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Home for Elderly People Built by the Community with Structural Elements of Laminated Bamboo Guadua in a Rural Area of Colombia

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Abstract. In the past four years the research project "Design and construction of housing with structural elements of bamboo guadua laminated" was developed in order to show the potential of industrial use of this material and to increase its demand for housing construction. As a result of the research, in the village of Ibama in the municipality of Yacopi, Department of Cundinamarca, Colombia, a home for elderly people was built using structural elements of laminated bamboo guadua, with the participation of the community under the supervision of the Universidad Nacional de Colombia (National University of Colombia). This paper presents the steps followed: the architectural and structural design based on the experimental results of samples and elements, the manufacture process, the test of a part of the structure and the construction on site.

Introduction

At the beginning of 2012 the research project "Design and construction of Housing with structural elements of bamboo guadua laminated" developed by the Universidad Nacional de Colombia (National University of Colombia) with the financial aid of the Ministerio de Agricultura y Desarrollo Rural de Colombia (Ministry of Agriculture and Rural Development of Colombia) finished.

In the first part of the project, the production line of structural elements of laminated bamboo guadua was developed (Cortes et al. [1]). For this, it was necessary to train people, to adapt and build the necessary devices and equipment for the material production and establish two primary production sites near the bamboo forests.

The second part of the project included the test of samples with four different types of adhesives (Cortes et al. [2]) to define the adhesive that presented adequate mechanical behaviour to be used in the construction and to determine the mechanical properties of the material; the test of structural elements such as beams (Hackmayer et al. [3]), columns (Alvarado et al. [4]) and panels (Gonzalez et al. [5]) to find the design stresses and elastic values and the tests of frames with two types of bracing under lateral load (Luna & Takeuchi [6]).

The final part of the project included the construction of two housing prototypes, one of them in the village of Ibama in the municipality of Yacopi and the other one in the village of Pasuncha in the municipality of Pacho, both, in the Department of Cundinamarca, Colombia. The prototype of Ibama has two floors and its final use is for elderly people while the prototype of Pasucha has one floor, with the possibility of being extended to two floors, and it will be for office use.

General Description

The construction of the prototype was planned taking into consideration the manufacture of the structure previously in the workshop and a quick assembly in its final location, using simple connections between elements and unskilled labour. On site, only the foundation work and service networks such as water, plumbing and electrical systems were carried out and the final assembly of the structure.

To construct the building, it was necessary to undertake the following:

- The architectural design, the analysis of the structure and the design of elements and connections
- The manufacture of the laminated bamboo guadua elements
- The preassembly of all the structure and the test under vertical load of the central module
- The transportation of the materials
- The construction of the foundation, the assembly of the structure and collocation of the secondary elements, roof and finishes.

Architectural Design

In the architectural design of the prototype (Rodriguez, [7]), the laminated bamboo guadua was incorporated as a main material of the structure, looking for an economical and attractive design. Taking into consideration its excellent appearance, the material was visibly exposed both indoors and outdoors. To be visible, it was decided that some elements of the side trusses protrude from the plane of the walls (Fig. 1).

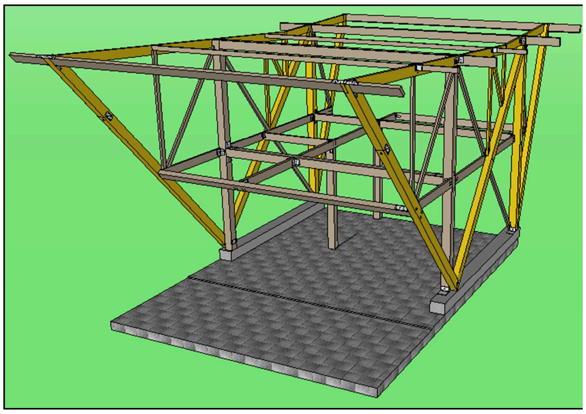

Fig.1. Structure of the prototype. *Ref. [8]*

Because these elements are exposed to weather conditions, it was necessary to protect them in order to extend their useful life, for this reason, the architectural design contemplates the roof cantilevers to protect the lateral facades from water and sunlight (Fig. 2).

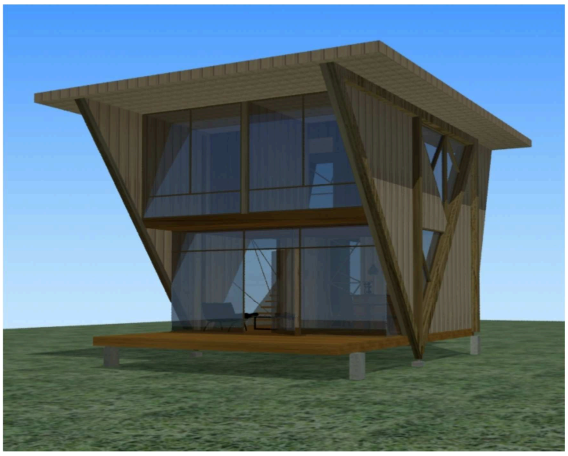

Fig. 2. Perspective of the prototype. *Ref. [7]*

To protect its frontal and back facades, the geometry of the prototype was designed as a two-level volume with sloped facades, where their sides form triangular shapes (Fig. 3).

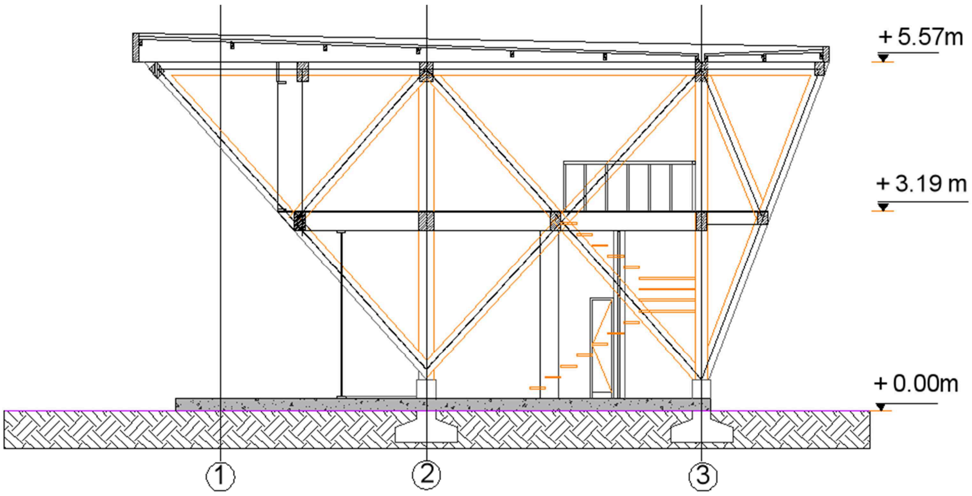

Fig.3. Lateral view of the prototype. *Ref. [7]*

The house, with a covered area of 90 m^2, including lateral cantilevers of 0.80 m wide, was projected on two floors. The social areas and the kitchen are on the first floor (Fig. 4) and the bedrooms and bathroom are on the second floor of 45 m^2 (Fig. 5). The house has a flexibility of spaces on the second level where the distribution of the walls can be modified according to user needs.

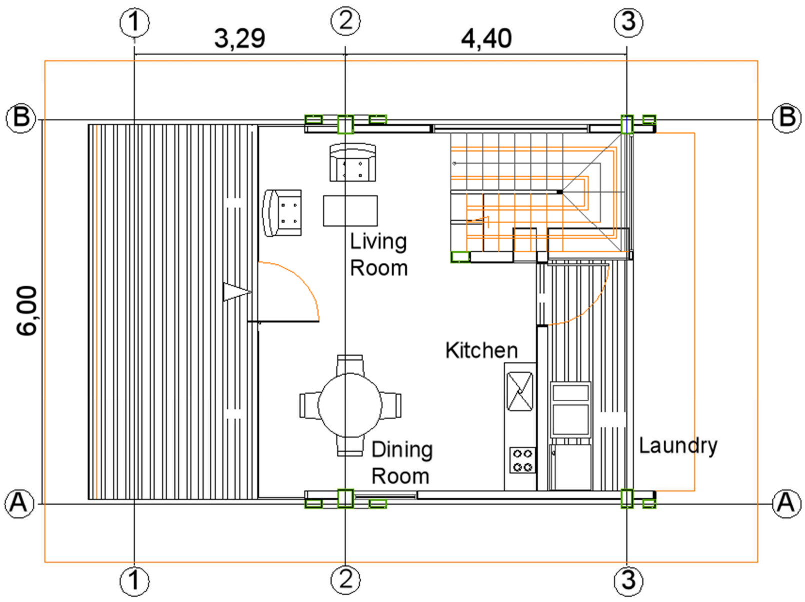

Fig. 4. First floor of the prototype. *Ref. [7]*

As is observed on Fig.3 at the main entrance there is a covered porch that allows extension of the social areas. In the exterior of the back part of the house there is a small covered place for the laundry area (Fig.4).

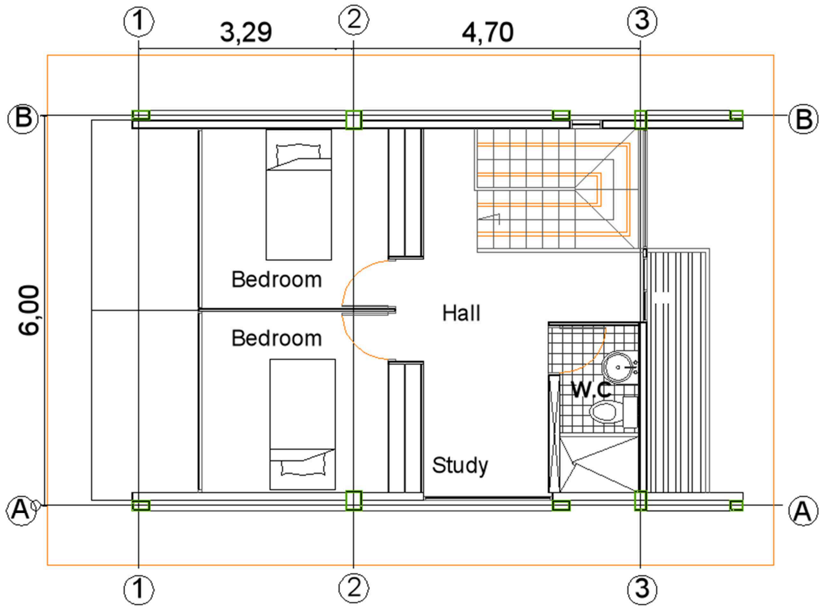

Fig. 5. Second floor of the prototype. *Ref. [7]*

The main front is completely open with glass windows and door, so the social area on the first floor and the rooms on the second floor are very light spaces. On the sides, small windows are found, allowing light to enter specific places such as the bathroom on the second floor and the kitchen on the first floor. At the back, there is a large window in the stairs area. The height between the floor and the ceiling is large, considering the warm weather at the location of the house.

The facade walls were designed as modular sandwich panels with vertical slats of bamboo at the outside, horizontal slats at the inside and between them, cardboard sheets glued to form a honeycomb shape that works as an isolating material that provides a good indoor climate.

Structural Analysis

The seismic system of the structure in the short direction, consists of three frames of a single span, one of them sloped. In the large direction, the resistance is provided with flat trusses. The principal vertical elements of the trusses are the columns of the frames (Fig. 6).

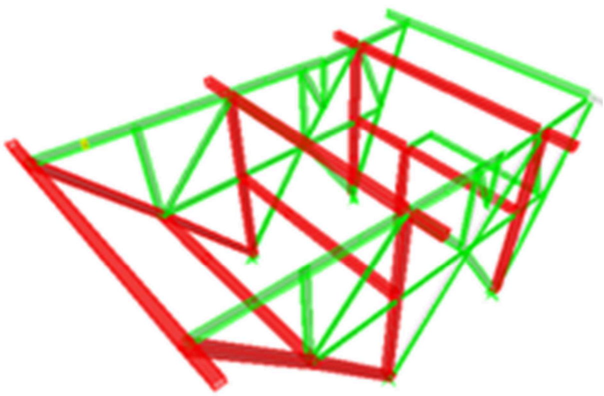

Fig.6. Structure of the prototype *Ref. [8]*

On the frames, all the beam column connections were considered rigid. In the lateral trusses, the beams and columns were considered as continuous elements and the diagonals and the beam ends, were articulated. All the supports were considered articulated.

For the analysis of the structure, carried out with the software ETABS®, a spatial model was made. As the elements of the lateral trusses were in two planes, the eccentricities at the connections were taken into account.

The determination of dead, live, wind and earthquake loads was made following the methodology established by AIS [9] in the Normas Colombianas de Diseño y Construcción Sismo Resistente NSR 98 (Colombian code for design and construction of earthquake resistant structures) valid at the time that the structural design was developed.

For the determination of the dead loads of the mezzanine the weight of the wood joists, the oriented strand boards (OSB), the wood floor finish and the plaster divisions were considered. For the dead loads of the roof the weight of the wood ceiling, the wood roof joist and the metal roof were considered. Also the weight of the laminated bamboo structure was considered. In the analysis, the live load of the mezzanine was 0.0018 MPa and the live load for the roof was 0.0005 MPa, considering its low slope.

For the evaluation of the wind, a design speed of wind of 86 kph was considered, determined with a basic wind speed of 100 kph, a topography coefficient corresponding to the mountaintop, a land roughness coefficient of an open field without obstructions and a safety and lifetime coefficient of normal occupancy buildings. A density coefficient corresponding to a 1000 meters over sea level was considered.

For seismic load evaluation, the elastic acceleration spectrum was determined with an acceleration coefficient of Aa = 0.20 (that corresponds to middle seismic hazard zone), with a site coefficient for the most unfavourable soil condition (because a soil study had not been undertaken) with the coefficient of importance used for residential use and with a fundamental vibration period of 0.19 seconds. Considering that the laminated bamboo guadua is not contemplated as a structural material in the NSR 98, and according to the behaviour observed in the tests of frames under cyclic load, the coefficient of basic energy dissipation was taken as 2.0 (proposed by the NSR 98 for a structural system of frames made of wood).

In the analysis of the structure done for the determination of internal forces of elements, it was considered that the mezzanine works as a rigid diaphragm. The OSB boards and beams work together as composed elements.

Based on the results of tests of samples, columns and beams of laminated bamboo , two different materials were considered, one for elements with flexural behaviour (beams) and the other for elements with axial behaviour (columns and diagonals of lateral trusses). So, the modulus of elasticity for the first material that was used in the structural analysis was 15300 MPa and for the second material was 20000 MPa.

It was verified that the maximum drift of the building was within the limits set by the NSR 98.

Structural design elements

The structural design of elements was based on the allowable stress method, where the values of allowable stress were determined by the strength values found in different mechanical tests of samples (Cortes et al. [2]), beams (Hackmayer et al. [3]) and columns (Alvarado et al. [4]) shown in Table 1.