USE OF BAMBOO FOR BUILDINGS – A SUSTAINABLE, STRONG, VERSATILE AND ECONOMIC OPTION FOR THE PRESERVATION OF TIMBER IN GHANA

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Abstract

Bamboo is used mainly for fencing and for cladding of simple buildings in Ghana. Native intelligence and observation is that bamboo is strong and versatile, without any scientific basis for this conviction. This, coupled with the short useful working life (due to insect and fungi attack), has limited the use of bamboo locally. This is unlike Asia and South America where its use is more widespread, including prominently, as structural elements in scaffolding.

There is presently a heightened interest in bamboo as a structural material because of the rapid depletion of both primary and lesser used timber species (LUS). This interest is being held back by the almost complete absence of locally derived mechanical and strength data on bamboo, the high cost/non-availability of fast preservation methods, the absence of bamboo specie with near uniform dimensions and the dearth of relevant skills in construction with bamboo.

Collaborative effort by INBAR/BRRI/TRADA/BARNET/FORIG has enabled the nursing of imported bamboo specie of more uniform dimensions, the look at methods of improvement of the design life of bamboo through preservation, the start of research activities aimed at obtaining design/mechanical property values and an illustration of design and construction in bamboo by the building of a prototype 3-unit classroom block at Fumesua, near Kumasi.

This paper highlights the collaborative efforts in the foregoing and expands on areas where the construction of buildings in bamboo can be made easier and cheaper. Also of interest, is the proposed research effort at the indirect generation of strength properties of bamboo, by the testing of bamboo trusses, a component that holds much promise for the popularizing of the use of bamboo.

Keywords: bamboo, strength, mechanical, data preservation, construction, trusses.

1.0 INTRODUCTION

There is an increasing realization in Ghana that both primary and secondary timber species (Lesser Used Timber Species, LUS), are becoming difficult to find, and, where these are available, are expensive. There is therefore the need to look at other structural materials that are cheap, locally available and sustainable if exploited. Bamboo comes on its own in such a situation. However, constraints to the development of bamboo as a modern structural/construction material is the lack of locally-derived mechanical/engineering data, availability of safe, effective and cheap preservation methods and the non-availability of plantation grown bamboo (which tend to have more uniform dimensions).

Efforts have been made at establishing the design rules and engineering data in Asian and South American countries. A start should be made at establishing the rules for Ghanaian bamboo if more is to be done structurally with bamboo beyond its present use for temporary buildings of poor quality and for props in construction. For a start, data established in Asia and South America can b used. Research has started at the Building and Road Research Institute at the indirect generation of engineering data by the testing of full size bamboo trusses, of varying joint fastening and subjected to varying loads.

Plantation bamboo seedlings have also been acquired from Asia by BARNET (Network of Bamboo and Rattan) for cultivation in Ghana with the aim of obtaining bamboos of near uniform internode lengths and culm thickness as these will make construction easier, cheaper and products more aesthetically pleasing. Through the collaboration of INBAR/BRRI/TRADA/BARNET/FORIG and the British Embassy, an experimental 3-unit classroom building was put up in Fumesua, Kumasi, to illustrate the skills of building in bamboo.

The foregoing activities are briefly highlighted in this paper and suggestions made for ways of minimizing the present weaknesses in bamboo construction and the other threats to the technology in Ghana.

2.0 PRESENT AVAILABILITY OF TIMBER IN GHANA

The timber stock in Ghana, both primary and LUS is fast-dwindling as illustrated by the following statistics of the cost of timber. The cost of a primary timber Odum (Irokko) is exorbitant (a lumber of 50x150x5000mm is $11.00) and generally unavailable on the local market. Hitherto, LUS species such as Dahoma and Kusia (Opepe) were the norm for construction. In October, 2002, a cubic metre of Dahoma was $35. In June, 2003 it was $65 and presently it is about $90. Part of this increase in price is due to higher royalties and other statutory charges. However, the main reason for this situation is the increasing difficulty in getting timber.

An answer to this situation is for a material that can be used for construction, which is readily available in the country, relatively cheap, have satisfactory structural properties for construction, and be renewable. Bamboo easily has all these attributes and would be more than an adequate substitute for timber if its undesirable properties are minimized or eliminated.

3.0 BAMBOO AS A CONSTRUCTION MATERIAL

Bamboo, a grass, is widely available in tropical climates and has been used by generations for construction purposes and as artifacts. However, until lately, it has been considered a constructional material for 'poor' settlements. Bamboo is a superior construction material as compared to timber because it has excellent mechanical (tension and bending) and anatomical properties for its low weight.

3.1 Anatomical Structure

A bamboo pole (culm) is made up of diaphragms, rings, nodes, internodes, culm wall and cavities (Fig. 1).

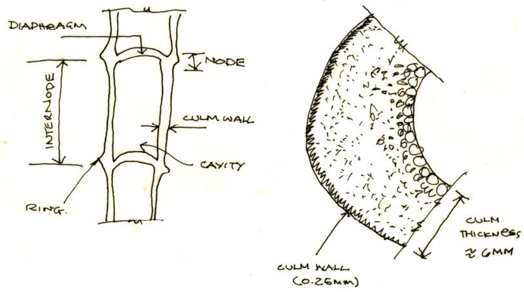

FIG.1 – SECTION THROUGH BAMBOO CULM AND WALL

The microstructure is made up of a dense culm wall, about 0.25mm thick, which is rich in silica. Under the culm wall (towards the interior of the culm) are cellulose fibres together with vessels; the density of these fibres decreasing towards the interior of the culm. Cellulose fibres act as reinforcement, similar to glass fibre in fibre-reinforced plastic. These fibres are concentrated near the outside of the hollow bamboo and the density of the fibres is akin to a steel tube with high tensile steel on the outside of the wall and normal mild steel on the inside of the wall. The stiffness that this distribution pattern creates is 10% more than what a similar tube with a more even fibre distribution pattern would give (Janssen, 2000). The vessels (which are conduits for transportation of liquid for the bamboo) are surrounded by "parenchyma" which is a matrix in which the fibres are embedded (like concrete between steel reinforcement). A bamboo culm has about 40% fibres, 10% vessels and 50% parenchyma. A cross-sectional structure of bamboo culm does not show 'rays' as in wood. Rays are for the transportation and storage of food, mostly sugar, and, they weaken the wood material. Thus, bamboo is stronger than wood, especially in shear (Janssen, 2000).

3.2 Mechanical and Structural Properties

Bamboo, being a circular, hollow structure has certain mechanical and structural advantages and disadvantages as compared to a rectangular solid timber of the same cross-section. These advantages/disadvantages are, in other instances, complemented or accentuated by the cellulose fibre make-up of the bamboo. These comparative analyses are tabulated in Table 1.0. Some rules of thumb for the relationship between the mass per volume of bamboo and some mechanical properties have been derived by INBAR and

Janseen (1991). These are given in Table 2.0. Also, various tests for strength and mechanical properties and design rules have been put forward by INBAR (ISO-22156, 22157, ISO/DTR-23157.2).

Table 1.0: **Comparative Mechanical Properties of Bamboo and Rectangular Lumber (*Janssen, 2001)***

Property		Bamboo	Rectangular Lumber	Assumptions
1.	Moment of Inertia, I	$I = 0.40A^2$	$I = 0.16A^2$	• For most bamboos, d = internal diameter = 0.82D • For timber, mostly h = 2 x b
2.	Optimum Material Use, EI	$4900A^2$	$2240A^2$	• Ecellulose = 70,000N/mm^2 • Efibre = 35,000N/mm^2 • 50% of cross-section of fibre is cellulose. • E≈350x% of fibres. • In bamboos, fibre is 60% on outside and 10% on inside, hence Eoutside = 350x60 = 21,000N/mm^2 and Einside = 350x10 = 3500N/mm^2 • Edahoma = 14,000N/mm^2
	Bending	• Compression stress during bending may result in transverse strain in fibres of top face of culm. Lignin in fibres is weak in strain. Coherence in cross-section is lost and EI drops dramatically. • If load removed culm returns to original straight form.	• Timber will not regain original length when load is removed.	• Poisson coefficient for bamboo = 0.3.
4.	Shear	• Shear in neutral layer = 1.3x shear for timber • Smaller thickness to resist shear. • Larger forces on bolt fastnesrs at joints. • Advantage of not having a ray structure is nullified by hollow nature.	• Larger thickness to resist shear. • Has rays. Rays are mechanically weak. Hence, timber material is weaker in shear than bamboo material.	
5.	Torsion	• Better torsional resistance due to circular shape.	• Poorer torsional resistance because of sharp corners.	

Table 1.0 **(Cont'd)**

Property		Bamboo	Rectangular Lumber	Assumptions
6.	Wind Resistance	• Bending stress due to wind is constant over height of culm. • At top (near skin) vessels decrease and cellulose replaces vessels, leading to increase resistance to bending stress.		
7.	Compression	• Because of hollow nature and thus greater distance of solid mass from center, longitudinal shortening is greater and thus greater the likelihood of lateral strain in lignin. • Friction due to clamping at top and bottom of culm reduces lateral strain. • Amount of lignin determines compressive strength not cellulose.	• Solid nature makes for better compres-sion resistance and reduced lateral strain.	
8.	Density	700 – 800kg/m^3	850kg/m^3	

Table 2.0: **Rules of Thumb Factors for Mechanical Properties of Bamboo**

	Bending	Compression	Shear	E
Air-dry bamboo	0.14	0.094	0.021	24
Green bamboo	0.11	0.075		
Ultimate stress (N/mm^2) = Factor x mass/volume (in kg/m^3) Allowable stress $\approx \frac{1}{7}$ x Ultimate stress				

3.3 Earthquake Resistance

Bamboo, being lightweight and hollow, makes it naturally highly resistant to earthquake (because it has high stiffness in relation to its weight). That, it does not shatter at failure means that when the earthquake is over the building can be left standing with relatively minor damage; providing shelter whiles the damage is being repaired. In a 7.5 magnitude earthquake in April, 1961, in Costa Rica, 20 bamboo houses were left standing near the epicenter (Janssen, 2000).

3.4 Bamboo Availability in Ghana

About five species of bamboo are available naturally in Ghana and are found growing in natural forests or homesteads, mainly in the lower half of the country. Of these, only two are of significant construction/ structural use. They are the *Bambusa Vulgaris* and *Bambusa Arundinacea.* The former is more plentiful and grows to a matured size of about 100mm in diameter. The latter (also known as thorny bamboo) can grow much bigger to about 200mm diameter.

No definite information exists on the total availability nationwide, since they are essentially wild-growing. It is believed, however, that should a sustained use be made of the bamboo for building construction beyond the limited used as props and temporary housing as exists presently, they will not be sustainable without a concerted programme of plantation cultivation.

3.4.1 Problems with Ghanaian Bamboos

i) Structure

The available bamboo tends not to be very straight, have variable diameters, culm thickness and show marked tapering. These attributes have a costly effect on preliminary attempts at construction in bamboo, as will be indicated later.

ii) Insect and Fungi Attack

More than anything else, the problem with bamboo is pest and fungi attack. Insect attack is through the relatively softer tissues in the inside wall of the cavity wall and at the budding points in the nodes. Fungi attack is severe when the bamboo is exposed to damp conditions. Various methods exist for prevention of these attacks (Jayanetti and Follet, 1998). They range from the sophisticated modified Boucherie process, through immersion in a boric acid/borax mixture in water, injection and painting with creosote, to hanging in a flowing stream immediately after harvesting for at least a week for the sugary ingredients to be washed out.

Traditional preservation methods also exist such as curing, smoking and lime-washing. The real effects of such traditional methods are not known since they have not been documented and quantified.

4.0 POSSIBLE USES OF BAMBOO IN GHANA

At present, the use of bamboo in construction, apart of temporary structures and buildings in villages, is as props for reinforced concrete floor elements. This restrictive use does not exploit the full potential of bamboo as a construction material. New uses that can be explored locally, as pertains in other countries , are:

(i) Trusses

Fabrication of roof trusses is about the most promising use of bamboos. Literally, any span of truss is possible, and as indicated in Section 5, a Fink truss of about 8.5m span can be carried by three workmen and installed by about 5 workmen. The property of lightweight with strength and stiffness is manifested here. Also, substantial savings in the non-use of heavy lifting equipment results.

(ii) Scaffolding

Bamboo has been used for centuries as scaffolding in Asian countries and, despite competition with many metal scaffolding systems, remains one of the most preferred system in both China and Hong Kong (Fu, 1993). Owing to its high adaptability and low construction cost, it can be constructed to any layout to follow various irregular architectural features of a building within a relatively short period of time (Chung, et al., 2003). They are used in construction sites to provide temporary access, working platforms for construction workers and supervisory staff, and to prevent construction debris from falling on passers-by. In Hong Kong, they are used as Single Layered Bamboo Scaffolds (SLBS) for light work and Double Layered Bamboo Scaffords (DLBS) for heavy work (Chung and Sin, 2002).

Bamboo scaffolding, like any other, must possess integrity and must be laterally stable. The foregoing is ensured by the provision of bracing. The bracing is by two pieces of bamboo fixed in an ‘X’ shape and at an angle of 60^o-70^o over the section of bamboo to be braced. For multi-storey structures it is required to tie the scaffolding to the building often through 6mm Ø mild steel bars (putlogs) pre-fixed to concrete at every floor. A prop is also required between the building and the scaffolding to prevent the leaning of the scaffolding towards the building.

(iii) Disaster Mitigation

The lightness of bamboo, wide availability and possibility of building shelter from modular units lends it for use for post-disaster shelter. A project is in the offing by the UNHCR where temporary shelters are fabricated from A-shaped bamboo support frames with horizontal members at the apex and at mid-heights of the A-frame. A water-proof sheet is draped over this frame for cover.

(iv) Bridges (Jayaneti and Follet, 1998*)*

Bridges attempted consist of:

(a) **<u>Footbridges</u>*:*** Simple cross-braced frames with the walkway formed at the crutch. Culms of 50-75mm diameter are bound by bamboo lashings. They are suited to rivers with muddy or sandy bottoms where the height above bed does not exceed 5m. A typical crossing might be 20m long.

(b) <u>Handcart Bridge</u>: The construction is more elaborate with abutments and pilings. The abutments are formed from pairs of culms staked to the ground. A pair of horizontal culms form the pile cap and diagonal braces stabilize the assembly. To form the roadway, three longitudinal bamboo beams of 100mm Ø are lashed to the caps and tied together at the center of each bay with a cross-member.

5.0 PROPOSED RESEARCH ON BAMBOO TRUSSES AT THE BRRI

It is proposed to carry out research at the BRRI, on full-size bamboo roof trusses to:

(i) Determine the relative strengths and stiffnesses of bamboo as compared to a conventional truss in Ghana using Dahoma.

(ii) Indirectly, determine the Young's Modulus (E) of bamboo by comparing actual load-displacement values with analytical predictions using various values of E (modeling). The predicted E that gives almost exact configuration as the deformed truss will be nearer the actual E value.

(iii) The effect on (i) and (ii) by the use of a plywood gusset plate/steel bolts as fasteners at the joints and plywood gusset plate/dahoma timber dowels.

The span of the truss will be 6.0m and the pitch of the Finkt truss will be 20^{o}. Samples of Bambusa Arundinacea have been identified and consent obtained for their felling. Efforts are on-going to obtain equipment for accurate measurement of the displacement at the nodes. In all, 6 bamboo trusses and 2 timber trusses will be used (Fig. 2.0).

The preservation of the bamboo culms will be by immersion in a 'dursban' (anti-termite) solution in split oil-drum baths. The culms will be pierced longitudinally through their diaphragms to allow maximum penetration of the preservative.

6.0 EXPERIMENTAL BAMBOO CLASSROOM

6.1 Basic Structure (Paudel and Solomon-Ayeh, 2004)

An experimental 3-unit classroom block was constructed at Fumesua, near Kumasi in 2003, to illustrate the use of local bamboo in building. It was a collaborative effort of INBAR/BRRI/TRADA/BARNET/FORIG. The construction was made up of:

i) 3-unit classroom block, each classroom of 7.2m x 6.0m;

ii) a 2.4m wide verandah on one longitudinal side of the building;

from modular a structural skeleton made up of bamboo poles at 1.2m centers in the main building and 2.4m centers on the verandah;

iii) a vertical and horizontal matrix of split bamboo strips, at 150mm centers and lashed to the bamboo poles through 6mm Ø mild steel horizontal dowels embedded in the bamboo poles;

iv) two layers of chicken wire mesh on the outside and inside faces of the poles and lashed to the strips by steel binding wire;

v) a timber (50 x 100mm) wall plate on the tops of the bamboo poles to hold the poles vertically in place and form a seat for bamboo trusses;

vi) a sloping Fink bamboo truss (15^o pitch) of 8.4m span and at 2.4m centers;

vii) a cement:sand mortar mix application to the strip/chicken-wire/pole wall matrix to form a more solid cladding on both sides of the wire mesh;

viii) openings, 1.2m wide, in the walls for windows and doors;

ix) 50x75mm hardwood purlins at 1050mm centres;

x) two toilets (male and female)

xi) aluzinc roof sheet covering.

The floor plan is shown in Fig. 3.0 and parts of the preparation of strips, preservation and construction are shown in Fig.4.0 to 15.0

6.2 Cost

The sub-structure (foundation) of the classroom was similar to that of a traditional sandcrete building, with the exception that vertical mild steel rods were installed in the foundation to act as dowels for the installation of the poles.

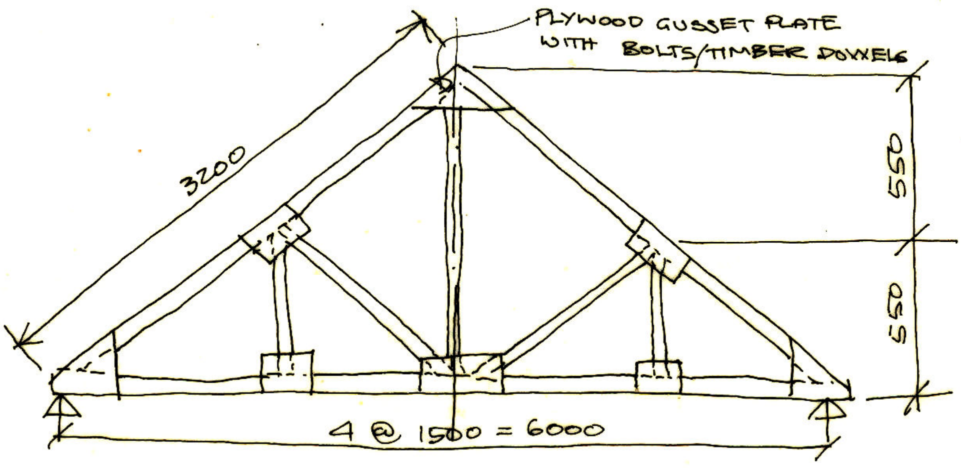

FIG. 2.0 - CONFIGURATION OF TRUSS FOR TESTS

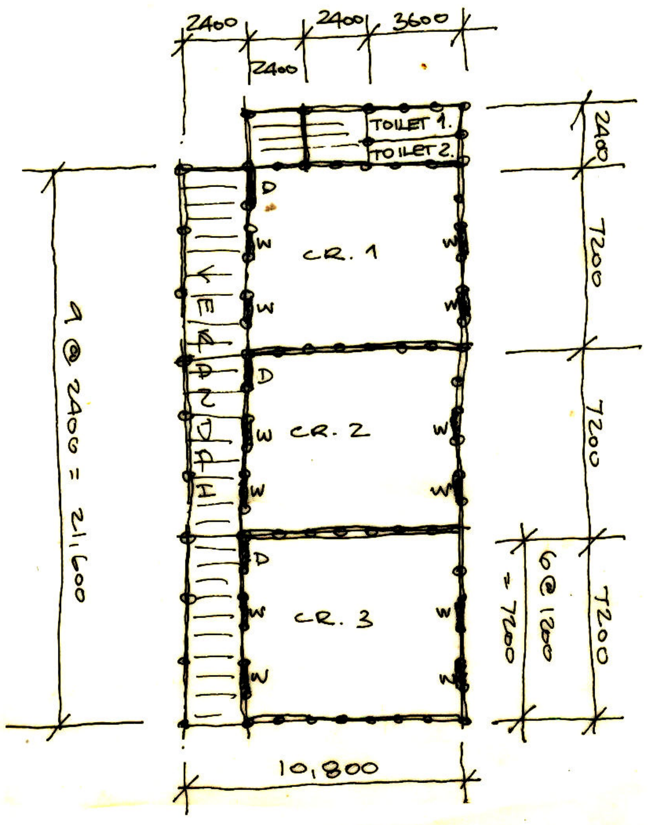

FIG. 3.0 - PLAN OF EXPERIMENTAL BAMBOO CLASSROOMS (FUMESUA, KUMASI)

FIG 4

FIG 5

FIG 6

FIG 7

FIG 8

FIG 9

FIG 10

FIG 11

FIG 12

FIG 13

FIG 14

FIG 15

The building took three months to construct and cost ¢79 million ($9,800), made up of:

		Materials (¢)	*Labour (¢)*	*Labour:Materials*
1.	Preliminaries	-	200,000	-
2.	Substructure	14,582,660	4,520,000	0.31
3.	Superstructure	13,802,000	6,200,000	0.45
4.	Roofing	16,033,200	5,680,000	0.35
5.	Windows/Doors	3,840,000	1,645,000	0.43
6.	Floor screeding	3,230,000	850,000	0.26
7.	Plumbing (2 toilet bowls)	717,000	70,000	0.10
8.	Painting	1,984,000	750,000	0.38
	Total	**54,188,860**	**19,915,000**	
9.	Supervision, transportation, fuel, tools, storage, contingency	4,459,500		
	Grand Total	**¢78,563,360 ($9,800)**		

6.3 Advantages

(i) The cost of the completed building at ¢78.6 million was 60% of that of a sandcrete building of similar dimensions (¢130,000,000/$16,250).

(ii) The construction time was 3 months which was marginally faster than a traditional building. The construction of the pole and strip skeleton was only about 3 weeks; the bulk of the construction time being taken up by roof installation and cement:sand mortar plastering and floor screeding.

(iii) Fabricated trusses were light and were carried to site by three workmen and hoisted into place on the wall plates by five workmen.

(iv) The building is light and has a very comfortable internal ambiance.

6.4 Disadvantages

(i) The lack of straightness and uniform culm thickness presented problems with keeping the poles plumb and in line. This had implication for the mortar use for cladding; much more mortar was used to try to keep the wall as straight as possible and consequently higher labour costs.

(ii) The outer skin of the culm is rich in silica and this easily blunts drill bits.

(iii) The structural use of bamboo for buildings (especially for trusses) being fairly new and coupled with the lack of uniform dimensions requires skilled labour for fabrication initially and also a lot of packing was done to keep the purlins level enough to receive the roofing sheets.

(iv) The cost of labour as a percentage of cost of materials is relatively higher than for the traditional sandcrete and timber truss buildings. For the specific cost centers of wall cladding and roof construction the ratios are 20% and 25% and 45% and 35% for traditional and bamboo buildings respectively. The cost of bamboo buildings can be reduced further if the labour input of these cost centres are reduced; and this will come about with more exposure on such construction.

6.5 Possible Measures to Reduce Costs of Construction

Aside of the use of plantation bamboo to keep the purlins level and the walls more straight, the following were identified as measures that could reduce the overall cost of the bamboo building further:

(i) Grids for the bamboo strip (skeletal support for wall cladding) can be increased from 150x150mm to 200x200mm.

(ii) Chicken wire mesh need be placed on only one side of the strip in (i); mortar plastering of the wall will then need to be plump on the external section of bamboo pole/mesh. The inner surface of the bamboo pole need not be covered in mortar and further, only a thin layer of mortar is needed over the interior section of the bamboo grid, between poles, for smoothening purposes.

(iii) As a consequence of (i). the 6mm∅ steel dowels need only be at 200mm centres.

(iv) Use of plantation bamboo as purlins.

7.0 THE WAY FORWARD

- A lot of the cost of construction in bamboo comes from adopting measures in vertical dowels, jointing and wall cladding to make for the lack of straightness in bamboo culms and the widely varying wall thickness. Plantation bamboo (from cultured cutlings) will have more uniform dimensions and hence make construction planning and fabrication processes cheaper.
- Training of manpower skilled in bamboo fabrication will reduce labour costs and construction time.
- Serious efforts are needed at engendering an industry in prefabricated bamboo units for use in scaffolding, bamboo mat wall cladding, roof trusses and post-disaster shelter.
- For structural use of bamboo, experiments need to be done to establish local strength/mechanical properties of Ghanaian bamboos or, at least, efforts made at collating such data from pieces of experimental work done and those planned and yet to be carried out.
- For a start, useful engineering/design data can be obtained from work carried out in Asia and South America for design purposes.

8.0 CONCLUSION

Mechanical properties that make bamboo a good substitute for timber in some forms of construction have been highlighted and the possible use of bamboo in Ghana have been indicated.

The construction of an experimental bamboo classroom building at Fumesua, Kumasi, indicated that the cost of materials and construction is competitive and can be reduced further if labour costs and construction times are reduced, and construction methods improved. This can come about only with resort to plantation bamboo, a trained skilled labour pool, and the encouragement of an industry in the production of bamboo modular units.

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