STRUCTURAL ARCHITECTURAL SYSTEMS WITH LIGHTNESS AND BEAUTY AESTHETICAL OF DESIGNING -THE COLUMN "DIAMOND"

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Abstract: A structural architectural system is defined by the concepts of design and construction, and this is clearly highlighted in designs using the lightness and structural concepts of aesthetic beauty. Under these assumptions, and analyzing a timely manner the role of support columns, this element should be designed primarily for the uniqueness and simplicity. Related to this, one can define it as a support column just to play its traditional role of transferring the load to the soil, in contrast to those designed without these attributes. The objective of this paper is to present and demonstrate the application of these concepts in the original results and relevant to the construction industry, especially when using wood structural elements. The methodology involves the analysis of tree-shaped of the, a notion in his prime project design. This system provides a large number of case studies and their specific and unique characteristics allow its implementation in different soil slopes. It was used the CYPECAD software, version 2007 -1.i to calculate this structural system. Specifically, focusing on the column "diamond", which is the main element of a structural system as a tree-shaped. The application of these two concepts considered above has resulted in an excellent performance from laboratory tests.

Keywords: Plastic Intentionality, Simplicity, Singularity, Support Column, Timber Structural System

1. INTRODUCTION

1.1 The Concepts of singularity and simplicity

The concepts of singularity and simplicity applied in timber structural systems design and construction express very clearly of the architectonic artifact excellence. This excellence is not only concerned to structural lightness and esthetic beauty, but above all in the most explicit way, the maximization of its *Structural Performance* defined as the ratio between the constructed area and the volume of material (in the case of wood m²/m³ and for steel m²/kg), used in the structural system (GONCALVES, 2007).

Singularity is considered a main concern in the academic circles, specifically in the PhD, by the way, essential for these purposes.

An emblematic example of this approach was the design and the artifact construction of *Park Hotel* (1944), by Architect Lucio Costa, a two-storey hotel with ten suites located in Nova Friburgo/RJ/BR, where the Architect uses precisely four of five principles of Modern Architecture defined by Le Corbusier (pilotis, clean plant, horizontal window, clean front area), on the first floor. On the second storey, his conceptions revisit the traditional Brazilian and Portuguese Architecture and extract from the pole-and-beam structural system.

In the international context *Olympic Hall* (1992) has been recognized as one of the best projects in timber material. It had been conceived by Niels Torp Partners for the Winter Olympic Games in Norway for 13,000 spectators, presenting a constructed area of 25,000 m² (100 m x 250 m), using 2000 m³ of glued laminated timber beams, 100 m span of (STUNGO, 1998), Figure 1.



Figure 1 – Building construction: *Olympic Hall*, at right side, (Stungo, 1998).

According to the thematic concerning the use of timber material in these constructions, its current application is focused on the building construction, mainly in the elaboration of structural elements, and, in contrast to the usual way of thinking, these structures may be adapted to different and several architectural case studies, from one or multi-family houses to multi-purpose rooms and research centers, hangars to keep airplanes, and others.

1.2 Tree-Shaped Structural System

Tree-Shaped was thought in accordance with an Architecture that has privileged serious concerns with Nature and its preservation, causing minimal impact on the surroundings. Furthermore, the system would have few support points on the soil, be

modular prefabricated with constructive rationality and its elements made of renewable material, and be comfortable to human touch. At the same time, it could expend less energy for its process, when compared with conventional materials; therefore, legal and certificated wood was a natural choice.

If all these hypotheses and conditions are put together, the ideal structural system will resemble a metaphorical image of a tree, such as the masterpiece *Sacred Family* in Barcelona/ESP, whose author was the Architect Antoni Gaudí I Cornet (1852 – 1926), Figure 2. Gaudí inverted the logical of the gothic concepts, light weights below and heavy above. He used to have always in minded the figure of the tree in the Nature. *Tree-Shaped* follows the same idea, using the timber pieces connected by steel plates.



Figure 2 -Conception of columns: Case study: *Sacred Family*, (TOMIE OHTAKE INSTITUTE ,2004).

One more projected specificity is the bio-climatical aspect involved in this structural system, concerning natural ventilation and chimney effect due to special characteristics related to emptiness of the superior part of the structural system.

Tree-Shaped is formed by slab plans, with three timber columns, six faces "diamond" shaped, named "diamond" column which is placed above these columns, resulting three spatial trusses; all these elements linked by metallic connections, Figure 3.

In accordance with this technology, it is possible to visualize some benefits of this system, since its design is favorable to distribution of loads, consequently decreasing the number of columns on the soil. Also, the weight of the structure is substantially lighter than other conventional timber structural systems, therefore, requiring simpler foundations.

The technology of *Tree-Shaped* is understood as a product innovation, as well as a process innovation, consequence of its particular and singular assembly process, when compared with similar technologies.

Tree-Shaped is a timber structural system that provides a large number of case studies. The specific and singular these system characteristics allow its implementation in different declivities of the soil.



Figure 3 -Model in scale of 1:50, showing *Tree-Shaped* case study of Single Family Housing of 385 m² c.a.

It requires small construction site areas because its structural modules can be displaced in pallets, occupying reduced space in load trucks. The legal and certificated timber material is used in all elements; the other material, steel, is present as regular material in metallic connections.

The design is singular due to its specific support structures and particular nodes, also providing the structural implementation on different soils with variable topographies, because its concrete columns adapt to several heights in accordance with a variety of declivities.

The system is provided with metallic connections, which has the capacity of establishing continuity to the members as well as strength and stability to the system; similar to elements of a living tree, with rigid nodes, while *Tree-Shaped* (trussed beams) has articulated nodes. These characteristics result in aerial configuration full of structural lightness, characterized by a light-frame construction and the system could be defined as a beautiful architectonic artifact.

Besides, for all described its characteristics make it a singular structural system, according to Dias (2008): "...this system has a great potential of generating natural resources in the carbon market, (one carbon credit is equal to one ton of equivalent C0₂, which means, for instance, to drive a car for 2.084km) and to be registered as a clean technology in the United Nations.

This fact reaffirms the utilization of wood in a constructive manner is an effective guarantee of carbon sequestration by the plants.

Tree-Shaped is registered in the National Institute of Industrial Property-INPI/BR under P.I. 0.600.454-7 of January 27, 2006, whose title is "Tree-Shapep Modular

Structural System", existing a patership of both University of Sao Paulo -USP, which is the sponser of this patent holder, and one of the authors – Decio Goncalves.

Tree-Shaped won one of CONFEA (National Federal Council of Enginneering, Architecture and Agronomy) Award held in Brasilia/Br at the WORLD ENGINNER'S CONVENTION 2008 – WEC 2008 (December 2-6, 2008).

1.3 "Diamond" Shape Timber Column-DC

DC has unique characteristics of projected and constructive concepts. Visually, it looks like a tree-shaped metaphoric image, characterizing a harmonious and singular set, with plenty of marked plastic beauty, Figure 4.



Figure 4 -Modeling of Tree-Shaped.

At the same time, from its constructive elegance and visual lightness, conditions of dissipating loads through its elements are created, reducing intensity of loads that are working on these elements, so loads are transferred to concrete columns on the soil.

Because of the production rationality involved in whole project, the amount of workforce is not significant for the false work; it needs one chief-carpenter and small staff (two or three carpenters). As the structure weight is light there is no need of large equipment for assembling the system in the working area.

There is a minimal environment impact with the *Tree-Shaped* implementation, because the building has only three support columns in contact on the ground. This system presents an excellent cost-benefit, when thought in the market scale, making possible the application of several case studies, such as single-family housing, multifamily housings, malls, plane hangars, researchable centers, etc.

Tree-Shaped has specific projected characteristics, consequently provides easy industrialized processes; all components are packed in pallets and moved to the working area. Its assembly is similar to *LEGO* toys.

The insertion of this system in this article is due to the concern from the beginning of its creation of having in mind a definitive conceptual idea, i.e., a special configuration, which would be tree shaped, using wooden material and above all, causing minimum impact on natural surroundings.

Tree-Shaped can be reused in other locations, because of its assembly process; metallic connections are made with fasteners that allow disassembling the structural system easily.

2 MATERIAL

The wooden material is taken away from the forest areas, but unfortunately not always in an appropriate manner, with no attention to the main procedures used to obtain and process it. The forests are formed by trees, from where wooden material is pull out. This material is very important on the global context. because extracts the carbon monoxide from the Nature during the day time, and give it back as oxygen gas at night time, minimizing the huge damages caused by the global warming impacts, causing the greenhouse effect.

When conveniently treated with appropriated chemical elements last in good shape for long time. In the opposite what people think in general the wood is very resistant against fire effects, considering specifically solid wooden planks over one inch thickness.

In this situation, the fire will be spread out destroying the superficial lay very rapidly and after that, in the slow manner, in function of resistant thin layer that is formed and finally protects the wood against the action of the fire. This fact avoids fast fire spreading in direction to the inner part of the wood, therefore decreasing its fire velocity.

Related to fire wooden strength, according to Moura Pinto (2005), referring to consider a structure as secure in burning conditions, this author states that is one those: "with or without protection against burning it has great probability of resisting to the solicitations in high temperature, in order to avoid its collapse".

The wood is a nature material, so renewable, disposal in great quantity of deferent types of essences particularly in Brazil, needs for its complete process needs small quantity of energy, comparing with other materials, such as steel, concrete, plastic and etc. It is very pleasant to sense of touch, ease to work out, but unfortunately in Brazilian country is poorly applied on the civil engineering, specifically on structural systems the most.

In accordance with Bertolini (2011), "the increasing of wooden availability, mainly in principal species consolidated in Brazil, it was given in consequence to the use of new silvicultural technologies and the growth of investments in researches and genetic improvements in this area. Brazil presents great performance relating to hardwood species, as well as software ones, in comparison with others strong traditional countries in forest plantation, which have consistent forest bases".

It's necessary to be emphasized the relevancy on the Brazilian structural system application on this historical concerns, through their advanced and constructive methods concerning to the implementation of an innovative structural systems around the whole Brazilian country, using reforestation timber.

3 DESIGN, MODEL AND NUMERIC SIMULATION

A numerical simulation was done to establish the dimensional calculation of theirs elements, in order to construct a Module, finally named as "Prototype". CYPECAD software, version 2007, was used to calculate the bar solicitations. It is based in Finite Elements Method, which considers ABNT NBR 7190:1997 (Brazilian Code) requirements. Three dimensional elements to represents timber pieces were considered in structure discretization, Figure 5. There are two nodes and in with bar element and three degrees of freedom per node, in other words, these elements do not allow translations according to axes x, y and z, furthermore, free rotations around the same ones.



Figure 5 -Discretization of bar elements and joints of Tree-Shaped to CYPECAD.

The bar elements are responsible for tension efforts and axial compression, considering that all bar elements had their extremities articulated, with exception of the joints of the base. This numerical simulation has allowed the detailed analysis of the aspects of interest as the concentration of tension in the areas of larger effort and the connections, not possible of clearly detecting in lab tests.

This paper focuses on the main characteristics of *Tree-Shaped* one of most relevant characteristics of this system is the complexity of its connections, which required the application of the CYPECAD software version 2007 to solve the problems related to this question. The efficiency of this system could be confirmed through a variety of lab tests carried out with these connections. It uses, the theoretical and numerical analyses proving that *Tree-Shaped* is efficient and light for using in timber roof structures.

4 CONSTRUCTION, EXPERIMENTAL ANSWERS AND RESULTS

The aim of these lab tests was to confirm the performance of "diamond" column (DC), related to physical characteristics, specifically, its parallel compression across its fibers. Prototype was constructed in Mechanical Work of Sao Carlos Engineering School, presenting the followings characteristics:

• *Support elements*: 16 centimeters medium diameter cylindrical bars made of *Pinus occarpa C30*;

• *Metallic Connections*: Stainless steel plate pieces of 4,18 mm thickness plates and 15 centimeter diameter tubes. The welded plates were provided with two holes in order to insert wooden dowels to connect "diamond" column (DC) elements

• *Dowel connectors*: 16 mm diameter dowel (it was used *Peltogyne recifencis Ducke* species, or *Roxinho* in local commercial language)



Figure 6 – (left): Top part of metallic connection, and (right): Botton part of metallic connection.

This test was done with "diamond" column (DC) in horizontal position, the way to facilitate the application of compression efforts that were applied on the (DC) structural elements, Figures 6.

All the efforts were applied by handled hydraulic cylinder of 50 kN nominal capacity. Effort transitions to structural composition were processed by metallic support device and it was integrated by bars (previously gauged) and plates. The readings were done by *Kiowa*: STRAIN INDICATOR, model SM-60B, Figure 7.



Figure 7 -Effort transitions to structural composition were processed by metallic support device.

The maximum efforts employed in the tests were of 15 kN range, subtly superior to the double calculate through the CYPECAD software (7.3 kN).

Relative displacements between metallic components of structural solidified compounds were measured through comparison clocks of 0.01 mm range. These displacements were considered insignificant (0.03 mm was the maximum measured displacement).

The experimental analyses were development in four repetitions and confirmed the excellent performance, under solicitation, from "diamond" column (DC).

The prototype was assembled in the Structural Engineering Department– LaMEM in Sao Carlos Campus I – EESC/USP, in the inverted position, Figure 8, in accordance with the constructive and logistical necessities. For a while, it is waiting for the final location, where this architectural artifact will be installed in this Campus.



Figure 81 -Prototype assembled in LaMEM/SET – EESC/USP, in the inverted position.

Tree-Shaped is a timber structural system that provides a large number of case studies. Its specific and singular characteristics allow its implementation in different declivities of the soil; its cost-effective is considerable favorable for investments in many areas, particularly in housing ones.

Relating to the calculation, CYPECAD software, version 2007-1.i was used to compute bar solicitations in this structural system. Tests confirmed that the calculation previously done through the CYPECAD software had outstanding performance.

Finally, focusing the "diamond" column (DC), which is the main structural element of the *Tree-Shaped Timber Structural System*, the application of both concepts: the structural lightness and aesthetic beauty; it resulted in excellent performance in lab compression tests. In another words, (DC) is completely approved to be used in several architectonic artifacts.

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