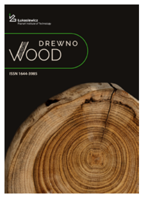
Article citation info:
Icha A.A., Adewole N.A., Asu D.K. 2026. Discrete Element Modelling and Partial Replacement of Metal with Wooden Components in a Mobile Bamboo Stalk Splitter. *Drewno. Prace naukowe. Doniesienia. Komunikaty.* https://doi.org/10.53502/wood-214558

Łukasiewicz Poznań Institute of Technology

Drewno. Prace naukowe. Doniesienia. Komunikaty
Wood. Research papers. Reports. Announcements

Journal website: https://drewno-wood.pl



Discrete Element Modelling and Partial Replacement of Metal with Wooden Components in a Mobile Bamboo Stalk Splitter

Asibong Asibong Icha[a] *
Nureni Adedapo Adewole[b]
Donatus Kekung Asu[a]

[a] Department of Wood Products Engineering, University of Cross River State, Calabar, Nigeria
[b] Department of Wood and Biomaterial Engineering, University of Ibadan, Nigeria

Article info
Received: 24 September 2025
Accepted: 21 November 2025
Published: 13 August 2026

Keywords
agricultural machinery Splitter
ANSYS simulation
performance
Bambusa vulgaris

The preliminary processing of bamboo culm involves ripping and planing it into uniform strips in most modern applications. Existing woodworking machines are quite ill-suited and grossly inefficient in executing this process. Although high-tech industrial facilities may have been built in more developed countries, the excessive cost of the specialised machines has made them inaccessible to potential users in developing countries. In identifying this gap, this study developed a Mobile Bamboo Culm Splitting Machine (MBCSM) suitable for in-situ ripping of bamboo culm at the harvest site to enhance yield and reduce handling challenges. The MBCSM was designed in SOLIDWORKS in accordance with industrial standards. The frame's metallic components were analysed using ANSYS Static Structural Software 2021. While all the materials used in the prototype construction of MBCSM were sourced locally from the study area, the MBCSM metal frame was replaced with Brachystegia eurycoma during construction with a 1hp internal combustion engine, as well as pulley, belt and shaft sizes that can be sourced from the local market. The MBCSM design was made simple enough to be constructed by an operator of a small-scale metal workshop and with a bias for cost effectiveness. The MBCSM was experimentally evaluated by using it to convert bamboo culms with diameters ranging from 60mm to 80mm and a maximum of 400mm length. This study was able to fabricate a prototype of a Wooden MBCSM that is suitable for adoption by a one-person business type at N98,100 (US$211.39) by 2023, with about 68.5% performance efficiency.

DOI: 10.53502/wood-214558
This is an open access article under the CC BY 4.0 license:
https://creativecommons.org/licenses/by/4.0/deed.en.

Introduction

Bamboo has been classified as one of the currently patronised engineering materials globally (Obiri et al., 2020; Ahmad et al., 2021). In Nigeria, it has been reported to be in abundant supply, seldom restricted for harvest and use, making it very cheap to acquire (Onilude 2006; Ladapo et.al., 2017). *Bambusa vulgaris Schrad* had been identified as the dominant available species in Nigeria and found to possess excellent mechanical, physical and chemical properties comparable to those of familiar wood species in the country (Okanlawon et al., 2023). Nevertheless, the major uses of the species had been for several traditional applications and largely used in culm form: local bed constructions, studs and scaffolding in building construction, stacking of crops in farmland, antenna poles, firewood and temporary sheds (Ogunwusi and Onwualu, 2013; Olorunnisola,

* Corresponding author: ichaasibonga@gmail.com

2023). This use has little or no industrial value, and its contribution is insignificant to economic development. In many developed countries such as China or Japan, bamboo has been employed as a supplement for wood in structural and furniture-making industries (RMRDC, 2010; Jamatia, 2012; Okwori and Chado, 2013; Ahmed and Singh, 2018).

Currently, one of the hurdles on the path of harnessing the potential of bamboo culm for modern applications in Nigeria is suitable machines to reduce bamboo culm into uniform strips as a preliminary processing stage. This preliminary processing of bamboo culm entails ripping and planing before further processing into intermediate raw material for modern applications (Adewole et al., 2017; Xia, 2023; Godina Rodriguez, 2023). A rich body of literature has attested to the fact that the existing woodworking machines are quite ill-suited and grossly inefficient in executing the preliminary processes (Qisheng et al., 2002; Omoniyi et al., 2013; Ogunsanwo et al., 2015; Atanda, 2015; Abate and Irfaan, 2016; Fagbayide and Ogedengbe, 2017). The major barrier has been that the woodworking machines, when used in bamboo culm processing into uniform strips, generate far too low recovery and are associated with the generation of huge waste. In another vein, the excessive cost of specialised high-tech industrial facilities that are available in more developed countries has made them inaccessible to potential users in developing countries, including Nigeria (Khoo, 2004; Nor-Azar, 2006; Adewole et al., 2017; Icha and Odey, 2024; Icha et al., 2024)

Nevertheless, there appears to be growing interest in exploring bamboo for modern uses in Nigeria, especially at the cottage-industrial level to create sustainable use for locally available alternative raw material to wood with a view to enabling them to contribute to job creation and economic advancement. Plethora of previous studies on the current means of processing bamboo culm into intermediate raw material in Nigeria have observed that the use of the existing wood working facilities is fraught with avoidable drudgery, generation of huge amounts of waste and consumption of considerable energy with time (Imli, 2003; Adewole, 2016; Adewole et al., 2017; Olorunnisola, 2021; Okokpujie et al., 2020).

This challenge has necessitated the need to develop an affordable and efficient specialised machine that can be used even for cottage processing of bamboo culm for modern uses. The first two stages of the major challenges of adopting bamboo for modern applications are handling from the harvesting location and ripping with enhanced yield (Adewole et al., 2017; Olorunnisola, 2024). These two challenges were established as the concern of this study and hence the decision to explore the possibility of developing a specialised bamboo splitter, which has been reported to be capable of minimising the time of processing operations (Seyoum, 2008). In an attempt to evolve cost cost-effective machine and to resolve handling challenges, this study conceived the development of a Mobile Bamboo Culm Splitting Machine (MBCSM) that is suitable for in-situ ripping of bamboo culm into strips at the place of harvest to enhance yield efficiency.

Materials and methods

1. Materials

The development of a MBCSM entails four interdependent stages. Preliminary information to guide the experimental design of the machine, as well as engineering details of parts that can be purchased off the shelf in the study location, was collected. The conceived MBCSM was graphically designed using SOLIDWORKS software; the designed machine was exported to ANSYS 2021 for structural and mechanical analysis. The MBCSM was constructed using cost-effective materials available within the study area.

2. Parts Design and Material Selection

The basic components were designed using SOLIDWORKS software, with all parts carefully considered during the design process. A metal-framed sheet (1mm) thick was used as the skeletal framework for the construction of the machine. Flat bars (85 x 25mm) were used as beams and columns for structural support of the machine. A large pulley wheel was driven by a combustion engine and required to rotate the pulley belt with a suspender to hold the large pulley of the machine and prevent excessive vibrations.

A cutting blade was inserted between two square bars (20 x 20 mm) to support the blade at the base and at two ends vertically during splitting. A flat bar (30 x 3 mm) was designed to act as a motion stopper for the bamboo culm splitting machine. This helps to prevent the slider from moving further backwards away from the chain used for its sliding motion. A square hollow cross bar (50 x 50mm) was used for the pulley wheel support below the chine wheel. A small sprocket shaft was used to connect the two constrained slider components and the small sprocket to the gear. A push plate is attached to the slider to move the bamboo towards the blade for splitting.

A shaft with a diameter of 65mm was required for the gear chain motion. Three 65mm shafts were needed in total, one for the large pulley and the driving

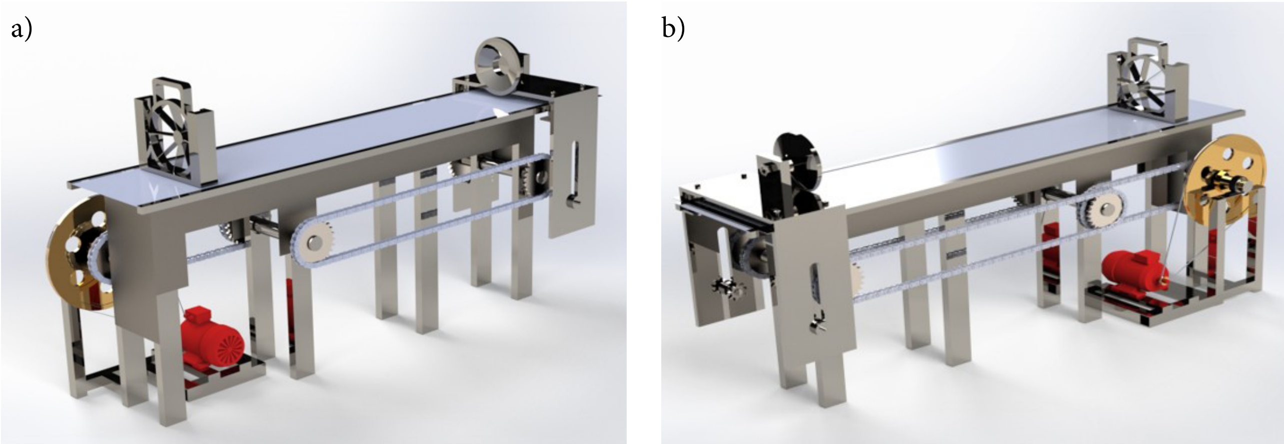


Fig. 1. a) Right view of conceptual design of the Mobile Bamboo Culm Splitting Machine (MBCSM)
b) Left view of conceptual design of the Mobile Bamboo Culm Splitting Machine (MBCSM)

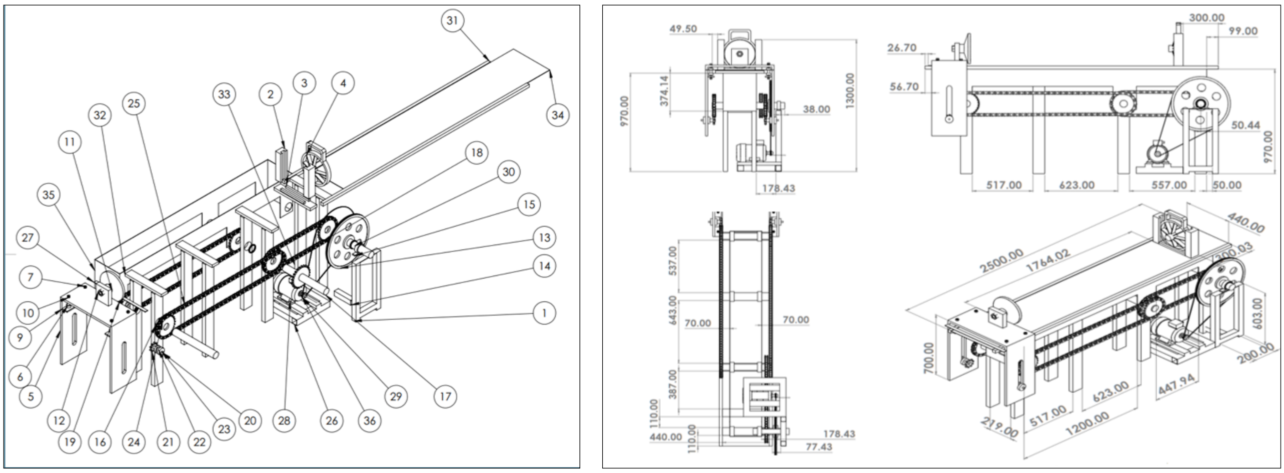


Fig. 2. a) Exploded view of MBCSM showing the arrangement of the major components: 1. big pulley support, 2. bamboo blade support, 3. 20 × 20 mm square bar for bamboo blade support, 4. cutting blade, 5. slider, 6. roller, 7. roller shaft, 8. AFBMA 20.1 - 20-10 - 8, SI,NC,8,68, 9. roller support, 10. B18.2.4.6M heavy hex nut (M12 × 1.75 – W-N), 11. push plate, 12. big pulley wheel, 13. 50 × 50 mm square hollow mild steel cross bar for wheel support, 14. pillow block bearing, 15. 65 mm mild steel shaft for big gear chain motion, 16. chain wheel DIN 8192 - A 25Z 40A-1 -- 25A6SN, 17. gear assembly moving the bamboo slider, 18, 19. constrained slider components (1 and 2), 22. electric motor stand, 23. 30 × 3 mm mild steel flat bar motion stopper, 24. electric motor, 25. small pulley, 26. 65mm mild steel shaft for big pulley wheel, 27. slider frame, and 28. 85 × 25 mm flat bar for structural support
b) Detailed dimensional drawing of the MBCSM showing key measurements for fabrication

chain, while the other two were interlinked along the machine, one carrying two gears and the other three gears for the motion of the slider. The same shaft was required for the large pulley wheel connected to the smaller pulley of the motor. The combustion engine transmitted mechanical energy that drives the large pulley belts and wheels, which in turn rotate the gear assembly, moving the bamboo slider with a stand to provide a base for support and balance. A gear assembly is attached to the slider and undergoes a reciprocating motion while moving along the chain at an optimum speed to exert enough force on the bamboo culm to the blade.

The roller assembly is the combination of a roller, two bearings and a roller shaft provided for the rollers. It is connected to the slider to help suspend the slider and also support the motion of the slider. It is welded to the slider at a suitable distance where the roller can be placed. A slider and slider frame to support the push plate aids in the motion of the push plate as the slider moves along its frame with the aid of the rollers. A top metal sheet is used to cover the structures at the top to give a fine finish. The pictorial views of the machine are shown in Fig. 1. An exploded view and the detailed dimensions of the MBCSM are presented in Fig. 2.

3. Parts Design Considerations

In the analytical design of the MBCSM, consideration was given to the force required to run the machine, the pulley systems, the velocity gear ratio, the speed of gears, the force exerted by the slider, and the chain tension. The parameters appropriate for the machine were determined using established equations as indicated below.

Pulley System and Ratio: The pulley system and ratio were calculated using equation (1) as recommended by Khurmi and Gupta (2005)

$$\frac{d_2}{d_1} \tag{1}$$

Where d_2 = small pulley (diver) diameter, d_1 = big pulley (driven) diameter, d_1 = 500 and d_2 = 100, the speed radiation = $\frac{100}{500}$ = 0.2

Speed of large pulley: The large pulley (driver) speed is calculated using equation (2) as recommended by Khurmi and Gupta (2005)

$$\frac{d_2}{d_1} = \frac{N_2}{N_1} \tag{2}$$

Where N_1 = Large pulley speed, N_2 = small pulley speed; X ratio N_1 = 1000 x 0.2 = 200rpm

Velocity Gear Ratio: The velocity gear ratio was determined using equation (3) as recommended by Khurmi and Gupta (2005)

$$\frac{T_2}{T_1} \tag{3}$$

Where T_1 = Number of teeth on driver, T_2 = Numbers of teeth on driver, Taking T_1 = 25 and T_2 =26, The speed reduction is $\frac{26}{25}$ = 1.04

Speed of Gears: The speed of the driver gear was determined using equation (4) as recommended by Khurmi and Gupta (2005)

$$\frac{d_2}{d_1} = \frac{N_1}{N_2} \tag{4}$$

Where N_1 = speed of driver gear, N_2 = speed of driven gear, $\frac{26}{25} = \frac{200}{N_2}$ = 192.3rpm

Force Exerted by the Slider: The force exerted by the slider was calculated using equation (5).

$$F = 19.812 \text{ x } \frac{v}{t} \tag{5}$$

$$F = 19.812 \text{ x } \frac{V}{t} \tag{5}$$

Where V = velocity, t = time, = 19.812kg x $\frac{2.057 \text{ m/s}}{18}$ = 40.75 kgm/s^2 = 40.75 N

Chain Tension: The chain tension to help select the right chain was determined using equations (6 and 7) as recommended by Iwis (2010).

$$P = \frac{T.V}{1000} \tag{6}$$

$$T = P \text{ x} \frac{1000}{V} \tag{7}$$

P = Power transferred by driver (kw), V = chain velocity (m/s), T = Tension, where electric motor horsepower (hp) = 1, kw = 0.75, torque = 4.1Nm, Rpm = 1000

$$V = \frac{D_1 \pi n1}{60} = \frac{0.19639 \text{ x } \pi \text{ x } 200}{60} = 2.057 \text{ m/s}$$

d = Pitch dimeter, N = Speed of gear = V = 2.057 m/s

$$T = 0.75 \text{ x} \frac{1000}{2.057} = 364.6\text{KN}$$

Chain type is 40A – 1, Chain wheel DIN8192 -A25Z 40A-1 25SA65N

4. Finite Element Analysis

The structural analysis of the MBCSM was carried out using ANSYS static structural software. The stress analysis was carried out on three major parts of the machine (the frame sheet, the cutting blade and the mover/slider as shown in Fig. 3) to see how the material chosen for the machine construction will perform in service. The material properties and boundary conditions established for the simulation process of the frame sheet are shown in Table 1. The material properties and boundary conditions established for the simulation process of the cutting blade are shown in Table 2. The material properties and boundary conditions established for the simulation process of the mover/slider are shown in Table 3. Deformation, maximum and minimum stresses and strain, the factor of safety, and its fatigue life were recorded. The simulation considered all components as solely metallic, hence isotropic. The results of the structural analysis conducted were documented and presented.

Table 1. Boundary Conditions and Material Properties for Frame Sheet Simulation

Geometry Statistics Components	
Nodes	12384
Elements	6387
Mesh Metric	None
Material	
Assignment	Structural Steel
Statistics	
Nodes	12384
Elements	6387
Sizing	
Size Function	Adaptive
Relevance Canter	Fine
Element Size	5.e-003 m
Definition	
Type	Force
Define By	Components
Coordinate System	Global Coordinate System
X Component	0. N (ramped)
Y Component	-200. N (ramped)
Z Component	0. N (ramped)
Suppressed	No
Fixed Support	No
Size Function	Adaptive
Relevance Centre	Fine
Element Size	3.e-003 m
Statistics	
Nodes	229985
Elements	59884
Step Controls	
Y Component	200.75 N (ramped)
Structural Steel > Constants	
Density	7850 kg m^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat Constant Pressure	434 J kg^-1 C^-1
Isotropic Thermal Conductivity	60.5 W m^-1 C^-1
Isotropic Resistivity	1.7e-007-ohm m
Structural Steel Characteristics	
Density	7850 kg m^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat Constant Pressure	434 J kg^-1 C^-1
Isotropic Thermal Conductivity	60.5 W m^-1 C^-1
Isotropic Resistivity	1.7e-007 ohm m
Compressive Yield Strength	2.5e+008 Pa
Tensile Yield Strength	2.5e+008 Pa
Tensile Ultimate Strength	4.6e+008 Pa
Zero-Thermal-Strain Reference Temperature	22^{0}C
Isotropic Relative Permeability	10000
Strength Coefficient	9.2e+008 Pa
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient	1.e+009 Pa
Cyclic Strain Hardening Exponent	0.2
Young’s Modulus	2.e+011 Pa
Poisson’s Ratio	0.3
Bulk Modulus	1.6667e+011 Pa
Shear Modulus	7.6923e+010 Pa

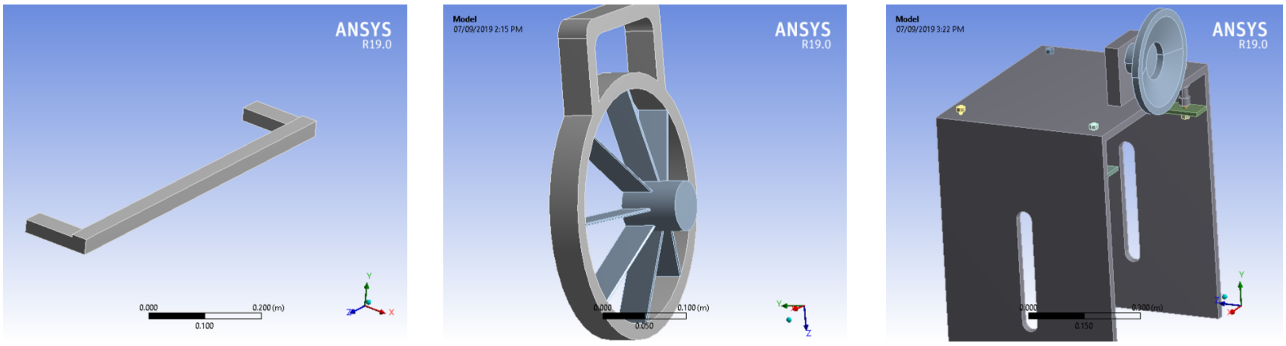


Fig. 3. Finite Element Model (FEM) of critical parts of the MBCSM using ANSYS:
(a) frame sheet, (b) cutting blade, and (c) slider

Table 2. Boundary Conditions and Material Properties for Cutting Blade Simulation

Strain-Life Parameters	
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.5e+008 Pa
Tensile Yield Strength	2.5e+008 Pa
Tensile Ultimate Strength	4.6e+008 Pa
Strength Coefficient	9.2e+008 Pa
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient	1.e+009 Pa
Cyclic Strain Hardening Exponent	0.2
Isotropic Elasticity	
Young's Modulus	2.e+011 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+011 Pa
Shear Modulus	7.6923e+010 Pa

4. Machine Fabrication and Evaluation

The evolved design of the MBCSM was fabricated at the metal workshop of the Hope Waddle Training Institute, Calabar, Nigeria. The top of the frame was made with *Brachystegia eurycoma* wood with dimensions (800x600x775) mm, with a 6mm corner angle steel bar (50x50) mm placed on the wood to serve as the conveying surface. The tabletop was (50x600x800) mm. The shaft length was 560mm with a 35 mm diameter round bar of 145mm length beater and the 110mm length beater on the blade side, with 305mm between them. The pulley diameter (driver) was 70mm and the outer diameter of the bearing was 50mm, while the inner 30mm. The diameter of the motor's pulley (drive) was 200mm, and the wooden frame constructed for the machine and other construction components are shown in Fig. 4. The shaft was placed horizontally under the tabletop with the pulley. The parts of the machine were assembled and finished.

The developed machine parts were evaluated theoretically with a computer-aided design tool, and their efficiency was practically evaluated with harvested bamboo culms from the study locality. For the theoretical evaluation of the machine members, the interface for the experimentation was activated and set up based on the procedure for evaluating stress and deformation on each of the critical members during loading in the meshing of the design that was automatically

Table 3. Boundary Conditions and Material Properties for Frame Sheet Simulation

Structural Steel > Geometry Properties	
Volume	2.2355e-002 m³
Mass	175.49 kg
Structural Steel > Sizing	
Size Function	Adaptive
Relevance Centre	Fine
Element Size	3.e-003 m
Structural Steel > Statistics	
Nodes	1018508
Elements	564136
Type	Force
Y Component	200.75 N (ramped)
Structural Steel > Constants	
Density	7850 kg m^-3
Isotropic Secant Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat Constant Pressure	434 J kg^-1 C^-1
Isotropic Thermal Conductivity	60.5 W m^-1 C^-1
Isotropic Resistivity	1.7e-007 ohm m
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.5e+008 Pa
Tensile Yield Strength	2.5e+008 Pa
Tensile Ultimate Strength	4.6e+008 Pa
Strain-Life Parameters	
Strength Coefficient	9.2e+008 Pa
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Cyclic Strength Coefficient	1.e+009 Pa
Cyclic Strain Hardening Exponent	0.2
Structural Steel > Isotropic Elasticity	
Young's Modulus	2.e+011 Pa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+011 Pa
Shear Modulus	7.6923e+010 Pa

Fig. 4. Stages in the fabrication process of the Mobile Bamboo Culm Splitting Machine (MBCSM). (a) Locally sourced machine parts and components, including chains, sprockets, and gears; (b) machining of shafts for the gear and pulley assembly. (c) Wooden and mild-steel structural frame under construction; assembled frame with chain and gear mechanism mounted

carried out using SOLIDWORKS. The machine ripping efficiency was determined using the machine to rip bamboo culms of diameters ranging from 60-80 mm and 400 mm as the maximum length.

Results and discussion

1. Simulation Analysis of the Steel Frame Component

Table 4 shows the results of structural analysis carried out on the frame sheet of the MBCSM when a force of 200.75N is applied. The directional deformation, the Elastic strain equivalent, the von Mises stress and total deformation are presented at minimum and maximum levels. The directional deformation values of the frame sheet of the MBCSM, which indicate the amount by which the object changes in shape in a particular direction, range from a minimum of -7.9569e-007 m to a maximum of 1.6332e-006 m with an average value of 3.4658e-007 m. The equivalent elastic strain of the frame sheet, which measures the ratio of deformation to the original length of the machine and provides an indication of its elasticity, ranges from a minimum of 5.1178e-008 to a maximum of 2.0782e-005 with an average of 5.1532e-006. The von Mises stress experienced values of the frame sheet, which indicates the

Table 4. Simulation Results on the Frame Sheet

Object Name	Directional Deformation	Equivalent Elastic Strain	Equivalent Stress	Total Deformation
Minimum	-7.9569e-007 m	5.1178e-008	6361.8 N/m^2	0. m
Maximum	1.6332e-006 m	2.0782e-005	4.1564e+006 N/m^2	2.8548e-005 m
Average	3.4658e-007 m	5.1532e-006	9.7846e+005 N/^{m}2	1.3057e-005 m

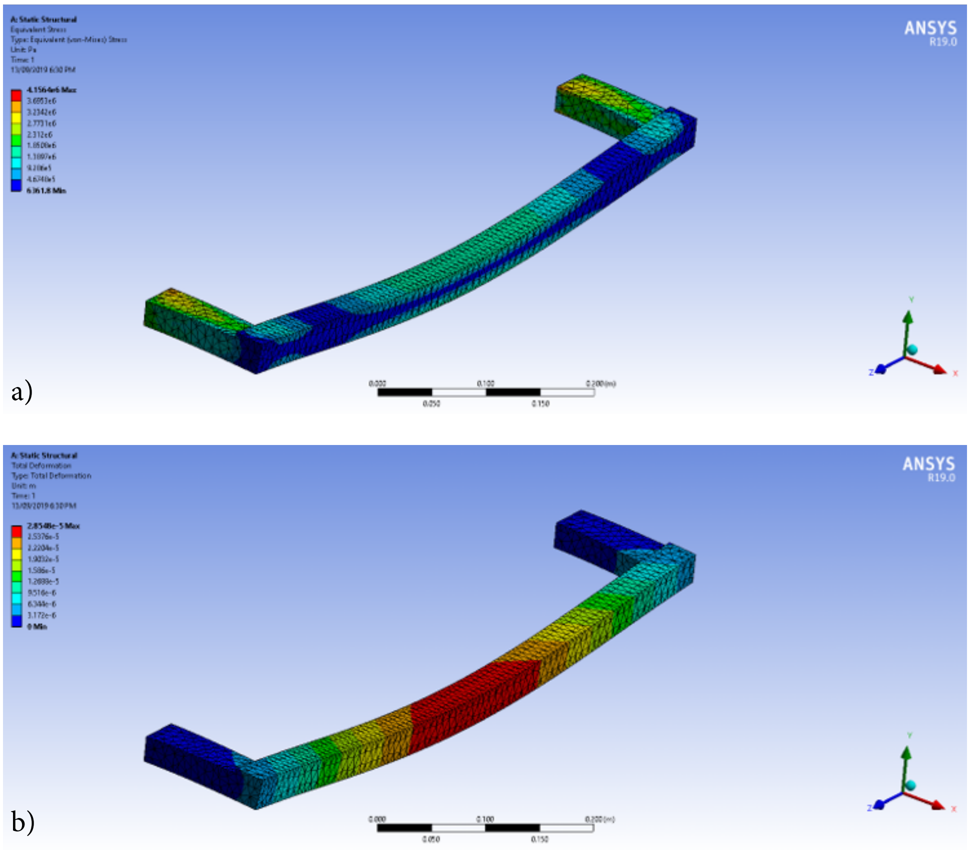


Fig. 5. Simulation results for the steel frame element of the MBCSM: (a) stress distribution and (b) corresponding deformation under applied loading conditions

internal forces acting on the machine, resulting from external loads or deformation, range from a minimum of 6361.8 N/m2 to a maximum of 4.1564e+006 N/m2 with an average of 9.7846e+005 N/m2. The total deformation on the frame sheet is presented at a maximum of 2.8548e-005 m and an average of 1.3057e-005 m.

Fig. 5 shows a schematic representation of the stress and deformation analysis of the frame structure of the MBCSM. For Fig. 5a, it is observed that stresses are higher on the leg area of the frame structure, with moderate distributions at the sides of the middle frame structure. The centre area of the frame structure shows lower distributions. For Fig. 5b, a high tendency to deformation is observed at the middle area of the frame structure, reducing as it moves away from the centre and toward the leg areas. However, there was no failure of the steel frame structure as analysed.

2. Simulation Analysis on the Steel Cutting Blade Structure

Table 5 presents the result of structural analysis carried out on the steel cutting blade of the MBCSM when a force of 200.75N is applied. The total deformation, equivalent elastic strain, the von Mises stress and the equivalent stress are presented at minimum and maximum levels. The total deformation values of the steel cutting blade, which indicate the amount by which the object changes in shape in a particular direction, range from a minimum of 0 m to a maximum of 1.0682e-007 m with an average value of 1.2918e-008 m. The equivalent elastic strain of the steel cutting blade, which measures the ratio of deformation to the original length of the machine and provides an indication of its elasticity,

Table 5. Simulation Results on the Steel Cutting Blade

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress
Minimum	0. m	8.4147e-012	4.956e-008 N/m^2
Maximum	1.0682e-007 m	2.3053e-006	4.6106e+005 N/^{m}2
Average	1.2918e-008 m	4.956e-008	9610.2 N/^{m}2

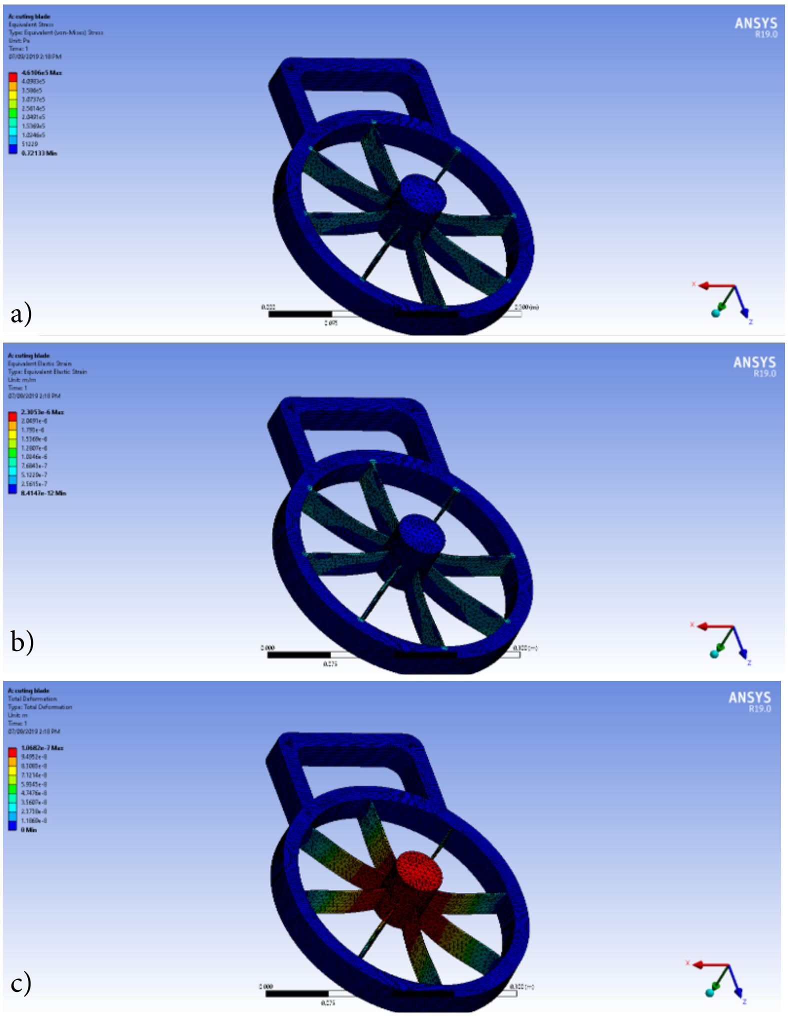


Fig. 6. Simulation analysis of the cutting blade: (a) stress distribution, (b) strain distribution, and (c) deformation profile indicating points of maximum deflection

ranges from a minimum of 8.4147e-012 to a maximum of 2.3053e-006 with an average of 4.956e-008. The von Mises stress experienced values of the cutting blade, which indicates the internal forces acting on the machine, resulting from external loads or deformation, range from a minimum of 4.956e-008 N/m2 to a maximum of 4.6106e+005 N/m2 with an average of 9610.2 N/m2.

Fig. 6 (a, b, c) illustrates the schematic diagrams of the stress, strain and deformation analysis on the steel cutting blade. For Fig. 6a, the von Mises stress shows maximum stress at the cutting angles where the bamboo culm intersects with the cutter. The joint between the blade and the circumference appears to have a slightly higher stress distribution than the blade itself. The von Mises stress is least at the outer circumference of the cutter blade. For Fig. 6b, the strain distributions are similar to those displayed by the stress diagram. However, the displayed values are less than those of the stress. The total deformation diagram (Fig. 6c) shows maximum values at the centre of the blade spreading towards the cutters to the circumference in decreasing order. Minimum values are also found at the circumference of the blade. However, there was no failure of the steel cutting blade structure as analysed.

3. Simulation Analysis on the Steel Slider Structure

Table 6 presents data of structural analysis carried out on the Mover/Slider structure of the MBCSM when a force of 200.75N is applied. The total deformation, equivalent elastic strain, the von Mises stress and the equivalent stress are presented at minimum and maximum levels. The total deformation values of the steel cutting blade, which indicate the amount by which the object changes in shape in a particular direction, range from a minimum of 0 m to a maximum of 7.5761e-007 m with an average value of 7.9161e-008m. The equivalent elastic strain of the Mover/Slider structure, which measures the ratio of deformation to the original length of the machine and provides an indication of its elasticity, ranges from a minimum of 0 to a maximum of 1.5786e-006 with an average of 1.5786e-006. The von Mises stress experienced values of the mover/slider structure, which indicates the internal forces acting on the machine, resulting from external loads or deformation, range from a minimum of 0 N/m2 to a maximum of 2.9324e+005 N/m2 with an average of 3254.9 N/m2.

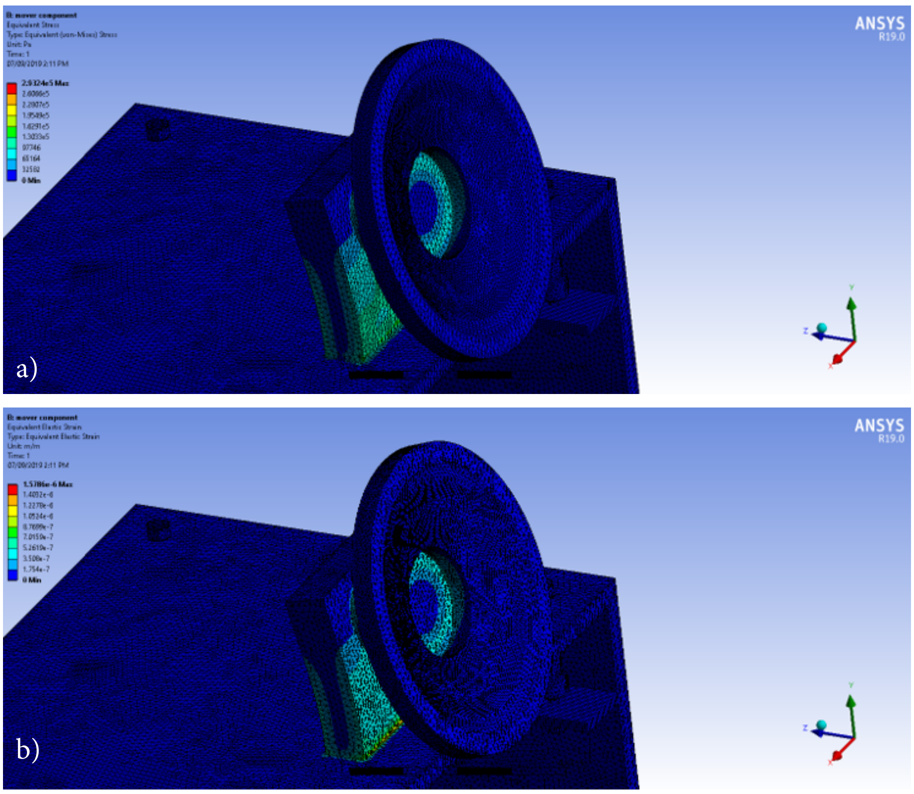
Fig. 7 (a, b, c) illustrates the schematic diagrams of the stress, strain and deformation analysis on the push plate and slider structure. For Fig. 7a, the von Mises stress distribution indicates maximum stress at the push nub; other areas portray minimum stress distribution. Similar observations are found on the strain distribution of the push nub components (Fig. 7b). However, more strain values are observed at the joint between the slider and the push nub, causing a slight displacement backwards. For the total deformation (Fig. 7c), the upper tip of the push plate shows the highest distribution of deformation, decreasing towards the centre and to the push nub. The joints between the push nub and the slider portray the least deformation distribution. Generally, the slider is observed to have low stress, strain and deformation distributions (Fig. 7d, e, f).

4. Fabrication: Materials, Production Cost and Efficiency

From the generated details, the components of the designed MBCSM were bought and fabricated as indicated in the prepared bill of quantities for the

Table 6. Simulation Results on the Push Plate and Slider

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress
Minimum	0. m	0	0. Pa
Maximum	7.5761e-007 m	1.5786e-006	2.9324e+005 Pa
Average	7.9161e-008 m	1.5786e-006	3254.9 Pa



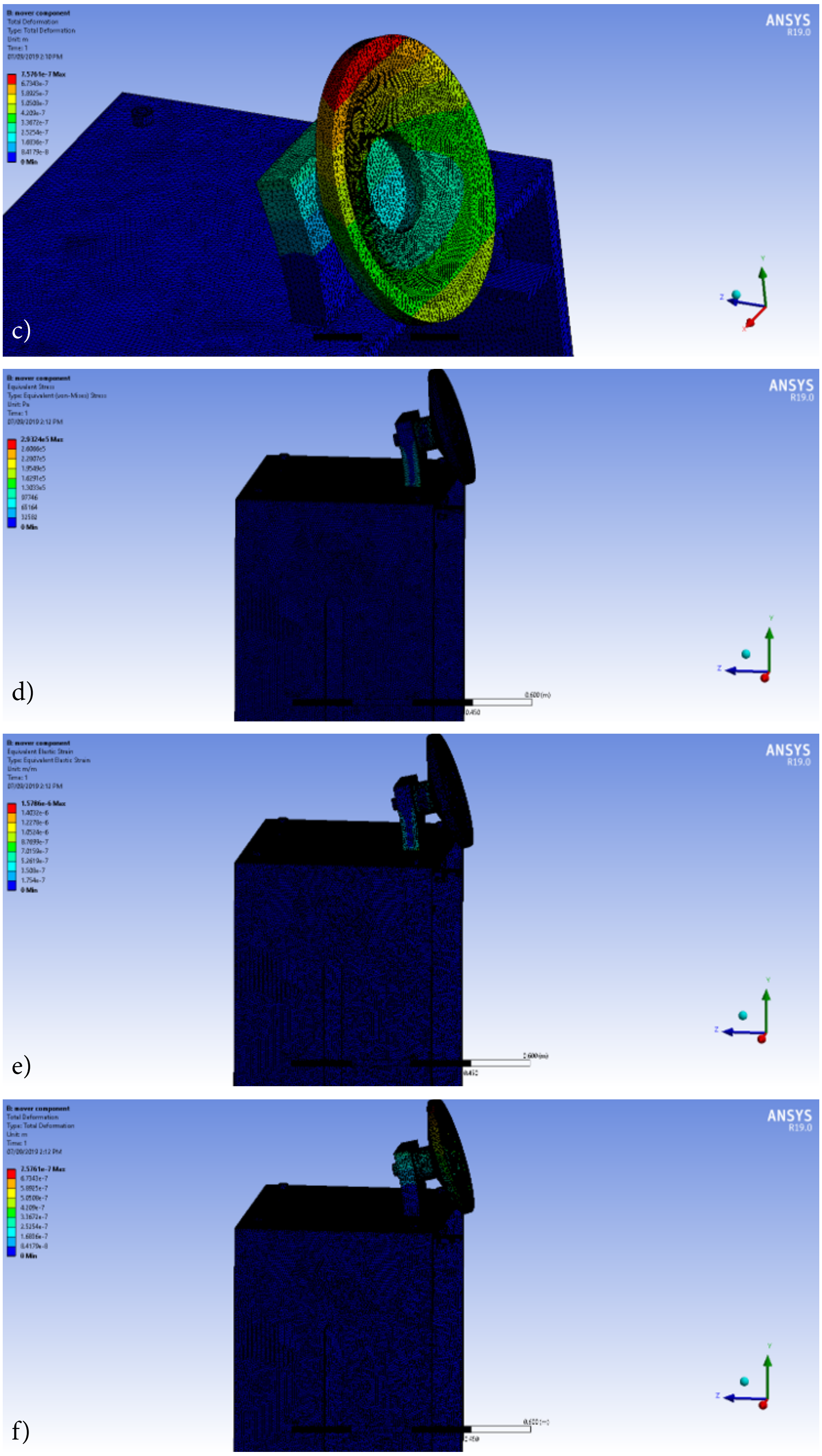


Fig. 7. Simulation results for the push plate and slider assembly: (a, d) stress distribution, (b, e) strain distribution, and (c, f) deformation contours, highlighting critical load-bearing regions

machine in Table 7. The components were assembled. The fabrication and assembly processes were simple enough for a typical one-person business type operating a metal workshop to carry out at a prototype cost N98,100 (US$211.39) in 2023. Nevertheless, to import an equivalent machine from any Asian country at the same period, one will need not less than US$4,500. The assembled Wooden MBCSM is presented in Figure 8.

Table 7. Material and Labour Cost of Fabricating WBCS

Description of Item	Qty	Unit	Rate	Amount
Electric Motor	1	No	30,000	30,000
2” x 4mm angle bar	2	Lengths	3,000	6,000
50 x 100mm Wood (camwood)	3	Lengths	2,000	6,000
25 x 150mm wood (camwood)	1	Lengths	1,500	1,500
Complete Clutch axis	1	Set	2,500	2,500
Machine Shaft	4	Pieces	1,000	4,000
Small Sprockets	5	Pieces	300	1,500
Small motorcycle Sprockets (3”)	1	Pieces	1,000	1,000
Big motorcycle Sprockets (6”)	3	Pairs	3,000	9,000
Complete machine gear	10	Pieces	200	2,000
Drilling Pen	1	Pack	800	800
Screw nails	3	Pairs	1,500	4,500
Bearings	7	Pieces	300	2,100
Paint	4	tin	500	2,000
Painting brush	2	Nos	100	200
Transportation				5,000
Workmanship				20,000
TOTAL				**98,100**

5. Machine Ripping Efficiency

The developed machine converted with ease bamboo culms of varying dimensions of 60mm to 80mm in diameter and a maximum of 400mm long into splits shown in Fig. 8. The mobile BCSM was run only under loading. The performance efficiency of the developed mobile BCSM was 68.5% and was suitable for medium-capacity work. It is also suitable for use as workshop equipment for engineering teaching and research. The ripping efficiency obtained for practical experimentation is 87%.

The design of the MBCSM prioritised affordability and mechanical feasibility using locally sourced materials to satisfy the need for a cost-effective solution for small-scale operators. While the machine's functional quality is validated by its high ripping efficiency of 87% and confirmed structural integrity of metallic components via FEA, its low production cost of N98,100 means that it does not inherently include the costs associated with full industrial occupational safety compliance and detailed regulatory documentation. Moving this project from a prototype to commercial scaling would require mandatory incorporation of legal compliance measures, formal risk assessments, the inclusion of specified guarding (fixed and movable), and the preparation of comprehensive technical documentation and maintenance instructions.

Conclusions

This study was able to design and fabricate a mobile bamboo splitting machine using locally sourced and available materials. The performance evaluation on the wooden MBCSM indicated that it converted an average of 60 culms of bamboo of varying diameter, 40mm to 60mm and a maximum length of 400mm per hour. The machine was operated by a 1hp internal combustion engine at a speed of 192.3rpm. The MBCSM performed optimally with a determined efficiency of about 68.5% at a production cost of N98,100, an equivalent of US$211.39. The estimated cost of the full-scale machine is N223,100.00, equivalent to US$617.99 as of 2020. The Mobile BCSM, due to its simplified, cost-effective design suitable for local

Fig. 8. Prototype of the Mobile Bamboo Culm Splitting Machine during field evaluation with bamboo culms of varying diameters, demonstrating its operational performance

fabrication, is suitable for small-scale operation at an affordable cost to potential users in Nigeria and also serves as a teaching aid in institutions and research facilities. It is recommended that the project be fully scaled during production for commercial use, at which time all required occupational safety and production planning costs must be integrated to ensure full regulatory compliance. Further research could focus on comparing model and empirical test results for the developed prototype. Also, designing machines for processing bamboo and other useful industrial plants using modern modelling methods.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

References

Abate, K. M., & Irfaan, M. (2016). Designing and Manufacturing of Bamboo Processing Machine. International Journal of Advanced Engineering Research and Science, 3(11), 236929. https://dx.doi.org/10.22161/ijaers/3.11.33

Adewole, N. A. (2016). Challenges of using carpentry personnel and workshop facilities for bamboo culm processing into modern products in Ibadan, Oyo State. Journal of Agriculture, Socioeconomics and Sustainable Environment, 4(2), 24–32.

Adewole, N. A., Etta, P. N., & Ibor, B. B. (2017). Characteristics of selected properties of parquet laminate produced from Bambusa vulgaris Schrad harvested from Akamkpa Local Government Area, Calabar, Nigeria. International Journal of Emerging Trends in Engineering and Development, 3(7), 183–192. http://www.rspublication.com/ijeted/ijeted_index.htm

Ahmad, Z., Upadhyay, A., Ding, Y., Emamverdian, A., & Shahzad, A. (2021). Bamboo: Origin, habitat, distributions and global perspective. In Biotechnological Advances in Bamboo: The "Green Gold" on the Earth (pp. 1-31). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-16-1310-4_1

Ahmed, D., & Singh, B. (2018). Design and manufacturing of bamboo processing machine with sanding bamboo surfaces, grinding knots & splitting functions. International Research Journal of Engineering and Technology, 10(5), 1404–1413.

Atanda J. (2015). Environmental impacts of bamboo as a substitute constructional material in Nigeria. Case Studies in Construction Materials. 3 33- 39. https://doi.org/10.1016/j.cscm.2015.06.002

Fagbayide, S., D., & Ogedengbe, K. (2017). Effect of bamboo (Bambusa vulgaris (Schrad)) basic joint principles and techniques for irrigation and drainage network water supply system in agricultural systems. International Journal of Agriculture and Food Science. 6(17):1037-1045. https://eprints.federalpolyilaro.edu.ng/701/

Godina Rodriguez, M. C. (2019). Design framework for bamboo culms—a study of bamboo reciprocal structures [Doctoral dissertation, University College London]. UCL Discovery. https://discovery.ucl.ac.uk/id/eprint/10080507/

Icha, A. A., & Odey, S. O. (2024). Modelling and simulation of a tenoning jig to predict performance and failure mode on a circular saw machine. International Wood Products Journal, 15(1), 44–54. https://doi.org/10.1177/20426445241226534

Icha, A., Odey, S., & Ekpe, H. (2024). A finite element approach to investigate the performance and reliability of an extension stand in table saw machines. Wood Industry and Engineering, 6(2), 1–13. https://dergipark.org.tr/en/pub/wie/issue/89190/1503930

Imli, T. N. (2003). Bamboo processing machine (Arulepsa). India.

Isukuru, E. J., Ogunkeyede, A. O., Adebayo, A. A., & Uruejoma, M. F. (2023). Potentials of bamboo and its ecological benefits in Nigeria. Advances in Bamboo Science, 4, 100032. https://doi.org/10.1016/j.bamboo.2023.100032

IWIS. (2010). Handbook for chain engineering design and construction: Examples of calculation. https://www.iwis.com/as-handbook/iwis-handbook-for-chain-engineering-design-and-construction.pdf

Jamatia, S. (2012). Livelihood of the bamboo base: Challenges and opportunities. In Proceedings of the 54th Society of Wood Science and Technology Conference on Sustainable Development of Wood and Biomass in Our New Global Economy (p. 20). International Bamboo and Rattan.

Khurmi, R. S., & Ghupta, K. K. (2005). A textbook of machine design (SI unit). Eurasia Publishing House.

Ladapo, H. L., Oyegoke, O. O., & Bello, R. O. (2017). Utilization of vast Nigeria's bamboo resources for economic growth: A review. Journal of Research in Forestry, Wildlife and Environment, 9(2), 29–35. https://www.ajol.info/index.php/jrfwe/article/view/158945

Obiri, B. D., Oduro, K. A., Obeng, E. A., Pentsil, S., & Appiah-Kubi, E. (2020). Bamboo value chain study. International Bamboo and Rattan Organisation. https://www.inbar.int/wp-content/uploads/2020/10/Oct-2020_WARO_Bamboo-Value-Chain-Study-Ghana-1.pdf

Ogunwusi, A., & Onwualu, A. (2013). Prospects for multi-functional utilisation of bamboo in Nigeria. Chemistry and Materials Research, 3(8), 58–70. https://core.ac.uk/download/pdf/234666186.pdf

Ogunsanwo O. Y., Terziev N., Panov D., & Daniel G. (2015). Bamboo (Bambusa vulgaris Schrad.) from moist forest and derived savanna locations in South West Nigeria – Properties and gluability. BioResources. 10(2): 2823-2835. DOI: 10.15376/biores.10.2.2823-2835

Okanlawon, F. B., Olaoye, K. O., Badmus, M. O., Ogunbamowo, P. O., Areo, O. S., & Adelusi, F. T. (2023). Farmer's willingness to adopt bamboo (Bambusa vulgaris) in agroforestry along selected areas in Ido Local Government Area, Oyo State, Nigeria. Agro-Science, 22(3), 67–71. https://www.ajol.info/index.php/as/article/view/282002

Okokpujie, I. P., Akinlabi, E. T., & Fayomi, O. O. (2020). Assessing the policy issues relating to the use of bamboo in the construction industry in Nigeria. Heliyon, 6(5), e04042. https://doi.org/10.1016/j.heliyon.2020.e04042

Okwori, R. O., & Chado, M. D. (2013). Nigeria and bamboo plants as a forest product. Journal of Agriculture and Veterinary Science, 3(6), 55–59.

Olorunnisola, A. (2024). Recent Advances in Bamboo Research, Product Development and Utilisation in Nigeria. Bamboo-Recent Development and Application. http://dx.doi.org/10.5772/intechopen.109199

Olorunnisola, A. O. (2023). The past, present and future outlook of the wood industry in Nigeria. In Wood industry—Past, present and future outlook. IntechOpen. https://doi.org/10.5772/intechopen.105794

Olorunnisola, O. A. (2021). Potentials of wood, bamboo and natural fibre-reinforced composite products as substitute materials for fabricating affordable agricultural equipment and processing machines in Africa. IntechOpen. https://doi.org/10.5772/intechopen.98265

Omoniyi T. E., Akinyemi B. A., & Olusoji A. O., (2013). Development of bamboo – Rice husk ash and cement mixture for livestock house roofing sheets. American Journal of Scientific and Industrial Research. 4(2):201-209

Onilude, M. A. (2006). Potential of bamboo as raw materials for the wood industries in Nigeria. Department of Agricultural and Environmental Engineering, University of Ibadan.

Qisheng, Z., Shenxue, J., & Yongyu, T. (2002). Industrial utilization on bamboo. Beijing, China: International network for bamboo and rattan. https://www.aha-kh.com/wp-content/uploads/2022/01/1-inbar-industrial-utilisation-on-bamboo.pdf

Raw Materials Research and Development Council (RMRDC). (2010). Report of the multi-disciplinary survey on wood and wood product (p. 210). RMRDC Publication.

Seyoum, K. (2008). Testing of two Ethiopian bamboo species for value-add products. Addis Ababa, Ethiopia.

Xia, Y. (2023). Drying and heat treatment process of bamboo strips [Doctoral dissertation, University of British Columbia]. https://doi.org/10.14288/1.0427377