Joints covers Bamboo and membrane; Design, Manufacturing and Assembly

Frederick Rosalino da Silva, Rafael Oliveira Poubel

Domebambu Estruturas Ltda

Catholic University of Brasilia-Brazil

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Abstract: This paper presents the results of a project to build a disassembled structure geodesic dome shape with the use of bamboo and metal connectors and cover membrane of PVC and polyester. Is shown throughout the process of manufacture and assembly of structures Domebambu as actions to make processes with minimal generation of impacts.

The project began in March 2009 in the assembly of the first diameter dome in Puroritmo Festival, the proposal is to bring sustainability to the events. It began with the construction of a geodesic dome 20 meters in diameter and frequency 3V and covered area of 314 m², and from this event, Domebambu started a successful path, consolidating as a company specialized in manufacturing and lease structures in bamboo for events, and account in 2014, with more than 3,000 square meters of roofing bamboo, metal and membrane.

The challenges encountered during the process occurred due to the pioneering spirit of the technical staff in relation to the project, especially the need to create demand, develop the product and train personnel for manufacturing and assembly of structures.

The Domebambu has been consolidated as a reference for Brazil in sustainability and contributes significantly to the spread of bamboo's potential as structural element, sustainable and environmentally friendly society.

1. Introduction

Bamboo is a very common plant in Brazil and other countries, such as Colombia, Indonesia, and India. These countries have the tradition to take the mechanical properties of this plant structures in construction.

In Brazil, however, bamboo structures still possess little application in construction as compared with the use of reinforced concrete structures, steel structures, prestressed concrete and wood structures. However, bamboo is a building material that meets the strength requirements, is a flexible material, light and beautiful. It is characterized by having a cross section in the form of hollow tubular section and low density.

The roofs and roof market demountable for events in Brazil is basically dominated by metallic syculms, whose assembly occurs rapidly in a few days and even in a few hours. The challenge to perform a disassembled structure using bamboo as a main structural element is anchored in the main material properties that allow its use for this purpose requirements of lightness, practicality, beauty, strength and sustainability.

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The Domebambu Structures Ltda. developed a series of disassembled structures Bamboo with coverage membrane which are used in various events in Brasilia and Brazil. The manufacturing process of the structure under study was that demanded greater effort, both from a technical point of view of design as in their implementation.

Combined with technology and design, the geodesic domes Domebambu promote intense sensory experience, following quality standards based on the principles of environmental efficiency and social responsibility.

1.1 Sustainability

The Bamboo material used in Domebambu covers, is a grass that, properly managed, allows successive regrowth, generates raw material permanently and still an efficient carbon sequestration, making it covers less environmental impact. High resistance, mechanical properties and variable size, are bamboo an excellent resource for environmentally responsible construction processes.

The bamboo used in Domebambu covers are collected respecting technical standards that ensure the regrowth capacity and perpetuation of the woods or bamboo clumps. Are treated in environmentally controlled conditions for the proper conservation of the pieces and the minimum emission of waste.

These procedures adopted by the company , together with the own product, gives the customer the possibility to add an image of sustainability to the event, and further awaken people who participate in them to a new material and its multiple possibilities

The architectural design in geodesic shape allows for greater coverage area with reduced use of materials when compared to other structures, making the domes of low environmental impact structures by saving materials and the reduced need for transport in terms of volume and weight.

The Domebambu adopts the following social and environmental responsibility criteria:

• Production, acquisition and bamboo planting along to family farmers;

• Collection and treatment in environmentally controlled conditions without the use or release of toxic products;

• Use of bamboo handicraft waste, energy production and return to the bamboo production cycle (fertilization);

• Reuse materials discarded by industry: carbon steel plates for production of roofing connections;

• Storage in bamboo shed;

• Lifetime of bamboo structures for an average period of five years with reuse of parts replaced;

• Neutralization of carbon emissions from the manufacture of structures through the planting of bamboo groves in consortium with forest species.

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2. Development

From the first demand for the construction of the first geodesic dome Bamboo and membrane (Figure 01), the Domebambu prepared the planning of this project, which included the definition of stages of geometry and materials to be used, the structural design to manufacturing the assembly and disassembly, taking as a premise, the development process based on the concepts of sustainability

Figura 01: Imagem DOME_20 with cristal membrane

2.1 Project Design

The company's initiative to design and build a structure of this complexity was mainly driven by the passion for the technical structures in bamboo. We knew that there would be many challenges ahead, but the difficulties were greater than those provided.

We attempted to technical articles from various sources which we could base the design of the structure, the main inspiration a work developed by Ronald Laude (2003/2004), which develops a metal bonding of high complexity to the junction of bamboo pieces, presenting also the results of tests for determining the amount of bars necessary to support determined effort.

We tried to identify a geometry that allied light weight, low cost manufacturing, assembly speed, sustainability, beauty and strength. The geodesic domes, whose invention is attributed to Richard Buckminster Fuller, are structures with extraordinary strength and lightness winning large spans with a minimum amount of material, thus we chose this type of geometry. The structure consists of rods of any material which can be made in any size, since the size of its bars are calculated correctly.

Moreira and Ghavami (2009) examined the behavior of bamboo lattice structure proving to be suitable for use for this type of solution, however, studies suggest that must be undertaken to identify long-term behavior, with improved forms of such unions between bamboos.

From the selected publications were started the design process of the structures, parts of diameter, wall thickness, metal pipes and plates and other elements that made up the structure.

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To determine the size of the geodesic, length and quantity of pieces, number of nodes, frequency, shape, angles and other information was used Cadregeo Design V6 system, the company Cadre Analytic Engineering services and applications.

2.1.1 Structural analysis

The structural analysis is carried out by physical, mathematical and computational models which allows to compare these test results with the actual behavior of the structure.

Thus, an analysis was made of the forces acting on the structure of the bars to evaluate the behavior of same in order to allow an optimum and safe design.

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The analysis was performed using the computer program SAP2000 v.10.0.7, the company Computer and Structures Ind. (CSI), as illustrated in Figure 02 launch, the numerical formulation is based on the Finite Element Method (FEM).

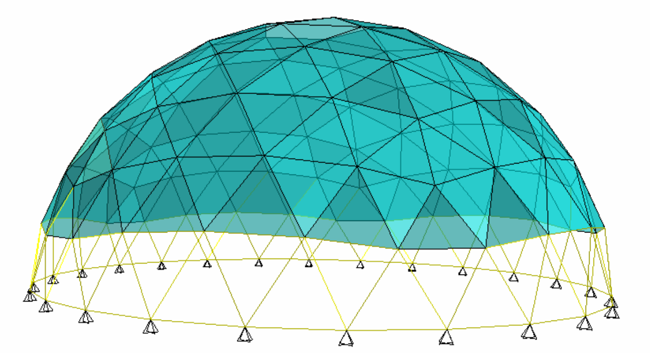


Figure 02: Release Diagram

The following actions were considered in the design:

a) permanent Actions

Were considered as distributed loads the menbrane and connecting elements. The data used were:

• menbrane = 0.75 kg / m².

• connection elements = 0.13 Kn / m².

b) Variables Actions

In this case, action variables were regarded as an overload 0.25 kN / m2, the effect of wind, which will be described in more detail in the following section.

c) Actions due to wind

The main issue with respect to wind speed that is different regions of the earth is subject to different wind speed conditions.

General information:

• building Location: São Paulo - DF.

• Purpose of building: Coverage.

• Wind Basic Speed: V = 45 m / s.

• Topographic Factor: flatness - S1 = 1.0.

• terrain roughness and dimensions of the building: S2 = 0.95.

• Flat land with low and scattered buildings: Category III.

• Increased size of the building <20 m: Class A.

• Safety statistical factor S3 = 1.0.

• Building with high load factor

speed feature

$$V_K = V_0 * S_1 * S_2 * S_3$$

$$V_K = (45\ m/s) * 1{,}0 * 0{,}95 * 1{,}0 \ = 42{,}75\ m/s$$

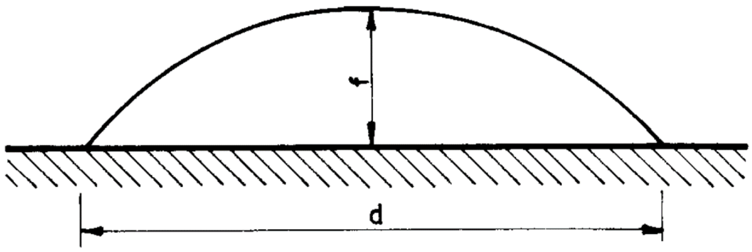
Pressure obstruction

$$q = 0{,}613 * {V_k}^2 = 1{,}1203\ kN/m^2$$

Coefficient of external pressure (Cpe or Pec)

According to NBR 6123, only external pressure coefficient approximate values (Pec) may be given to the cupolas or domes, due to variations in the distribution of pressures with wind characteristics, the relationship between the dimensions of the building and the outer surface of dome.

• The relationship between the dimensions of the structure:



$$\frac{f}{d} = \frac{15\ m}{30\ m} = \frac{1}{2}$$

With the aid of NBR-6123 can obtain the following external pressure coefficients for the analyzed structure:

Internal pressure coefficient (CPI)

To consider the internal pressure coefficient (CPI) for the dome analyzed, it becomes applicable the item 6.2.6 of ISO-6123 standard, reproduced below: "6.2.6 - To effectively sealed buildings and fixed windows that have a negligible probability of being broken by accident, consider the most harmful between values = -0.2 CPI or CPI = 0 ".

In this work, the CPI = -0.2.

2.1.2 Selection of Bamboo

It was foreseen the use of bamboo species Phillostachys bambusoides (Figures 03 e 04), due to its characteristics suitable for this purpose in addition to their availability in the region of Brasilia, the city where works Domebambu structures. The main features of this species are:

• Height of the culms - 10 to 20 meters and stem diameter - 7-15 cm;

Figure 03: *Phyllostashys bambuzóides forest*

Figure 04: Detail of bamboo culm *Phyllostashys bambuzóides*

The species used in Domebambu cover is quite suitable for this use, therefore, has great especially resistance to tensile and compressive efforts. Table 01 presents resistance tests performed on stalks harvested at different ages, reinforcing the need for the harvest is carried out over 3 years after the birth of the shoot.

Properties	Avarage	Age (yars)				
		1 a 2	3 a 4	5 a 6	7 a 8	9 a 10
Tension (Mpa)	163,5	91,1	176,4	184,1	177	189,1
Compressive (Mpa)	63,8	63,5	63,6	63,4	64,7	63,6
Bending (Mpa)	159,1	153,7	162,2	158,6	161,2	160
MOE Traction (Mpa)	11656	11909	11229	11457	12416	11267
MOE Comprassion (Mpa)	8207	7716	8448	7607	9041	8221
MOE Flexion (Mpa)	10897	10770	10370	11323	10893	11131

Table 01 - Change in mechanical properties of bamboo Phyllostashys bambuzoides at different ages of the culms.
Source: CHUN, 2003

Compared to other materials such as steel, aluminum and cast iron, bamboo has superior mechanical characteristics when considering its density (Table 02):

Material	Tension σ_1 (N/mm²)	Specifc mass u (N/mm² x 10⁻²)	R = $\sigma_1.10^2.u$	R/R steel
Steel	500	7,83	0,63	1,00 (ref)
Bamboo	140	0,8	1,75	2,77
Aluminum	304	2,7	1,13	1,79
cast iron	281	7,2	0,39	0,62

Table 2: Relationship between the tensile strength and the specific gravity (Ghavami, 1992)

2.1.3 Metal Unions

Unions used are metal on carbon steel plates ASTM 1020 # 36 3/16 "with MIG welding, the company manufactures Badaruco Iron and Steel, located in Brasilia. The parts of the finishing is done with electrostatic paint making it fully protected against oxidation.

The metal connectors were designed obeying the efforts identified in the calculation of the structure, detailed in CAD environment and reported to the company that manufactures metal structures (Figure 05).

Figure 05: Detail connective system Domebambu

In order to identify the junction of the resistance of the metal connectors like bamboo, was carried out some tests in Civil Engineering Laboratory of the University of Brasilia. As resources for the tests were limited was possible only to draw, because this was the biggest effort identified in the design of the structure. The results approached 40 KN, to the breaking of threaded bars prior to rupture of the bamboo, which shows that the structure was scaled accordingly (Figure 06).

Figure 06: Test of resistance metal bamboo-union

Tests conducted as metal bamboo-set union gives sufficient strength to withstand stresses involved in DOMEBAMBU covers.

The setting of the bamboo plates are made with threaded rods, nuts and washers with zincs bath in order to prevent corrosion of the bars whose specifications are as follows:

- Construction - ANSI B 18.2.2
- Mechanical Properties - Standard SAE J 995
- Thread - ANSI B1.1 - Class 2B

The nodes in the structure are joined by screws 5/8 "GERDAL the mark with the following specifications:

- Construction - ANSI B 18.2.1
- Mechanical Properties - Standard SAE J 429
- Thread - ANSI B1.1 - UNC TOL 2nd

2.1.4 bolting

The toppings are cable-stayed to the ground using the belt type with ratchet equipment as specified:

-Ability To load: 3:05 tons
-Material Of Ratchet: Galvanized Steel
-Material Strap: Polyester yarn high tenacity produced according to NBR 15637-1.

2.1.5 Membrane

The membrane used in Domebambu covers are made of PVC fabric laminate reinforced with high tenacity polyester yarn has the following characteristics:

-Weight: 750g / m²
-Resistance Traction; 156/154 daN / 5cm
-Resistance Tear: 35/25 daN
-Finish: Different colors
-Resistance Fire. Does not spread flames

2.1.6 Reinforcements in bamboos

In order to combat the compressive forces perpendicular to the fiber, ie, the crushing at the junction of metal connectors, are carried at the ends of the reinforcement parts is used for this purpose, the type pine wood turning, glued to the inside of the stem with structural adhesive resin Polyurethane Plant the Mamona base.

The Polyurethane Resin Plant the Mamona base (Figure 07) is considered low impact on the environment, therefore much of its raw material comes from the mamona oil, the result of a very common plant in Brazil.

Figure 07: PU Mamona resin used for bonding ribs

2.3 Manufacturing designs

After completion of the project and details of the structure, defining the number of pieces, size and type, then set off to harvest in place near the city of Brasilia. Once in the woods, choosing the right bamboo requires knowledge both technical and experience. the selection of the culms should be made according to the maturity of the plant, and making the cuts properly to provide the health of the bamboo grove (Figure 08).

Figure 08: Selection of the appropriate diameter culms

The culms are gathered for an outdoor drying process (Figure 09) and follow posteriromente for treatment by immersion in a tank with octoborato for at least 10 days.

Figura 09: Treatmant area

After reaching the humidity of 15% for the following DOMEBAMBU factory to be processed and transformed into frames for roofs and other structures that the company manufactures.

The structures are manufactured in DOMEBAMBU STRUCTURES's headquarters, located in Administrative Region of Paranoá, Brasilia-DF (Figure 10). The company has qualified personnel and tools necessary for the manufacture of frames (bamboo pieces already ready and installed connections).

Figura 10 : Domebambu Fabric

The metal connectors are installed with the aid of jigs to ensure the accuracy required for the best performance of the structure (Figure 11). After this step, the pieces receive a marine varnish layer to increase the durability and impermeability of the material, and finally given a flame retardant product (Figure 12).

Figure 11: Installing the metal connectors on bamboo

Figure 12: Parts ready for application of protective resin

2.4 Assembly

The Domebambu Covers has the advantage of greater ease of assembly and disassembly. DOME20 meets, for example, has 20 meters in diameter and covered area of 314m², takes only 10 hours to be mounted and 5 hours for the disassembly.

The process of assembling and disassembling can be considered as the most complex part of the process. The methodology was developed over five years, with the revaluation of cases to assembly and disassembly, aiming to speed with the least amount of assemblers.

The coverage of up to 20 meters in diameter can be mounted without the need for cranes, however, from this dimension, equipment of this type is needed, however, as in many places of Brazil is not the leasing of large equipment, the goal is that even larger coverage can be assembled and disassembled only with hoists equipped of assemblers, scaffolding and ladders (Figures 13, 14 and 15).

Figure 13: On Assembly

Figure 14: Assembly Process of the covers

Once finished, the pieces are stored in a cool place with controlled humidity, thus ensuring longer durability for the material (Figure 15).

Figure 15: Assembly Process of the covers

Figure 16: Coverage of different sizes mounted on event

Figura 17: Cover Assembly on RIO+20 Conference

3. Conclusion

The use of bamboo and roofing membrane, although it shows acceptance of difficulties at first, appear as fully viable economic and technical point of view, and, after the customer's first contact with the product, realizing the security structures and provide all the benefits that add to the event, satisfaction is reflected in future leases.

The activity that Domebambu Structures has developed over 6 years of existence, involving the community, academia and the public sector, is consolidated as a work of excellence, combining the technique with social and environmental responsibility, with reference to all of Brazil as environmentally responsible company, so this aim, drawn by the founders since its foundation.

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4 References

LAUDE, R., Bambu, Recurso sostenible para estruturas espaciales, Universidade Nacional de Colombia, Medellin, 2003/2004

MUÑOZ, L.F., Diseño de uniones y elementos em estructuras de guadua, Pereira, mayo 16-17 y 18 de 2002

MOREIRA, L.E., Ghavami, K., Bamboo Space Strucutre, (NOCMAT,2009)

MOREIRA, L.E., 1991, Desenvolvimento de Estruturas Treliçadas Espaciais de Bambu, dissertação de mestrado, PUC-Rio, Rio de Janeiro, Brazil.

MOREIRA, L.E., 1998, Aspectos Singulares das Treliças de Bambu: flammenbraneem e conexões, Tese de Doutorado, PUC-Rio, Rio de Janeiro, Brazil.

SILVA, R, Frederico, Aplicação de Bambu em Estruturas: Estudo de Cao Sobre a Estrutura da Exposição"O Paisagista Roberto Burle Marx"", 2010.

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