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DEVELOPMENT OF GUADUA ANGUSTIFOLIA PREFABRICATED PANELS

R.G. Morán[1], H.F. Silva[2], J.J. García[3]*

[1,3] Universidad del Valle, Escuela de Ingeniería Civil y Geomática, Cali, Colombia.
[2] Universidad del Valle, Escuela de Arquitectura, Cali, Colombia.

*Corresponding author; e-mail: josejgar@gmail.com

Abstract

Guadua angustifolia (GA) is a species of bamboo indigenous of South and Central America. It is a fast growing plant and thus its controlled use does not threat the natural plantations, which play an important role to control water cycles, to reduce erosion and to sequester carbon. It is a fiber reinforced anisotropic sustainable material that has been used to construct rural houses and temporary structures due to its wide availability, low cost, and good mechanical properties along the axial direction of the culm. However, due to the hollow cylindrical shape and the geometrical irregularities of the culms as well as the low strength of the material on the planes of fibers, the construction of mechanical joints for GA structures is a tedious task, which increases labor costs and prevents the widespread use of GA in house projects. With the aim to overcome this difficulty, we present a methodology based on using small steel parts in the joints for the production of prefabricated panels, which may be easily combined and manipulated for the construction of different types of structures. Two of those joints are proposed in this paper. As the material displays a ductile behavior under compression along the radial direction, one of the proposed joints is composed of a bolt, a nut and thin steel elements that are used to distribute compression along the thickness and provide confinement to the material, interlocking of the fibers and friction increase for a higher force transmission. Pilot trials of these joints applied to GA slats have showed an excellent behavior. Current efforts are aimed to analyze the mechanical behavior of other types of joints using finite elements in order to produce prefabricated panels.

Keywords:

Guadua, metal connectors, prefabricated panels.

1 INTRODUCTION

Guadua angustifolia kunt (GA) is a species of bamboo highly available in South America, mainly in Colombia, Venezuela, Ecuador and Brazil [Cobos 2007]. This plant is characterized by a rapid growth and a fast period of development and maturation, which may be of 5 years. Like other species of bamboo, it displays a high axial strength, a low density, a great resilience, and it is readily available at a relatively low cost [Janssen 2000]. It is considered to be an ecofriendly material for construction because their plantations do not threaten ecosystems and have a high capacity to capture CO_2, reduce soil erosion, and control water cycles [Archila 2012]. We hypothesized that an increase of GA use in construction would appreciate the material and create economic incentives for the farmers to increment cultivated areas.

In Colombia this material has historically played an important role in our culture. For instance, the development of the Antioquia region during the eighteenth and nineteenth centuries was mainly stimulated by the availability of GA. Many houses, particularly in rural areas, have been built using ancestral technologies based on GA. Some of these buildings survive even today, demonstrating the capacity of this material to withstand earthquakes, e.g. many houses made of GA survived the Armenia earthquake in 1999 while many others made of brick and mortar failed [Salas 2006]. This experience served to reaffirm the importance of GA as a construction material. Currently, some Colombian architects still continue using the material to build large and beautiful buildings that have served as a platform to encourage their usage.

Even though GA has been included as a construction material in the latest version of the Colombian construction norm (NSR-10 2010), it is not still widely used due in part to the lack of quality control, the technical difficulties to mechanically join the elements, and the misuses of the material. These issues have created the beliefs that GA is a low class material.

Some of the difficulties associated to build GA structures are due to the round hollow shape of the culms, the variable dimensions of its members, and the fiber reinforced nature of the material, which explains the high axial strength compared to the low strength of GA in the planes of the fibers [Luna 2014]. This usually leads to failures near the joints under concentrations of circumferential and shear stress. Therefore, the mechanical joints for structures are built in a custom basis, which increases fabrication costs respect to other conventional construction systems. Hence, efforts have to be made to improve the efficiency of the joints and create construction processes that can be used in massive projects, e.g. for housing. One method widely used to improve construction quality and reduce costs and execution times has been the implementation of technologies using prefabricated parts, which have been effectively applied in the manufacture of timber houses [Midon 1996]. However, there are very few cases where these methodologies are used for structures made of GA or any other species of bamboo [Ribeiro 2009, Rodriguez 2014]. In order to overcome this difficulty, a methodology is proposed for the development of a construction system with GA based on the use of cheap prefabricated panels joined with small steel parts, which can be produced at a low cost.

2 PREFABRICATED MODULES OF GA

The construction of prefabricated houses has more than three centuries of history. The first references show that components of houses were manufactured in England and shipped to the fishing village of Cap Ann in Massachussets in 1624 [Panjehpour 2013]. The prefabricated systems were developed as an alternative to on-site construction methodology, following the trends of industrialization adopted by consumer goods manufacturers. The principles of prefabrication are based on the premise that good production in a repetitive manner and in an appropriate space like a workshop or a plant helps reduce costs and time and improve product quality. In addition, material waste and deterioration of outdoors elements during the construction period is also reduced [Ganiron 2014, Waskett 2003].

Over the last few years, prefabricated housing has become even more attractive to users because the designs can be customized according to demands, which is possible due to the automation of processes and the use of advanced technologies such as CNC (Computer Numeric Control) cutting that allows instant changes in the production systems [Rippon 2011].

Despite the attractive features of GA as a sustainable construction material, GA constructive systems lack of technological innovations that may promote their use. A methodology for the development and application of prefabricated GA panels for house construction is proposed in this paper. These panels can be easily built by using metal cost-effective connectors and simple straight cuts and drilled holes in the culms. Next, these panels may be readily assembled to form modular housing structures (Fig. 1).

Fig. 1: Example of a GA house structure built with prefabricated panels.

3 PROPOSED METHODOLOGY

The proposed approach for the development of prefabricated panels is based on the use of metal connectors, which allow an easy assembly of the panels, combined with simple straight cuts and circular holes in the culms.

In the proposed methodology (Fig. 2), input variables and constraints have to be defined first. Among the input variables are the general dimensions of the panels needed to build a typical familiar house as well as the geometrical characteristics of the material, e.g. the acceptable range of diameters and thicknesses of the culms has to be defined at this stage. A range of mechanical properties such as the strength and the Young´s modulus are also required in order to estimate the load capacity and deflections of the panel. Additionally, it is important to estimate the typical loads that the panels have to bear, which depend on the site of construction and the risk of earthquakes or strong winds. Other constrains may be related to cost, good appearance, and ease of assembly.

The next step is the mechanical design of the connectors. At this stage, a mechanical design process is recommended, in which many options should be initially considered and evaluated before finding those that fulfill all the constraints at the lower cost. In this step, the use of theoretical analyses with finite element programs, is an excellent cost-effective tool in order to mechanically analyze and compare alternatives. Few acceptable solutions should be next constructed in order to validate their performance according to the established criteria. Changes can be made in the final stage to optimize the design according to the results of the mechanical tests complemented with computer simulation using finite element programs.

After having developed and validated the prefabricated panel it will be necessary to qualify the performance of the construction system according to technical regulations, e.g. the NSR10-2010 for Colombia. This may require building two-story prototypes that should be tested to determine the stiffness, strength and ductility. Again, theoretical analyses with finite element programs are an important tool to take decisions with respect to the joints needed to connect the panels. The qualification will allow using the construction system in massive projects supported with state funds.

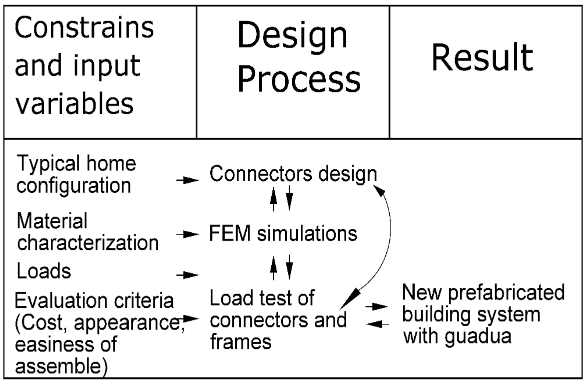

Fig. 2: Summary of the proposed methodology.

4 FIRST RESULTS

4.1 Proposed panels

In prefabrication technology there are two common available options, use of panels or prefabricated modules. Prefabricated panels are usually structural portions of walls typically assembled on the construction site to form a module. On the other hand, prefabricated housing modules usually include floors, walls and the roof system. They are ready to be installed in a proper previously constructed foundation [Rippon 2011].

In the use of housing modules the construction time on site is minimal as well as the staff involved. However, there are constrains due, for instance, to size limits imposed by transport facilities or the capacity of the cranes available in the building site. On the other hand, prefabricated panels require more time and number of personnel for the assembly, but allow greater flexibility in transportation. Considering the transportation constraints of Colombia, we chose panels as the preferred system. Two types of panels are proposed, as sketched in Fig. 3, which differ in the kind of metal connectors. Considering a pilot house configuration similar to that of Fig. 1, panels dimension were defined to be 1 m wide and 3.81 m high.

4.2 Description of the joints

Metal connectors to join elements of bamboo and GA are not new. Several authors [Janssen 2000, Albermani 2007, Laroque 2007, Jayanetti 1998] show complete inventories of connectors using several kinds of accessories such as bolts, screws, clamps and bars.

However, many of those connectors have no practical application or functionality because some of them are too flexible and others very complex and expensive. For instance, connections recently proposed for GA houses (Fig. 4) are based on the use of fish-mouth cuts and grouting [Camacho 2002]. These joints work reasonably well but are custom-made, difficult to standardize, and add a considerable weight to the structure.

Fig. 3: Proposed Panels. Left: Gusset plate connectors with bolts and preload washers, Right:. Bolted connections based on metal plates.

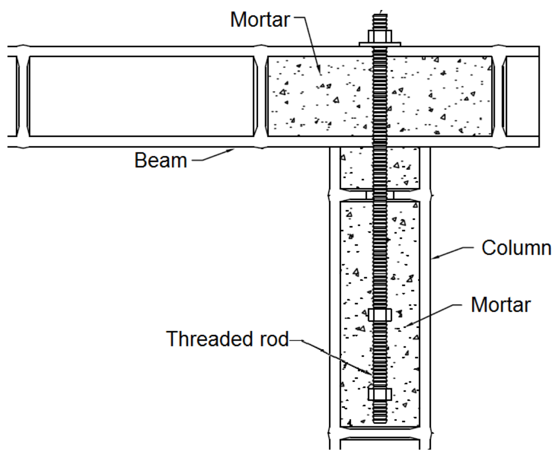

Fig. 4: Typical connection using bolt and mortar [Camacho 2002].

In a first stage, we propose two joints that are thought to be amenable for standardization, functional, and cheap to build. (Fig. 5, 6). In the first connection (Fig. 5), each of the two gusset plates can be easily assembled and fixed to the walls of the GA culms by bolts of 9.5 mm (3/8”) diameter and 25 mm length. Around the holes and at the sides of the culm walls, there should be curve steel washers, which are intended to confine the material and prevent cracking when the bolts are tighten to apply compression along the thickness of the culm.

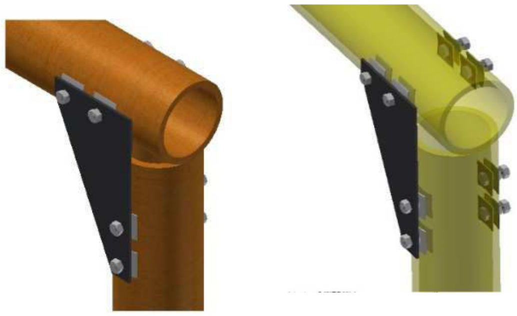

Fig. 5: Gusset plate connection using preloaded bolts and curved steel washers.

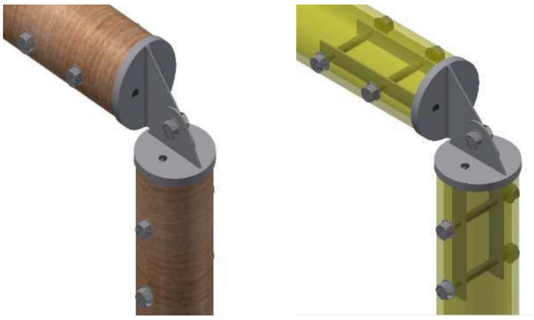

Fig. 6: Bolted connection using plates and welded brackets.

This radial compression has shown to increment the efficiency of joints for GA slats. Stress concentrations and cracking initiation around the hole are mitigated due to the confinement of the washers and the compressive pre-stress along the thickness of the material, as GA has shown to have a ductile behavior under radial compression [Orozco 2014].

The other connection (Fig. 6) uses four 12.7 mm (1/2”) bolts to transfer the load from the culm wall to a couple of internal gussets that are connected to a circular lid that covers the end of the culm. In turn, the circular lid is welded to a small plate that is connected with the corresponding plate of the other culm by a bolt. Unlike the previous connection, this joint is designed to transfer only axial load. Diagonals can be added in order to get a triangular stiffer shape so that the panel is capable to withstand horizontal loading.

4.3 Mechanical Performance Simulations

Currently, finite element (FE) simulations of these connections are carried out in order to evaluate their mechanical performance. The FE software ABAQUS (SimuliaCorp., Providence,RI, USA) is being used in these simulations that take into account the anisotropy of GA.

A vertical distributed load range of 100-150 Kg/m^2 is expected to be supported by modules like those of Fig.1, which is representative of typical dead and live loads considered in the design of these structures. Then, for a 3 x 3 m module a maximum total vertical load of 1630 N/m was considered for an individual panel.

Culms were assumed to have an external diameter of 114 mm and a thickness of 10 mm, which may be typical of GA culms. The steel gussets and bolts were assumed to have a Young’s modulus of 200 GPa and a Poisson’s ratio of 0.3. Anisotropic elastic properties of GA were extracted from reported data [Ghavami 2005, García 2011] as shown in Tab. 1, where the axes 1, 2 and 3 are respectively aligned along radial, circumferential, and axial directions of the culm. In addition, the letters E and G refer to Young´s and shear moduli, while the Greek letter v describes the Poisson´s ratios.

Tab.1. Elastic properties considered for GA

E_{11} (MPa)	E_{22} (MPa)	E_{33} (MPa)
400	400	15100
v_{12}	v_{13}	v_{23}
0.22	0.1	0.1
G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
164	600	600

For this load case, a quarter of panel was simulated considering symmetry. The vertical load was distributed along the horizontal member while the ends of the culms were constrained with border conditions consistent with the symmetry.

Initial pilot simulations of the second prototype under this loading case showed a good mechanical performance, as maximum vertical deflections were below 1 mm, radial stresses were in the range of -1.39 - 0.98 MPa and transversal stresses in the range of -8.31 - 1.84 MPa, both of which are well below reported strengths of GA, indicating the integrity of the joint under this type of loading (Fig. 7). More analyses have to be accomplished under combinations of vertical and horizontal loading, such as those that may be caused by earthquakes and winds.

5 CONCLUSIONS

The use of prefabricated building systems based on panels facilitates the assembly of structures and can be used to build GA houses for massive projects. This methodology allows producing quality and affordable structures under shorter construction times.

Two types of prefabricated panels as an alternative to build housing modules were proposed. Culm connections are accomplished with small steel parts, which facilitate the assembly of panels. In addition, only straight cuts, perpendicular to the axes of the culms, and drilled holes are required in the proposed joints, compared to involved fish-mouth cuts required in traditional joints.

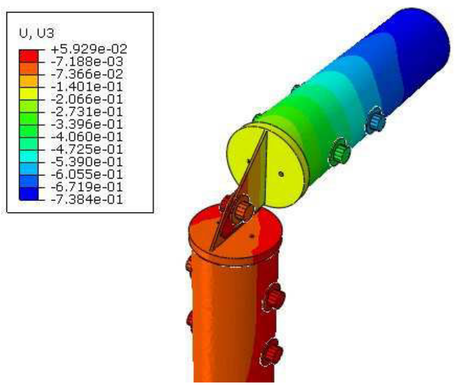

Fig. 7. FE deflections results of bolted and brackets connection.

Engineering tools like CAD technology and FE simulations are useful for the design and analysis of mechanical connectors. However these simulation results must be validated through experimental trials. Our current efforts are aimed to complete FE analysis and perform full scale test of the panels and connections.

As warnings for world warming have increased over the last few years, it is mandatory to explore alternatives to reduce the use of traditional construction materials such as concrete and steel. In this respect, GA appears to be an excellent alternative. The development of a construction systems based on the methodology proposed in this paper may constitute an important step to replace traditional materials for the construction of house projects. Currently, the commercial value of GA is quite low so that GA-plantation owners do not have economic incentives to increase or even maintain the cultivated areas.

In this respect, under the trends of a free market economy, we hypothesize that an increase use of GA in construction will create the economic incentives to increment the area of plantations. Research centers and universities are called to promote this process which can bring benefits to the environment and economic development of the regions.

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