests carried out on both treated and untreated bamboo culms to get the effects. The results of the experiment proved that some tested treatment methods increased and enhanced the durability and the compressive strengths of treated bamboo specimens, when compared with untreated bamboo species. The paper concluded that the best compressive strength was attained from the bamboo culms treated without toil nothing that oil was used only for cooling, while bamboo specimens treated at 180 _C had the best resistance to fungi and to water absorption.

In another study carried out by Sulaeman, *et al.* (2018) titled 'Quality Enhancement of Bamboo Utilization: Preservation, Modification and Application', the authors reviewed the preservation and modification techniques of bamboo for better efficiency and durability. The paper is a review paper which summarises the importance of preservation and modification process, its principles and the challenges in quality and durability enhancement of bamboo product. The study included bamboo application with particular reference to modern technology and discussed its further advancement. The authors noted that recent technological development has revealed that bamboo has several advantages in both interior and exterior usage in areas of furniture, packaging, transport, bio-composite and buildings. The paper concluded that

since bamboos have low durability, protection against biotic and abiotic degradation, it therefore required preservation and modification treatment.

The study by Kaur *et al.* (2016a) on 'Eco-friendly preservation of bamboo species: Traditional to Modern Techniques is fascinating. The focus of the study was on eco-friendly preservation of bamboo involving both traditional and modern techniques. The study also discussed the developments in the field of environment-friendly. It emphasized that biomass species like bamboo are always under serious attacks by fungi and termites under storage and service conditions. This has necessitated the protection treatment of bamboo but with high amount of chemical which are toxic and harmful to both humans and the environment. The authors opined that traditional methods involving water leaching technique and smoke treatment were very much effective as chemical-based preservatives when tested under laboratory conditions. The study concluded that various plant extracts and oil-based preservatives such as oil, organic acids, essential oil and eco-friendly chemical-based preservatives were also in use but that their effectiveness needed to be further tested and investigated for approval.

Advantages of Bamboo in Housing Construction:
According to Raj and Agarwal (2014), bamboo has the following advantages in building construction

i. Bamboo is renewable natural building material
ii. It can be useful to build in areas prone to earthquakes.
iii. It is very cheap and affordable
iv. Readily available and accessible to the people.
v. It is Light, strong and versatile.
vi. It is eco-friendly and sustainable.
vii. It is highly productive and grows rapidly

Properties of Bamboo

Due to its versatility and properties, bamboo is regarded as a viable building material alternative for steel, concrete and masonry. The properties which make bamboo very unique are as follows;

a. Tensile Strength

According to Baksy (2013), bamboo possess a high tensile strength of about 400 N/mm2 which is higher than those of steel (350 N/mm2) and wood (50 N/mm2) respectively. The high tensile strength is due to the bamboo fibres with elastic vascular bundle that runs axially especially with slimmer bamboo tubes. This characteristic to a large extent makes bamboo very useful in building construction.

b. Rigidity and Durability

Bamboo fibre is very rigid and durable compared to wood because the fibres are longer and therefore has some greater advantage in both physical and mechanical properties. In addition, bamboo is lighter in weight, straight, smooth; with hollowness advantage makes for its easy splitting are properties that make bamboo versatile for use in construction activities.

c. Strength and Flexibility

The strength and flexibility of bamboo as a property couple with the strength-weight ratio advantage gives bamboo its resilience against high velocity wind forces thereby making bamboo a suitable material for building construction that can withstand earthquakes and hurricanes (Bureau of Indian standards [BIS], 2005).

d. Environmental protection

Bamboo is one rare building material that acts as a sequestration agent. This means that bamboo has the characteristic of removing carbon dioxide from the environment, replacing it with the needed oxygen that supports human life. According to Baksy (2013), bamboo produces approximately 35% more oxygen than corresponding stands of trees

e. Maturity and Economy

Bamboo has been described as the world's fastest growing woody plant. This is because it grows approximately 7.5 to 40cm a day, with world record being 1.2m in 24h in Japan. Bamboos grow at least three times faster than most tree or woody species and attain full maturity in four to five years. Thereafter, bamboo can be harvested for building every second year for about 120 years or more depending on the species (Chaowana, 2013). This makes bamboo an economic building material surpassing any other naturally growing resource use for low cost building construction.

f. Lightness and Flexibility

Bamboo is a light, flexible plant which consumes less energy than wood during processing. The method of use in construction is simple and straightforward. Therefore, bamboo plant is an exceptional material for constructing prefabricated housing and it is replaceable form of shelter that is accessible and affordable to all (Kaminski, 2013).

Preservation of Bamboo

Bamboo, like any other woody plant used in construction has its lifespan. The durability or service life of bamboo is determined by rate of attack by micro-organisms/insects. It has been established that untreated bamboo culms has a short service life ranging from about 2-5 years, that is the reason why preservation is necessary in bamboos (Xu *et al.*, 2013). The reasons for preservation of bamboos among others are to extend their life (enhance durability), reduce costs and improve safety of the structures constructed with bamboos.

In this paper, attempt has been made to discuss the two major methods employed to treat bamboo to enhance durability. The methods are the traditional/ non- chemical methods (used only by builders and owners of houses in the study area) and the modern/chemical method. The former is more sustainable and economical to the low-income group and therefore emphasized in this paper.

Traditional Method

Traditional methods of preservation also known as non-chemical methods is simple, cost-free and very natural without the use of chemical additives, thus it is readily available to all, expertise or special skill is not required and therefore very sustainable as low-income groups are able to carry out this type of preservation method. The traditional methods of bamboo preservation include curing, smoking, soaking and whitewashing.

(i) Curing: This involves a simple process of harvesting the bamboo culms with branches and leaves intact and leaving it in open air. This makes the leaves to experience continuous transpiration thereby reducing the starchy content of the culms. This is carried out before the bamboos are stacked in the storage yard.

(ii) Smoking: this method involves using the heat generated by fire to destroy the starchy content of the culms by placing the bamboo culms above a fireplace in the house. The heat/smoke treats the culms, dries it and protects it against insects and fungi attack by leaving the culms black in colour. During the smoking period, the hydrocarbons, organic acids, phenols, ketones, alcohol and other chemical substances in the wood smoke helps in improving the durability of the bamboo (Hadi *et al.*, 2012; Kaur *et al.*, 2016b).

(iii) Soaking: This method is one of the easiest and most effective ways of treating bamboo against fungi and insect attack. It involves placing the culms in water or mud completely submerged for some weeks. Thereafter, the culms are left to dry before using it for construction of building. This method is also known as water leaching method of bamboo preservation (Kaur *et al.*, 2016a).

(iv) White washing: This method is similar to painting of timber with chemical to prolong its lifespan. It involves painting the bamboo culms and mat with slaked lime. This helps to reduce the water absorption capacity of the bamboo which prevents fungal attack, thereby prolonging the lifespan and also enhancing the appearance of the bamboo for aesthetic appeal.

(v) Good harvesting practices: This talks about when and how bamboos are harvested to get the best use of bamboos. The durability or otherwise of bamboo is determined by the harvesting time, thus durability is affected by the seasons of the year in which the bamboos are harvested (Lies and Kumar, 2003). It has been discovered that the best time to harvest mature bamboo culms is either during the raining season or immediately after the raining season. Also, bamboo culms are harvested with the leaves still in-tact, this is because the leaves help to facilitate the natural process of evaporation of the free capillary water in the culms.

(vi) Special Construction Practice: over the years, low-income rural dwellers have consistently maintained a culture of good construction practice which helps to enhance the durability of bamboo used in construction. These practices include avoiding the bamboo to have direct contact with the natural ground or soil; not placing the culms on the cement-base ground, the use of mud-coating as well as plastering with cement in order to fungi and termite attacks on the bamboos (Liese and Kumar, 2003; Uddain, 2008).

Chemical Methods

The chemical methods of bamboo preservation involve the use of chemical as preservatives to treat bamboo culms before they are used for housing constriction. Although, this method is more effective than the traditional methods, but they are very uneconomical, not practicable, harmful to humans and the environment as well as beyond the reach of the low-income groups. Since the thrust of this study is focused on the low-income group, the chemical methods will only be outlined here without emphasis. Accordingly, Janssen (1995) and Chaowana (2013) list the chemical methods to include the following:

(i) Boucherie method: This is a treatment measure whereby preservative in a container is placed above the bamboo culms to be treated and by gravity; the chemical is fed through pipes into the base end of the culms. The bamboo is then left to dry naturally in a shade for at least two weeks for effective preservation. This method is also referred to as sap-replacement preservative. It can be done by using natural capillary action or by one of a small range of simple pressurized techniques. Sap-displacement method was developed by Dr Boucherie of France in 1838 hence it is called Boucherie process (Sulaeman *et al.*, 2018).

(ii) Butt treatment: This method involves the process of continuous transpiration of culms by placing the butt end of freshly harvested culms with the leaves and branches in a barrel of chemical preservative. This takes several hours while constantly maintaining the preservative level in the barrel until full treatment is achieved.

(iii) Glue line treatment: This method involves addition of preservative to glue for the production of bamboo mat board specifically and adding additives to increase the bond strength.

(iv) Hot and cold bath process: As the name implies, this method involves placing the bamboo in a tank filled with preservative, then heating it to a temperature of 90oC for half an hour and allowed to cool. Thereafter, the bamboo is left to dry naturally.

(v) Cold soaking in Open Tank: This is the process of submerging sized culms in a water-soluble preservative solution in an open tank for several days and the culms are removed and allowed to dry.

(vi) Pressure treatment: this is an expensive but most effective preservative method which involves the application of pressure with special equipment and plants using creosote/water borne preservatives to treat bamboo culms.

However, there are other categories of preservatives which are very effective but are not harmful to either to human beings or the environment. These are classified as botanical extracts and eco-friendly chemicals.

(i) Botanical Extract: Based Preservatives: this involves the use of plant and tree extracts as preservatives for bamboos. it has been discovered that plants and trees contain some chemical substances such as alkaloids, glycosides, esters, phenols, alcohols and other water-soluble substances which have strong anti-bacterial and anti-fungal properties (Salem *et al.* 2016; Kadir *et al.*, 2014). Some of these plant extracts used as preservative for bamboos are neem oil, cedar oil, camphor (C. Camphora) and cashew nut shell liquid (Tumen *et al.*, 2013; Xu *et al.*, 2013; Li *et al.*, 2013). Other extracts used as bamboo and wood preservatives are Aleurites, Chengal, moluccana, nerium oleander and essential oil (Salim *et al.*, 2013; Mohareb *et al.*, 2013; Panek *et al.*, 2014).

(ii) Eco-Friendly Chemicals: Although most chemical preservatives have been found to be harmful to humans and the environment, advancement in research has also produced some environmentally-friendly non-toxic chemical-based preservatives. Some of these non-toxic chemical-based preservatives are Bio-oil, paper mill effluent and wood vinegar, organic acids (such as citric acids, hydrochloric acids, acetic acids, formic acids) tannin copper complex and Boron complexes (Temiz *et al.*, 2013; Durmaz *et al.*, 2015; Akong *et al.*, 2015; Percin *et al.*, 2015).

RESULTS AND DISCUSSIONS

The study area

The study area for this project is Uyanga, Akamkpa Local Government Area of Cross River State, Nigeria. The town was chosen because it has several of its building constructed with bamboo as its major building material.

Construction Process

The construction of bamboo houses begins with the initial preparations similar with the normal ways of planning to build with other materials. These include gathering all materials with mature bamboo as the major walling /building material and bamboo products, water, mud and chippings. The bamboos already are prepared by treatment for preservation and against fungi/insect attack. This is followed by cutting and splitting the bamboo into various and required sizes. The floor plan of the proposed building prepared on paper or sketched on the floor by the local artisans is presented for implementation on the site, then, the setting out and pegging commences.

The next phase is the Bamboo Foundations: here, the bamboo foundation can be grouped into two types namely bamboo in direct ground and bamboo in concrete foundation respectively.

(i) Bamboo in direct ground contact

This type of bamboo foundation is the oldest type which has been practiced for several decades by the local builders/artisans. It involves placing bamboo canes directly into the ground to have contact with the earth as its footing. This was usually done after the bamboo canes have been treated with preservatives against fungi and insect attack as well as moisture effect. In order to enhance durability and strength, mature thick/large diameter bamboo with closely spaced nodes are used or two smaller sections tied together to get same effect. However, this type has its limitations as it requires frequent maintenance to prolong the lifespan of the building foundation but it is rarely in use today.

(ii) Bamboo in concrete foundation footings:

This involves the excavation of trenches of about 0.5 m (depth) and 0.3 m (width) respectively which are filled with concrete to form the strip foundation. In order to get the best result, it is recommended recently to prepare a formwork to form the plinth course along with the foundation. Thereafter, the bamboo cane/ column is now erected and placed on the plinth course and attached to the formwork to give it the proper vertical positioning during the concrete casting.

(iii) Construction of walls

This is undoubtedly the most extensive use of bamboo in construction. The main posts which are the bamboo canes or vertical bamboo column are erected at all corners and building envelope at about 1.2 m spacing apart. These posts and beams form the structural framework of the building which helps to carry both the live loads and dead loads of the building and also to withstand wind, weather and earthquakes in some cases. Hence, proper attention should be given to the jointing of the bamboo canes adequately to perform these functions efficiently.

The construction of the entire walls of the bamboo building requires infill between vertical bamboo columns or framing members to complete the walling (Figure 1). The infill usually take the two forms namely (i) Whole or halved bamboo culms which are used vertically by driving it directly into the ground or fixed back to the beams by tying with ropes and horizontally anchored to the beams by nailing or tying too. (ii) Split or flattened bamboo which can be attached vertically to in-between the bamboo columns by tying it or mortised into the posts, and also fixed horizontally directly to the posts.

Fig. 1: Building walls constructed with bamboo

In general, the purposes of the infill are to offer reinforcement and stability to the building in order to be able to withstand some external horizontal forces, enhance privacy and also to protect against harsh weather conditions and animals. Also, just as in normal brick/block construction, the windows are created to allow for lighting and ventilation as well as provision of doors for entrances and exits respectively to enhance overall architectural purpose and comfort.

(iv) Mud Application

In addition to the construction of bamboo walls above, the developers proceed to further strengthen and protect the building from external environmental forces by introducing the use of stabilized or rammed mud mortar to plaster the bamboo infill in and out to give the building an aesthetic appeal (Figure 2a and 2b). The use of mud mortar plaster is determined by the purpose the bamboo building is to serve. This marks the final stage of the bamboo wall construction as it concern the low-income group in the study area in their quest to finding solutions to the housing problem.

(a)

(b)

Figure 2a and b: Bamboo buildings finished with rammed mud mortar

(v) Roof construction

Although bamboo has been used in variety of forms in all parts of the roofing system in times past, including roof members /framework, roof covering and ceiling, this study however was limited to the use of bamboo as purlins, beams king post and rafters roof materials which was the construction practice in the study area. As much as possible, the roof structure should be light and Simple couple roof is adopted. The bamboo roof structure consists of cut bamboo trusses for rafters and culms used as ridge, purlin and eave beams. The rafters are fixed to the beam by nailing or tying, while halved culms are laid in convex sides up and down respectively in layers from the ridge to the eaves supported on the perimeter posts. Thereafter, the roof structure is then covered with roofing material such as thatch (which was commonly used in decades ago but no longer in vogue) and corrugated zinc sheets (Figures 3a and 3b) of different types which are now in use.

Fig. 3a: Thatch roof on bamboo house

Fig. 3b: Corrugated Zinc roof on bamboo house

Findings

The analysis of the relative significance index (RSI) in Table 1 below based on the reasons for the choice and use of bamboo in the construction of dwelling units in the study area indicated the following results. From the five variables listed, Affordability (low cost of building) with RSI value of 0.636 ranked first. This was closely followed by Availability (of bamboo as building material) with 0.660 RSI value ranked second. The next variable ranked third was Low Expertise (level of skill required) with 0.532 RSI value. The fourth ranked variable was Labour Support (Communal labour assistance) which had an RSI value of 0.508, while the least ranked variable with RSI value of 0.428 was others (unstated) reason.

Table 1: Relative Significance Index of Reasons for Building with Bamboos

Reasons	1	2	3	4	5	Total	TWC	RSI	RANK
Availability	1	11	18	18	2	50	159	0.636	2
Affordability	3	6	19	17	5	50	165	0.660	1
Labour Support	12	16	12	3	7	50	127	0.508	4
Low Expertise	7	18	14	7	4	50	133	0.532	3
Other reasons	16	17	12	4	1	50	107	0.428	5

Source: Author's field work, 2019

The result indicated that from the five variables examined in terms of the reason for the use of bamboo as main building material for construction of housing units in the study area, Affordability was the most significant, thus implying that it contributed most to the overall reason for the use of bamboo in constructing housing units, implying that bamboo is within the reach of the low-income group. This was followed by availability of bamboo in the study area which gives the poor the hope and encouragement that ownership of a building is very possible with little effort and determination even as there is the assurance that members of the community are ready to assist in the supply of labour for the building project.

Conversely, in Figure 4 and 5 , the analysis of the occupation of respondents in the study area revealed that out of the 50 respondents, 18 of them representing 36% were farmers, 6 of them (12%) were civil servants, 12 representing 24% were artisans while 8 (16%) and 6 (12%) were traders and other categories respectively. Also, on the analysis of house ownership, the results showed that 37 persons owned houses which were constructed with bamboo representing 74% while 13 persons representing 26% built their houses without using bamboo. Out of the 74% who built with bamboo, farmers and artisans had the highest of 26% and 20% (totalling 46%) respectively. This revealed that those respondents that embraced the use of bamboo for housing construction are proud house owners which are a strong indication that using bamboo as building material guarantees house ownership at very affordable cost, thereby enhancing sustainable housing delivery system for the low-income group.

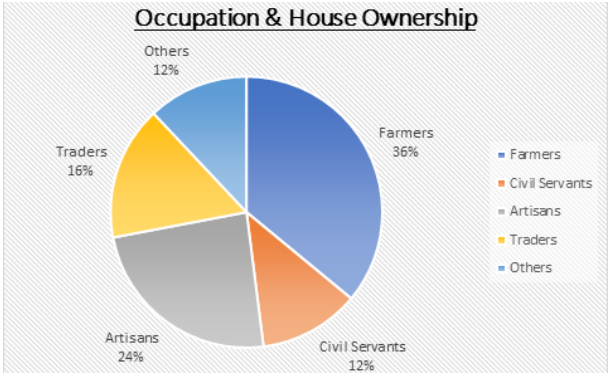

Figure 4: Occupation and House ownership in the study area. **Source**: Author's field work, 2019

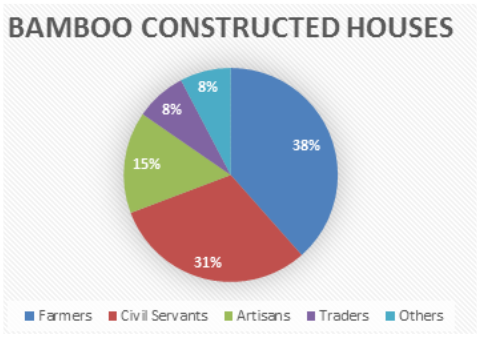

Figure 5: Bamboo constructed houses in the study area
Source: Author's field work, 2019

CONCLUSION

The study has demonstrated that the use of bamboo in today's world in building construction and other areas extensively have come to stay. Thus, the consciousness and recognition that bamboo remains the most versatile non-timber and fast-growing woody plant has stimulated researches on how to process, preserve and enhance the utilization of bamboo for effectiveness in construction. It has been revealed that the high utilization value of bamboo as an economic building material helps to protect the environment in addition to saving forest resources thereby reducing the effect of deforestation with its attendant problems.

Bamboos though versatile has some limitations regarding durability hence it needs some treatment by both traditional method (which include smoking, good harvesting practices, curing, water leaching methods among others) and non-toxic eco-friendly chemical methods (use of bio-oil, boron complexes and plant extract-based preservatives) for longer lifespan. Also, the various properties, nature and the constructional value of bamboos shows that in building construction alone bamboos could be used in walling, flooring, roofing, for doors and window production including furniture.

In addition, it has also been revealed that the use of bamboo in construction has led to a number of low-income groups especially the rural dwellers to own houses thereby reducing the challenges of homelessness in developing countries of the world. With advancement in technology owing to the various modifications, durability and quality of bamboos which has resulted in the multi-utility value of bamboo and as a better substitute for timber and other materials, it is hoped that the use of bamboo in housing construction will be appreciated and embraced by all income groups and government for sustainable housing delivery.

However, the study recommends advocacy enlightenment by government agencies on the benefits and application of bamboo in construction, change of orientation/perception on the use of locally available materials by all for building construction. Also, the use of modern methods of building houses completely with bamboo and its by-products is missing in the case study area due to lack of technological know-how. Hence, training of professionals and artisans on the modern use of bamboo in all aspects of building construction is highly recommended.

REFERENCES

Baksy A, (2013). 'The Bamboo Industry in India Supply Chain Structure, Challenges and Recommendations', Centre for Civil Society, New Delhi, India.

Bohra ED, Pathak KC, Deka B, Neog D, Bohra K. (2008). Utilization Aspects of Bamboo and its Market Value. Rain Forest Institute, Jorhat, Assam.

Bui QB, Grillet AC, Tran HD. (2017). A Bamboo Treatment Procedure: Effects on the Durability and Mechanical Performance'. Sustainability, 9: 1444

Bureau of Indian Standards [BIS] (2005). National Building Code of India 2005, New Delhi, India.

Chaowana P. (2013). Bamboo: An Alternative Raw Material for Wood and Wood-Based Composites. J. Mat. Sci. Res. 2, 90-102.

Chavan MM, Altar AC (2013). Study feasibility of preservative chemicals and its effects on load carrying capacity of bamboo. Int. J, Sci, Eng. Res. 4:1271- 1278

Dhawan S, Mishra SC (2005). Influence of felling season and moon phase on natural resistance of bamboo against termites. Indian Forest. 131:1486-1492

Hossain MF, Islam MA, Numan SM. (2015). Multipurpose Uses of Bamboo Plants: A Review. Int. Res. J. Biol. Sci. ISSN 2278-3202. 4(1)2, 57-60.

Jambal N and Gambhir ML (2011). Building Materials: Products, Properties and Systems. 1st edn. Tata, McGraw–Hill Education.

Janssen JJA. (1995). Building with Bamboo: a handbook, Second edition, Intermediate Technology Publications: London, UK.

Jena H, Pradhan AK, Pandit MK. (2014). Studies on water absorption behaviour of bamboo-epoxy composite filled with cenosphere. J. Reinforced Plas. and Comp. 33(1)1, 1073-1082.

Kaminski S. (2013). Engineered bamboo houses for low-income communities in Latin America. The Structural Engineer, 91:10, 14–23.

Kaur PJ (2018). Bamboo availability and utilization potential as a building material. Fores. Res. and Eng. J. 2(5), 240-242, ISSN: 2577-8307

Kaur PJ, Kardam V, Pant KK, Naik SN, Satya S. (2013). Scientific Investigation of Traditional Water Leaching Method for Bamboo: Bamboo Science and Culture. The Journal of the American Bamboo Society, 23:1, 27-32

Kaur PJ, Kardam V, Pant KK, Naik SN, Satya S. (2016a). Characterization of commercially important Asian bamboo species. Eur. J. Wood and Wood Prod. 74(1), 137–139

Kaur PJ, Kardam V, Pant KK, Naik SN, Satya S. (2016b). Bamboo: the material of future. Int. J. Ser. Multidis. (IJSMR), 2(2), 27-34, ISSN: 2455-2461

Kaur PJ, Kardam V, Pant KK, Naik SN, Satya S. (2016c). Eco-friendly preservation of bamboo: traditional to modern techniques. BioResources 11(4), 10604–10624

Kaur PJ, Pant KK, Kaushik G. (2019). Properties and Importance of Various Bamboo Species for Multi-Utility Applications. In: Jhariya M, Banerjee A, Meena R, Yadav D. (eds). Sustainable Agriculture, Forest and Environmental Management. Springer, Singapore

Kaur PJ, Satya S, Pant KK, Naik SN. (2015). Eco-Friendly Preservative Treated Bamboo Culm: Compressive Strength Analysis. Int. J. Chem., Nucl, Metal and Mat Eng. 9(1), 43-46.

Kumar N, Mathur U, Phulwari B, Choudhary A. (2017). Bamboo as a Construction Material. IJARIIE. 3(1). 2395-4396.

Li Q, Lin JK, Liu J (2013). Decay resistances of wood treated with extracts of Cinnamomum Camphora Xylem. BioResources. 8: 4208-4217

Nguyen TBN (2002). Investigation on preservation of bamboo used for construction. PhD Thesis, Forest Science Institute of Vietnam, Vietnam.

Philmmachanh S, Ying, Z, Beckline M. (2015). Bamboo Resources Utilization: A potential source of income to support rural livelihoods. Applied Ecol. Environ. Sci. 3: 176-183

Raj D, Agarwal B. (2014). Bamboo as a Building Material. J. Civ. Eng. and Env. Tech. 1(3), 56-61.

Razak W, Tamizi M, Othman S, Aminuddin M, Affendy H, Izyan K. (2010). Anatomical and physical properties of cultivated two and four-year-old Bambusa Vulgaris. Sains Malaysiana; 3: 571-579

Schmidt O, Wei DS, Liese W, Wallenberg E. (2011). Fungal degradation of bamboo samples. Holzforschung, 65:883-888

Shibata S (2012). Effects of forming processing conditions on the flexural properties of bagasse and bamboo plastic composites. BioResources. 7: 5381-5390

Sulaeman A, Dungani R, Nuridin N, Harttati S, Karliati T, Aditiawati P, Hadiyane A, Suhaya Y, Sulistyono (2008). Review on Quality Enhancement of Bamboo Utilization: Preservation, Modification and Application. Asian J. Plant Sci 17(1), 1-18

Suprapti S (2013). Decay resistance of five Indonesian bamboo species against fungi. J. Trop. For Sci. 22: 287-294

Tumen I, Eller FT, Clausen CA, Teel JA. (2012). Antifungal activity of heartwood extracts from three Juniperus species. BioResources. 8: 12-20

Virdi KS, Rashkoff RD. (2014). Manual on Building Bamboo Houses. Engineering Structures Research Centre at City University, London: Village Volunteers

Wahab R, Mustafa MT, Mohammed A, Samsi H, Rasat MSM. (2013). Extractives, Holocellulose, X-Cellulose, Lignin and Ash contents in 3 year-old Bamboo culms Giganto Brang; G. Levis; G. Scartechinii and G. Wrayi.Res. J. Pharm. Biol. Chem. Sci. 4:1235-1247

Wahab R, Mustafa MT, Sudin M, Mohamed A, Rahman S, Samsi HW, Khalid I. (2013). Extractives, holocellulose, α-cellulose, lignin and ash contents in cultivated tropical bamboo Gigantochloa brang, G. Levis, G. scortechinii and G. wrayi. Current Res. J. Bio. Sci. 5(6), 266–272

Wei D, Schmidt O, Liese W. (2013). Durability test of bamboo against fungi according to EN Standards. Eur. J. Wood Prod. 71: 551-556

Accepted 17 December 2019

Citation: Atamewan EE (2020). Use of Bamboo for Sustainable Housing Construction in Developing Countries. International Research Journal of Architecture and Planning. 5(1): 102-110.