Estimation of Longitudinal and Transverse Elastic Moduli of Native Brazilian Woods by Static Bending Tests

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Wood plays an essential role in civil construction due to its structural and sustainable properties. The longitudinal (*E*) and the transverse (*G*) modulus of elasticity are crucial for designing beams under bending, where combined deformations occur due to normal and shear stresses. However, the estimation of *G* for native Brazilian species still lacks standardized experimental procedures, with the simplified normative relation $G = E/16$ being commonly adopted. This study aims to estimate both *E* and *G* based on the Euler-Bernoulli and Timoshenko beam theories through three-point and four-point static bending tests. Four native Brazilian species and five ratios between the length and height of the cross-section (*L/h*) were analyzed. The results showed that, for *L/h* ratios below 18, the apparent modulus of elasticity was significantly affected by shear effects, exhibiting reductions of up to 18.47%. The *E/G* ratio ranged from 14.84 to 21.15, corresponding to a reduction of up to 7% and an increase of up to 32%, respectively, about the value proposed by ABNT NBR 7190-1 (2022). These results highlight the importance of considering specimen proportions and shear effects in the estimation of wood elasticity moduli obtained from bending tests.

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INTRODUCTION

Wood has gained prominence in global construction due to its renewability and sustainability, especially in light of climate change and the growing demand for housing (Zhang *et al*. 2022). It can serve as a long-term carbon sink (Mishra *et al*. 2022) while offering an excellent strength-to-density ratio (Baar *et al*. 2015; Ramage *et al*. 2017) when used in structural applications.

Unlike isotropic materials such as steel, wood is an orthotropic material whose physical and mechanical properties vary in longitudinal, radial, and tangential directions (Mascia and Lahr 2006). In addition, its chemical composition — mainly consisting of cellulose, hemicellulose, lignin, and extractives — may also present significant variations depending on the species and processes, such as heat treatment (Perçin *et al*. 2024).

In beams, considered one-dimensional solids, the highest loads act predominantly along the longitudinal axis, aligned with the wood fibers. In this configuration, normal and shear stresses are concentrated along this same axis, thereby reducing the influence of orthotropy and justifying its adoption as the primary reference in design.

In this context, two fundamental mechanical properties stand out: the longitudinal modulus of elasticity (E or Young's modulus), which represents the wood's stiffness to axial loads, and the shear modulus (G), which measures the resistance to deformation caused by shear stresses. Higher moduli indicate greater stiffness and less deformation under load, while lower values result in greater displacement for the same load.

Elastic moduli characterization is essential for structural design and the numerical modeling of timber structures, the development of reinforcement systems, and the improvement of technical standards. Reliable values for these parameters support computational simulations (such as those performed using finite element methods), structural classifications, and the optimization of native species usage in engineering applications.

Several standard methods are used to determine E, including compression and tensile tests (ABNT NBR 7190-3 2022), as well as bending tests (ABNT NBR 7190-3 2022; BS EN 408 2010; ISO/FDIS 13910 2014). Non-destructive methods, such as ultrasound and transverse vibration, have also shown promising results for this purpose (De Novais Miranda *et al*. 2022; Acuña *et al*. 2023).

However, G is often estimated based on empirical relationships, as in ABNT NBR 7190-1 (2022), which adopts $G = E/16$ and does not provide a specific experimental procedure for native woods. This approach is partly justified by the difficulty of obtaining a pure and uniform shear state under laboratory conditions (Bilko *et al*. 2021). Furthermore, currently known testing methods, such as torsion tests (Brabec *et al*. 2017; Krüger and Wagenführ 2020), require specific and often inaccessible equipment.

In light of these limitations, Lahr (1983), Zangiácomo *et al*. (2013), and Lahr *et al*. (2017) proposed the use of bending tests as an indirect alternative to obtain E and G simultaneously. Timoshenko beam theory was applied in these investigations, accounting for both bending deformations and those associated with shear stresses when calculating displacement. As a complementary tool, the Virtual Work Method (VWM) uses displacement fields, which may be derived from Timoshenko's theory, to estimate stiffnesses based on the balance between internal energy and external virtual work.

Although this type of test is not the usual method for characterizing these parameters, it has proven particularly effective in the context of timber structures, whether reinforced or not, by enabling a more representative assessment of the mechanical behavior of flexural elements (İşleyen *et al*. 2021a,b; Mercimek *et al*. 2024).

Therefore, this study aimed to estimate the longitudinal and shear moduli of elasticity of Brazilian native woods through three- and four-point static bending tests. For this purpose, both the classical Euler-Bernoulli beam theory and Timoshenko theory were applied, with the latter used to consider shear effects on displacement and to derive equations to estimate G.

Additionally, the study investigated how different ratios between the specimen length (L) and the cross-sectional height (h) affect the apparent longitudinal modulus of elasticity, allowing the evaluation of shear deformation impacts on displacements and justifying the adoption of Timoshenko theory for specimens with low L/h ratios. Thus, this research sought to improve the methods for characterizing wood stiffness and to deepen the understanding of its elastic behavior under different loading conditions and specimen geometries.

MATERIAL AND METHODS

General Considerations

In this study, four native wood species were used: Sapucaia (*Lecythis* spp.), Cupiúba (*Goupia glabra*), Tatajuba (*Bagassa guianensis*), and Roxinho (*Peltogyne* spp.). The wood was supplied by Madeireira do Cesar, located in Brotas, São Paulo, Brazil, and originated from certified areas of the tropical forest in southern Pará, Brazil. The specimens were taken from the central part of the trunk, where the sawing process is most efficient.

The wood samples, prepared with the dimensions specified for the tests, were stored for five months in an environment with an average temperature of (20 ± 2) °C and an average relative humidity of (65 ± 5)% at the Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering, São Carlos School of Engineering – University of São Paulo (EESC-USP), located in São Carlos, São Paulo, Brazil. This environmental condition during the storage period ensured that the specimens reached an equilibrium moisture content close to 12%, as established by the ABNT NBR 7190-1 (2022) standard. Each specimen had a cross-sectional dimension of 50 mm × 50 mm and a length of 1150 mm.

Experimental Procedure

The tests were carried out at LaMEM using an Amsler electro-hydraulic universal testing machine (Alfred J. Amsler & Co., Schaffhausen, Switzerland) with a capacity of 250 kN. Each specimen was tested according to ISO/FDIS 13910 (2014), BS EN 408 (2010), and ABNT NBR 7190-3 (2022). The tests aimed to determine the E in bending, considering five span-to-height (L/h) ratios. Given the specimen height of 5 cm, the support spans adopted were 105, 90, 75, 60, and 50 cm.

Considering the four wood species, six specimens per species, the five aforementioned spans, and two test configurations (three-point and four-point static bending), a total of 240 tests were performed. Notably, the test configurations for ISO/FDIS 13910 (2014) and BS EN 408 (2010) are similar. Therefore, a single test was conducted for both standards, with distinct calculations and displacement measurements.

The tests were conducted under geometric linearity, with the maximum displacement limited to $L/300$ (L in cm), as defined by the small displacement criterion in ABNT NBR 7190-1 (2022). The load was applied to the sample in two loading and unloading cycles at a 10 MPa/min rate, as specified by the same standard. The cycle limits were defined as $L/300$ for maximum displacement and $L/500$ for intermediate displacement.

The value of E was calculated from the slope of the load (F) *versus* displacement (δ) curve, determined by the points (F_{300}; δ_{300}) and (F_{500}; δ_{500}) corresponding to displacements of $L/300$ and $L/500$, respectively.

Three-point static bending test

The Brazilian standard ABNT NBR 7190-3 (2022) uses a three-point bending test to determine bending stiffness, with the load applied at the center of the specimen span. The test configuration is shown in Fig. 1.

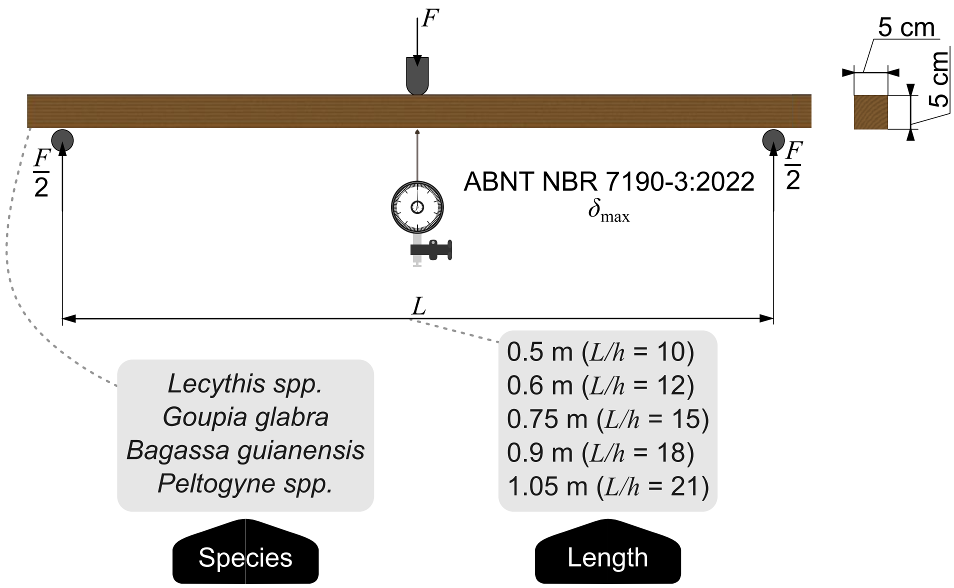

Fig. 1. Overview of the three-point bending test

According to this standard (ABNT NBR 7190-3 2022), the longitudinal modulus of elasticity (E_m) of wood in bending is given by Eq. 1:

$$E_m = \frac{(F_{300} - F_{500})L^3}{(\delta_{300} - \delta_{500})4bh^3} \tag{1}$$

In Eq. 1, F_{300} and F_{500} are the loads corresponding to the displacements $\delta_{300} = L/300$ and $\delta_{500} = L/500$, respectively. These displacements were recorded using a Mitutoyo analog dial indicator model 2109S-10, with a precision of 0.01 mm. The variables b, h, and L represent the specimen's width, height, and length, respectively.

Four-point static bending test

The ISO/FDIS 13910 (2014) and BS EN 408 (2010) standard employ a four-point bending test to determine bending stiffness, where the load is applied at the third point of the span. The test setup is shown in Fig. 2.

Displacements at three different points, denoted as δ_1, δ_2, and δ_3, were measured using Linear Variable Displacement Transducers (LVDTs) with a full-scale range of 10 mm. Measurements were recorded electronically at intervals of 500 ms throughout the test duration. The force values considered corresponded to displacements of $L/500$ and $L/300$ at the midspan between the supports only.

ISO/FDIS 13910 (2014)

According to this standard (ISO/FDIS 13910 2014), the E_m of wood in bending is given by Eq. 2:

$$E_m = \frac{(F_{300} - F_{500})}{(\delta_{2,300} - \delta_{2,500})} \frac{a(3L^3 - 4a^2)}{4bh^3} \tag{2}$$

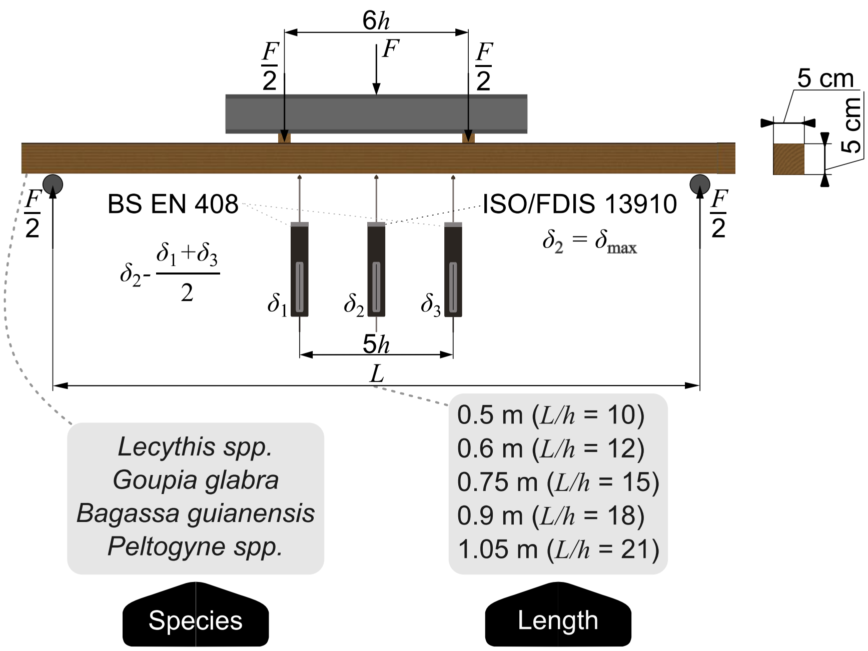

Fig. 2. Overview of the four-point bending test

In Eq. 2, F_{300} and F_{500} represent the loads corresponding to the displacements at point 2 (midspan), as shown in Fig. 2, of $\delta_{2,300} = L/300$ and $\delta_{2,500} = L/500$, in that order. The length L is the span between supports, and a is the distance between the support and the load application point. Additionally, b and h are the width and height of the specimen's cross-section, respectively.

BS EN 408 (2010)

An adaptation was made for this research. Instead of measuring relative displacement directly, the absolute displacements of points 1, 2, and 3 (see Fig. 2) were recorded relative to a common reference. The relative displacement was then calculated mathematically using the differences, as shown in Eq. 3 and Eq. 4:

$$w_{300} = \delta_{2,300} - \frac{\delta_{1,300}+\delta_{3,300}}{2} \tag{3}$$

$$w_{500} = \delta_{2,500} - \frac{\delta_{1,500}+\delta_{3,500}}{2} \tag{4}$$

In Eqs. 3 and 4, w_{300} and w_{500} are the relative displacements of point 2 concerning points 1 and 3, corresponding to central displacements of $\delta_{2,300} = L/300$ and $\delta_{2,500} = L/500$, respectively. Meanwhile, ($\delta_{1,300}$; $\delta_{1,500}$) and ($\delta_{3,300}$; $\delta_{3,500}$) are the displacements at points 1 and 3.

According to this standard (BS EN 408 2010), the E_m of wood in bending is given by Eq. 5:

$$E_m = \frac{(F_{2,300}-F_{2,500})\, aL_{1,3}^3}{(w_{300}-w_{500})\frac{4bh^3}{3}} \tag{5}$$

In Eq. 5, $L_{1,3}$ denotes the distance between points 1 and 3, as illustrated in Fig. 2. The other parameters are as previously defined.

Estimation of the Longitudinal and Transverse Modulus of Elasticity

The estimation of the longitudinal (*E*) and shear (*G*) moduli of elasticity was carried out through three- and four-point static bending tests using the Virtual Work Method (VWM). This method allows the derivation of analytical expressions for the mid-span displacement, considering the combined effects of bending moment and shear force, as established by Timoshenko beam theory. The general displacement equations, presented in Eq. 6 and Eq. 10, were derived following the approach described by Süssekind (1977) and serve as the basis for the equations used to calculate *E* and *G*, as demonstrated below.

According to this methodology, two successive experimental tests must be performed on the same specimen for each configuration. In the first test, the sample is positioned with a support span of L_1, and the force F_1 is determined for a displacement $\delta_1 = L_1/300$. In the second test, the supports are brought closer together, and the force F_2 is obtained for the displacement $\delta_2 = L_2/300$.

Ten span combinations were analyzed to estimate *E* and *G* using the corresponding equations presented later. Nine showed instability in the *G* values for three-point static bending. The only stable combination considered in this study was for spans L_1 = 90 cm and L_2 = 50 cm.

Three-point static bending

The total displacement for three-point bending is given by Eq. 6:

$$\delta = \frac{FL^3}{4Ebh^3} + \frac{3FL}{10Gbh} \tag{6}$$

By employing F_1, F_2, L_1, L_2, δ_1, and δ_2 in Eq. 6, the system represented in Eq. 7 is obtained:

$$\begin{cases} \frac{F_1 {L_1}^3}{4Ebh^3} + \frac{3F_1 L_1}{10Gbh} = \delta_1 \\ \frac{F_2 {L_2}^3}{4Ebh^3} + \frac{3F_2 L_2}{10Gbh} = \delta_2 \end{cases} \tag{7}$$

By solving the system of Eq. 7, the longitudinal (*E*) and transverse (*G*) elastic modulus are derived as follows:

$$E = \frac{F_1 F_2 L_1 L_2 (L_2^2 - L_1^2)}{4bh^3(\delta_2 F_1 L_1 - \delta_1 F_2 L_2)} \tag{8}$$

$$G = \frac{3F_1 F_2 L_1 L_2 (L_1^2 - L_2^2)}{10bh(\delta_2 F_1 L_1^3 - \delta_1 F_2 L_2^3)} \tag{9}$$

Four-point static bending

The theoretical displacement at the beam's mid-span for this bending type is given by Eq. 10:

$$\delta = \frac{F}{4Ebh^3}(3aL^2 - 4a^3) + \frac{6Fa}{10Gbh} \tag{10}$$

For the four-point static bending test, applying F_1, F_2, L_1, L_2, δ_1, δ_2, a_1, and a_2 in Eq. 10 leads to an equation system as follows:

$$\begin{cases} \frac{F_1}{4Ebh^3}\left(3a_1 {L_1}^2 - 4{a_1}^3\right) + \frac{6F_1 a_1}{10Gbh} = \delta_1 \\ \frac{F_2}{4Ebh^3}\left(3a_2 {L_2}^2 - 4{a_2}^3\right) + \frac{6F_2 a_2}{10Gbh} = \delta_2 \end{cases} \tag{11}$$

Solving the equation system yields:

$$E = \frac{F_1F_2\left(a_1(3a_2L_2{}^2-4a_2{}^3)-a_2(3a_1L_1{}^2-4a_1{}^3)\right)}{4bh^3(\delta_2F_1a_1-\delta_1F_2a_2)} \quad (12)$$

$$G = \frac{6F_1F_2\left(a_2(3a_1L_1{}^2-4a_1{}^3)-a_1(3a_2L_2{}^2-4a_2{}^3)\right)}{10bh(\delta_2F_1(3a_1L_1{}^2-4a_1{}^3)-\delta_1F_2(3a_2L_2{}^2-4a_2{}^3))} \quad (13)$$

Statistical Analysis

The Tukey mean comparison test, with a 5% significance level, was used to compare the mean elasticity modulus values obtained based on the three normative documents previously mentioned, considering the five support span distances. Additionally, the analysis was applied to compare the *E* and *G* values concerning the different methodologies employed in this research.

In the Tukey test, “A” represents the treatment with the highest mean property value, “B” the second highest mean, and so on. Identical letters indicate treatments with statistically equivalent means.

RESULTS AND DISCUSSION

The average values, coefficients of variation (CV), and results of the Tukey mean comparison test at the 5% significance level for the apparent longitudinal modulus of elasticity (E_{ap}), obtained according to the three standards presented in this study and the five *L/h* ratios investigated, are presented in Table 1.

Table 1. Results of the Apparent Longitudinal Modulus of Elasticity and Tukey’s Test (Tu) by Species

Wood type	*L/h*	ABNT NBR 7190-3 (2022)			BS EN 408 (2010)			ISO/FDIS 13910 (2014)		
		E_{ap} (GPa)	CV (%)	Tu	E_{ap} (GPa)	CV (%)	Tu	E_{ap} (GPa)	CV (%)	Tu
Sapucaia	21	21.04	12.96	A	20.66	12.53	A	23.58	6.24	A
	18	21.43	6.25	A	23.15	13.61	A	22.94	6.14	AB
	15	21.48	8.05	A	20.50	11.03	A	22.05	6.45	AB
	12	20.16	7.19	A	23.47	13.85	A	21.14	6.36	BC
	10	19.47	9.13	A	20.25	7.41	A	19.57	6.27	C
Cupiuba	21	14.62	8.14	A	14.70	8.59	A	15.70	2.73	A
	18	14.41	10.86	A	14.56	10.05	A	15.08	2.56	AB
	15	13.85	2.96	AB	15.21	14.14	A	14.68	2.80	BC
	12	13.32	5.04	AB	15.48	6.26	A	14.19	5.45	C
	10	12.44	3.47	B	12.90	17.45	A	12.80	2.65	D
Tatajuba	21	16.78	8.19	A	15.99	14.29	A	16.53	8.85	A
	18	16.50	7.85	A	15.06	10.31	A	16.14	9.46	AB
	15	15.89	5.83	AB	15.32	13.54	A	16.08	5.78	AB
	12	14.94	6.63	AB	14.91	21.59	A	14.83	7.60	AB
	10	14.36	7.04	B	14.17	11.06	A	14.25	6.34	B
Roxinho	21	17.88	6.75	A	18.24	2.82	A	20.39	3.54	A
	18	18.43	6.63	A	18.35	8.03	A	19.49	3.76	AB
	15	18.52	6.78	AB	18.10	5.47	A	19.35	4.11	AB
	12	17.77	6.50	AB	20.33	13.19	A	18.16	5.40	BC
	10	16.28	6.66	B	19.17	13.68	A	16.81	5.36	C

Considering the twelve cases analyzed, five showed statistically equivalent E_{ap} values for the same species, regardless of the *L/h* ratio, with all classified as "A." These cases occurred mainly in the tests conducted according to BS EN 408 (2010). The methodology of this standard proved to be more reliable for estimating the longitudinal modulus of elasticity (*E*) by considering only the displacement in the region of the specimen with zero shear force and maximum, constant bending moment. On the other hand, ABNT NBR 7190-3 (2022) showed consistency only for the Sapucaia species, while ISO/FDIS 13910 (2014) did not show statistical equivalence in any of the cases.

In the remaining seven cases, a significant reduction in E_{ap} values was observed with a decreasing *L/h* ratio, especially for Cupiúba wood tested according to ISO/FDIS 13910 (2014), with a reduction of up to 18.47%. This trend was accompanied by progressive changes in the classifications ("A" to "AB," then to "B," and even to "C" or "D"), indicating a greater influence of shear deformation on the total displacement. This factor compromises the estimate's accuracy and results in an apparent modulus of elasticity values. Based on the analysis of Table 1, an *L/h* ratio of 18 was identified as the minimum recommended limit to minimize shear effects in bending tests aimed at determining *E*.

Given the effects of the *L/h* ratio on bending tests, the VWM combined with Timoshenko theory was applied to simultaneously obtain *E* and *G*. To evaluate the influence of the type of loading and compare the values obtained according to the methodologies of the adopted standards, the Tukey test at a 5% significance level was used. Tables 2 and 3 present the results by species, with "Eq. System" being the designation adopted for the system of equations.

Table 2. Results of the Estimated Longitudinal Modulus of Elasticity and Tukey's Test (Tu) by Species

Wood type	Bending Type	Treatment	*E* (GPa)	CV (%)	Tu
Sapucaia	4-point	*E (Eq. System)*	24.81	5.43	A
		E (L/h = 21)	23.58	6.24	AB
	3-point	*E (Eq. System)*	22.82	6.39	AB
		E (L/h = 21)	21.04	12.96	B
Cupiúba	4-point	*E (Eq. System)*	16.88	2.79	A
		E (L/h = 21)	15.70	2.73	AB
	3-point	*E (Eq. System)*	14.59	5.80	B
		E (L/h = 21)	14.62	8.14	B
Tatajuba	4-point	*E (Eq. System)*	17.29	8.85	A
		E (L/h = 21)	16.53	9.74	A
	3-point	*E (Eq. System)*	17.11	7.05	A
		E (L/h = 21)	16.78	8.19	A
Roxinho	4-point	*E (Eq. System)*	21.28	4.22	A
		E (L/h = 21)	20.39	3.54	A
	3-point	*E (Eq. System)*	19.96	5.21	A
		E (L/h = 21)	17.88	6.75	B

In Table 2, a decreasing trend in the longitudinal modulus of elasticity (*E*) values is observed for all species in the following methodological order: *E* (4-point – Eq. System) > *E* (4-point – *L/h* = 21) > *E* (3-point – Eq. System) > *E* (3-point – *L/h* = 21). This outcome indicates that applying Timoshenko's theory in four-point bending tests resulted in the highest *E* estimates. For Tatajuba, the estimates were statistically equivalent across methods, revealing lower sensitivity to methodological variations. For the other species, significant differences were observed, with changes in classification from "A" to "B".

Table 3. Results of the Estimated Transverse Modulus of Elasticity and Tukey's Test (Tu) by Species

Species	Bending Type	Treatment	*G* (GPa)	CV (%)	Tu
Sapucaia	3-point	*G (Eq. System)*	1.30	20.99	A
		G (E/16)	1.31	12.96	A
	4-point	*G (E/16)*	1.47	6.24	A
		G (Eq. System)	0.75	14.17	B
Cupiúba	3-point	*G (Eq. System)*	0.98	21.70	A
		G (E/16)	0.91	8.14	A
	4-point	*G (E/16)*	0.98	2.73	A
		G (Eq. System)	0.43	15.41	B
Tatajuba	3-point	*G (Eq. System)*	1.05	19.24	A
		G (E/16)	1.05	8.19	A
	4-point	*G (E/16)*	1.03	9.74	A
		G (Eq. System)	0.65	33.28	B
Roxinho	3-point	*G (Eq. System)*	0.94	24.19	AC
		G (E/16)	1.12	6.75	AB
	4-point	*G (E/16)*	1.27	3.54	B
		G (Eq. System)	0.69	32.39	C

The values obtained agree with the data reported in the literature. Cupiúba, Dias, and Lahr (2004) reported *E* values of 14.12 GPa (in compression), 14.44 GPa (in tension), and 13.15 GPa (in bending). For Tatajuba, the values were 18.57 GPa, 16.75 GPa, and 17.90 GPa, respectively. Kuniyoshi *et al*. (2024) estimated that for Roxinho wood, 24.23 GPa (in compression), 22.46 GPa (in tension), and 20.93 GPa (in bending). This study's ranges ranged from 14.59 to 16.88 GPa for Cupiúba, 16.53 to 17.29 GPa for Tatajuba, and 17.88 to 21.28 GPa for Roxinho. No comparative data were found for Sapucaia, highlighting the novelty of these results.

Table 3 presents the shear modulus (G) values indirectly estimated by $G = E/16$, according to ABNT NBR 7190-1 (2022). Although showing low variability, these values merely reflect the consistency of E. In this context, the approach proposed in this study stands out, as it estimates G by considering the contribution of shear deformation.

Among the configurations evaluated, the combination of three-point bending tests and the application of the Equation System proved to be the most effective for estimating G due to the greater sensitivity of displacement to shear in short spans and lower L/h ratios. Although presenting slightly higher coefficients of variation, the G values were higher and, in most cases, significantly greater than those obtained from four-point bending, as indicated by the Tukey test. It is also worth noting that, in three-point static bending tests, shear forces act along the entire length of the specimen, unlike in four-point bending tests, where shear is zero in the region between the applied loads.

The study by Lahr (1983) supports using three-point bending as a simple and effective method for estimating G, with statistical validation at a 95% confidence level. Based on his results, E/G ratios of approximately 32, 34, and 43 were obtained for three different wood species. Complementarily, Zangiácomo *et al*. (2013) applied the same methodology to round structural members, obtaining $E/G = 56$.

The results of this study indicate *E/G* ratios of 21.15 for Roxinho, 17.54 for Sapucaia, 16.30 for Tatajuba, and 14.84 for Cupiúba. Compared to the normative value of 16, the observed variations were +32.19% (Roxinho), +9.62% (Sapucaia), +1.87% (Tatajuba), and –7.25% (Cupiúba). This fact demonstrates the inadequacy of using a fixed *E/G* value and reinforces the need for specific experimental tests to characterize native species accurately.

CONCLUSIONS

1. The span-to-height ratio (*L/h*) significantly influenced wood's apparent longitudinal modulus of elasticity (E_{ap}) in static bending tests, with statistical equivalence observed in only 5 out of the 12 cases analyzed.
2. The BS EN 408 (2010) standard proved more consistent and reliable in determining the longitudinal modulus of elasticity (*E*), as it adopts measurements in the specimen zone with zero shear and maximum constant bending moment. In contrast, the ISO/FDIS 13910 (2014) standard showed greater sensitivity to the *L/h* ratio, with reductions in E_{ap} of up to 18.47%.
3. The results indicate that all standards evaluated are applicable for estimating E, provided that a minimum *L/h* ratio of 18 is adopted, which reduces shear effects on displacement and ensures the validity of Euler-Bernoulli beam theory, especially for ABNT NBR 7190-3 (2022) and ISO/FDIS 13910 (2014).
4. Combining the Virtual Work Method with Timoshenko's theory resulted in an equation for mid-span displacement that accounts for both bending and shear deformations. With two consecutive tests at different spans (L_1 = 90 cm and L_2 = 50 cm), it was possible to establish a system of equations that allowed the simultaneous estimation of *E* and *G* for wood. Among the configurations evaluated, the three-point bending test was the most representative and accurate for determining the shear modulus (*G*), demonstrating its greater sensitivity to shear effects.
5. The *E/G* ratios ranged from 14.84 to 21.15, representing a decrease of up to 7.25% and an increase of up to 32.19%, respectively, relative to the conventional normative value (*E/G* = 16), reinforcing the need for a specific characterization method.

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