BAMBOO AS AN ENGINEERING MATERIAL IN A GREEN ECONOMY

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Abstract
The increasing threat to sustainable economic growth in the light of increased rate of consumption and dependencies on natural resources has called for serious intervention for sustainable livelihood and continued human existence. These finite natural resources are fast disappearing, depicting the negative influence of economic dependence on natural resources on the environment. Increased human population have contributed in one way or the other to the depletion of the natural environment due to ever increasing demand and wanton exploitation of natural resources at the expense of the environment. The rate at which the ecosystem is been degraded is becoming alarming. It becomes expedient in striking a balance between development and environmental sustainability through consideration and transiting to a green economy. Bamboo, an environmentally friendly natural resource has been recognized as having great potential in shifting to a more sustainable greener economy. This paper examined the properties of bamboo in relation to its utilization by reviewing the chemical, anatomical, physical and mechanical properties. This paper further provides a general overview of bamboo in a diversifying economy by appraising the environmental, economic and social benefits of bamboo in a transformed green economy. The prospects of bamboo as a sustainable green constructional material were also discussed in the light of carbon storage, climate change mitigation and poverty alleviation for sustainable development.

Keywords: *Bamboo, Environment, Green Economy, Sustainability, Properties*

Introduction

Bamboos can be found around the globe and are naturally occurs in tropical, subtropical and warm temperate areas around the equator. Bamboo are giant grasses of over 40 m in height and 30 cm in diameter, it propagates rapidly by expansion of underground rhizomes (Tewari, 1992). In general, bamboos are known for rapid growth with a hollow tapered tube (culm), with internodes separated by nodes and supported by an intricate rhizome system. This growth and lignification processes found in bamboo made it to have high biomass production yield that is an advantage over other renewable resources. Due to the properties displayed by bamboo, the utilization potentials of bamboo around the world have increased from food to furniture and construction. It has been noted that each species is peculiar to it application (Zea *et al*., 2019). About 20 species of woody bamboos are considered as key species for construction purposes (Ramanuja and Sastry 1996).

The variation in the applications of bamboo for any engineering purpose is due to it vascular bundles with fibre bundles that can vary in sizes. The distribution of fibres around the conductive tissue can also affect the application (Zea *et al*., 2019). It has been estimated that bamboo has about 37 million hectares of forests cover area which is amounts to 4% of the world's total forest coverage (Phimmachanh *et al*., 2015). It is also reported that Africa has more than 40 bamboo species covering more than 1.5 million hectares (Phimmachanh *et al*., 2015). Despite its widely availability, bamboo in Africa is less valued than wood products and its uses are mainly traditional (Endalamaw *et al*., 2013, Ingram and Tieguhong 2013). In Nigeria, bamboo is widely distributed in the south and middle belt regions where the average diameter of the bamboo culms ranges from 3.2 to 9.1 cm (Atanda, 2015). It is also reported that the rate of utilization of bamboo in Nigeria is very low (Atanda, 2015). Traditionally, bamboo in Nigeria is used for scaffolding, shade houses, fencing, and furniture making (Ladipo *et al*., 2017). It is also used in rural areas to construct mud houses where the culms serve as structural frames (Atanda 2015). Other uses of bamboo include structural element for buildings, bamboo based panels, and furniture (Ladipo *et al*., 2017). This review study provides basic information on utilization patterns of bamboo to boost green economy in Nigeria.

Properties of Bamboo in Relation to Utilization

Chemical Composition of Bamboo

The major chemical components of bamboo include cellulose, hemi cellulose and lignin while resins, waxes, inorganic salts and tannins are minor constituents. When compared with wood, bamboo has higher alkaline extractives, ash and silica contents (Tomalang *et al*., 1980; Chen *et al*., 1985). It has also been reported that chemical composition did not vary among the age different of bamboo (Yusoff *et al*. (1992). Bamboo also contains other organic composition in addition to cellulose and lignin. Durability of bamboo against bio

deteriorating agents (mold, fungal and borers) is strongly associated with its chemical composition, age, species and climatic condition (Liese 1980). The durability and service life of the bamboo is a function of the carbohydrate content which makes it non-durable. The ash content found in bamboo is made up of inorganic minerals which are primarily silica, calcium, and potassium. While manganese and magnesium are the two other common minerals found in bamboo. This content adversely affects the processing machinery. The silica content is the highest in the epidermis with very little found in nodes (Mabilangan *et al.*, 2002). The differences in chemical composition of node and internode fraction of bamboo are and this is insignificant to the utilization potentials of the plant for engineering products (Scurlock, 2000).

Anatomical Structures

The structure of a bamboo culm transverse section is characterized by numerous vascular bundles embedded in the parenchymatous ground tissue (Grosser and Liese 1971) compose of parenchyma cells and vascular bundles. Generally, the plant has thick-walled fibers. Bamboo culms consist of special distribution and arrangement of the vascular bundles from the inner layer to the outer layer. The arrangement is such that vascular bundle increases toward the outer layer, while distributions of the ground tissue which is mainly parenchyma cells decrease from the pitch ring to the thin bark layer (Zakikhani *et al.,* 2017). It is well known that the anatomical characteristics of bamboo affect it utilization or the manufacturing process of products. The higher and parenchyma percentages as well as the lower cellulose and lignin constituents in the inner layer of bamboo leads to the lower residue content (Xie *et al*., 2014). The absorption of preservatives into the inner culms is influenced by the anatomical features of bamboo (Liese and Schmitt, 2006).

The cross-sectional arrangement of bamboo fibrils was either pentagonal or hexagonal, in a honeycomb pattern, separated by thin walls of matrix (Ray *et al.*, 2004). The wall thickness between two sclerenchyma cells ranged from 1 to 5 mm and the width of the same varied from 10 to 20 mm. Again, the fibril contains many continuous elongated celluloses, staggered in a twisted nature, like a metal cable formed by many twisted wires. Gritsch *et al*., (2004) reported that multi-layered structure of fiber cell walls in bamboo was formed mainly during the first year of growth by the deposition of new wall layers of variable thickness, which resulted in a high degree of heterogeneity in the layering patterns among individual fibers. This anatomical structure and performance of the bamboo cell wall are attributed to the better mechanical properties displayed by bamboo. The difference in the anatomical structure of bamboo and trees are presented in Table 1.

Table 1. Comparison of Structure between Bamboo and Trees

	Bamboo	**Woody plants**
Origin	Bamboo is the primary product, and without secondary growth. The height growth is happened only during short time. Bamboo has no diameter growth.	The proportion of the primary product is the minimum and the most part of wood is the secondary product. A tree has height growth and diameter growth during the whole lifetime.
Structural elements	Structural elements of internodes arrange in the longitudinal direction. Bamboo has no rays	Structural elements arrange in the longitudinal and radial directions. Wood has rays.
Vascular tissue	Vascular tissue has no cambium. Fibers distribute around the vascular tissue together. Xylem contains vessels.	Vascular tissue has cambium. Fibers are dispersed under microscopic scale. Xylem of most hardwood trees and a few softwoodtrees contains vessels.
Nodes	With nodes	Without nodes
Distribution of vascular bundles	The vascular tissues are embedded in the ground tissue.	Vascular tissues are around the pith at the position of treetop with primary growth. Vascular tissues connect each other and present a sole tube-shape.

Source: Yin, (1996)

Physical and Mechanical Properties

Specific gravity (SG) of bamboo varies between 0.4 and 0.8 depending on the anatomical structure. The moisture content found in bamboo also varies vertically from the bottom to the top portions and horizontally from the outer layer to the inner layers. Bamboo possesses very high moisture content. The tensile strength and young's modulus in bamboo are attributed to anatomical arrangement and contents of the fibers. This makes bamboo an important raw material for the pulp and paper industry (Hammett 2001) Fiber morphology has an important influence on the physical properties of bamboo pulp, it varies with the age and the height of the culm (Chauhan 2000). The height of bamboo has much influence on SG and other properties of bamboo, it drops from

the top portion to the bottom. The increase in weight is cumulative and directly related with the age of the bamboo. Strength properties of bamboo vary in relation to the culms both in natures and height (Kabir *et al*., 1991). In Nigeria, interest in bamboo has increased tremendously and as a result, several studies have been done to evaluate bamboo's properties in relation to utilization potential as an alternative to wood resources

Prospects of Bamboo in a Diversifying Green Economy

Green Economy Concept

There has been lopsided imbalance between economic development and environmental sustainability of the forest as a result of heightened dependencies on finite natural resources and dramatic impact of climate change. This necessitated the emergence of the green economy concept in fostering the integration of economic development with the environment thus enhancing low carbon emissions, increasing resource utilization efficiency and promoting growth of social inclusiveness.

A green economy is defined as an economy which results in "improved human well-being and social equity, with significant reduce in environmental risks and ecological scarcities (UNEP 2010). It is hinged on an enabling economic growth and investment while increasing environmental quality and social inclusiveness" (UNEP 2011). Green economy is considered as a veritable platform for economic development and diversification by harnessing and leveraging on the huge opportunities and prospects in the environment. As a matter of fact, it is fulcrum of national economic growth as it traverses across every aspects of a nation's economy.

The conception of the green economy model is driven towards providing prospective solutions to contemporary global economic and environmental crises. It is considered as the pivotal mechanism by which sustainable development can be practically achieved in form of improvement of green technology, efficient utilization of resources, conservation of biological resources, renewable energy, reusing, reducing and recycling of materials and green infrastructure. As posted in Table 2, the transition to green economy with benefits to the environmental, economic as well as social dimensions and implications (Harrison *et al*., 2015).

Table 2: Benefits of a Transformed Green Economy

Components		Benefits
Environmental	•	Sustainable management of natural assets and resources
	•	Reduced greenhouse gas and other emissions
	•	Better adaptation to climate change and resilience to natural disasters
	•	Improved environmental quality
Economic	•	Reduced poverty and inequality
	•	Increased economic growth and employment
	•	Improved training and skills
	•	Development of new markets and specialisation
	•	High productivity, commodity and agricultural yields
	•	Improved energy security
	•	Improved competitiveness and trade balances
Social	•	Reduced poverty and reduced social inequality
	•	Increased employment
	•	Improved training and skills
	•	Better public services
	•	Improved health outcomes

Green Economy and Sustainability of Natural Resources

There is increasing threat to sustainable economic growth if the rate of consumption and dependencies on world's natural resources is left unchecked (Gordon-Harper, 2017). The social and economic systems of a nation's economy depend on her inherent naturally endowed resources. Unfortunately, these finite resources are fast depleting, portraying the negative influence of economic reliance on natural resources derived from its environment. Human development and its use of the ecosystem have pushed the planet beyond the limits of stability due to increasing consumption of fossil fuel and natural resources (UNCTAD, 2011). The rate at which the ecosystem biodiversity is been degraded may results in mass extinction if it is allowed to continue (Barnosky *et al*., 2011). It has been noted that over 60 % of the world's ecosystems degraded or utilized unsustainably in

which about 13 million hectares of tropical forests are destroyed annually (MA, 2005; UN FAO, 2011). Increase in human population contributed significantly to the depletion of the natural resources due to the pressure quest for development at the expense of the environment (Parnell and Walawege, 2011). Population growth is in the rise, the global population is projected to increase from 7.7 billion in 2019 to 9.8 billion by 2050 and 11.2 billion by the end of the century in 2100 (UN, 2017; Max, 2020), while Nigeria present population of 206 million is expected to double to 401 million people in 2050 (UNDESA, 2019; Worldometer, 2020).

Meeting up with the consumption demands of the rising population is a big challenge, particularly the rural population who directly depend on the natural environment for sustenance and improved livelihood. Increasing supply to meet up with the demand of continued economic growth is not feasible unless an holistic approach is met. If not, the result will further caused depletion of the natural resources endowment, deterioration of the natural ecosystems and acceleration of global climate change (UNCTAD, 2011). Beyond improving the economy's environmental performance and sustainability, it is of paramount importance in striking a balance between development and sustainability by transiting to a green economy. This is as all developed, developing and emerging nations will sooner or later transit into green economies (Polity, 2012).

Bamboo and Green Economy

Bamboo is also known as "wonder plant", "poor man's timber", "green gold", contributes significantly to ecological sustainability because of its uniqueness in providing environmental, economic and social benefits to mankind (Scheba *et al*., 2017; Manandhar *et al*., 2019). It is generally considered as a green alternative to other constructional materials due to its green growth, sustainable harvesting and wood-like properties. Though not classified as a wood, bamboo is a fast-growing woody grass species that can serve as a good alternative raw material to wood thus reducing the demanding pressure on wood and wood products and thereby ameliorating the high rate of forest depletion (Atanda, 2015). It has been referred to as one of the fastest growing plants on earth with short gestation period of 3 to 5 years (Figure 1) to maturity and harvest (Atanda, 2015). Its fast growth rate makes it suitable for afforestation purpose in a way that it can be harvested and replanted within seven years compared to 10 to 50 years of some indigenous tree species (Mohamed 2003; Basumatary *et al*., 2015)

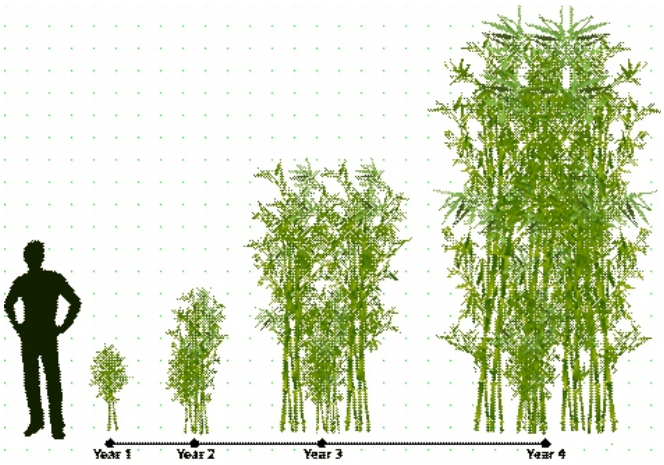

Figure 1: Growth Cycles of Bamboo
Source: https://nsjstylishstore.com/how-eco-friendly-are-bamboo/

Environmental Benefits of Bamboo in a Sustainable Green Economy

Carbon Sink and Sequestration Potential of Bamboo

The greenness of a product is a function of whether the product is derived in a sustainable and rapidly renewable manner which is peculiar of bamboo. Bamboo is an under-utilized natural resource that provides decisive solutions to combating global land degradation, desertification, climate change mitigation and adaption ((Holt 2019, INBAR, 2014). It is a fast-growing species that sequesters more carbon than indigenous and exotic wood species. It produces 30 % more oxygen than hardwood species. When utilized as a constructional material, it stores carbon and keeps it from going back into the atmosphere for a very long time. Bamboo is estimated to store 30 to 121mg carbon per hectare and sequester 6 to 13mg carbon per ha per year (Nath *et al*., 2015).

Embodied sustainable energy potential of bamboo

As presented in Table 3, the production of constructional materials such as concrete, steel and wood contribute significantly to the deterioration of the environment and global climate change issues because these materials

have high production energy efficiency than bamboo making it to be of better production energy efficiency (Laroque, 2007). The production process of cement which is the major component of concrete requires increasing the heating temperature of limestone and other constituents to 1,400°C by burning fossil fuels. This implies that for every ton of cement produced will emits at least one ton of carbon-dioxide (CO_2). Consequently, considerable volume of global carbon-dioxide emissions comes from cement production and transportation (Bhalla *et al*., 2012). Likewise, in steel industry, more than 2 tons of carbon dioxide is released into the atmosphere following the production of every ton of steel (Ghavami, 2007). However, from the greener environmental point of view, approximately 2 tons of carbon dioxide is sequestered from the production of every ton of bamboo equivalently releasing fresh oxygen into the atmosphere (Bhalla *et al*., 2012).

Table 3: Production Energy Requirement for Construction Materials

Building Materials	Density (kg/m3)	Energy for production (MJ/kg)
Concrete	2400	0.8
Steel	7800	30
Wood	600	1
Bamboo	600	0.5

Source: Laroque, (2007)

Environmental Pollution Amelioration Potential of Bamboo

Bamboo is an environmentally friendly renewable natural resource that plays important roles in protecting biodiversity (Gichohi, 2014). The strong root of bamboo helps to improve soil stability and control soil erosion. It reduces deforestation rate, makes better use of wasteland leading to improved soil conservation and mitigation of flood disasters. Large quantity of nitrogen is absorbed and converted into nutrients for physiological growth (Nwoke and Ugwuishiwu, 2011).

Benefits of Bamboo for Green Building Materials

Bamboo has been recognized as a quality green environmentally friendly material. Various studies and findings have x-rayed the prospects of bamboo as a sustainable green constructional material. The benefits of bamboo as identified by different authors are presented in Table 4 below;

Table 4: Benefits of Bamboo as Sustainable Green Constructional Material

Benefits Identified	References
❖ Fast growth in raw materials	Fang *et al*., (2018)
❖ Shorter rotation	
❖ Higher mechanical strength	
❖ Abundant and sustainable resource	
❖ Carbon storage	Chang *et al*., (2018)
❖ Mitigating the effect of climate change	
❖ Environmentally friendly	
❖ Fast growing	
❖ Energy conservation	
❖ Reduction of CO2 emissions	
❖ Biochemical fuel substitution	
❖ Short rotation age	
❖ High tensile strength	
❖ Sequester high levels of CO2	Escamilla *et al*., (2018)
❖ Job creation and the improvement of income levels in rural and urban areas	
❖ Economical advantage because of shorter rotation	Puri *et al*., (2017)
❖ Abundant resource	
❖ Consumption of CO2 and release of oxygen	
❖ Less energy use in production process	
❖ Pliable, lightweight, excellent tensile strength	
❖ Low cost	
❖ Durable and easy to use in its natural state with less processes	Opoku *et al*., (2016)
❖ Easy to obtain	
❖ Simple technical knowledge required	
❖ Good strength	
❖ Beautiful in its appearance	
❖ Multiple uses in building construction	
❖ Low cost	
❖ Good economic potential	Seixas *et al*., (2014)
❖ Abundance	
❖ Lightweight	
❖ Light, strong, and versatile	Shah *et al*., (2012)
❖ Environmentally friendly	
❖ Accessible to the poor	
❖ Renewable resource	
❖ Fast growing	
❖ Less energy use in production process	Yu *et al*., (2011)
❖ Able to consume carbon emission during the growth process	
❖ Renewable	Mahdavi *et al*., (2011)
❖ Biodegradable	
❖ Sequestering carbon	
❖ Low embodied energy	
❖ Creating less pollution in production	
❖ Great mechanical and aesthetical properties	Laroque, (2007)
❖ Grows quickly	

Industrial utilization Potential of Bamboo in a Sustainable Green Economy

The existence of bamboo as a raw material in the world has been since man days on earth (Atanda, 2015). Bamboo as a fast growing forest plant has a lot of industrial potentials due to its properties displayed and it availability as raw material in Nigeria could be sustained through adequate policy (Onilude 2006; Ogunsile and Uwajeh, 2011; Ogunwusi and Jolaoso 2012). Through advanced technology, bamboo is known to be the new super material used for almost 4000 commercial items or products that ranges from textiles to construction purposes (Singh, 2008, Wooldridge, 2012; Musau, 2016; INBAR, 2015). Some of the domestic bamboo products are shown in Figure 2.

Figure 2: Diverse Products from Bamboo
Source: https://nsjstylishstore.com/how-eco-friendly-are-bamboo/

New technologies and techniques in processing bamboo made it a stiff competitor to a number of other industrial raw materials with strong capability to act as alternative to wood, brick, steel and glass. It is environmentally friendly, cheap and locally accessible, it can be use as a substitute material for flooring and reinforcement. The reliance of forest industries in Nigeria on diminishing forest trees has been observed to be unsustainable (Ogunwusi and Jolaoso, 2012). An attempt must be made to start supplementing the wood made products to bamboo made products for sustainability of the diminishing forest woody resources. There is need for development of bamboo as a valuable sustaining, climate friendly alternative with wide arrays of prospects of alleviating the social, economic and environmental problems in Nigeria.

Conclusions

Bamboo has been identified as a resource of high-value products that has over 10,000 uses. When processed, it can fetch more money to boost the economy. The uses to green economy are listed below;

✓ In the furniture industry and a variety of building and roofing materials, from fencing poles to veneer, floor tiles, panels for walls and ceilings, scaffolding material, door and window frames and window blinders.

✓ In the paper and pulp industry, bamboo can be made into newsprint, toilet paper and cardboard, which would help to conserve Africa's finite resources, such as its forests.

✓ Domestic items like mats, baskets, canoes, fishing kits, bicycles, fences, toothpicks, school desks, pencils and rulers, to name just a few products are made from bamboo.

✓ Bamboo is also a source of bio-energy

✓ Protecting the environment by mitigating the effects of climate change through rapid reforestation, slowing soil erosion and repairing damaged ecosystems. It also serves as an excellent large-scale carbon sink, each plant taking in almost double the carbon dioxide of a tree.

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