Analysis of study cases for structural design of guadua *Angustifolia Kunth* buildings designed according to the requirements of the NSR-10, Title G.12

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**Abstract.** Since the publication of the Colombian earthquake-resistant building code of 2010 (NSR-10), the guadua *Angustifolia Kunth* was recognized in Colombia, as a suitable structural element; however, structural designs made for this type of constructions are not common. In this paper, there are several case studies, where guadua *Angustifolia Kunth* was used as the main material. Different architectural designs, commonly used in Colombia were selected; therefore, a structural system that will adjust to the different architectural distribution was chosen. The structural simulation was made in the commonly used program SAP2000; moreover, the structural design of each of the elements was carried out following the requirements of the NSR-10, and finally the respective structural drawings were finished. In general, it was found that the bamboo is subjected to relatively low stress, as long as, an adequate structural system and low loads of design are used. Nonetheless, in most of the cases, the structural design significantly affects the buildings’ architecture. The most critical stresses are due to the low capacity that the bamboo has to tolerate perpendicular compressive and shear. Also it was evident that, there are fundamental parameters for numerical simulation and for the design of each element, such as Poisson's relation, the coefficient of thermal expansion and the mechanical properties in different directions parallel to the fiber that have not yet been reported in the NSR 10.

**Introduction**

The Bamboo Guadua (*Angustifolia Kunth*) is a species of bamboo; mainly found in Colombia, that many communities have used it in the country along history. Nowadays Guadua is increasingly used by architects, engineers, and constructors due to it is a material with excellent physical and mechanical properties among them: versatility, lightness, flexibility, mechanical strength, hardness, environmental adaptability, seismic – resistant, quick growing, high renovation rate, easy handling, good visual warmth, and it also can be used as raw material in building. Currently sustainable projects seek the implementation of biodegradable materials that have a minimal environmental impact, and that achieve mitigating the damage done to the planet because of the use of traditional building materials like steel and concrete as others. Unfortunately, the increasing use of such material has taken to an inaccurate development since the lack of knowledge of its behavior as structural element, which, in many cases, can be seen in structures with robust and heavy elements, or on the other hand it can also be seen in structures with an inaccurate balance of load solicitation.

A high deficit in dwellings is made evident, especially for marginalized society, which do not have enough resources to get the houses and apartments that the conventional market offers. Construction in guadua affords a very economical alternative, due to the low cost in extraction and transformation of the raw material to be used as structural element. Likewise, such structures generate a very low ecologic fingerprint, since that the guadua growing up stage, it means during the production of the raw material, guadua crops transform CO₂ into O₂; and during the extraction and transformation the ecological and energetic impact is minimal compared to other conventional materials used in construction.
Nevertheless, most of constructions made with guadua as principal structural element do not count with a trustable structural design yet, neither with a guide or manual of design that allows for interested in these types of works of construction to make safe buildings before natural acts such as earthquakes or wind loads. Thanks to the inclusion of guadua as structural element in the last seismic- resistant building code, [2] nowadays we count with a series of parameters that allow to make a structural design much more accurate to the real behavior of the structure.

In order to evaluate and analyze the structural behavior of different buildings designed in guadua following established parameters in the NSR 10, several research works were done at Universidad La Gran Colombia named as “Diseño de una vivienda modelo eco-amigable en el municipio de Guaduas Cundinamarca” that translates as “Design of an eco-friendly model dwelling in Guaduas municipality, Cundinamarca, the second document is named “Comportamiento estructural de una edificación construida con guadua Angustifolia Kunth diseñada con diferentes valores de esfuerzos admisibles propuestos en Colombia” translated in this document as “Structural behavior of a building constructed in guadua Angustifolia Kunth designed with different allowable stresses proposed in Colombia”, the third research document carries the title of “Diseño de una estructura en guadua para un centro de rehabilitación y protección de animales en estado de abandono en Bogotá” translated as “Design of a structure in guadua for an animal under abandonment state rehab and protection center in Bogotá”, all of them developed by students that belong to the guadua research groups enrolled to the mentioned college.

Starting from these paperwork, as well as other paperwork developed in the professional field, we pretend to introduce some of the most common characteristics in structural design for buildings that use guadua as main structural element, contributing to the evaluation of all parameters established in the new seismic-resistant building code, and generating recommendations that can reach the continuous improvement of the structural designs with this material.

**Methodology**

**Setting up the architectural design.** At first stage some architectural designs of some structures built in guadua were chosen. Every case was checked particularly taking into account the minimal requirements demanded by the seismic – resistant building code of 2010 for buildings constructed in guadua Angustifolia Kunth which are: building site, size, geometrical configuration, height, and storey regularity. Once the checking up of different options was done, we proceeded to the determination of the four buildings. The first a single storey detached dwelling, located in Guaduas, Cundinamarca; the second design to be evaluated was a detached kiosk of one storey located in the city of Neiva, Huila; the last two chosen designs were: a small animals’ shelter of one storey with a single deck roof and a stable, similar to the proposed by Architect Simon Velez in some of the books where his constructions have been presented [4, 9, and 10].

**Analysis and structural design.** Once the different cities where the buildings are going to be located were identified, the seismic conditions, wind loads, temperature, and relative humidity, of each building were evaluated. With the placement of each structure, respective design spectrums were determined and seismic forces of each building were obtained. Likewise, wind loads of each structure were calculated. Dead loads were obtained from the analysis of each construction, having as premise using principally light materials which could fit the load capacity of the material. Having all loads to be used in each model set up different load combinations were determined. It is known that from NSR 10, guadua must be designed by the method of allowable stresses.

Once each one of the design parameters of each structure were established, we proceeded to shape the geometry of each structure and to enter each one of data found in the SAP2000 software which
the structural analysis of each structure was done. In the current code only the elastic module, and allowable stresses to the way fibers are oriented are specified. This condition makes impossible that the material could be shaped for its real conditions like its orthotropic condition. This situation takes that at the time the material is shaped like if it had an isotropic behavior, which differs considerably with its real behavior. It is important to mention that the structure named stable did not make part of the seismic resistance, therefore its behavior before seismic loads was not evaluated.

Once internal forces in the structure were revised, found with the help of SAP2000 software, we proceeded to do the structural design of each one of the elements. In some cases it was necessary to modify architectures initially evaluated in order to add or remove elements that were part of the structure. That is the case of the animals’ shelter where it was necessary to add diagonals to increase the stiffness of the structure in one of the ways. Something similar happened in the case of the kiosk in Neiva, where it was necessary to add diagonals between columns to give more stiffness to the structure and to guarantee the work in set of all frames. We also had to add the number of elements in one of the sides of the columns to accomplish the establish limits of drift. On the other hand, in the rural house located in Guaduas, the change in the original architecture design was more transcendental since it was necessary to move the columns to be alienated in all the ways. It was also necessary to add diagonals in several division walls and the facade that took to change the position of some doors and windows of the building.

However, after doing all these modifications in the structural system it was found that the four structures had an excellent behavior in relation to the strength of elements submitted to axial tension and compression (parallel compression to the fibers) due to none of them suffered, bended, or sag. As most of submitted elements principally to bending, like the roof straps, major deformations were found, and in some cases some elements had to be reinforced near the supports due to low resistance of perpendicular compression or sagging. About to deflections, none of the evaluated elements overloaded the specified limits in the building code.

**Drawing up of sketches.** After having the structural design of each one of the elements we proceeded to generate a set of sketches in each one of the projects. In figures 1 to 6 some images of the original architectural designs and the structural sketches elaborated for each building are presented.

1) **Eco-friendly dwelling in Guaduas Municipality, Cundinamarca**

![Figure 1. Architectonical design of the dwelling, Isometric View.](image1)

![Figure 2. Frame in axis 2 where geometrical distribution of the structure is observed.](image2)
2) Design of a structure in guadua for an animal under abandonment state rehab and protection center in Bogota

![Figure 3. Typical Section cut of the stable’s main beam](image1)

![Figure 4. Transversal cut for the animals’ shelter](image2)

3) Structural behavior of a building constructed in guadua Angustifolia Kunth designed with different values in allowable stresses proposed in Colombia

![Figure 5. Typical Section of the kiosk’s main beam](image3)

![Figure 6. Longitudinal cut of the kiosk’s frames](image4)

**Discussion.** Since guadua is a highly Renewable material that accomplishes with many of the criteria to be considered a sustainable material [1], we intended that also the architectural designs kept some of the sustainability principles described in several articles and texts [1,4]. It was observed that sustainability in a criterion highly studied therefore in these cases some principles were followed as the use of local materials that takes to diminishment of energetic costs as a product of the transportation to materials; and also materials highly renewable that require a little transformation. Furthermore, it is important to highlight that the main aspects of sustainability are the economical, social, and environmental, thus a project is sustainable when it is in a balanced state of these three aspects.

About the structural design, it was determined that localization of the dwelling not only sets up the environmental loads that affect the structures like wind and earthquake, but also physical and mechanical properties of the material, which, in the end, determine the self resistance of the material what turns into a big difference with the conventional materials.

In the NSR -10 it is mentioned that the frames should be braced by diagonals that, also all knot should be articulated. This condition implies that the guadua structures are generally very rigid structures, which easily accomplish with the drift limits exposed in the NSR 10, and any other building code.
In the design of dwellings, it is needed that initially, non-structural elements like division walls become in structural elements since the need to use diagonals for the conformation of the braced frames, which finish being installed inside the same walls.

It was found that guadua is a material that works very well before axial forces parallel to fibers of the material, either tension or compression. For the elements submitted to bending, this design is highly governed by crushing due to the little strength to the perpendicular compression of the material. The final section of the element finishes being determined by the phenomena of cutting and crushing due to bending.

**Conclusions**

It is evidenced that the guadua *Angustifolia Kunth* is a material of excellent behavior when it is submitted to axial stresses. In the analyzed projects none element of the structure was submitted to high stresses of tension or compression parallel to fibers, due to the stresses generated by the overlapped loads to the structure did not reach the 50% of the allowable stresses established by the code. In contrast, it was found respect to the elements submitted to bending where in various cases it should be modified the section of the material due to little resistance that offers the material before perpendicular compression to the fiber and the shear stress. This induces that in the possible means, it is necessary that the guadua structures will be conceived as plane or spatial truss loaded in knots, with the purpose of conducting that the material works principally submitted to axial stresses.

It could be observed that the structural design of a dwelling in guadua can reach to compromise in meaningful manner the architectonical design if it does not contemplate since the beginning of the project the necessary diagonals for the conformation of the braced frames, which are necessary to accomplish with the basic parameters of mechanical strength included in the NSR -10

For modeling of structures al physical and mechanical properties established in the Colombian building code for seismic resistant construction were taken into account, nevertheless it could be established that data as the stiffness module (G), Poisson´s ratio (ν) and the coefficient of thermal dilatation still have not been established by the code, therefore such values were taken of the research called “Propiedades físicas-mecánicas de la guadua (“Angustifolia kunth”) y aplicación al diseño de baterías sanitarias del Iasa II” translated in this document as “the Physical - mechanical properties of guadua (“Angustifolia kunth”) and application to the design of sanitary batteries of Iasa II” [3]

This analysis also allowed to demonstrate the need of having the values of each one of the mechanical properties in the perpendicular directions to the fiber, like is the radial and tangential direction, since, without these data, the modeling done in computer software to do the structural analysis are done assuming that the material is isotropic, which totally differs with the real behavior of the structure.

In the design it was also evidenced the need to adjust the equation to design the elements submitted to crushing, particularly in the unions, since as the code says it is mandatory the collocation of mortar to inside the knots, what increases considerably the resistance in the union.

Due to low weight of guadua structures, generally foundations present dimensions much minor respect to a structure made with conventional materials like steel, concrete or brick. We recommend to use concrete made with recycled material to mitigate the environmental impact generated for such material.

**References**


