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ARTÍCULO

Laminated bamboo lumber beams: An evaluation of structural behavior and bonding quality

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Abstract:
Laminated bamboo lumber is a lignocellulosic composite with a wide range of applications in construction. Despite its growing use in structural applications, the structural behavior of laminated bamboo lumber has not been sufficiently investigated through advanced numerical modelling approaches, and the influence of species–adhesive combinations on bonding performance remains insufficiently understood. This lack of integrated numerical–experimental studies represents a critical research gap for the reliable structural analysis of bamboo-based elements. This work aimed to address this gap by numerically and experimentally evaluating laminated bamboo lumber elements submitted to three-point bending tests and by assessing the bonding performance of four distinct species-adhesive combinations (*i.e. Dendrocalamus asper*, *Phyllostachys pubescens*). The physical and mechanical properties of the lamellas were obtained from the experimental characterization of bamboo. A finite element modeling was developed to simulate the structural response, incorporating orthotropic behavior and physical non-linearity. The constitutive model adopted for bamboo followed Hill's criterion, simulating elastic-plastic behavior through bilinear curves. The numerical and experimental results showed good agreement, and the model was able to simulate the behavior of beams in bending, including the identification of critical stresses regions along the element. The species-adhesive combinations showed high delamination and shear strength at the glue lines. The results demonstrate the capability of the proposed numerical framework to predict the bending behavior of laminated bamboo lumber and highlight the importance of appropriate species–adhesive selection, contributing to the development of reliable design and manufacturing strategies for structural bamboo products.

Keywords: Bonding performance, *Dendrocalamus asper*, finite element modeling, laminated bamboo lumber, *Phyllostachys pubescens*, structural analysis

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Introduction

The use of bamboo as a structural material in civil construction has attracted increasing interest due to its renewable nature, high tensile strength, and significant potential for carbon fixation (Araujo *et al.* 2026). However, despite these advantages, the reliable structural application of bamboo remains challenging because of its natural variability, anisotropic mechanical behavior, and sensitivity to processing and bonding conditions. These characteristics raise concerns regarding the mechanical reliability and predictability of bamboo-based structural elements. Although bamboo exhibits rapid growth, with height increases of 80 mm to 100 mm within 24 h, and is a low-cost, rapidly renewable resource (Khatib and Nounu 2017), its safe and efficient implementation in load-bearing applications requires a deeper understanding of its structural performance and associated uncertainties.

One of the most important structural applications of bamboo is in production of Laminated Bamboo Lumber (LBL), a composite material developed to improve the use of bamboo in engineered products. LBL is considered one the most promising application of bamboo in the Brazilian market, enabling its use in furniture, boards, coverings, lining, frames and floors (Alves *et al*. 2025). Although the LBL manufacturing method has been studied since the late 1990s and the material is increasingly used in structural elements such as trusses, floors, beams, and columns, several technical challenges relevant to its structural performance remain unresolved. In particular, variability in mechanical response, material heterogeneity, and the quality of bonding between lamellas can significantly affect the mechanical reliability and load-bearing capacity of LBL elements. Despite its classification as an environmentally friendly material due to lower energy requirements during manufacturing when compared to wood, steel, and aluminum (Liu *et al.* 2024), these unresolved issues continue to limit the broader and more reliable application of LBL in load-bearing structures.

One of the main challenges associated with the structural use of bamboo in Brazil is the limited availability of specific technical standards, which constrains both design practice and research development. The first version of the bamboo standard in Brazil, ABNT NBR 16828-2 (2020), was only recently approved, reflecting the early stage of regulatory consolidation in this field. In parallel with these regulatory limitations, significant scientific gaps persist, particularly regarding numerical modelling approaches and the systematic evaluation of bonding quality in bamboo-based structural products. Currently, the only Brazilian document providing recommendations for delamination and glue-line shear strength tests is ABNT NBR 7190-6 (2022a); however, this standard is explicitly developed for glued laminated timber (glulam) elements and does not account for the anatomical, mechanical, and bonding specificities of laminated bamboo lumber. As a result, there is a lack of validated methodologies and modelling frameworks specifically tailored to assess the structural behavior and bonding performance of LBL, highlighting a critical gap between existing standards and the requirements for reliable structural applications of bamboo composites.

In Brazil, most native species of bamboo are classified as ornamental; however, several genera present characteristics that make them suitable for structural applications. Among the species occurring in the country, those belonging to the genus *Gigantochoa, Pseudosasa*, *Bambusa, Sasa*, *Sinoarundinaria, Dendrocalamus*, *Guadua*, and *Phyllostachys* have been identified as having potential for engineering use (Correal and Arbeláez 2010, Alves *et al.* 2025). In particular, *Dendrocalamus*, *Guadua*, and *Phyllostachys* stand out due to their favorable mechanical properties, culm geometry, and availability, which explain their more frequent application in the manufacture of Laminated Bamboo Lumber. The selection of these species is therefore directly related to structural performance considerations and bonding behavior, reinforcing the need to evaluate their response within engineered products such as LBL.

In Brazil, the majority of studies on bamboo are predominantly experimental and focus on the determination of physical and mechanical properties. While these investigations are essential, they provide limited insight into the structural behavior of bamboo-based elements under complex loading conditions. Numerical simulations, on the other hand, offer a powerful tool for project optimization and for the analysis of localized stress and deformation mechanisms computer simulation (Hu *et al.* 2021, Zhu *et al.* 2026). However, most numerical studies developed for bamboo and glued bamboo elements, consider only the elastic properties in the generation of the model (Chen *et al*. 2016, Fu *et al*. 2017, Kingsley *et al*. 2015, Lefevre *et al*. 2019), neglecting material nonlinearity and damage-related behavior. This simplification limits the ability of existing models to accurately represent failure mechanisms and stress redistribution in structural elements. Although Li *et al*. (2015) demonstrated that incorporating plastic behavior in numerical simulations of LBL under axial compression leads to improved predictive capability compared to purely elastic models, such approaches remain scarce and are rarely extended to bending-dominated behavior or integrated with assessments of bonding performance. As a result, there is a clear lack of comprehensive numerical frameworks that combine nonlinear material modelling with experimental validation and bonding quality evaluation for laminated bamboo lumber.

In response to the identified lack of validated numerical frameworks and limited knowledge regarding bonding performance in laminated bamboo lumber, this work aimed to experimentally evaluate the bending behavior of LBL beams and to calibrate a numerical model capable of identifying stress distributions and critical mechanical regions along the elements. By incorporating nonlinear material behavior into the modelling approach, the proposed methodology directly addresses the limitations of existing elastic-based numerical studies. In addition, the bonding quality of different bamboo species–adhesive combinations is evaluated through experimental testing, contributing to the assessment of glue-line performance in the absence of standards specifically developed for LBL. Together, the combined numerical–experimental approach adopted in this work seeks to advance the understanding of structural behavior and bonding reliability of LBL, supporting the development of more robust design and manufacturing strategies for bamboo-based structural elements.

Materials and methods

Experimental methodology

Two bamboo species were used: giant bamboo (*Dendrocalamus asper* (Schult.) Backer) and moso bamboo (*Phyllostachys pubescens* syn. edulis). These species were selected due to their widespread use in structural and engineered bamboo products, as well as their distinct geometric and mechanical characteristics, which make them representative candidates for laminated bamboo lumber applications. Giant bamboo is known for its large culm diameter and high mechanical strength, with external diameters between 82 mm and 106.5 mm and wall thickness between 5.3 mm and 14.7 mm, making it particularly suitable for load-bearing structural elements. Moso bamboo, one of the most commercially available bamboo species worldwide and widely used in engineered bamboo products, presented external diameters between 54.6 mm and 110.1 mm and wall thickness between 6.0 mm and 24.3 mm. The inclusion of both species allows the assessment of LBL performance considering differences in culm geometry and material properties that may influence mechanical behavior and bonding quality. The bamboos were cut to approximately two meters long and stacked vertically in a covered and protected place for drying.

The longitudinal sectioning of the bamboo was carried out with a star-type knife, developed especially for this purpose, to remove the bamboo lamellas. The bamboo diaphragms were removed by a narrow band saw and a rotary sander and a laboratory thickening planer was used to remove the cross-section curves. For a more detailed description of the bamboo lamellas production process see the reference Santos (2019).

The following properties were determined experimentally for both bamboo species: density (ρ), tensile strength parallel to grain (f_{t0}), shear strength parallel to grain (f_{v0}), longitudinal stiffness (E_{c0}) and compressive strength parallel to the grain (f_{c0}). These properties were selected because they directly govern the bending response, stress distribution, and failure mechanisms of laminated bamboo lumber elements subjected to structural loading. Density is required for material characterization, while stiffness and strength parameters in tension, compression, and shear are essential for calibrating constitutive models and defining failure criteria in finite element simulations. In particular, tensile and compressive strengths parallel to the grain are critical for representing bending-induced stresses, whereas shear strength is directly related to glue-line performance and interlaminar behavior. The methodologies were based on Ghavami and Marinho (2005) and Luna *et al.* (2014) to ensure consistency with established testing procedures and reliable input data for the numerical analyses (Figure 1).

Figure 1: Mechanical tests performed on bamboo species. (a) Tensile strength parallel to grain, (b) Shear strength parallel to grain, (c) Compressive strength parallel to the grain.

Non-destructive mechanical classification of the bamboo lamellas was carried out before the manufacture of the LBL beams (Harries *et al*. 2017). This procedure was adopted to reduce the inherent variability of bamboo by grouping lamellas according to their longitudinal stiffness, thereby improving the homogeneity and predictability of the structural response of the beams. Each bamboo lamella had its longitudinal stiffness (MOE) determined through three-point static bending test, since MOE is a key parameter governing bending behavior and is commonly used as a sorting criterion in engineered wood and bamboo products. The MOE-based classification allowed the more efficient distribution of lamellas within the LBL beams, contributing to enhanced mechanical performance and providing more consistent input parameters for both experimental testing and numerical modelling.

In the manufacture of LBL beams, the lamellas with greater MOE were placed in the layers furthest from the neutral line of the beams, where the greatest stresses act during the bending tests. The beams were made with six lamellas with a thickness of 50 mm each. The dimensions of the LBL beams respected the ratio (length over height less than 20) to eliminate the shear portion in the deflection of the beam. The span between supports considered for the bending tests was 630 mm.

The bonding of the LBL beams was performed with two types of adhesives: polyurethane bi-component (PU Bi), manufactured by Kehl, and polyurethane mono-component (PU mono), by

Tekbonde. The moisture content of bamboo lamellas on the day of manufacture was between 9 % and 15 %. The weight used for the adhesives was 200 g/m² (Lima *et al*. 2014), with the application of adhesive on a single surface of the lamella interface. The curing time of the two types of adhesives was 24 h. The bamboo lamellas were pressed using six type C clamps, distributed along the length of the beams, with pressure control applied by a torque wrench (Ogunsanwo *et al.* 2019). The bonding pressure used was 2,5 MPa (Lima *et al*. 2014). Bonding performance was evaluated according to ABNT NBR 7190-6 (2022a) through delamination and glue line shear strength tests.

A total of 16 LBL beams were produced for each bamboo species, 10 beams with two-component PU adhesive and 6 beams with one-component PU adhesive. The bending tests (Figure 2) followed the recommendations of the standard ABNT NBR 7190-3 (2022b), because at the time of development of this work, the standard ABNT NBR 16828-2 (2020) was not yet available for national consultation in the country.

Figure 1: Three-point bending test performed on a LBL beam.

The analyses of the experimental results obtained for the physical and mechanical properties of the bamboo, as well as for the strength and stiffness of the LBL beams, were made using the statistical software R version 4.0.4, through the t test and Tukey ANOVA, with significance level of 5 %

Numerical methodology

The numerical simulation was performed for a representative LBL beams produced with bamboo of the species giant bamboo (*Dendrocalamus asper* (Schult.) Backer) and bonded with two-component PU adhesive. This beam was selected because it exhibited mechanical behavior consistent with the average experimental response observed during bending tests, making it suitable for model calibration and validation. ANSYS software (2005), version 12.0, was used, which is based on the Finite Element Method. The SOLID45 hexahedral element (with 8 nodes and three degrees of freedom per node: translations in x, y and z) was used to represent the bamboo lamellas, since this element allows the consideration of the material elastic and plastic behavior (Calil-Neto *et al*. 2017).

Two models were used to evaluate the behavior of the LBL beam in bending: a linear elastic model and another model with physical non-linearity. In the calibration of the elastic model, only the elastic properties of each of the bamboo lamellas were considered, that is, longitudinal modulus of elasticity (E), shear modulus (G) and Poisson's ratio (ν).

In the nonlinear model the plastic properties (longitudinal compressive strength, longitudinal tensile strength and respective tangent modules) were considered, in addition to the elastic properties. For both models, an orthotropic behavior was considered, *i. e.*, different mechanical properties for each of the three orthogonal directions of the material (longitudinal, tangential, and radial). In numerical models, the longitudinal direction corresponded to the ANSYS z direction, the tangential direction to the x direction and the radial direction to the y direction. Hill's yield criterion, which is formulated as an anisotropic extension of the von Mises criterion and inherently assumes identical yielding behavior in tension and compression, was used for the simulation of the behavior of the LBL. The adopted constitutive model simulated elastic-plastic behavior through bilinear curves. Because Hill’s model does not distinguish between tensile and compressive strength values, the mechanical behavior of bamboo in tension and compression was considered equal in the numerical simulations. For this reason, the longitudinal tensile strength was adopted as the reference parameter to define the remaining strength properties required for modelling the LBL. This modelling choice is consistent with the theoretical formulation of Hill’s criterion and enables a simplified yet effective representation of the global nonlinear bending response of laminated bamboo lumber, while acknowledging that local tension–compression asymmetry is not explicitly captured. For the linear model, the constitutive relations between the elastic properties of bamboo, for each lamella of the LBL beam, were defined according to Molina (2008). The mesh of the model was discretized into 4080 hexahedral elements, with 10 mm sides. This discretization was considered satisfactory based on the use of regular cubic elements and practical considerations related to available computational power, providing stable displacement and deformation responses. The selected mesh represents a balance between numerical accuracy and computational efficiency for the global bending behavior analyzed. The numerical model was constrained and loaded in accordance with the experimental bending tests, as shown in Figure 3. One of the beam's end supports had their translations restricted to x, y and z, while the second end support had the x and y translations restricted. The load was distributed in a total of 18 central nodes of the upper beam of the beam (upper lamella).

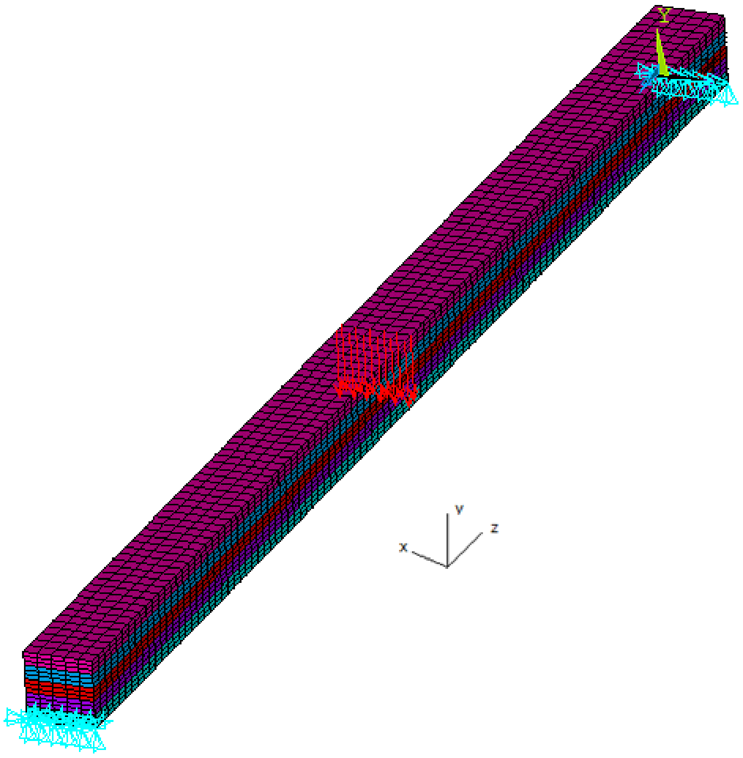


Figure 2: Mesh discretization, constraint and loading conditions.

The validation of the models was performed by comparing the global load–displacement behavior obtained numerically and experimentally (Figure 4). The load–displacement response was selected as the primary validation criterion because it directly reflects the global stiffness, nonlinear response, and overall bending behavior of the LBL beams, which are the main aspects of interest in this study. In the calibration of the models, the displacement of the central node of the lower lamella of the LBL beam was considered. Although local stress and strain distributions were analyzed qualitatively, the validation focused on the global response due to the inherent variability of bamboo and the experimental limitations associated with local measurements. The numerical curve was plotted up to the point where the convergence of the results was possible (displacement of approximately 30 mm) for the non-linear model, considering a tolerance of 0,001 which is usually admitted for numerical models (Molina 2008).

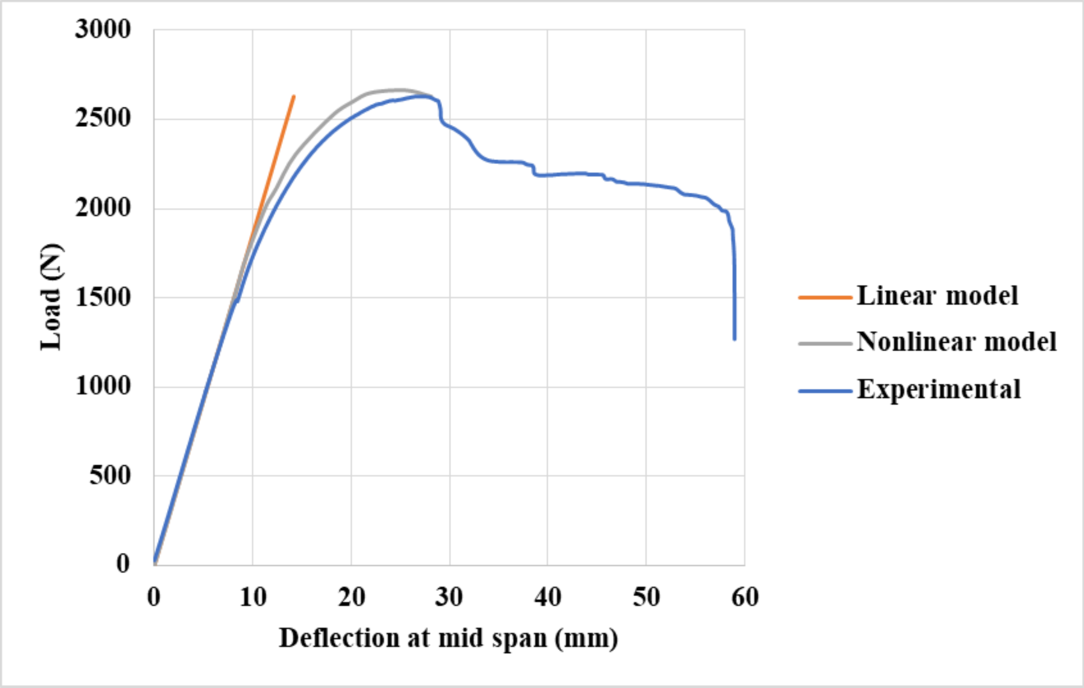


Figure 3: Validation curve of LBL beams numerical models.

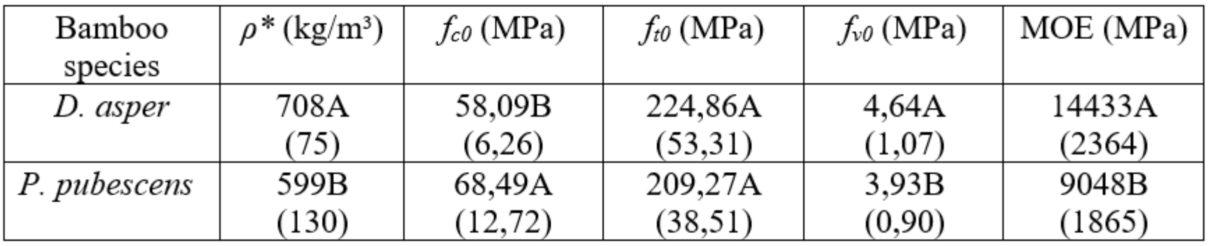
The von Mises and longitudinal tensile and compressive stresses (in the z direction) were obtained from the numerical simulations. It was possible to identify the beam’s regions with higher levels of stress concentration and to verify the rupture modes obtained experimentally.

Results and discussion

Experimental results

Table 1 shows the average results obtained in the experimental characterization of bamboo species, along with the standard deviation in parentheses. Equal letters in the vertical indicates that there was no significant difference at a 5 % significance level.

Table 1: Physical-mechanical properties of bamboo species.



Bamboo species	ρ* (kg/m³)	f_{c0} (MPa)	f_{t0} (MPa)	f_{v0} (MPa)	MOE (MPa)
D. asper	708A (75)	58,09B (6,26)	224,86A (53,31)	4,64A (1,07)	14433A (2364)
P. pubescens	599B (130)	68,49A (12,72)	209,27A (38,51)	3,93B (0,90)	9048B (1865)

*ρ: density; f_{c0}: compressive strength parallel to grain; f_{t0}: tensile strength parallel to grain; f_{v0}: shear strength parallel to grain; MOE: modulus of elasticity in static bending

According to the Brazilian standard ABNT 7190-1 (2022c), the species giant bamboo (*Dendrocalamus asper* (Schult.) Backer) could be classified in the resistance class D40, indicating a mechanical performance comparable to medium-density hardwoods when loaded parallel to the grain. This classification highlights the suitability of giant bamboo for structural applications requiring moderate load-bearing capacity. On the other hand, the species moso bamboo (*Phyllostachys pubescens* syn. edulis) was classified in the resistance class D60, which places its structural performance in a range comparable to high-density hardwoods. The higher resistance class of *P. pubescens* reflects its superior load-bearing potential, reinforcing its applicability in more demanding structural elements. Overall, these results demonstrate that both bamboo species exhibit mechanical performances compatible with structural timber materials, supporting their use in engineered products such as laminated bamboo lumber.

The moso bamboo (*Phyllostachys pubescens* syn. edulis) and giant bamboo (*Dendrocalamus asper* (Schult.) Backer) showed tensile strength parallel to grain within the range of expected values (Rosa *et al*. 2016), confirming their suitability for structural applications dominated by tensile stresses. When compared to wood species, both bamboos showed substantially higher tensile strength, with values up to three times greater, which highlights their significant potential for use in elements subjected to bending and tension-controlled failure modes. This superior tensile performance is particularly relevant for laminated bamboo lumber, where tensile stresses govern the behavior of the outer lamellas under flexural loading. The bamboo species moso bamboo (*Phyllostachys pubescens* syn. edulis) had an apparent density 15 % lower than the species giant bamboo (*Dendrocalamus asper* (Schult.) Backer), indicating a more efficient strength-to-weight ratio that may be advantageous for lightweight structural components and optimized material use.

Table 2 shows the average results obtained in the bonding quality and bending tests of the LBL beams, along with the standard deviation in parentheses. Same horizontal letters indicate means that there was no significant difference at a 5 % significance level.

Table 2: Bending strength and stiffness of LBL beams.

Bending properties	Species-adhesive combinations			
	D. asper - PU mono	*D. asper* - PU bi	*P. pubescens* - PU mono	*P. pubescens* - PU bi
Delamination (%)	55,31a (11,80)	47,71a (14,97)	31,69b (11,97)	25,59b (13,64)
Glue line shear strength (MPa)	6,69a (1,69)	6,55a (1,56)	4,66b (1,79)	5,53b (1,52)
MOE (MPa)	17680a (915)	18982a (3357)	10477b (1588)	11884b (1161)
MOR (MPa)	158,28a (22,50)	142,44a (33,69)	120,82a (26,11)	141,14a (16,82)

The delamination averages of the BLC beams produced from moso bamboo (*Phyllostachys pubescens* syn. edulis) bamboo species were lower than those observed for the glued laminates of giant bamboo (*Dendrocalamus asper* (Schult.) Backer), indicating comparatively better bonding performance for the moso bamboo-based elements, as seen in BLC bonded with polymeric isocyanate and PVA adhesive in Rosa *et al.* (2016). Despite this relative improvement, the delamination percentages obtained in this study were high when compared with normative reference values established for other engineered wood products. For glued laminated timber, recommended delamination limits range from 4% to 6%, while for cross-laminated timber (CLT) the limit is 10% (ABNT 2022a). Although no delamination limits are currently defined for laminated bamboo lumber, the exceedance of these reference thresholds highlights potential limitations in bonding quality that may compromise the long-term structural performance and durability of LBL elements. These results reinforce the need for species-specific bonding assessment and the development of acceptance criteria tailored to laminated bamboo products.

The glue line shear strength of moso bamboo (*Phyllostachys pubescens* syn. edulis) BLC ranged between 4,6 MPa to 5,5 MPa and for the BLC from 6,5 MPa to 6,7 MPa, which were close to previously presented paper in the subject (Lapo and Beraldo 2008, Paes *et al.* 2009).

The average stiffness of the LBL beams, for the different species-adhesive combinations, were within the expected range for this type of material, that is, between 10000 MPa and 30000 MPa (Fu *et al*. 2017, Sharma *et al*. 2017). On the other hand, the average strength ranged from 120 MPa to 158 MPa according to the species-adhesive combination, significantly higher than the values obtained by Sharma *et al*. (2017). According to Fu *et al*. (2017) the bending strength of reconstituted bamboo elements ranges from 86 MPa to 140 MPa, close to the values obtained in this work.

Previous studies have investigated laminated bamboo composites focusing on the influence of adhesive type and chemical treatments on bonding performance. In these studies, delamination of bamboo lamellas was frequently observed during testing and was directly associated with inadequate adhesion, leading to ductile failure modes and bending strength values typically ranging between 40 MPa and 70 MPa. In addition, variations in lamella configuration and surface conditions were shown to influence failure mechanisms, with delamination occurring in specimens with external lamellas, while failure by normal tension was observed in configurations without bark. Reported stiffness values ranged between 4000 MPa and 14000 MPa, depending on lamella quality and adhesive type. (Beraldo and Rivero 2003 and Lima *et al*. 2014)

In comparison, the LBL beams analyzed in the present study exhibited higher bending strength and stiffness, indicating an improved structural performance relative to previous works. These results suggest a more efficient stress transfer within the laminated structure, although bonding-related limitations remain evident, particularly in relation to delamination behavior (Nogueira (2008)

Numerical results

The comparison between the linear and nonlinear numerical models revealed clear differences in their ability to represent the structural response of LBL beams under increasing load levels. The linear model, which considered only the elastic properties, provided acceptable predictions only at low load levels, but failed to capture the stiffness degradation and deformation behavior as the applied load approached rupture. This limitation indicates that elastic modelling alone is insufficient for representing the structural response of LBL beams under ultimate loading conditions.

On the other hand, the nonlinear model showed a significantly improved representation of the bending behavior at higher load levels, successfully capturing the progression of stresses and the response close to failure. Figure 5 shows the stress distributions obtained from the nonlinear simulation, which are consistent with the experimentally observed rupture mode, characterized by failure in the fibers of the lower lamella under tension.

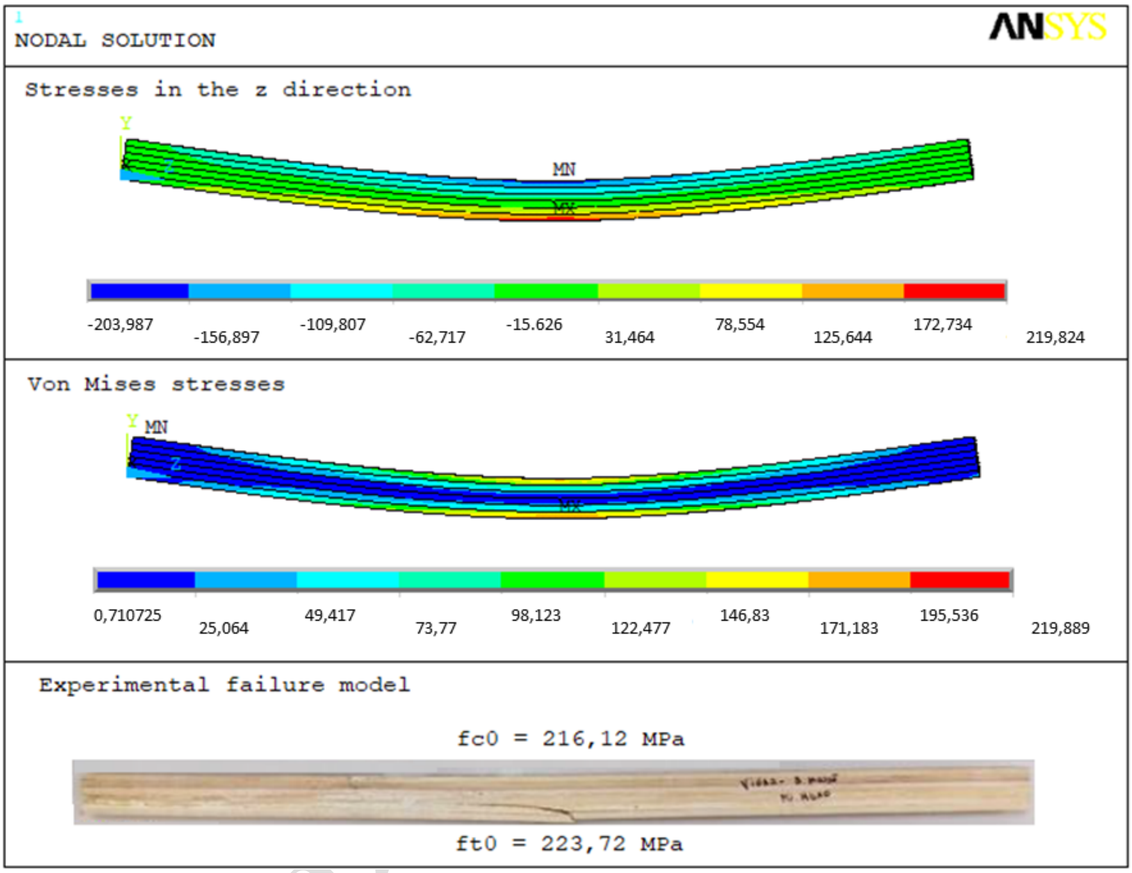


Figure 4: Beam stresses (MPa) and rupture mode obtained experimentally in the bending test.

The maximum longitudinal tensile stress in the z direction obtained by the numerical model, in the lower fiber, was 219,8 MPa, close to the experimental value of 223,7 MPa. However, the beam breaks first by crushing due to normal compression at the point of application of the load (upper lamella), and for a lower stress value $f_{c90} = \frac{1}{4} f_{c0}$ (54,03 MPa, as obtained in the experimental analysis). The numerical value of strength in compression normal to fibers (f_{c90}) obtained by ANSYS was 51 MPa (since $f_{c0} = 203{,}9$ MPa for longitudinal compression in the z direction).

The maximum von Mises stress obtained by the numerical model was 219889 MPa. This value also approached the experimental value of the tensile strength in the z direction (of the upper lamella) obtained experimentally.

Lefevre *et al*. (2019) obtained in their numerical study the strength and stress distribution in glued bamboo culms, while Fu *et al*. (2017) and Kingsley *et al*. (2015) performed the same type of analysis in a back chair of recombinant bamboo and bamboo bicycle frame, respectively.

Chen *et al*. (2016) evaluated the stress distribution in BLC beams subjected to bending. The authors disregarded the plastic deformations and the element strength in the vertical axis, due to the use of shell elements. Numerical results were not found regarding the stress distribution in LBL subjected to bending using plastic properties and 3D-solid elements.

The numerical simulation approach adopted in this study demonstrated applicability for the analysis of LBL beams with the tested geometry, bamboo species, adhesive system, and loading configuration. Within this scope, the methodology may be extended to LBL beams with larger dimensions or manufactured from other bamboo species, provided that their mechanical properties and bonding efficiency are experimentally characterized beforehand. The applicability of the model is therefore conditional on the availability of reliable orthotropic elastic and plastic properties of the bamboo lamellas, as well as tensile strength values consistent with those considered in the present study. Under these conditions, it is possible to obtain the numerical results of stress in any region of the element following the described methodology and to assess their consistency through comparison with experimental results, when available. Accordingly, the numerical framework should be interpreted as a tool applicable to scenarios similar to those investigated herein, rather than as a generalized model for all laminated bamboo configurations.

Conclusions

The combined experimental–numerical approach demonstrated that incorporating material nonlinearity is essential for accurately predicting the structural response of LBL beams, providing a more reliable framework for structural analysis of engineered bamboo elements. In this context, the present study addressed the challenge of evaluating the mechanical performance and numerical modeling of laminated bamboo lumber (LBL) beams by combining experimental testing with linear and nonlinear numerical approaches. The analyzed bamboo/adhesive combinations exhibited structural performance consistent with high-strength timber classes, confirming the feasibility of LBL for load-bearing applications, while highlighting bonding performance as a relevant factor influencing structural response. The results further showed that linear numerical models are adequate when plastic deformations remain limited, while nonlinear models are required to represent the initiation of yielding and the early nonlinear behavior of bamboo lamellae under bending. By enabling the assessment of both the global load–deflection response and localized stress distributions, the numerical simulations provided valuable insight into the overall structural behavior and critical regions of the beams. These findings contribute to the advancement of engineered bamboo by supporting the adoption of nonlinear finite element modeling in structural design and by providing a scientific basis for improving modeling strategies, material selection, and future development of LBL structural elements.

Authorship contributions

J.V.F.S: Formal analysis, methodology, software, visualization, writing – original draft preparation, writing – review & editing. T.O.S.: Data curation, investigation, methodology, writing – original draft preparation. J.C.M.: Conceptualization, methodology, project administration, supervision, validation, writing – review & editing.

Conflicts of interest

The authors declare there are no conflicts of interest for each author.

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