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STUDY OF THE AERODYNAMIC AND STRUCTURAL BEHAVIOR OF AN ARCHED BAMBOO GREENHOUSE

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Abstract. Greenhouses used for agricultural production are structures to control soil and climate conditions, such as temperature, air humidity, radiation, soil, wind, and atmospheric composition. Thus, increasing the productivity and quality of the plants grown in this system. Bamboo considered a sustainable material because it is renewable, absorbs carbon dioxide, uses solar energy for its growth, and is incorporated into nature at your life cycle end. The aim of this paper was to analyze the technical feasibility of bamboo in the construction of a greenhouse for protected cultivation. To do this, the aerodynamic and structural behavior was analyzed, aiming to get the safety margins for this construction. With the computational fluid dynamics method, the external pressure coefficients of the greenhouse were obtained, which enabled the determination of the wind loads acting on the structure. The loads generated in the previous step served as a boundary condition for a static linear analysis. With this gets the primary stresses, which were used in the design based on international standards for bamboo construction. At the end, the safety margins between acting and accepted stresses were obtained, which validated the plausibility of bamboo as a structural element for the proposed greenhouse.

Keywords: greenhouse, bamboo, finite elements, CFD, structural analysis.

1. INTRODUCTION

Currently, the construction of greenhouses in the system of protected cultivation is another alternative to circumvent the climatic adversities and create a favorable environment for agriculture, even in regions where the climate or soil are unfavorable. Today there are in the market several materials used for the manufacture of these structures, but they demand high cost and non-renewable raw materials such as synthetic polymers (PVC) and metallic materials. Aiming at the use of renewable materials many farmers opt for timber, especially eucalyptus, which requires chemical treatment to withstand the conditions of use. As a result, the cost rises and treatment residues can contaminate the environment. (PURQUERIO; TIVELI, 2010).

Rethinking the use of materials in construction to make it more sustainable from the environmental point of view, bamboo appears as an effective proposal. This is because it is a material with excellent mechanical properties at the same time that is not polluting, does not require large energy consumption in its production process, its source is renewable and low cost (BERALDO; PEREIRA, 2016).

Even with several positive aspects, bamboo is still a material undervalued in our society. For this reason, there is a deficiency of standards and criteria for tests and trials of its mechanical properties, making the structural application of this material expensive.

The lack of technical knowledge for the application of bamboo as a structural element limits the benefits presented by this material. Hence, this paper aimed to analyze the technical feasibility of bamboo in the construction of a greenhouse for protected cultivation. As a parameter to evaluate the fulfillment of the objective, the safety margins were evaluated based on the sizing of the sections through the limit state equations proposed by Kaminski et al. (2016). For this, it was necessary to obtain the wind loads through a computational fluid dynamics analysis and then evaluate the tensions acting on the structure through a finite element linear static structural analysis.

The finite element program adopted in this work was the *RFEM* software, because it is a powerful software for quick and easy modeling, structural analysis and design of 2D and 3D models consisting of member, plate, wall, folded plate, shell, solid, and contact elements. (DLUBAL, 2021).

2. THEORETICAL FRAMEWORK

Anatomically, bamboo is composed of: culm, leaves, branches, rhizome, and root. The canes are formed by hollow internodes separated transversely by the diaphragms, thus conferring rigidity and resistance to the plant. (BERALDO; PEREIRA, 2016).

According to Ghavami (1995) bamboo is a natural material with a multitude of factors that influence its mechanical properties. These properties are defined by the age of the plant, climatic conditions, harvest time, moisture content, location in relation to the length of the culm, presence or absence of nodes in the sample, and type of test performed. Furthermore, bamboo is an orthotropic material with similar strengths in the longitudinal direction and different in the transverse direction. In the longitudinal direction there are cellulose fibers, which are strong and hard; in the transverse direction there is lignin, which is malleable and fragile. Thus, bamboo can be characterized as a unidirectional reinforced composite, with low tangential capacity and a tendency to shear.

Due to the distribution of the fibers in the direction parallel to the axis of the thatch, bamboo presents high longitudinal tensile when compared to timber species. The compression loads must be applied parallel to the direction of the fibers, since the compression perpendicular to the fibers is not adequate to bamboo because it has a tubular section with thin walls, which compromises its resistance to this type of stress. In relation to bending, bamboo thatch presents high resistance and a flexible behavior until its rupture, this is due to the conditions imposed by nature, since in the bamboo plant the sticks are constantly submitted to the wind. The shear strength transverse to the fibers of bamboo is close to 30% of its flexural strength, and its longitudinal shear strength to the fibers is around 15% of its compressive strength. The modulus of elasticity of bamboo is between 20 GPa and 25 GPa, which is higher than that of wood, close to that of concrete, and much lower than that of steel. (BERALDO; PEREIRA, 2016).

Due to the lack of Brazilian standards for the use of bamboo as a structural element, Marçal (2018) analyzed in his work the different international standards that govern bamboo constructions, thus defining the most compatible standard with the reality of bamboo use in Brazil. Kaminski et al. (2016) proposes a method of limit state design encompassing factors from international standards such as: ISO 22156 (2004) Bamboo — Structural design, ISO 22157-1 (2005) Bamboo — Determination of physical and mechanical properties. With this method, Silva (2019) evaluated the possibility of producing a roofing system composed of trusses for small and medium spans using bundles of bamboo species *Bambusa tuldooides*, where the results presented the technical feasibility of using this material.

When it comes to the numerical analysis of wind actions for arch structures, Takano (2019) develops his work aiming to determine and evaluate, through numerical models performed in *Ansys CFX* software, the pressure coefficients due to wind loads around sheds with arch roofs and exhibiting various amounts of roof spans.

The finite element method is a numerical method for solving typical engineering problems, such as structural, heat transfer, fluid mechanics, and mass transport problems. For its formulation, a continuous system is discretized into a finite number of elements and nodes. After this process, stiffness matrices are generated for each element and an interpolation function between the nodes. From the nodal displacements it is then possible to find an approximate global solution of the structure's behavior. (ALVES FILHO, 2013).

According to Alves Filho (2013), because it is a numerical method, the finite element method provides an approximate solution that depends on the quality and quantity of the elements used. For the model result to converge to the real result, it is necessary to use elements that correspond to the physical behavior of the analyzed structure, whether it is a beam, a plate, a shell, a solid or a thin-walled beam. Furthermore, one must choose an adequate discretization so that the elements remain regular, without significant variations in internal angles, because this leads to an increase in the model's singularity and decreases the accuracy of the results. To verify the quality of the mesh, parameters such as aspect ratio, internal angle, orthogonal quality, warping, and skewness, among others, are used.

3. MATERIALS AND METHODS

For the development of this study, an arched greenhouse of 224 m² was used. That structure is composed of nine frames spaced at 3.5 m apart. Each of these frames consists of a main column 4.0 m high, two side columns 2.5 m high, and two intermediate columns 3.6 m high, all spaced at a distance of 2.0 m. A 200-micron plastic film covering is applied over the structure, supported by arches with a spacing of 1.75 m, which are embedded in connecting beams that connect all the frames. Between those beams are added lateral braces in 3/8" Gerdau CA-50 steel rebar connecting one arch to the other, in order to reduce the effective lengths of these elements. The graphical representation of the structure is shown in Figure 1.

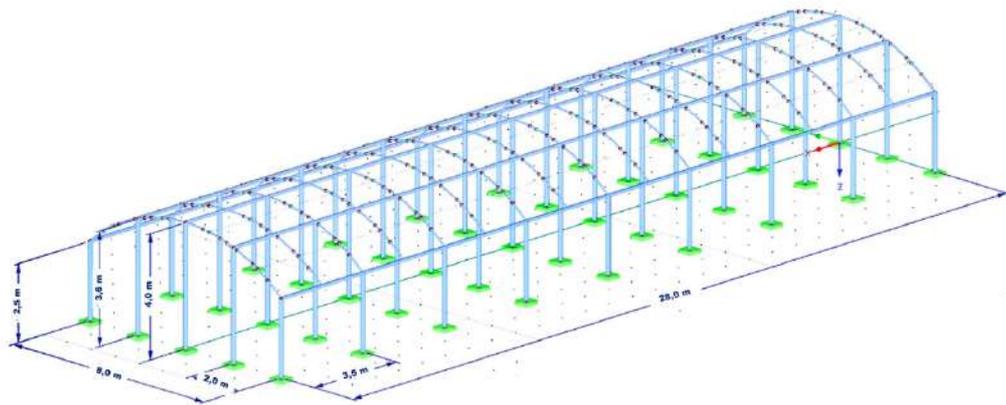


Figure 1 - Three-dimensional representation of the greenhouse. Source: The Author (2021)

The bamboos used in the analysis were considered as adult sticks of the species *Dendrocalamus asper* and *Bambusa tuldoides*, because with the maturity of the culms there is a stability in the mechanical properties. The cross sections of the culms used are shown in Table 1.

Table 1 - Cross sections of the construction elements used. Source: The Author (2021)

Elements	External diameter [mm]	Wall thickness [mm]	Species
Columns	150	25	<i>Dendrocalamus asper</i>
Beams	120	20	<i>Dendrocalamus asper</i>
Arches	60	15	<i>Bambusa tuldoides</i>

The mechanical properties of the species used are presented in Table 2 according to Gonçalves et al. (2001).

Table 2 - Mechanical resistance of the bamboo species used.
Source: Adapted from Gonçalves et al. (2001)

Property	<i>Dendrocalamus Asper</i>	<i>Bambusa tuldoides</i>
Density [Kg/m ³]	744	712
Longitudinal Elastic Modulus [GPa]	21.9	22.5
Poisson's Ratio	0.26	0.26
Tensile Strength parallel to the fibers [MPa]	103.9	85.5
Compressive strength parallel to the fibers [MPa]	30.8	26.2
Flexural Strength [MPa]	83.2	71.6
Shear strength transversal to the fibers [MPa]	35.4	41.6

3.1 Computational fluid dynamics

Ansys CFX software was used as an analysis tool for the computational fluid dynamics method. This software uses the finite volume method to solve the Navier-Stokes's differential equations. The fluid used in the analysis was considered as Newtonian and incompressible, presenting turbulent flow and a steady state analysis.

With the assistance of the *Ansys* software *SpaceClaim* tool, the greenhouse modeling was prepared and an analysis domain was created following the dimensions recommended by *Ansys* (2016). This process was developed to avoid the interference of external influences on the wind flow around the structure.

According to Takano (2019) a model using tetrahedral elements with a discretization refinement in the region of interest was elaborated as indicated in Figure 2. The dimension of the elements on the greenhouse surface was obtained using Equation (1), where the thickness of the first layer, y , is given relative to the turbulence model used.

$$y = \frac{Y^+ \mu}{\rho u^*} \quad (1)$$

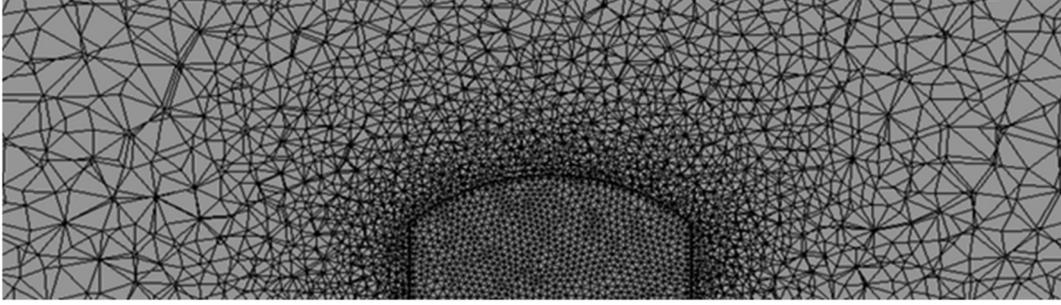


Figure 2 - Mesh used for the analysis with Ansys CFX. Source: The Author (2021)

Where in the Equation (1), μ and ρ are the dynamic viscosity and the air density respectively. To determine the fluid friction velocity (u^*), parameters provided by ABNT NBR6123:1988 were used, such as the average wind speed and roughness length, besides that the value of 0.41 was used for the Von Kármán constant. As a dimensionless parameter Y^+ referring to a turbulence model $\kappa\text{-}\epsilon$ a value of 200 was adopted, respecting the condition that according to Wilcox (1998) should be $30 \leq Y^+ \leq 300$ so that the Reynolds stress is constant and approximately equal to the stress on the wall.

Orthogonality, aspect ratio and Skewness checks of the constituent elements were used to evaluate the mesh quality. In addition, the size of the first layer was evaluated, thus gauging whether the value adopted for Y^+ satisfies the premise made based on the turbulence model used.

Orthogonality refers to the deviation of the angle between the vector connecting the center of adjacent volumes and the vector normal to the surface between them. Therefore, by recommendation of Ansys (2016) the closer to 1.0 the better the orthogonal quality of the mesh in question, moreover the minimum accepted values should be between 0.15 and 0.20.

The aspect ratio is the ratio between the largest and the smallest edge of the element. Therefore, the value of the aspect ratio should be 1 to ensure the regularity of the element and consequently better results. For three-dimensional elements the aspect ratio is given by the ratio between the radius of the circumscribed circle and the radius of the inscribed circle in the element.

The skewness parameter is directly related to the deviation of the vector connecting the centers of the volumes and the vector normal to the face, and therefore directly affects the accuracy of the numerical approximation of the flows. Thus, high values of skewness can easily degrade the numerical solution. The closer to zero the better the quality of the mesh and per Ansys (2016) recommendation, maximum acceptable values are between 0.80 and 0.94.

With the definition of the model to be analyzed and the finite volume discretization, the boundary conditions were then applied. The average wind speed was determined in the potential form following Equation (2).

$$\underline{V}_z = b Fr \underline{V}_{(ref)} \left(\frac{z}{z_{ref}} \right)^p \quad (2)$$

This equation matches the average velocity \underline{V}_z at Z meters over the terrain to an average velocity $\underline{V}_{(ref)}$ at Z_{ref} meters over the ground. the exponent P depends on the terrain roughness and the gust time interval, the parameter b makes the correction for the building class and the parameter Fr corresponds to a gust intensity factor. The adopted values were defined based on ABNT NBR6123:1988.

With the application of the boundary conditions in the model, the convergence criterion for the solution of the analysis was then determined. For this, the standard RMS (Root Mean Square) obtained through Equation (3) was used. Where R_i is the calculated residual in each mesh element and RMS the value of the average residual adopted for this work as 10^{-4} .

$$RMS = \sqrt{\sum R_i^2} \quad (3)$$

After solving the computational model, the external pressure coefficients (C_{pe}) acting on the structure are obtained through Equation (4). For this, the aerodynamic characteristics of the building are considered, where the regions of overpressure ($C_p > 0$) and suction ($C_p < 0$) are obtained. The overpressure acts on the face of the building where the direct incidence of wind occurs (windward) and the suction on the opposite face (leeward).

$$C_{pe} = \frac{\Delta P_e}{q} \quad (4)$$

Where ΔP_e is the external pressure variation obtained through the analysis with Ansys CFX and q is the dynamic wind pressure defined by NBR6123:1988 which is presented by Equation (5)

$$q = 0,613 \cdot (V_0 \cdot S_1 \cdot S_2 \cdot S_3)^2 \quad (5)$$

The velocity V_0 and the coefficients S_1 , S_2 and S_3 were defined based on ABNT NBR6123:1988 considering the location of the structure, the occupation factor, the meteorological parameters and the rugosity of the ground where the greenhouse is installed. For the consideration of the building openings, the internal pressure coefficients (C_{pi}) are used, which were defined according to NBR 16032:2012 through the greenhouse dimensions, the overpressure and external suction values, the location of the openings and the wind direction. The wind loads for a greenhouse building were obtained through Equation (6) following the criteria defined by ABNT NBR16032:2012 where C_p is the difference between the external and internal pressure coefficients and L is the distance between the frames.

$$F = C_p \cdot q \cdot L \quad (6)$$

3.2 Structural analysis with the finite element method

Because it is a reticulated structure and doesn't present localized stresses, the greenhouse model was elaborated from beam type elements, in other words, elements in which the length is predominant in relation to the cross section. With this it was not necessary to create a mesh, since the interpolation function of the one-dimensional element is exact and its discretization doesn't alter the results. To simplify the structural model, bamboo was considered as a uniform cylindrical element, without diaphragms and taper effect.

The material properties were inserted considering the middle of the culms with the presence of nodes, but without geometric modification due to the simplification of the model into a beam element, which models the components considering only their centroid line.

To represent the constraint boundary conditions, fixed beams were defined between the columns and the ground, simplifying a concrete-bearing condition. Since the most common connections involving bamboo elements are made with studs and dowels, the joints between beams and columns were considered fixed, equal to the connections between the arches and the beams.

As a way to consider the loads due to the use of the greenhouse was adopted according to ABNT NBR16032:2012 an overload of 0.25 kN/m^2 , in addition was considered the self-weight of the building elements defined by the density of the material and the volume of the components. With these loads associated with wind conditions at 0 and 90° were generated 46 load combinations, 32 combinations of ultimate limit state and 14 combinations of service limit state divided into rare and frequent.

With the definition of the structural model, material properties, application of constraints and loads, a static linear analysis was processed, aiming to obtain the reactions of bending moments, shear forces, normal forces and displacement of all building elements. These results serve as inputs for the design of the components and consequently obtaining the safety margins for the greenhouse.

3.3 Sizing and checking

A limit state method proposed by Kaminski et al. (2016) was used to verify the sections. The characteristic strength of the design ($X_{i,d}$) is obtained through the characteristic strength of the material (X_k) determined by tests, by factors that consider the class of service, the duration of force and the load applied to the system (k_{mod}). In addition, a safety factor (γ_m) is used as presented in Equation (7).

$$X_{i,d} = k_{mod} k_{sys} \frac{X_k}{\gamma_m} \quad (7)$$

The value of k_{sys} for a continuous load distribution that supports load redistribution can be adopted as 1.1, in this same case a factor of safety (γ_m) as 1.5 was adopted.

To determine the maximum bending moment (M_m) Kaminski et al. (2016) propose to use the elastic modulus ($S_{elastic}$) combined with the design shear strength (X_{md}). Equations (8) and (9) define this procedure.

$$S_{elastic} = \frac{\pi(D_e^4 - [D_e - 2t]^4)}{32D_e} \quad (8)$$

Where D_e is the outer diameter of the bamboo and t is its thickness.

$$M_m = X_{md} S_{elastic} \quad (9)$$

The verification regarding the maximum shear force F_v is performed through Equation (10) where the capacity of the element to withstand shear stress is analyzed.

$$F_v = X_{vd} K_{cr} \frac{3\pi t(D_e^4 - [D_e - 2t]^4)}{8(D_e^3 - [D_e - 2t]^3)} \quad (10)$$

The risk of a single split by thatch cracking K_{cr} should be adopted as 0.5
 For analysis as to maximum axial tension F_T , the net-section area (A) by the design axial stress X_{tod} was used, as shown in Equation (11).

$$F_T = X_{tod} A \quad (11)$$

According to Kaminski et al (2016) the parts analyzed for axial compression, should be sized according to their slenderness ratio (λ), this is because local fiber crushing can occur in short parts, fiber separation in medium parts, and global Euler buckling in long parts.

The Equation (12) is used to rate the compressed element by its slenderness ratio.

$$\lambda = \frac{l_e}{r} \quad (12)$$

$$l_e = kL \quad (13)$$

The coefficient k in Equation (13) is defined by the condition of the supports, where k=1 for both hinged ends and k=2.1 for one end with restriction to rotation and displacement and the other free. This coefficient multiplied by the element length L defines the effective length of the element l_e .

The radius of gyration (r) is obtained from Equation (14), where the moment of inertia (I) and the cross-sectional area (A) of the element are related.

$$r = \sqrt{\frac{0.9I}{A}} \quad (14)$$

To verify the slenderness of the elements, the limit slenderness between the short and long parts C_k is calculated according to Equation (15).

$$C_k = \pi \sqrt{\frac{E_{0.05}}{\gamma_E X_{cod}}} \quad (15)$$

Where $E_{0.05}$ is the modulus of elasticity in the 5th percentile of the tests and is between the range of (7500-13000), γ_E is the safety factor for the material, adopting it as 1.5, and X_{cod} is the design characteristic compressive stress. With this and the slenderness index it is possible, analyzing Table 3, to classify the part as short, intermediate or long.

Table 3 - Classification of the elements as to slenderness index. Source: Kaminski et al (2016)

Elements	Slenderness
Short	$\lambda < 30$
Intermediate	$30 < \lambda < Ck$
Long	$Ck < \lambda < 150$

For elements with $\lambda < 30$ Equation (16) is used.

$$F_C = X_{cod} A_{tot} \quad (16)$$

For elements with $30 < \lambda < Ck$ Equation (17) is used.

$$F_C = X_{cod} A_{tot} \left(1 - \frac{2}{5} \left[\frac{\lambda}{C_k} \right]^3 \right) \quad (17)$$

For elements with $Ck < \lambda < 150$ Equation (18) is used.

$$F_c = \frac{0.6\pi^2 A_{tot} E_{0,05}}{\gamma_E \lambda^2} \quad (18)$$

Structural elements that are simultaneously subjected to compressive and bending forces must be calculated using the allowable stresses to comply with Equation (19).

$$\frac{f_c}{F_{rc}} + \frac{k_m f_b}{F_b} \leq 1 \quad (19)$$

Where f_c is the acting compressive stress parallel to the fibers, F_{rc} is the admissible compressive stress parallel to the fibers, f_b is the acting bending stress and F_b is the admissible bending stress. The moment expansion coefficient k_m can be calculated by Equation (20). Where N_a is the acting compressive load and N_c is the Euler's critical load that can be calculated by Equation (21).

$$k_m = \frac{1}{1 - 1.5 \left(\frac{N_a}{N_c} \right)} \quad (20)$$

$$N_c = \frac{\pi^2 E_{0,05} I}{l_e^2} \quad (21)$$

Structure members that are simultaneously subjected to axial tensile and bending forces should be designed to comply with Equation (22). Where f_t and F_{rt} represent the acting and admissible tensile stress respectively.

$$\frac{f_t}{F_{rt}} + \frac{f_b}{F_b} \leq 1 \quad (22)$$

The Safety margins are calculated to show how far a part is from structural failure. Equation (23) represents how these margins are obtained.

$$MS\% = \left(\frac{Admissible}{Operating} - 1 \right) \times 100 \quad (23)$$

4. RESULT AND DISCUSSION

4.1 Computational fluid dynamics

Table 4 presents the results obtained with the mesh quality check. The values presented in the orthogonal quality are 13% lower than the minimum limit recommended by Ansys (2016), but as they are in a tiny amount of elements, outside the region of interest and with a low standard deviation, they were accepted to decrease the computational cost of the analysis. The other parameters present values within the expected limits.

Table 4 - Mesh quality parameters used in the model. Source: The Author (2021)

Model	Orthogonal Quality		Aspect Ratio		Skewness		Y ⁺
	Minimum	Average	Maximum	Average	Maximum	Average	Maximum
Wind 0°	0.13	0.81	204.30	14.26	0.90	0.20	268
Wind 90°	0.12	0.80	205.18	13.20	0.79	0.19	287

Based on the flow lines shown in Figure 3 it is possible to observe that vortices are generated on the leeward face, in other words, the opposite side where the wind blows and on the sides of the structure, these places where flow separation occurs. It is also observed that the wind that falls to windward, on the face where the wind falls directly is drained to the sides and top of the structure, thus causing an increase in velocity at these points.

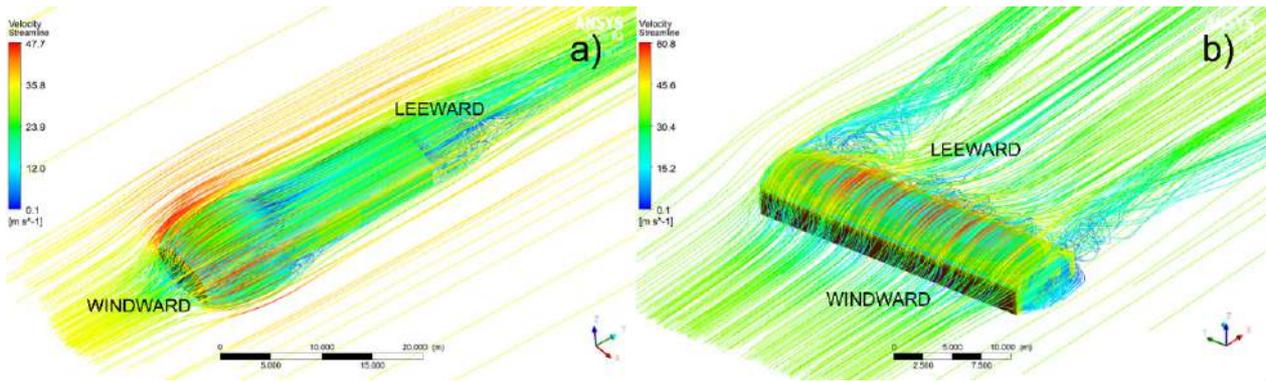


Figure 3 - a) Flow lines for wind 0° b) Flow lines for wind 90°. Source: The Author (2021)

Comparing the distribution of the external pressure coefficients represented in Figure 4 with the ranges specified by ABNT NBR6123:1988, defined in Figure 5, a similarity between the results is verified. It is also possible to analyze in Figure 4 the regions of overpressure (positive) and suction (negative) along the model.

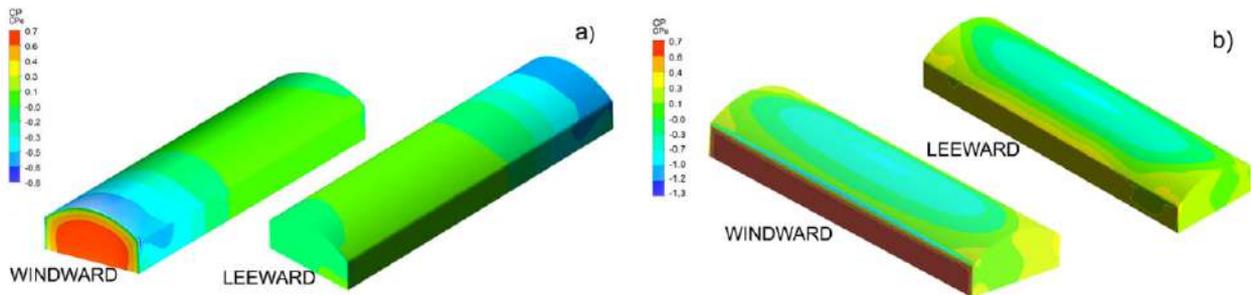


Figure 4 - a) External pressure coefficients for wind 0° b) External pressure coefficient for wind 90°. Source: The Author (2021)

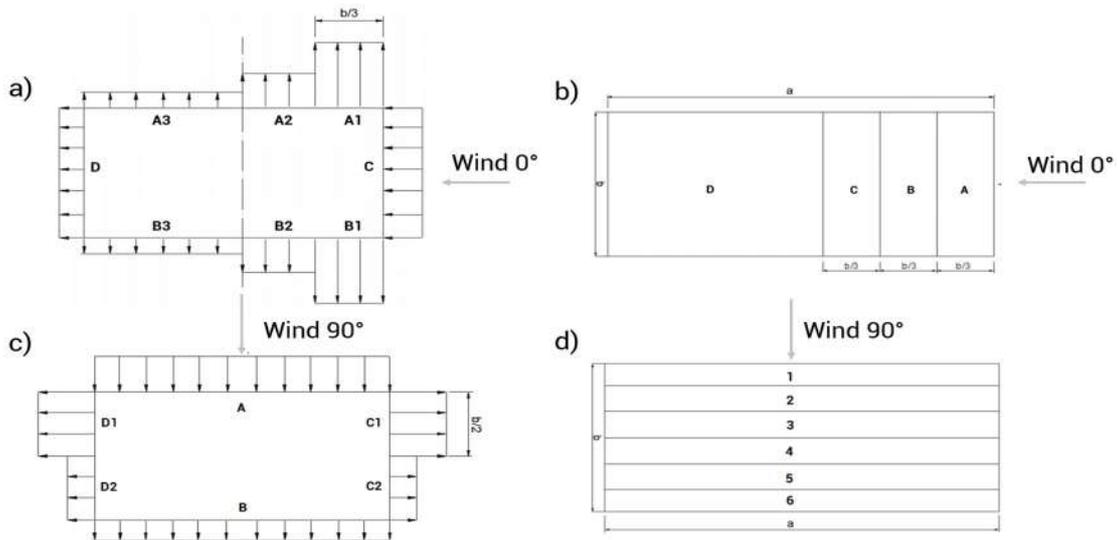


Figure 5 - a) Incidence of wind 0° on the walls b) Incidence of wind at 0° on the roof c) Incidence of wind 90° on the walls d) Incidence of wind 90° on the roof. Source: Adapted from ABNT NBR6123:1988

Through data processing the maximum and minimum values of the external pressure coefficients for each region indicated in Figure 5 were obtained. The values obtained are presented in Table 5

Table 5 - Values of external pressure coefficients for wind conditions at 0° and 90° in different regions of the structure. Source: The author (2021).

Wind 90°				Wind 0°			
Roof	C _{pe}	Wall	C _{pe}	Roof	C _{pe}	Wall	C _{pe}
1	-1.3	A	0.7	A	-0.8	C	0.7
2	-0.7	B	-0.5	B	-0.5	D	-0.2
3	-1.2	C1/D1	-1.1	C	-0.4	A1/B1	-0.8
4	-1.2	C2/D2	-0.5	D	-0.2	A2/B2	-0.4
5	-0.4					A3/B3	-0.2
6	-0.3						

Through parameters catalogued by the standard ABNT NBR16032:2012 and with the pressure coefficients obtained previously it was possible to determine the wind loads acting on the structure. These loads are presented in Table 6.

Table 6 - Load due to wind per unit area in different regions of the structure. Source: The Author (2021)

Wind 90°				Wind 0°			
Roof	Load [kN/m ²]	Wall	Load [kN/m ²]	Roof	Load [kN/m ²]	Wall	Load [kN/m ²]
1	-1.37	A	0.46	A	-0.97	C	0.48
2	-0.82	B	-0.64	B	-0.68	D	-0.39
3	-1.23	C1/D1	-1.19	C	-0.58	A1/B1	-0.97
4	-1.23	C2/D2	-0.64	D	-0.39	A2/B2	-0.58
5	-0.55					A3/B3	-0.39
6	-0.46						

4.2 Structural analysis with the finite element method

The Table 7 presents the values of displacements and critical loads obtained from the finite element analysis. It is denoted that due to the crimping the columns suffered the greatest action regarding the bending moment. In relation to the displacements presented in Figure 6, the arches were the most requested due to their slenderness and the action of the suction wind affecting these components with greater modulus.

Table 7 - Critical forces and displacements acting on the structure. Source: The author (2021)

Operating	Columns	Beams	Arches
Maximum deflection [mm]	16.9	7.60	21.9
Maximum bending moment [N.mm]	11450000	4710000	1200000
Maximum shear force [N]	15230	3380	3380
Maximum normal force [N]	9660	11420	8120

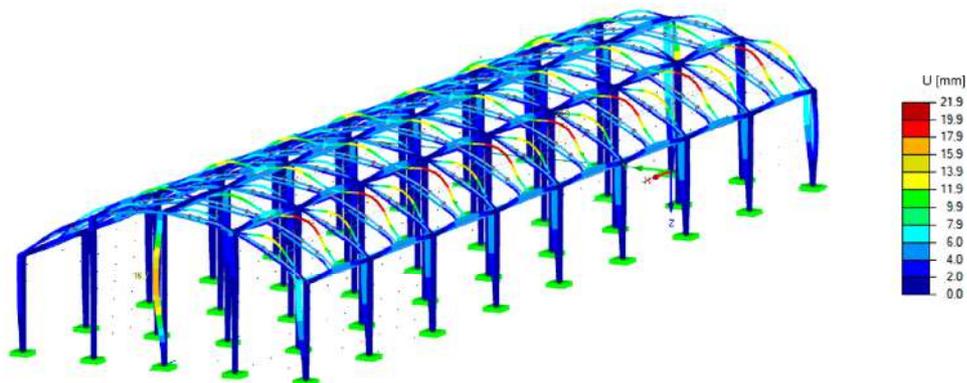


Figure 6 - Displacements acting on the structure. Source: The author (2021).

4.3 Sizing and checking

With the data of mechanical and geometric properties, it was then used the limit state equations proposed by Kaminski et al (2016), with this, together with the acting loads obtained by finite element analysis it was obtained the safety margins for the structure through Equation (23), presented in Table 8. As a design requirement was adopted a minimum safety margin of 15% and analyzing the results obtained it was found that for all cases the minimum margin was achieved.

Table 8 - Safety margins for the structural elements analyzed in relation to different loads. Source: The author (2021).

Safety margins	Columns	Beams	Arches
Minimum safety margin	15%	15%	15%
Displacement	58%	54%	33%
Bending moment	93%	171%	19%
Shear force	486%	1589%	599%
Axial tensile	10464%	5619%	2132%
Axial Compressive	244%	56%	63%
Axial tensile + bending	99%	98%	95%
Axial Compressive + bending	99%	98%	95%

5. CONCLUSION

In this study, developed based on an agricultural greenhouse, applying the numerical analysis method of wind actions through computational fluid dynamics and later a finite element structural analysis, it was verified that bamboo can be incorporated in these structures as an alternative to conventional materials, because it presents technical feasibility determined by the safety margins presented in Table 8. It is worth pointing out for future works the importance of mechanical and thermal tests to determine the properties of this material, the types of treatment applied to the bamboo, as well as an in-depth practical study on the joints between the structural elements used.

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