Recycling of Bamboo (*Bambusa vulgaris* Schrad) Recovered from Scaffold into Material for Furniture Production

[†]Nureni Adedapo Adewole and Kabirat Omobolanle Bello
Department of Agricultural & Environmental Engineering, Faculty of Technology, University of Ibadan, Nigeria
[†] Corresponding author contacts: an.adewole@mail.ui.edu.ng or dabukyo@yahoo.com ; +234 803 396 3707

Abstract
Interest is growing daily on the utilization of bamboo as a reliable supplement to wood in furniture production to mitigate the scarcity of wood raw material supply. This study explored the viability of recycling bamboo recovered from scaffold into intermediate raw material for indoor furniture production. Strips were processed from the recovered *Bambusa vulgaris* Schrad and were subjected to conventional treatment methods with some modification to simplify the treatment. The durability of the treated strip was evaluated in accordance with ASTM D2017. A storage shelf was designed and fabricated using laminates made from the bamboo strips. The diameter and wall thickness of the recovered bamboo culms ranges from 6.00cm -10.00cm and 10.00mm-12.70mm respectively. The result shows that ordinary soaking of the strips in water for 3 weeks could make the strips to be sufficiently resistant to termite attack but fairly resistant to powder post beetle. Application of kerosene as a secondary treatment will make the resistance of the bamboo strip effective to powder post beetle. A Complete-Knock-Down (CDK) Magazine shelf suitable for office use was fabricated using road side carpentry workshop tools. This study was able to recycle Bambusa vulgaris recovered from scaffolding material into suitable raw material input for the manufacturing of indoor furniture.
Keywords: Scaffolding-bamboo**, R**ecycling Bambusa vulgaris, Strip treatment, CKD-Furniture manufacturing

1. Introduction

It is increasingly difficult to meet human demand for wood supply for diverse end uses in view of the alarming shrinkage in its supply. There have been deliberate efforts to create supplement or alternative to wood whenever possible from plastics, concrete, steel, aluminium amongst others. The provenance of these non-fibrous materials for high environmental hazards, relatively low strength, high cost of procurement and processing, high technological capacity requirement, need for specialized skill and power requirement were the bane of their patronage in developing countries, especially Nigeria (Kumar and Gupta, 2008; Kumar, 2008; Adewole and Olayiwola, 2011). But the un-ending dwindling in wood resource supply to wood based industry continue to underscore the need to think beyond absolute reliance on wood. Meanwhile, some studies have confirmed the effort by China to ameliorated wood scarcity via creation of suitable alternative from many renewable fibrous materials in their locality (Zhang, 1995; Zhao and Yunshui, 2002; Zhong, 2002). The leading fibrous material used is bamboo and the choice was strengthened because of its tremendous economic potential; excellent mechanical, physical and chemical properties.

Apart from China, bamboo utilization as a supplement for wood in furniture industry appears to be gaining marked interest in other Asian countries like Japan, Indian among others. The Asian exploit is thus spurring the interest of researchers in many developing countries that are making efforts to harness the potential of bamboo in their countries. In Nigeria for instance, deliberate efforts have been made to ascertain the commonest and abundant distribution of bamboo in her locality. Reports by INBAR (2001), Onilude (2006) and Adewole and Olayiwola (2011) affirm the wide availability and distribution of *Bambusa vulgaris* in Nigeria but quantitative assessment is yet to be carried out. The *Bambusa vulgaris* Schrad is reported to be an open-clump type bamboo species that matured between 3-4 years (Lam, 1998). The adequacy of strength, versatility and beauty in both natural and finished states of *Bambusa vulgaris* had been investigated by Farrelly (1984); Janssen, (2000**)** and Yan, (2008). The excellent properties shared by *Bambusa vulgaris* Schrad with wood is an indication of its suitability for use in producing household items to enhance rural livelihood in a developing country like Nigeria. Record has shown that it is indeed suitable for the production of innovative items for both commercial and domestic use (Anon, 1990; Bansal and Zoolagud, 2002; Xiaobo, 2002; Adewole and Olayiwola, 2011).

However, its potential remains largely untapped in Nigeria despite its abundance. Knowledge gap on the means of processing it into modern products may be largely responsible for this. Parts of the attributes of *Bambusa vulgaris* is that its fiber is stiffer and stronger than most wood fiber while also attaining maturity in short time (Zhong, 2002). These attributes would particularly present a significant solution to increasing shortage of useful lumber in developing countries. Evidences has shown that bamboo use is still currently of a minor status in Nigeria, as an item for shed making, fence construction, wall reinforcement, pole and furniture production (Plate 1). This uses is common in rural setting and users engaged bamboo mainly in round form without attracting economic value.

Plate 1: Bamboo Reinforced Mud-wall
Source: Anon, 2012.

Aside rural use, the overriding use of *Bambusa vulgaris* in Nigeria is as scaffolding material during modern building construction. Bamboo attracts little economic value when used for scaffolding purpose in Nigerian except that it ended up being wasted after use. But before bamboo is sourced for scaffolding, it is always ensured that it is mature and adequate in strength (Chung and Yu, 2002). Since bamboo that is recoverable from its use for scaffolding would still remain largely strong and fairly dried due to the duration of use, it will likely lend itself to use for production of intermediate raw material applicable in furniture manufacturing. This study intends to leverage on this advantage to manufacture an indoor furniture from bamboo recovered from scaffold use.

2. Materials and Method

Bambusa vulgaris culm recovered from the stock used in a construction site within the University of Ibadan, Ibadan, Oyo State, Nigeria for scaffolding was processed into strips. Plate 2 depicts the processes involved in the strips production from the recyclable bamboo. The modification done to the conventional method is by making 4 treatment schedule viz soaking in water at room temperature, Soaked + 0.5%boric acid; Soaked +1.5%boric acid; Soaked + kerosene. The soaking was for 3 weeks and brush was used to apply kerosene treatment. The efficacy of the treated strips was investigated in accordance with ASTM D2017.The treated strips were air dried to 12-14% moisture content range before laminating on locally fabricated jig to produce bamboo-based intermediate raw material for the furniture manufacturing. A CKD shelf in Figure 1 was designed based on the assumptions that load will be uniformly distributed with each divider acting like a beam and the side panel being a column. If each divider will carry a maximum static load of 300 N assuming the bamboo density ranges from 300- 400kg/m^3, the divider self weight can be obtained using

Plate 2: Procedure for Recycling Scaffold Bamboo into Furniture Raw Material

Figure 1: 3D of the Designed Magazine Shelf

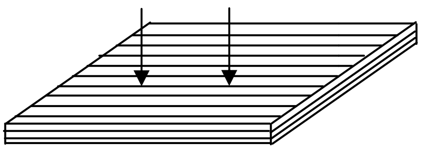

Figure 2: Section of a Typical Divider

Density = Mass / Volume *(Khurmi and Gupta, 2005)* (i)

Take Divider's self weight = 0.996kg, total load= 309.96N, w= $load/span = \frac{309.96}{560} = 0.55 N/mm$

Bending moment= M $= \frac{wl^2}{8}$ *(Khurmi and Gupta, 2005)* (ii)

$$\mathrm{Fb} = \frac{\mathrm{My}}{\mathrm{I}},\ \mathrm{Fb}\left[\frac{\mathrm{I}}{\mathrm{y}}\right] = \mathrm{M},\ \mathrm{Fb.S} = \mathrm{M} \qquad \textit{(Khurmi and Gupta, 2005)} \qquad \text{(iii)}$$

Where w = load (N/mm); L = span of the beam (mm);M = Bending moment (Nmm); S = Section modulus (bd^2/6)(mm³); Fb = Fibre stress in bending (N/mm²); b = breadth of the beam (mm);d = depth of the beam (mm); the volume $=101150mm^3 \geq 9240mm^3$ *and calculated design value is thus acceptable.*

To determine the shear force:

$$\mathrm{bd} = 3V/(2Fv) \qquad \textit{(Khurmi and Gupta, 2005)} \qquad \text{(iv)}$$

Where, b= Width (mm) ;Fv *= Horizontal shear (N/mm²); d= Depth (mm); V= Shear force (N)* $= 154.98N$
Therefore Fv = 0.5535N/mm². Since calculated Fv does not exceed tabulated, the design in Figure 2 is safe. The divider maximum deflection = L/200 = 560/200 = 2.8mm. The actual deflection was computed as 1.32mm using

$$\text{Deflection} = 5wL^4/384EI \qquad \textit{(Khurmi and Gupta, 2005)} \qquad \text{(v)}$$

L= beam span (mm), w= load in N/mm,E= modulus of elasticity,I = moment of inertia(mm⁴); Since 1.32mm < 2.8mm, the dimension of the designed divider is optimum. Also for figure 3, considering a total load of 645.5N, rectangular column with both ends pinned, i.e, le = L = 1200mm and, slenderness ratio = le =1200/ Dmin = 60/20 assuming rest parameters are constants except cpie cm, ct, cf, cd = 1

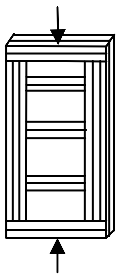

Figure 3: Magazine Shelf Side Panel

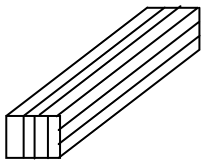

Figure 4: Runner

Plate 3: Bed Hooks Used

$$\mathrm{Cp} = \left(\left(1+\frac{Fce}{Fc}\right) \div 2c\right) - \left(\sqrt{\left(\left(1+\frac{Fce}{Fc}\right) \div (2c)\right)^2} - \sqrt{\left(\frac{Fce}{Fc}\right) \div (c)}\right) \qquad \textit{(NDS, 2005)} \qquad \text{(vi)}$$

$C_{p=}$ column stability factor,

$$\mathrm{Fce} = 0.3E \div \left(\frac{le}{d}\right)^2 \qquad \textit{(NDS, 2005)} \qquad \text{(vii)}$$

K_{CE}=0.3 for visually graded lumber; C = 0.9 glue laminated timber; Fc = 11.2N/mm²

Slenderness ratio equal 37.5mm, Fce = 2.26N/mm² and their ration = 0.2 The allowable stress = 2.19N/mm² greater than calculated stress = 0.056N/mm², therefore the load is safe. For the runner in figure 4 which is to support the divider using 6d bright wire nail to fix it to the side panel, the total load of 155.54N will generate Fb = 2497.5mm³ if loaded uniformly The maximum deflection of 0.16mm is also is less than the maximum allowable deflection from table (0.16mm ≤ 1.5mm) this make the runner dimension appropriate. For the connectors, the parameters of the nails used was determined using:

$$P = KD^{3/2} \qquad \textit{(Wood Handbook,1999)} \qquad \text{(viii)}$$

P = safe load in kg/nail, K= constant dependent on wood sp D= nail diameter in mm; t_s*= side member,* t_m *= main member*
The bed hook used was selected following the guide provided by *Wood Handbook,(1999).* The hook was made from bright steel and 3.5mm diameter screws was recommended by the book for the hook size used and loading configuration. The cutting list of the components of the fabricated magazine shelf is presented in Table 1. Bamboo processing and funiture manufacturing activities were carried out at the Department of Agricultural and Environmental Engineering, University of Ibadan.

Table 1: Cutting List for the Magazine Shelf

Description	**Dimension(mm)**	**Quantity**
Side-panels/ legs	32 x 75 x1200	6
Side connectors	32 x 210 x 1200	8
Back brace	32 x 75 x 415	4
Dividers	17 x 350 x 560	4

3.Results and Discussion

3.1Characteristics of the Recycled Bamboo

The recovery index and other features of the recycled *Bambusa vulgaris* culms are presented in Tables 2. The bamboo were extracted from Igbo Oloyin axis of Ojo in Akinyele Local Government. The matured recycled bamboo has initial moisture content ranged between 23% to 28%. Up to 13% of the total stock of the recovered bamboo was invested with powder post beetle while 6% had suffered physical injury which made them unsuitable for the recycling purpose. Also, about 3.5% were useless because of the defect suffered as a result of cyclc shrinkage and swelling. From the total stock used for scaffold, 79% was recoverable as a suitable input for strip production.

Table 2: Statistics of the Recycled Bamboo Culms

Bamboo Culm Parameters	**Percentage/ Range**
Internode (length)	368 – 432mm
Moisture content(fresh)	$\leq$ 28%
Outer diameter	110 – 120mm
Inner diameter	60 – 70mm
thickness	10- 12.7mm
Bamboo Recovery Index after Splitting	**Values (%)**
Percentage recovered	83.3
Percentage wasted	16.7
Recovery Parameters after Planning &Surfacing	**Percentage/ Range**
Thickness before planning	10-12.7mm
Average laminate thickness after planning	5-8mm
Percentage recovery	50-63%
Percentage wastage	37-50%

3.2 Strips Treatment Modification Result

Bamboo strips are characterized by the presence of starch that attract termites and powder post beetles and this obviously poses limitations on its usage for different applications. It was observed that by merely storing the strips in the laboratory under room condition, the untreated bamboo strip was attacked by powder post beetles as seen in Plate 4. Exposure of the soft epithelia layer that is rich in sugar content must have facilitated the infestation by bio-deteriorating agents. Hence, strip treatment should be carried out immediately, otherwise the strip may have to be stacked upright and without contact with the soil to minimize deterioration. Contrarily, none of the treated strips from all the treatment schedules were attacked by termite or powder post beetle despite as shown in Plate 5 after treatment efficiency evaluation.

Plate 4: Infested Strips before Treatment Plate 5: Treated Strips after treatment efficiency evaluation

3.3 Strips Lamination and Magazine Shelf Fabrication.

After air drying the strips for two weeks, the moisture content reduces about 10%. The laminates were produced using locally manufactured table jig (460 x 600 mm). This size limits the length of the laminate produced and the laminate production process was undertaken in batches. Screw press was adapted for the production of the bamboo plywood that was used to fabricate the shelf dividers. It takes an average of 20mins to set the strips when the strips were glued flat wise using the jig. Preparation of strips for edgewise gluing takes shorter time. Laminates were allowed to condition for 3 days after unloading from the jig to allow the glue line to cure properly. The magazine shelf members were fabricated at the wood processing workshop of the Department of Agricultural and Environmental Engineering, University of Ibadan, typical carpentry equipment and tools. Three dividers were produced from the bamboo plywood (Plate 6) made with strips glued flat-wise. The shelf is a complete knock down piece with bed hooks as the main connector used to connect side panels to the back panel. Bill of Engineering Measurement and Evaluation 'BEME' of the prototype of the bamboo shelf produced is presented in Table 3 and the shelf in unloaded and loaded mode is presented in Plate 6.

Table 3: BEME for the Fabricated Prototype of the Bamboo Magazine Shelf

MATERIAL	COST (Naira)
Bamboo Material Processing Cost	2,750
Sanding Sealer	250
Thinner	200
Sandpaper (P60, P150 & P220)	500
Bed hook and screw	500
Varnish	200
Top Bond	1600
TOTAL	**6, 550**

Plate 6: Manufactured Bamboo Magazine Shelf in loaded and Unloaded Mode

4. Conclusions

The study has been able to recycle bamboo recovered from its use as scaffold material into useful intermediate raw material for the production of indoor furniture. The portion of the used bamboo that was recyclable is 79% and the recovered bamboo had initial maximum moisture content of 24%. Mere soaking of the strips in water under room temperature for 3 weeks while changing the water every 3 days will make the bamboo strips to be resistant to termite attack. However, it is recommended that it should be further treated with kerosene to be adequately resistant to powder post beetle. A prototype of CDK bamboo-based magazine shelf was produced. The prototype costs Six Thousand, Five Hundred and Fifty Naira (₦6,550) and equivalent of forty USA dollars ($40). It was evident that specialized splitting and planning equipment would reduce the time, labour and wastage involved in bamboo processing into strip. Utilization of bamboo in a modern form can further expand employment opportunity in form of creating small entrepreneur businesses in Nigeria. It is therefore recommended that the strength characteristics of the laminate should be investigated.

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