Mahadi Mussa*, Lamesa Abara, Misganaw Wale, Tsegaye Wubushet,
Samson Waktole, Getachew Mezgebu, Getachew Desalegn, Daniel Gebeyehu[1]

Development of Laminated Bamboo Lumber from Lowland Bamboo (*Oxytenanthera abyssinica*) Culms Grown in Pawe, Ethiopia

Izrada lamelirane građe od stabljika nizinskog bambusa (*Oxytenanthera abyssinica*) uzgojenoga u Paweu, Etiopija

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 21. 9. 2024.
Accepted – prihvaćeno: 8. 7. 2025.
UDK: 582.546.2; 674.11
https://doi.org/10.5552/drvind.2025.0230

© 2025 by the author(s).
Licensee University of Zagreb Faculty of Forestry and Wood Technology.
This article is an open access article distributed
under the terms and conditions of the
Creative Commons Attribution (CC BY) license.

ABSTRACT • *The aim of this paper was to develop laminated bamboo lumber (LBL) from the two-culm position of Oxytenanthera abyssinica (O. abyssinica) and to examine its basic physical and mechanical characteristics. Samples of lowland bamboo (O. abyssinica) culms were selected and harvested from Pawe Agricultural Research Center site, Pawe, Ethiopia. Three-ply LBL samples were fabricated using urea formaldehyde resin, and then sample specimens were prepared from the fabricated LBL, and the selected basic properties were tested including density, static bending, impact bending and hardness strengths. The result depicted the mean values of density (863 kg/m^3), modulus of elasticity (15743 N/mm^2), modulus of rupture (149 N/mm^2), impact bending strength (18633 Nm/m^2), and side hardness (3145 N) obtained in the fabricated LBL of O. abyssinica culm. The results revealed that density and the tested mechanical properties in this study were significantly affected by culm position in the culm height, with the exception of the impact bending, which was not affected by culm position. Superior density and strength performances were observed in the middle position of bamboo compared to the bottom position. The laminated bamboo lumber produced from O. abyssinica culm has the potential to be utilized as a substitute for wood material in building and other end products.*

KEYWORDS: *culm position; density; hardness; modulus of elasticity; modulus of rupture*

SAŽETAK • *Cilj ovog rada bio je napraviti lameliranu građu od bambusa (LBL), i to od dva dijela stabljike Oxytenanthera abyssinica (O. abyssinica), i ispitati njezina osnovna fizička i mehanička svojstva. Uzorci stabljike nizinskog bambusa (O. abyssinica) odabrani su i ubrani s lokacije Poljoprivrednoga istraživačkog centra Pawe u Paweu u Etiopiji. Troslojni uzorci LBL-a izrađeni su upotrebom urea formaldehidne smole te su ispitana ova osnovna svojstva: gustoća, čvrstoća na savijanje, čvrstoća na udarce i tvrdoća. Za lameliranu građu od stabljike bambusa dobivene su ove srednje vrijednosti: gustoća 863 kg/m^3, modul elastičnosti 15 743 N/mm^2, modul loma*

* Corresponding author
[1] Authors are researchers at Ethiopian Forestry Development, Forest Products Innovation Center of Excellence, Addis Ababa, Ethiopia. https://orcid.org/0000-0002-4276-5760

149 N/mm², čvrstoća na udarce 18 633 Nm/m² i bočna tvrdoća 3145 N. Rezultati su pokazali da na gustoću i ostala testirana mehanička svojstva znatno utječe položaj uzorka s obzirom na visinu stabljike, osim na čvrstoću na udarce. Izrazito bolje vrijednosti gustoće i čvrstoće uočene su u uzoraka uzetih sa sredine stabljike u usporedbi s uzorcima s njezina donjeg dijela. Lamelirana građa proizvedena od bambusove stabljike može biti zamjena za drvni materijal u graditeljstvu i za proizvodnju drugih gotovih proizvoda.

KLJUČNE RIJEČI: *položaj na stabljici; gustoća; tvrdoća; modul elastičnosti; modul loma*

1 INTRODUCTION
1. UVOD

Bamboo is classified under the taxonomic groups of the Bambusoideae subfamily and the Gramineae family. According to Vorontsova *et al.* (2016) and Srivaro (2018), bamboo species are naturally found throughout the world's tropical, subtropical, and mid-temperate regions. All over the world, there are around 1,600 bamboo species under 90 genera covering about 36 million hectares (Khalil *et al*., 2012; Vorontsova *et al*., 2016). The most widespread non-timber forest product in Africa, especially in eastern Africa, is wild bamboo. Ethiopia is one of the East African countries that are home to two native indigenous bamboo species, *Oldeania alpina* and *Oxytenanthera abyssinica* with a combined total area of over 1.47 million hectares (Zhao *et al*., 2018). It was also reported that more than 850,000 ha is covered by the lowland bamboo (*O. abyssinica*) (Zhao *et al*., 2018).

Despite bamboo abundance in Ethiopia, it has not been extensively utilized in high quality products. Recently, it has been used for rural housing, fencing, firewood, rudimentary furniture, crafts, mats, household utensils, and other low-value products (Monaco, 2019). They are mostly used in their round culm shape, which requires less complex processing. Consequently, the sector provides low economic returns to farmers and other actors along the bamboo industry's value chains (Monaco, 2019). Although bamboo is native to many countries, it is employed as a structural building material. For instance, bamboo has historically been utilized in Asia for low-rise structures, footbridges with small spans, long-span roofs, and construction platforms (Anokye *et al*., 2016).

The growing demand for wood and wood products has resulted in a decline in forest products in Ethiopia. Because of this, bamboo must be creatively developed to replace those slow-growing hardwoods for both structural and nonstructural uses. Due to its fast growth rate, rapid renewable energy, low embodied energy, wide availability, and versatile uses, bamboo has garnered significant attention recently as a sustainable building material (Rittironk and Elnieiri, 2008; Sulastiningsih and Nurwati, 2009; Mahdavi *et al*., 2011). It also shares similarities with structural wood products in terms of physical and mechanical properties.

Bamboo is the world's fastest-growing plant on the earth, reaching a maximum height of 15–30 meters in about two to four months, and growing up to 100 centimeters in a single day (Liese, 1987). In contrast to most softwood and hardwood tree species, which have rotations of 10–50 years, bamboo has a maturity age of roughly 3–7 years for construction and furniture uses and a short rotation life that may be harvested in 3-5 years (Desalegn and Tadesse, 2014). In comparison to a stand of hardwood tree species of a similar size, bamboo not only replenishes quickly but also releases twice as much oxygen into the atmosphere and consumes three times as much carbon dioxide (Akarsu *et al*., 2012). Comparing bamboo structural use to other typical construction materials like steel and concrete, the quantitative lifespan study of bamboo had less adverse environmental impact (van der Lugt *et al*., 2006).

Bamboo culms have been utilized recently in many different engineering projects, such as scaffolding, fiber-reinforced composites, columns, beams, rafters, and bridges (Sharma *et al*., 2015; Kelkar *et al*., 2020). Mahdavi *et al*. (2011) stated that the geometric configuration of the bamboo material, along with the presence of nodes within its culm, hinders its potential for development as a construction material and further into other products. The bamboo culm structure is difficult to use in structural parts (beams and columns) and generally where flat surfaces are required. Moreover, pins cannot be inserted into bamboo culms due to their low shear resistance, which makes it difficult to build larger structures that require connections. Additionally, compared to the internode culm region, bamboo nodal structures often exhibit lower mechanical qualities (compressive strength and tension strength), and its physical and mechanical attributes vary along the culm positions. Many scholars (Zakikhani *et al*., 2014; Li *et al*., 2016; Huang *et al*., 2018; Xuan *et al*., 2021) reported that these characteristics differ significantly based on the species, climatic conditions, soil type, age, density, silvicultural practices, etc. Consequently, it has been of interest to make bamboo available in forms more appropriate for its existing structural use.

Laminated Bamboo Lumber (LBL), typically made as a board with a rectangular cross-section, was developed as a result of this desire. LBL is an engineered bamboo product made by bonding bamboo materials in different shapes and sizes (such as strips, strands, and mats) with glue to create boards or sheets with rectangular cross sections that resemble lumber (Sinha *et al*., 2014; Sun *et al*., 2020). According to earlier research, the material's qualities are similar to those of wood and engineered wood products (Xiao, 2016; Sharma *et al*., 2017). To ascertain the physical and mechanical characteristics of the material to be used in construction and other end products, validation testing is necessary, just like with other non-conventional materials (Sharma *et al*., 2021).

Like raw bamboo culms, many factors such as species, climatic condition, location site, harvesting method, age, density, moisture content, and culm position, etc. can affect the mechanical and physical characteristics of LBL (Huang *et al*., 2018; Dauletbek *et al*., 2022). In Ethiopia, there is little use of bamboo culms for engineered bamboo because of inadequate knowledge and technology. As a result, the objective of this work was to create LBL from lowland bamboo (*O. abyssinica*) in two culm locations and test their physical and mechanical characteristics.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Sampling site description
2.1. Zemljopisni položaj uzorkovanja

The lowland bamboo (*O. abyssinica*) culms were collected from the Benishangul Gumuz Regional State of Ethiopia's Pawe Agricultural Research Center site. It is located 575 km from Addis Ababa. The mean annual temperature and annual rainfall precipitation of the site were 24 °C and 788 mm, respectively. The latitude and longitude of the site were 11°18'40''−11° 19' 29''N and 36°24'2''−36°25'27''E, respectively.

2.2 Selection and harvesting of bamboo culm samples
2.2. Odabir i prikupljanje bambusovih stabljika

The matured culms of 4-year-old lowland bamboo (*O. abyssinica*) were selected and harvested at about 20 – 30 cm above the ground using a machete and axe. The harvested lowland bamboo sample culms were sectioned into three positions (Figure 1a) along the axial direction (bottom, middle, and top), but since its top position was thin and not suitable to split, only the bottom and middle positions were used for this study. The average diameter of the culm at breast height and bamboo height were 7 cm and 6 m, respectively. After that, the bamboo culms were moved to the laboratory of the Forest Products Innovation Center of Excellence (FPICE) for further process evaluation.

2.3 Fabrication of laminated bamboo lumber (LBL) from *O. abyssinica*
2.3. Izrada lamelirane građe od bambusa (LBL) *O. abyssinica*

The collected lowland bamboo (*O. abyssinica*) culms from each position (bottom and middle) were split into 2 cm width strips by using manual bamboo splitters (Figure 1b) and hammers. The strips were dried to 12 % moisture content level in a conventional kiln-dryer (Figure 1d). A thicknesser machine was used to remove the inner portion and the outside waxy/silica layer simultaneously from the split and dried strips, resulting in a rectangular cross-section size of 20 mm × 7 mm (Figure 1e). Eventually, strips devoid of defects were chosen to create laminated bamboo lumber (LBL) of *O. abyssinica*.

Figure 1 LBL manufacturing process: Bamboo culm harvesting and sectioning (a), culm splitting (b), split strips (c), kiln drying strips (d), plaining strips (e), and clumping strips which is glued with UF resin (f)
Slika 1. Proces proizvodnje LBL-a: a) prikupljanje i rezanje bambusovih stabljika, b) cijepanje stabljika, c) cijepanje traka, d) sušenje traka u peći, e) ravnanje traka, f) lijepljenje traka UF smolom

Urea-formaldehyde (UF) in powdered form was purchased from the local market and used for the manufacture of laminated bamboo lumber. This UF resin is manufactured by Sprea Misr Company in Egypt. It has pH value of 8.0 – 9.0 and characteristics of fast curing, low toxicity and high strength, which is excellent for wooden materials such as wood-based panels, furniture, load bearing constructions, and wooden building products. To attain a 50 % solid content, the powdered UF resin was gradually added to water at a 1:2 ratio. Throughout the resin preparation process, constant stirring was done to prevent coagulation. During the LBL fabrication process, UF resin was applied on the dried bamboo culm strips manually using a brush. Layers of adhesive-coated strips were layered on top of layers of unglued strips. The strips were put together with the grains running parallel to one another. The strips were clamped together and left for 24 hours at room temperature (20-25 °C) (Figure 1f). Although the exact pressure was not measured, the sufficiency of the pressure was visually evaluated using glue squeeze-out and continuous interfacial surface contact. After 24 hours, the assembled strips were removed and cured for four days. The final measurements of 2.1 cm × 4 cm × 100 cm (thickness, width, and length, respectively) were obtained by trimming all the sides of the fabricated LBL samples. Finally, twelve 3-ply LBL sample boards were made in order to get specimens ready for studies on their physical and mechanical characteristics.

2.4 Determination of physical properties
2.4. Određivanje fizičkih svojstava

2.4.1 Moisture content (*MC*)
2.4.1. Sadržaj vode

The specimens were prepared from the fabricated LBL panels with a dimension of 20 × 20 mm^2 and length of 30 mm. Moisture content (*MC*) of the sample board was evaluated based on oven drying method according to the procedure ISO 13061-1:2014. The test specimens were first weighed using a digital weighing balance to ensure accuracy of 0.01 g, and then oven-dried at 103 °C. The specimens were kept in the oven until they attained the target constant weight. The following equation was used to compute and determine the moisture content of LBL of lowland bamboo:

$$Moisture\ content\ (\%) = (\frac{m_g - m_{od}}{m_{od}}) \cdot 100 \qquad (1)$$

Where m_g – green weight of the specimen in gram, and m_{od} – oven-dry weight of the specimen in gram.

2.4.2 Density
2.4.2. Gustoća

Determination of density was conducted based on the procedure ISO 13061-2:2019. Density was determined using volumetric measurement method. The manufactured LBL panels were used to prepare a sample with dimensions of 20 mm × 20 mm × 30 mm. Specimen blocks were reweighed to determine the oven-dried weight after being oven dried at 103 °C until a consistent weight was reached. The following equation was used to calculate and find the density of LBL:

$$Density\ (\mathrm{kg/m^3}) = \frac{W}{V} \qquad (2)$$

Where W – specimen weight at test in kg, V – specimen volume at test in m^3.

2.4.3 Shrinkage
2.4.3. Utezanje

Specimens representing two culm heights were prepared from LBL of *O. abyssinica* culm with a dimension of 20 mm × 20 mm and length of 30 mm for determination of tangential, radial, longitudinal and volumetric shrinkages. The specimens were subjected to an oven drying process at (103±2) °C after the weight and dimensions were assessed with an analytical balance and digital caliper, respectively, yielding measurements with a precision of 0.001g and 0.001 mm. Until a consistent weight was achieved, the specimen weight and dimensions were measured repeatedly and recorded. The ISO 13061-13:2024 and ISO 13061-14:2016 standards were used to evaluate shrinkage. The percentage of shrinkage was determined using the following equation.

$$Shrinkage\ (\%) = (\frac{D_i - D_f}{D_i}) \cdot 100 \qquad (3)$$

Where D_i – specimen initial dimension before oven-dry in mm, and D_f – specimens final dimension after oven-dried in mm.

2.5 Determination of mechanical properties
2.5. Određivanje mehaničkih svojstava

2.5.1 Static bending
2.5.1. Čvrstoća na savijanje

The static bending (*MOE* and *MOR*) of this study was determined based on ISO 13061-3:2014 standard technique. Specimens with dimension of 20 mm × 20 mm × 300 mm were prepared from each culm portion for determination of *MOE* and *MOR*. The specimens were subjected to center loading on the Universal Testing Machine, type FM2750 (Figure 2). The specimen was loaded at a rate of one millimeter per minute in its center, with support at both ends. The following equations were used to determine *MOE* and *MOR* based on this test:

$$MOE\ (\mathrm{N/mm^2}) = \frac{P^1 \cdot L^3}{4 \cdot d^1 \cdot b \cdot h^3} \qquad (4)$$

$$MOR\ (\mathrm{N/mm^2}) = \frac{3 \cdot P \cdot L}{2 \cdot b \cdot h^2} \qquad (5)$$

Figure 2 Universal testing machine (UTM) for static bending test
Slika 2. Ispitivanje čvrstoće na savijanje uz pomoć univerzalnog uređaja za mehanička ispitivanja

Where *MOE* – modulus of elasticity, *MOR* – modulus of rupture, P^1 – load at the limit of proportionality in N, *P* – maximum load in N, *L* – span length in mm, and *d* – deflection at the limit of proportionality.

2.5.2 Impact bending strength
2.5.2. Čvrstoća na udarce

Impact bending strength was determined based on the ISO 13061-10:2017 standard technique. Specimens with dimensions of 20 mm × 20 mm × 300 mm were prepared from each culm portion for testing the impact bending strength. The specimens were set up on a pendulum hammer, type of Impact bending Testing Machine model PW5-S. The test machine force plate was used to read the joule value whereas the load was applied to the center. The impact bending strength was computed from the following equation.

$$\textit{Impact strength}\ (\mathrm{Nm/m^2}) = \frac{P}{b \cdot h} \qquad (6)$$

Where *P* – Joule value in Nm, *b* – specimen width in mm, *h* – specimen thickness in mm.

2.5.3 Hardness
2.5.3. Tvrdoća

According to Forest Products Laboratory (2010), the force needed to embed an 11.3 mm ball with half of its diameter into the wood is used to determine the hardness of wood. This information is collected using the Janka technique. Specimens with dimensions of 20 mm × 20 mm × 45 mm were cut from each designated portion for hardness strength testing. Hardness strength was determined based on the procedure of ISO 13061-12:2017 using universal testing machine.

2.5.4 Experimental design and statistical analysis
2.5.4. Postavke eksperimenta i statistička analiza

This study was carried out with a completely randomized design (CRD). To investigate the physical and mechanical characteristics of the fabricated LBL panels, twelve replications for each parameter with a single factor (culm height with two levels) were taken into consideration. The statistical software package for social science (SPSS) version 24 was used to analyze the data. The data were analyzed using descriptive statistics and one-way analysis of variance (ANOVA).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical properties of LBL
3.1. Fizička svojstava LBL-a

3.1.1 Moisture content
3.1.1. Sadržaj vode

According to the statistical analysis of variance (Table 1), the culm portion did not significantly affect the *MC* of the LBL at tests (Table 1), despite a decrease of *MC* percentage from the bottom to the middle portion. The *MC* percentage found in LBL fabricated from the bottom portion was 10.87 % and the middle portion was 9.82 % (Figure 3a). The mean value of *MC* at the test found in LBL ranges from 7.31 % to 12.59 %, which is in the range of the minimum *MC* allowed by ASTM for laminated board products. Many scholars reported the *MC* percentage of LBL panels in the range of 8 % to 16 % (Table 4).

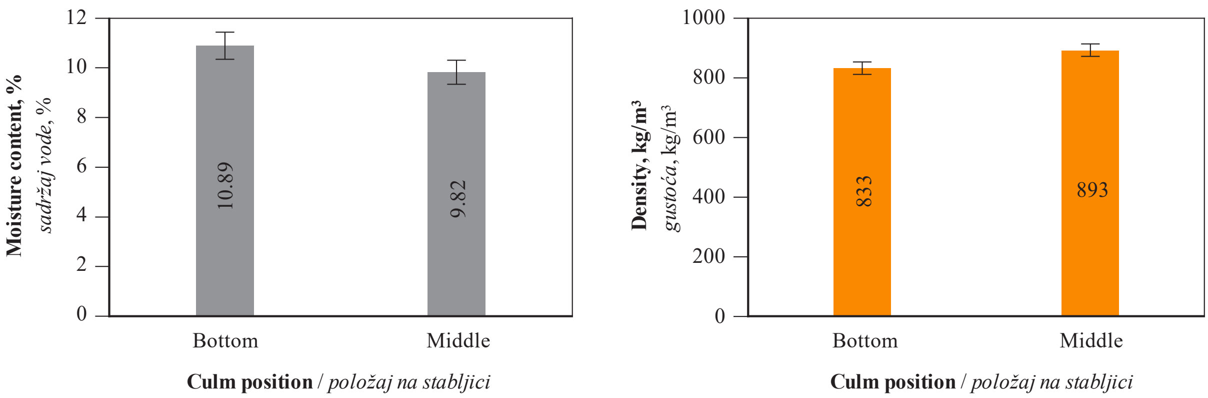

Figure 3 Moisture content (a) and density (b) variation of LBL within culm position
Slika 3. Varijacija sadržaja vode (a) i gustoće (b) LBL-a s obzirom na položaj na stabljici s kojega je uzorak uzet

3.1.2 Density
3.1.2. Gustoća

The result depicted that the culm portion significantly affected the density of the LBL at the test (Table 1). The density value obtained at the test of LBL fabricated from the middle portion was 892.80 kg/m³, which is significantly greater than from the bottom portion (833.31 kg/m³) (Figure 3b). The variation trend of this finding was similar to the trend reported in the raw bamboo *O. abyssinica* culms (Kelemwork, 2012).

Regardless of the variation along the culm height, the mean density of LBL fabricated from *O. abyssinica* culm varies from 778 to 926 kg/m³ with an average value of 863 kg/m³. The density value of the LBL found in this study was higher than the raw bamboo/original *O. abyssinica* of air-dried density (805 kg/m³) as reported by INBAR (2019), which is increased by 7.20 % compared to the raw bamboo culm. Similarly, Kelemwork (2012) also reported basic density ranges from 532 kg/m³ to 658 kg/m³ for the raw *O. abyssinica* pole, which is a lower value than that obtained in this study in the LBL of *O. abyssinica* culms. Similar density variation was obtained for both raw bamboo strips and LBL along the culm portion of *Dendrocalamus brandisii* (Kelkar *et al*., 2020). According to Sulastiningsih *et al*. (2016), the variation of density between the LBL and its raw bamboo is due to density of the component, the adhesive, and the pressing process used during fabrication process of LBL. They also state that the process of compaction that occurred during the compressing phase is impacted by glue. The trend to this finding reported in LBL manufactured from moso bamboo (*Phyllostachys pubescens*) was denser than in its raw bamboo culms and the variation was due to press treatments during the manufacture of LBL that results in an increased value of density (Nugroho and Ando, 2001). On the other hand, the mean density of this finding, which is 863 kg/m³, was greater than the density of cross laminated timber (CLT) of red oak and Southern pine tested at 12 % moisture content with mean vlues of 748 kg/m³ and 562 kg/m³, respectively (Omotayo *et al.*, 2024). Furthermore, the Gluelam density of *Pinus merkusii* (360 kg/m³) and *Anthocephalus cadamba* (0.73 kg/m³) were lower than the density of this finding obtained in LBL of *O. abyssinica* culm (Diza Lestari *et al*., 2018).

The density of this finding was greater than the density (730 kg/m³) of 3-ply LBL manufactured from the giant bamboo *Guadua bamboo* (Correal *et al*., 2010). In contrast, higher density (940 kg/m³) than this finding was reported for LBL manufactured from *Phyllostachys pubescens* (Nugroho and Ando, 2001). This difference may be associated with the species and thicknesses of the manufactured LBL panels. According to Manik *et al*. (2022), the density and mechanical characteristics of LBL observed an increment in line with the increased number of layers of the same thickness.

The density of LBL obtained was higher than that of the following solid lumber species in Ethiopia: *Eucalyptus globulus* (780 kg/m³), *Eucalyptus camaldulensis* lumber (853 kg/m³), *Pinus patula* (450 kg/m³), *Juniperus procera* (540 kg/m³), *Pouteria adolfi-friederici* (600 kg/m³), *Hagenia abyssinica* lumber (560 kg/m³), and *Pinus patula* (450 kg/m³) (Desalegn *et al*., 2012; 2015).

3.1.3 Shrinkage
3.1.3. Utezanje

A major element affecting the use of bamboo culms as a raw material is shrinkage. The statistical analysis showed that the culm portion did not show significant effects on the tangential, radial, longitudinal, volumetric shrinkages of the LBL fabricated from lowland bamboo culm (Table 1).

3.2 Mechanical properties of LBL
3.2. Mehanička svojstva LBL-a

3.2.1 Modulus of elasticity (*MOE*)
3.2.1. Modul elastičnosti (*MOE*)

The results showed that the bending stiffness or *MOE* was significantly ($P < 0.05$) influenced by the culm position (Table 2). The *MOE* increased with the increasing of bamboo height from the base to the mid-

Table 1 Statistical analysis of variance for physical properties of LBL fabricated from *O. abyssinica* culms
Tablica 1. Statistička analiza varijance za fizikalna svojstva LBL-a izrađenoga od stabljika *O. abyssinica*

Parameters *Parametri*	*DF*	Sum of squares *Zbroj kvadrata*	Mean square *Srednji kvadrat*	*F* value *F-vrijednost*	*Pr* (>*F*)
Density / *gustoća*	1	21237.930	21237.930	29.969	0.000***
MC	1	6.848	6.848	3.694	0.068ns
TS	1	0.704	0.704	3.201	0.870ns
RS	1	0.540	0.540	1.269	0.272ns
LS	1	0.015	0.015	2.611	0.120ns
VS	1	0.390	0.390	0.498	0.488ns

***significant at $P < 0.001$, **significant at $P < 0.01$, *significant at $P < 0.05$, nsnot significant at $P > 0.05$, *TS* – tangential shrinkage, *RS* – radial shrinkage, *VS* – volumetric shrinkage
****značajno pri P < 0,001, **značajno pri P < 0,01, *značajno pri P < 0,05, ns – nije značajno pri P > 0,05, TS – tangentno utezanje, RS – radijalno utezanje, VS – volumno utezanje*

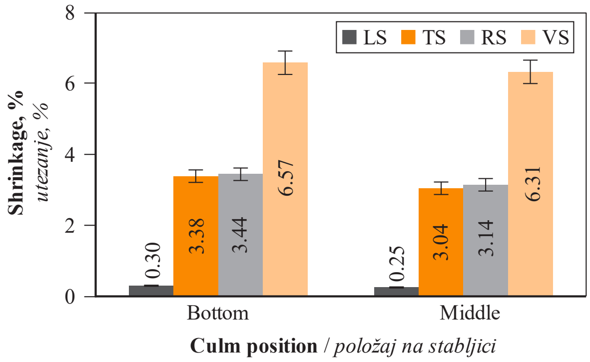

Figure 4 LBL shrinkages variation along the culm position of *O. abyssinica* (TS – tangential shrinkage, RS – radial shrinkage, LS – longitudinal shrinkage and VS – volumetric shrinkage)
Slika 4. Varijacije utezanja LBL-a duž stabljike *O. abyssinice* (TS – tangentno utezanje, RS – radijalno utezanje, LS – uzdužno utezanje, VS – volumno utezanje)

dle position. The mean value of *MOE* found in LBL produced from the middle position (16558 N/mm^2) was significantly greater than that from the bottom (14929 N/mm^2) position of *O. abyssinica* culms (Table 2). The *MOE* values reported in the original or raw bamboo of *O. abyssinica* culms (Kelemwork, 2012) exhibited a similar tendency of variation to this finding. The variation along the culm height of the bamboo might be associated with the anatomical characteristics of the bamboo culm. Siam *et al*. (2019) observed that the *MOE* of bamboo was impacted by the increased density with culm height from the base towards the top. They also noted that the higher number of vascular bundles along the culm height followed the increasing tendency of *MOE*.

Regardless of the variation along the culm height, the overall mean value of *MOE* for LBL was 15743 N/mm^2 (Table 3). In a previous study on the original *O. abyssinica* pole with node, Kelemwork (2012) found the average value of *MOE* (9099 N/mm^2) and without node (11293 N/mm^2) grown at Pawe, Ethiopia. On the other hand, the mean value of *MOE* obtained in this study of LBL was increased by 73 % and 39 % when compared to the original bamboo with node and without node, respectively. A similar significant difference was observed in LBL and raw bamboo strips reported in other bamboo species of *Dendrocalamus brandisii* (Kelkar *et al*., 2020).

The overall average value of *MOE* (15743 N/mm^2) was higher than *MOE* (10000 N/mm^2) of 3-ply LBL manufactured from *G. apus* (Sulastiningsih and Nurwati 2009). In addition, the value of *MOE* (14163 N/mm^2) of LBL manufactured from *O. alpina* culms (Kariuki *et al*., 2014) is lower than this finding of *MOE* (15743 N/mm^2). Furthermore, *MOE* of this study is higher than 4-ply LBL manufactured from *Phyllostachys pubescens* culms reported by Mahdavi *et al*. (2012). Similar to density, this variation may be associated with the type of species, number of layers, thickness of strips/ panels, type of resin applied. Compared to lumber derived from commercially recognized timber species in Ethiopia, the *MOE* value found in this study was greater than that of *Prunus africana* (12070 N/mm^2), *Eucalyptus globulus* (11655 N/mm^2), *Cordia africana* (6996 N/mm^2), and *Cupressus lusitanica* (6145 N/mm^2) (Desalegn *et al*., 2015). Omotayo *et al.* (2024) reported that the mean *MOE* of cross laminated timber (CLT) of red oak and Southern pine was 13,238 N/mm^2 and 9,406 N/mm^2, respectively. These values are lower than the *MOE* of this finding obtained in LBL of *O. abyssinica* (15743 N/mm^2). On the other hand, the *MOE* value reported for Gluelam of *Pinus merkusii* (5500 N/mm^2) and *Anthocephalus cadamba* (10600 N/mm^2) were lower than the *MOE* of this finding obtained in LBL of *O. abyssinica* culm (Diza Lestari *et al*., 2018).

3.2.2 Modulus of rupture (*MOR*)
3.2.2. Modul loma (*MOR*)

The result showed that the bending strength/ *MOR* was significantly ($P < 0.01$) affected by culm position (Table 2). The value of LBL fabricated from the middle position was (164 N/mm^2), which is greater than that from the bottom position (134 N/mm^2) of *O. abyssinica* culms. The increased value of *MOR* from the bottom to the middle position was reported for the raw/original *O. abyssinica* pole (Kelemwork, 2012). A similar variation of the trend to this finding was reported for LBL fabricated from other bamboo species of *Bambusa vulgaris* (Ojo *et al*., 2018).

Table 2 Statistical analysis for mechanical properties of LBL fabricated from *O. abyssinica* culms
Tablica 2. Statistička analiza mehaničkih svojstava LBL-a izrađenoga od stabljika *O. abyssinica*

Parameters *Parametri*	**DF**	**Sum of squares** *Zbroj kvadrata*	**Mean square** *Srednji kvadrat*	***F* value** *F-vrijednost*	**Pr (>*F*)**
MOE	1	15916959	15916959	6.462	0.0186*
MOR	1	5370	5370	10.99	0.00315**
Impact bending / *čvrstoća na udarce*	1	20417	20417	2.786	0.109^{ns}
Hardness / *tvrdoća*	1	6273038	6273038	37.33	0.000***

***significant at $P < 0.001$, **significant at $P < 0.01$, *significant at $P < 0.05$, ^{ns}not significant at $P > 0.05$
****značajno pri P < 0,001, **značajno pri P < 0,01, *značajno pri P < 0,05, ns – nije značajno pri P > 0,05*

Table 3 Average mechanical properties of LBL along the culm height of *O. abyssinica*
Tablica 3. Prosječna mehanička svojstva LBL-a duž stabljike *O. abyssinica*

Culm position *Položaj na stabljici*	***MOE*, N/mm²**	***MOR*, N/mm²**	**Impact bending, Nm/m²)** *Čvrstoća na udarce*, Nm/m²	**Hardness, N** *Tvrdoća*, N
Bottom / *donji dio*	14929±1584[b]	134±26[b]	18604±113[a]	2634±481[b]
Middle / *srednji dio*	16558±1555[a]	164±17[a]	18663±43[a]	3657±324[a]
Total / *ukupno*	15743±1746	149±26	18633±89	3145±658

Note: Within the same column, mean values denoted by a different superscript letter show a significant difference at $P < 0.05$.
Napomena: srednje vrijednosti označene različitim slovima unutar istog stupca pokazuju značajnu razliku pri P < 0,05.

The overall mean value of *MOR* for LBL fabricated from *O. abyssinica* culms was 149 N/mm² (Table 3). The *MOR* obtained in this study was 8 times higher than that of the original lowland bamboo poles without nodes and 18 times higher than that of bamboo poles with nodes grown at Pawe, Ethiopia (Kelemwork, 2012). A similar difference to this finding was reported between *MOR* of LBL and its raw bamboo strips of *Dendrocalamus brandisii* (Kelkar *et al*., 2020). This finding was greater than the *MOR* (111.03 N/mm²) of LBL produced from giant bamboo Guadua (Correal *et al*., 2010). Similarly, the value of *MOR* (95.1 N/mm²) reported for 3-ply LBL of *Gigantochloa apus* was lower than *MOR* (149 N/mm²) obtained in this study (Sulastiningsih and Nurwati, 2009). Furthermore, the *MOR* value obtained in this study was higher than 4 ply LBL of *Phyllostachys pubescens* as reported by Mahdavi *et al*. (2012). The value of *MOR* (149 N/mm²) of this result was greater than *MOR* of commercially well-known and endangered wood species of Ethiopia such as *Cordia africana* (64 N/mm²), *Cupressus lusitanica* (64 N/mm²), and *Juniperus procera* (87 N/mm²) (Desalegn *et al*., 2015). This indicates that LBL fabricated from *O. abyssinica* culms has a potential to substitute these commercial timber species as alternative raw material. Omotayo *et al*. (2024) reported that the mean *MOR* of cross laminated timber (CLT) of red oak and Southern pine was 52.77 N/mm² and 36.21 N/mm², respectively. These values are lower than the *MOE* of this finding obtained in LBL of *O. abyssinica* (149 N/mm²). On the other hand, the mean *MOR* values reported for Gluelam of *Pinus merkusii* (46.10 N/mm²) and *Anthocephalus cadamba* (86.20 N/mm²) were lower than the MOE of this finding obtained in LBL of *O. abyssinica* culm (Diza Lestari *et al*., 2018).

3.2.3 Impact bending
3.2.3. Čvrstoća na udarce

The resistance that wood specimens provide to abrupt shocks is known as impact bending. According to the statistical analysis of variance, there was no significant ($P > 0.05$) effect of culm portion on the impact bending strength (Table 2). The strength of impact bending of LBL fabricated from the middle position (18663 Nm/m²) was insignificantly higher than that from the bottom position (18604 Nm/m²) of *O. abyssinica* culms (Table 3). The overall mean value of impact bending found in this study was 18633 Nm/m². The impact bending strength value of glulam bamboo manufactured from *B. vulgaris* is reported in the range of 0.75 to 1.98 MPa (Ogunsanwo *et al*., 2019).

The result of this finding was considerably higher than that of solid lumbers of commercially known timber species in Ethiopia; for instance, the impact bending strength of *Cupressus lustanica* (5888 Nm/m²), *Pinus patula* (5187 Nm/m²), *Eucalyptus saligna* (12873 Nm/m²) and *Grevillea robusta* (18094 Nm/m²) (Desalegn *et al*., 2012; 2015). This indicates that the LBL fabricated from *O. abyssinica* culms has a potential to substitute these commercial timber species as alternative raw material in Ethiopia.

3.2.4 Hardness
3.2.4. Tvrdoća

The hardness was shown to be significantly ($P < 0.001$) influenced by the culm height (Table 2). The mean variation of hardness found in LBL fabricated from the middle position (3657 N) was greater than the LBL fabricated from the bottom position (2634 N) of lowland bamboo culm. Regardless of the variation along the culm height, the overall mean value of hardness found in LBL fabricated from *O. abyssinica* culm was 3145 N (Table 3). The result of this finding was considerably higher than that of LBL fabricated from other bamboo species of *Phyllostachys aurea* with a hardness value of 1,647 N (Rusch *et al*., 2019). Nonetheless, higher than this finding was reported in LBL fabricated from other species of bamboo *Guadua angustifolia* Kunth with hardness in the range of 5000-6500 N (Correal *et al*., 2014). The variation of this finding compared to other findings may be due to the difference of bamboo species and the species of this finding. Correal *et al*. (2014) noted that the value of hardness in LBL differed significantly among the species of bamboo culms. The mean values of hardness obtained in this study were higher than those of solid lumber of commercially well-known tree species of Ethiopia, such as *Pinus patula* (2179 N), and *Cupressus lustanica* (2761 N) (Desalegn *et al*., 2015).

Table 4 Average physical and mechanical characteristics of the manufactured LBL compared to specimens examined in earlier research studies of LBL, PSL, and LVL
Tablica 4. Prosječna fizička i mehanička svojstva proizvedenoga LBL-a u usporedbi s uzorcima ispitanim u dosadašnjim istraživačkim studijama LBL-a, PSL-a i LVL-a

Species *Vrsta*	**Product** *Proizvod*	**Number of ply** *Broj slojeva*	**Specimens size, cm** *Veličina uzorka, cm*	***MC*, %**	**Density, kg/m³** *Gustoća, kg/m³*	***MOE*, N/mm²**	***MOR*, N/mm²**	**Impact bending, Nm/m²** *Čvrstoća na udarce,* Nm/m²	**Hardness, N** *Tvrdoća,* N
*Oxytenanthera abyssinica**	LBL	3	2.1×2×100	7.31–12.59	863 (40)	15743 (1746)	149 (26)	18633 (89)	3145 (658)
Gigantochloa apus[a]	LBL	3	-	13.07 (1.2)		10000	95.1 (9.7)	-	-
Guadua bamboo[b]	LBL	-	-	9.0 (2.0)	756 (2.8)	13821 (5.8)	112 (8.6)	-	-
Yushania alpina[c]	LBL	-	-	<12	-	14163	91	-	-
Phyllostachys pubescens[d]	LBL	4	3.5[d]×5.08×76.2	15.81 (5.5)	-	9300 (594)	76.5 (4.58)	-	-
Phyllostachys aurea [e]	GLB	-	-	9.47	770	12746	99.40	-	1647
Guadua angustifolia Kunth[f]	GLB	-	-	8.33-11.90	741	12720	103	-	5000-6500
Eastern species[g]	PSL	-	2.54×2.54×40.64	-	-	11600	90.3	-	-
Phyllostachys pubescens Mazel[h]	LVL	-	2.54×2.54×40.64	-	-	11000	93.5	-	-
Moso bamboo (*Phyllostachys pubescens*)[i]	LBL	-	-	10.6	-	8870	111.5	-	-
G. apus	LBL	-	-	11.74 (0.80)	0.80 (0.02)	6,967.86	42.81	-	-

Note: LBL – laminated bamboo lumber, PSL – parallel strand lumber, LVL – laminated veneer lumber, GLB – glued laminated bamboo.
Napomena: LBL – lamelirana građa od bambusa, PSL – građa od lijepljenih traka furnira, LVL – lamelirana furnirska građa, GLB – lamelirani lijepljeni bambus.
[a]Sulastiningsih and Nurwati, 2009; [b]Sulastiningsih and Nurwati, 2009; [c]Kariuki1 *et al*., 2014; [d]Mahdavi *et al*., 2012; [e]Ni *et al*., 2016; [f]Correal *et al*., 2014; [g]Mahdavi *et al*., 2011; [h]Nugroho and Ando, 2001; [i]Chen *et al*., 2020; [j]Sumardi *et al*., 2022

4 CONCLUSIONS
4. ZAKLJUČAK

The physical and mechanical properties of LBL fabricated from the bottom and middle positions of lowland bamboo (*O. abyssinica*) culms have been studied. Density, MOE, MOR, impact bending and hardness tests indicate that LBL fabricated from upper position of *O. abyssinica* culm has superior properties when compared with LBL fabricated from the lower position of *O. abyssinica* culm. The density and mechanical properties found in LBL have been shown to be much higher than those of normal structural timber in Ethiopia and other countries, whereas compared to other laminated bamboo products, the manufactured LBL may be regarded as having average density and mechanical qualities. Compared to other wood species, shrinkage was less pronounced in radial and tangential directions; as a result, LBL may be regarded as dimensionally stable material. According to the present study, LBL can potentially be used as a substitute material for wood and wood-based products. The tested physical and mechanical properties of LBL obtained in this study fulfilled the minimum requirement of D60 strength class for hardwoods in BS 5268-2 standard for timber structural applications. Further research is recommended to examine other characteristics of the product, such as its bonding strength, biological resistance, fastener holding capability, and a connecting system.

Acknowledgements – Zahvala

The authors express their gratitude to the Ethiopian Forestry Development (EFD), Forest Products Innovation Research Directorate, and Forest Products Innovation Center of Excellence (FPICE) for financing this study. Our sincere thanks to our colleagues Eshetu Ayele and Kebede Yimer for their assistance in harvesting, sample preparation, manufacturing of LBL and specimen preparation for testing. We would like to thank Bahir Dar Ethiopian Forestry Development

Center for allowing us to harvest the bamboo culms from their site. Additionally, we would like to thank all of the staff of FPICE.

5 REFERENCES
5. LITERATURA

1. Anokye, R.; Bakar, E. S.; Ratnasingam, J.; Yong, A. C. C.; Bakar, N. N., 2016: The effects of nodes and resin on the mechanical properties of laminated bamboo timber produced from *Gigantochloa scortechinii*. Construction and Building Materials, 105: 285-290. https://doi.org/10.1016/j.conbuildmat.2015.12.083
2. Chen, G.; Yu, Y.; Li, X.; He, B., 2020: Mechanical behavior of laminated bamboo lumber for structural application: an experimental investigation. European Journal of Wood and Wood Products, 78 (1): 53-63. https://doi.org/10.1007/s00107-019-01486-9
3. Correal, J. F.; Ramirez, F., 2010: Adhesive bond performance in glue line shear and bending for glued laminated Guadua bamboo. Journal of Tropical Forest Science, 22 (4): 433-439.
4. Correal, J. F.; Echeverry, J. S.; Ramírez, F.; Yamín, L. E., 2014: Experimental evaluation of physical and mechanical properties of Glued Laminated *Guadua angustifolia* Kunth. Construction and Building Materials, 73: 105-112. https://doi.org/10.1016/j.conbuildmat.2014.09.056
5. Dauletbek, A.; Li, H.; Lorenzo, R.; Corbi, I.; Corbi, O.; Ashraf, M., 2022: A Review of Basic Mechanical Behavior of Laminated Bamboo Lumber. Journal of Renewable Materials, 10 (2): 273-300. https://doi.org/10.32604/jrm.2022.017805
6. Desalegn, G.; Abegaz, M.; Teketay, D.; Gezahgne, A., 2012: Commercial Timer Species in Ethiopia: Characteristics and Uses – A Handbook for Forest Industries, Construction and Energy Sectors, Foresters and Other Stakeholders. Addis Ababa University Press, Addis Ababa, pp. 324.
7. Desalegn, G.; Tadesse, W., 2014: Resource potential of bamboo, challenges and future directions towards sustainable management and utilization in Ethiopia. Forest Systems, 23 (2): 294-299. https://doi.org/10.5424/fs/2014232-03431
8. Desalegn, G.; Kelemwork, S.; Gebeyehu, D., 2015: Forest Products Utilization Research in Ethiopia: Highlights on Major Achievements and Contributions. Ethiopian Environment and Forest Research Institute, Addis Ababa, pp. 122.
9. Diza Lestari, A. S. R.; Hadi, Y. S.; Hermawan, D.; Santoso, A., 2018: Physical and mechanical properties of glued laminated lumber of pine (*Pinus merkusii*) and jabon (*Anthocephalus cadamba*). Journal of the Korean Wood Science and Technology, 46 (2): 143-148. https://doi.org/10.5658/WOOD.2018.46.2.143
10. Huang, X.; Xie, J.; Qi, J.; Hoop, C. F. D.; Xiao, H.; Chen, Y.; Li, F., 2018: Differences in physical-mechanical properties of bamboo scrimbers with response to bamboo maturing process. European Journal of Wood and Wood Products, 76 (4): 1137-1143. https://doi.org/10.1007/s0010 7-018-1293-0
11. Kariuki, J.; Nyomboi, T.; Mumenya, S., 2014: Effect of Orientation and Arrangement of Bamboo Strips on Structural Strength of Laminated Bamboo Beam. International Journal of Engineering Sciences & Emerging Technologies, 7 (2): 555-567.
12. Kelemwork, S., 2012: Influence of Growing Locations and Culm Positions on Physical and Mechanical Properties of Lowland Bamboo (*Oxythenantera abyssinica*). In: Forestry and Forest Products: Technologies and Issues Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia, p: 317-327.
13. Kelkar, B. U.; Sharma, S. K.; Shukla, S. R., 2020: Optimization of pressing parameters of PF-bonded laminated bamboo lumber from *Dendrocalamus brandisii*. Journal of the Indian Academy of Wood Science, 17: 149-157. https://link.springer.com/article/10.1007/s13196-020-00267-9
14. Khalil, H. A.; Bhat, I. U. H.; Jawaid, M.; Zaidon, A.; Hermawan, D.; Hadi, Y. S., 2012: Bamboo fibre reinforced biocomposites: A review. Materials & Design, 42: 353-368. https://doi.org/10.1016/j.matdes.2012.06.015
15. Li, H. T.; Wu, G.; Zhang, Q. S.; Su, J. W., 2016: Mechanical evaluation for laminated bamboo lumber along two eccentric compression directions. Journal of Wood Science, 62 (6): 1-15. https://doi.org/10.1007/s1008 6-016-1584-1
16. Liese, W., 1987: Research on bamboo, Wood Science Technology, 21 (3): 189-209.
17. Mahdavi, M.; Clouston, P. L.; Arwade, S. R.; 2011: Development of laminated bamboo lumber: A review of processing, performance and economical considerations. Journal of Materials in Civil Engineering, 23 (7): 1036-1042. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000253
18. Mahdavi, M.; Clouston, P. L.; Arwade, S. R., 2012: A low-technology approach toward fabrication of Laminated Bamboo Lumber. Construction and Building Materials, 29: 257-262. https://doi:10.1016/j.conbuildmat.2011.10.046
19. Manik, P.; Samuel, S.; Tuswan, T.; Jokosisworo, S.; Nadapdap, R. K., 2022: Mechanical properties of laminated bamboo composite as a sustainable green material for fishing vessel: Correlation of layer configuration in various mechanical tests. Journal of the Mechanical Behavior of Materials, 31 (1): 673-690. https://doi.org/10.1515/jmbm-2022-0075
20. Monaco, E., 2019: Sustainable Development and Bamboo Value Chains: Ethiopia's Green Growth Opportunities Within the "Sino-Dutch-East Africa Bamboo Development Programme 2016-19". Solutions: For a Sustainable & Desirable Future, 10 (4).
21. Mussa, M.; Desalegn, G.; Kaba, G.; Tesfaye, A., 2023: Physical and Chemical Properties of Highland Bamboo (*Yushania alpina*) Culms Grown in Ethiopia. Drvna industrija, 74 (3): 287-296. https://doi.org/10.5552/drvind.2023.0059
22. Ni, L.; Zhang, X.; Liu, H.; Sun, Z.; Song, G.; Yang, L.; Jiang, Z., 2016: Manufacture and mechanical properties of glued bamboo laminates. BioResources, 11 (2): 4459-4471.
23. Nugroho, N.; Ando, N., 2001: Development of structural composite products made from bamboo II: fundamental properties of laminated bamboo lumber. Journal of Wood Science, 47: 237-242.
24. Ogunsanwo, O. Y.; Adenaiya, A. O.; Adedeji, C. A., 2019: Effect of adhesive quantity on selected physico-mechanical properties of Bamboo glulam. Maderas. Ciencia y Tecnología, 21 (1): 113-122. http://dx.doi.org/10.4067/S0718-221X2019005000111
25. Ojo, A. R.; Areghan, S. E.; Ogutuga, S. O., 2018: Evaluation of the Utilization Potential of African Bamboo (*Bambusa vulgaris* Schrad. ex J. C Wendl) Glue-Lam Through its Strenghth properties. Journal of Forestry Research and Management, 15 (1): 173-185.
26. Omotayo, R.; França, F. J.; França, T. S.; Seale, R. D., 2024: Physical and Mechanical Properties of Hardwoods Cross-Laminated Timber. Forest Products Journal, 74 (4): 356-362. https://www.doi.org/10.13073/FPJ-D-24-00038

27. Rittironk, S.; Elnieiri, M., 2008: Investigating laminated bamboo lumber as an alternate to wood lumber in residential construction in the United States. In: Modern Bamboo Structures, CRC Press, pp. 95-108.
28. Rusch, F.; Trevisan, R.; Hillig, E.; Mustefaga, E., 2019: Physical-mechanical properties of laminated bamboo panels. Pesquisa Agropecuária Tropical, 49: 2-8. https://doi.org/10.1590/1983-40632019v4953714
29. Sharma, B.; Bauer, H.; Schickhofer, G.; Ramage, M. H., 2017: Mechanical characterisation of structural laminated bamboo. In: Proceedings of the Institution of Civil Engineers-Structures and Buildings, 170 (4): 250-264. https://doi.org/10.1680/jstbu.16.00061
30. Sharma, B.; Eley, D.; Emanuel, O.; Brentnall, C., 2021: Mechanical properties of laminated bamboo designed for curvature. Construction and Building Materials, 300: 123937. https://doi.org/10.1016/j.conbuildmat.2021.123937
31. Sharma, B.; Gatoo, A.; Bock, M.; Mulligan, H.; Ramage, M., 2015: Engineered bamboo: state of the art. Proceedings of the Institution of Civil Engineers-Construction Materials, 168 (2): 57-67. https://doi.org/10.1680/coma.14.00020
32. Sharma, B.; Gatóo, A.; Ramage, M. H., 2015: Effect of processing methods on the mechanical properties of engineered bamboo. Construction and Building Materials, 83: 95-101. https://doi.org/10.1016/j.conbuildmat.2015.02.048
33. Siam, N. A.; Uyup, M. K. A.; Husain, H.; Mohmod, A. L.; Awalludin, M. F., 2019: Anatomical, physical and mechanical properties of thirteen Malaysian bamboo species. BioResources, 14 (2): 3925-3943.
34. Sinha, A.; Way, D.; Mlasko, S., 2014: Structural performance of glued laminated bamboo beams. Journal of Structural Engineering, 140 (1): 04013021. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000807
35. Srivaro, S., 2018: Potential of three sympodial bamboo species naturally growing in Thailand for structural application. European Journal of Wood and Wood Products, 76 (2): 643-653. https://doi.org/10.1007/s00107-017-1218-3
36. Sulastiningsih, I. M.; Nurwati, 2009: Physical and mechanical properties of laminated bamboo board. Journal of Tropical Forest Science, 246-251.
37. Sumardi, I.; Alamsyah, E. M.; Suhaya, Y.; Dungani, R.; Sulastiningsih, I. M.; Pramestie, S. R., 2022: Development of bamboo zephyr composite and the physical and mechanical properties. Journal of the Korean Wood Science and Technology, 50 (2): 134-147. https://doi.org/10.5658/WOOD.2022.50.2.134
38. Sun, Y.; Zhang, Y.; Huang, Y.; Wei, X.; Yu, W., 2020: Influence of board density on the physical and mechanical properties of bamboo oriented strand lumber. Forests, 11 (5): 567. https://doi.org/10.3390/f11050567
39. Van der Lugt, P.; Van den Dobbelsteen, A. A. J. F.; Janssen, J. J. A., 2006: An environmental, economic and practical assessment of bamboo as a building material for supporting structures. Construction and Building Materials, 20 (9): 648-656. https://doi.org/10.1016/j.conbuildmat.2005.02.023
40. Vorontsova, M. S.; Clark, L. G.; Dransfield, J.; Govaerts, R.; Baker, W. J., 2016: World checklist of bamboos and rattans. INBAR Technical Report No. 37.
41. Xiao, Y., 2016: Engineered bamboo. In: Nonconventional and vernacular construction materials. Woodhead Publishing, pp. 433-452. https://doi.org/10.1016/B978-0-08-100038-0.00015-9
42. Xuan, Y.; Li, H.; Bei, Z.; Xiong, Z.; Lorenzo, R.; Corbi, I.; Corbi, O., 2021: Nodes effect on the bending performance of laminated bamboo lumber unit. Journal of Renewable Materials, 9 (6): 1143-1156. https://doi.org/10.32604/jrm.2021.015292
43. Zakikhani, P.; Zahari, R.; Sultan, M. T. H.; Majid, D. L., 2014: Extraction and preparation of bamboo fibre-reinforced composites. Materials and Design, 63 (2): 820-828. https://doi.org/10.1016/j.matde s.2014.06.058
44. Zhao, Y.; Feng, D.; Jayaraman, D.; Belay, D.; Sebrala, H.; Ngugi, J.; Maina, E.; Akombo, R.; Otuoma, J.; Mutyaba, J.; Kissa, S., 2018: Bamboo mapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery. International Journal of Applied Earth Observation and Geoinformation, 66: 116-125.
45. ***BS 5268-2, 2002: Structural Use of Timber. Part 2: Code of Practice for Permissible Stress Design. Materials and Workmanship. British Standards Institution, London.
46. *** ISO 13061-1, 2014: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Wood Specimens. Part 1: Determination of moisture content for physical and mechanical tests. International Organization for Standardization: Geneva, Switzerland, 2014.
47. *** ISO 13061-3, 2014: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Specimens. Part 3: Determination of Ultimate Strength in Static Bending. International Organization for Standardization: Geneva, Switzerland, 2014.
48. ***ISO 13061-10, 2017: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Specimens. Part 10: Determination of Impact bending Strength. International Organization for Standardization: Geneva, Switzerland, 2017.
49. ***ISO 13061-12, 2016: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Specimens. Part 14: Determination of volumetric shrinkage. International Organization for Standardization: Geneva, Switzerland, 2016.
50. ***ISO 13061-12, 2017: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Specimens. Part 12: Determination of Static hardness. International Organization for Standardization: Geneva, Switzerland, 2017.
51. ***ISO 13061-12, 2024: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Specimens. Part 13: Determination of radial and tangential shrinkage. International Organization for Standardization: Geneva, Switzerland, 2024.
52. ***ISO 13061-2, 2014: Physical and Mechanical Properties of Wood. Test Methods for Small Clear Wood Specimens. Part 2: Determination of Density for Physical and Mechanical Tests. International Organization for Standardization: Geneva, Switzerland, 2014.

Corresponding address:

MAHADI MUSSA USMAN

Ethiopian Forestry Development, Forest Products Innovation Centre of Excellence, Addis Ababa, ETHIOPIA, e-mail: mahadimussa20@gmail.com