Bamboo as an Industrialized Structural Urban Material

Proposals for Social Housing in Brazil

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ABSTRACT: Bamboo is a building material that presents various positive environmental characteristics; however, its use has been limited to detached single houses and mostly rural applications. The objective of this paper is to demonstrate the potential of bamboo for constructing multi-storey buildings in urban settings, as a substitute for conventional materials with high environmental impact. This article studies the application of innovative structural systems made of industrialized bamboo for social housing buildings in Brazil. This is a relevant example because several countries with a high demand for social housing also have high potential for growing bamboo. In these cases, bamboo proves to deliver lower construction phase environmental impact than conventional building materials – with construction quality and durability similar or better than wood – besides other social and economical benefits. The paper also demonstrates the high potential for production of industrialized bamboo, which not only improves the overall efficiency of the process but also delivers benefits to several stakeholders.

Keywords: Bamboo / Innovation / Structure / Urban / Environmental-impact

INTRODUCTION

Bamboo has proven to be, in various countries, an environmentally friendly building material, presenting advantages such as physical properties comparable with steel, high renewability with a rate of CO_2 absorption greater than wood and thus a closed life cycle material for buildings; besides its social benefits [1, 2]. However, its use has so far been limited to detached single houses and mostly rural applications.

The goal of this article is to contribute to a real shift in resource-use by focusing on the application of bamboo as a structural building material in cities. This organic material could be an excellent substitute for conventional structural materials, which generally present higher environmental impact. Moreover, bamboo is an adequate substitute for wood in various uses [2, 3], helping to protect native wood forests in the world. There are still many barriers to overcome for the use of bamboo to become widespread, such as lack of consideration in national building codes, prejudice in Western countries and competition with conventional materials.

Current research efforts often focus especially on the “use phase” of the buildings to lower their overall environmental impact, in detriment of the analysis of the construction phase impact [4, 19, 20]. The focus of this article is on the construction phase of a building and the right selection of supporting structures, which may be responsible for up to 70% of the environmental load of a building construction [5]. The use of renewable resources, the recycling, reuse and sustainable production of materials are also crucial and must always be taken into consideration.

The application study is based in Brazil, a country with one of the greatest number of bamboo diversities in the world, with approximately 135 species [6, 8] and a high demand for social housing. Unfortunately, lack of knowledge and acceptance of the material has, so far, limited its use in this country. This article proposes that more harvesting with proper management of bamboo could alleviate the overexploitation of wood forests in Brazil, one of the largest in the world. In addition, it alleviates the problem of transportation of Amazonian wood to other parts of the country, as it can be easily and quickly harvested in many regions of Brazil, generating a local raw material of high quality.

The proposals of structural bamboo presented are based on the credible development of the bamboo industry, which has potential to mirror the increasingly widespread use of manufactured wood timber in construction, including for multi-storey buildings.

Structural Bamboo and Wood

It is assumed that for an urban setting, processed bamboo elements are an adequate material option if they become standardized, industrialized and durable (protected), to be able to meet the large urban building demand for long-lasting buildings. Bamboo is seen here as a material adequate for industrial use, as it presents very fast growth (in Brazil, in three years the volume of bamboo cropped is the same as the eucalyptus in seven years [9]) with annual cropping, perennial forests and adaptability to a wide range of climates [6, 8], avoiding long-distance transportation. The processed bamboo industry overcomes many of the problems of the traditional natural bamboo industry, such as low productivity, instability and varying quality [12]. At the same time, industrialized bamboo can retain the distinct physical, mechanical, chemical and aesthetic features of natural bamboo. Industrialized bamboo started to be commercialized in Asian countries and has become increasingly popular in Western markets because of its quality, durability and wide range of applications [9,12]. These products can be used from structure to roofs and wall panel cladding, or to replace most other building elements made of industrialized wood [1, 7, 12].

There are few companies in the world that industrialize bamboo for structural purposes and the most important ones are found in China, United States and Belgium [10, 11]. The main structural processed bamboo element found is the glued laminated bamboo (GLB) [3, 12] called in the market as *lamboo*® or *glubam*® [10, 11]. The elements are sold as structure pieces such as pillars, beams or structural panels.

Analogous products to almost all timber products can be manufactured with bamboo, using the same principles and similar equipment [7, 9]. Besides, various sources state [1, 2, 6] that bamboo presents strength advantages because of the greater length of its fibers compared to wood fiber, as well as being lighter. With regards to wood structural systems, buildings of four or five stories have tradition in Central Europe and North America with the log-construction and platform systems [13]. Recently, new technologies, together with reformulations of fire protection regulations and new developments in sound insulation, have renewed interest in the use of timber in construction industry. For example, in Scandinavia and Northern Europe, the sandwich panel system and more recently the solid wall system are gaining ground for use in multi-storey building structures, with up to nine-floor buildings for solid wall systems [13].

METHODS OF ANALYSIS

Based on the research of the state-of-the-art industrialized structural bamboo elements and industrialized structural wood systems, five different structural bamboo systems for buildings are created. Four of them are focused on an urban setting and one is studied for baseline comparison. All are applied as proposals to meet the requirements of the Brazilian Social Housing Program *Minha Casa, Minha Vida* ("My Home, My Life") [14] in São Paulo, Brazil.

The use of bamboo is proposed for the main structure of the buildings, with three to five floors, as requested by the social housing program [14]. The typical floor plan can be seen in figure 1. Secondary materials, such as bamboo external protection and cladding options will not be detailed as they are not the focus of the present research. The vertical circulation core highlighted in black (Fig.1) will be made of reinforced concrete or bamboo, depending on each system and the stability it presents.

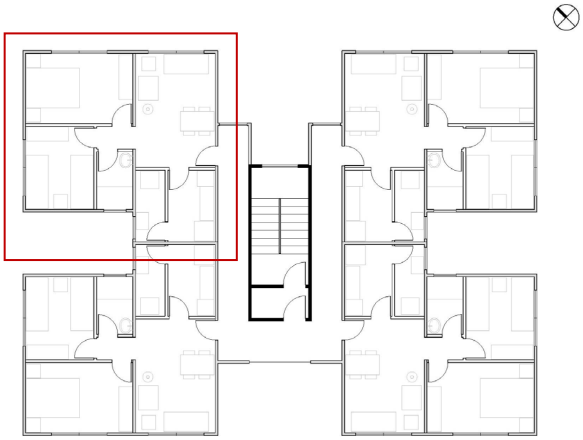

Figure 1: Typical floor plan, with four apartments per floor

The conditions in São Paulo specify the parameters for this study such as the chosen bamboo species, the high demand for social housing [14] and the possibilities for bamboo industrialization. The structure design is based on structural bamboo products that exist in the world market [10, 11], assuming that Brazil could develop the necessary technology to produce all elements and systems locally. This could be a development of the wood processing industries already existing in Brazil.

A preliminary structural sizing was calculated for each system, based on structural standards [15, 16] and on wood and bamboo data [15, 17, 18]; then structural drawings were developed. After each system was created and designed, an accurate quantification of the main materials needed was made, followed by the environmental impact calculation. The environmental impact analysis takes into consideration the main materials of the vertical and horizontal parts of the structure.

The environmental impact analysis is based on the following data: building weight (Kg/m^2), embodied energy (MJ/m^2) and CO$_2$ emissions (Kg CO$_2$/m^2). The data for the bamboo systems calculations are taken from two main sources: the website *Datalholz* [17] and the book *Construction Materials Manual* [19]. The data source for conventional materials is a thesis [20] that compares buildings with the same height as the present study, similar structures, same use of social housing and same data elements for environmental impact.

Due to the lack of studies about environmental impact data of glued laminated bamboo materials, the assumption that environmental impact of laminated wood products is applicable is made, as wood and bamboo have similar building roles, organic characteristics and the quantity and kind of glue used on these elements are very similar. The results obtained can deliver an order of magnitude of the impact that processed bamboo could achieve. The CO_2 emissions for bamboo production are considered zero, as this plant stocks CO_2, avoiding its release to the atmosphere [2, 5].

The results are used for two kinds of comparison: 1. to compare the bamboo systems between each other in order to get an indicator of the environmental impact influence with the selection of each system; 2. the bamboo systems are compared against systems based on conventional building materials to achieve an order of magnitude of how much lower the bamboo environmental impact is.

RESULTS AND ANALYSIS

The main systems developed during this research are presented here in a synthetic way, together with its environmental impact analysis. The five systems developed and analyzed are: System 1 - **Platform with Natural Bamboo**; System 2 - **Platform with Processed Bamboo**; System 3 - **Pillar-Beam**; System 4 - **Solid Wall** and System 5 - **Sandwich Panel**.

The structural systems are created with the species *Dendrocalamus giganteus*, commonly known as “Giant Bamboo”, in its natural and processed form (as laminated panels, boards, pillars and beams). This is one of the largest species of bamboo in the world and has sufficient strength for structural use [7, 9], also due to the thickness of the culm walls that are important for the lamination process. It is a species commonly found in the state of São Paulo (Brazil).

For all systems, it is considered that all bamboo elements must be protected externally and internally, mainly against water, moisture and fire. With the right protection, this organic material can construct long-lasting buildings [1,7, 12]. Mainly the vertical structures differ from one system to the other. All slabs are made of glued laminated bamboo (GLB) and the joists that support them are made of GLB in its upper and lower parts (8,9 x 6,4cm section) [10] and its central part is made of bamboo OSB (Oriented Strand Board) 16mm thick and total height of 22cm. All necessary connectors are made of steel.

System 1: Platform System with Natural Bamboo

Main elements: natural bamboo culms (studs), steel connectors and GLB boards (Fig.2). This system is based on the traditional wooden system with the same name, which, in traditional Latin American construction can be found made of bamboo culms [2]. It is composed of a grid made of studs with a separation of 50cm, together with boards nailed to them to stiffen the structure, creating a structural wall. The joists are different from the other systems and are composed of two bamboo culms on top of each other, connected by steel elements.

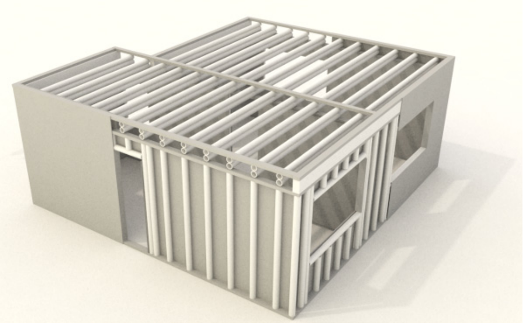

Figure 2: structure of one apartment – System 1

This system is not suitable for an urban environment mainly because of the lack of stability of the organic material for building various floors and the lack of replicability due to non standardized production. It is researched in order to be a reference for the other systems and for comparative purposes. The calculations allow the maximum height of **three floors.**

System 2: Platform System with Processed Bamboo

Main elements: GLB studs (6,4 x 6,4cm), steel connectors and GLB boards (16mm thick). This system (Figs.3 and 4) is similar to the previous one, but instead of using natural bamboo, GLB elements are used as the studs. As the processed bamboo enables more stability than the previous system, the maximum height is of **four floors. Stability:** reinforced concrete is needed in the vertical circulation core to stabilize the whole building. Assembly time is relatively long, as there are many separate pieces and connections.

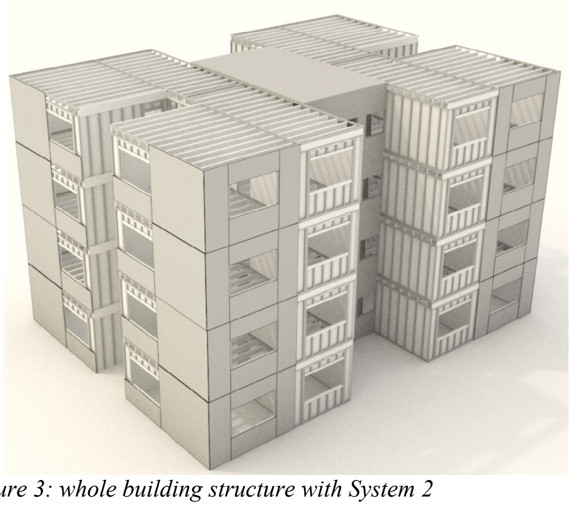

Figure 3: whole building structure with System 2

System 3: Pillar-Beam System

Main elements: pillars – GLB lumber (14 x 12,8cm) [10] beams - GLB lumber (28,6 x 8,9 cm). This is the only point-supported structure (Figs.4 and 5) presented in this work, where the structural element is not the whole wall. The cladding may be of GLB boards to maintain the level of prefabrication and a fast assembly time. The maximum height calculated is of **five floors**.

Figure 4: whole building structure with System 3

Stability: need of reinforced concrete in the vertical circulation core, steel connectors between the structural elements and metallic X-shaped stems as substructures to act against horizontal forces (Fig.4).

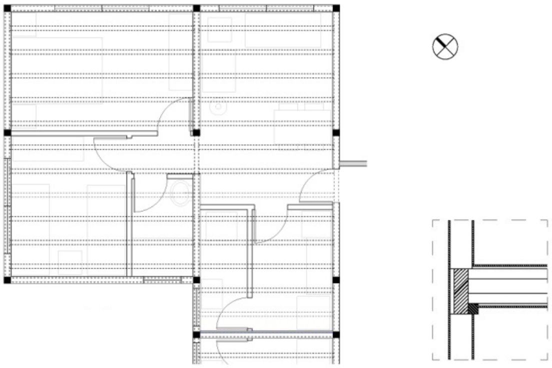

Figure 5: apartment plan with Pillar-Beam System (3) (section detail of wall-slab connection) – no scale drawing

System 4: Solid Wall System

Main elements: GLB panels (9,37cm thick - five panels ¾" thick [10] glued together). This system (Fig.6) is derived from the solid (wood) timber system and is based on large and entirely prefabricated structural walls made of glued laminated bamboo. This system presents the highest level of prefabrication and is the fastest one to be erected due to the fact that the whole walls are prefabricated, so fewer connections are needed, requiring less labor and generating less waste. This would be possible with the development of technologies similar to that for wood, which allows industries to fabricate large-scale format elements. The loads are carried via plate action (linear system).

Stability: no need of concrete core or any extra element, as it is very stable. It allows building various floors and here it is calculated for **five floors** without buckling.

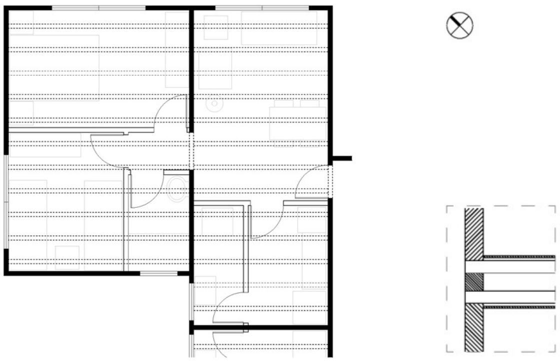

Figure 6: apartment plan with Solid Wall System (4) (section detail of wall-slab connection) – no scale drawing

System 5: Sandwich Panel System

Main elements: Sandwich panels (11,4cm thick, 1 or 0,5 meter wide), composed by GLB substructure (6,4 x 6,4cm section and height equal to the panel) that stands the two GLB panels (3,8cm thick) on both sides. The prefabricated structural panels are assembled *in loco*. This system (Figs. 7, 8) allows grid and modular arrangements, still permitting design freedom. This can be an adequate option for social housing projects, as it is built fast and costs are reduced with less waste. These dimensions present enough structure stability for building **five floors** without buckling and no need of concrete core.

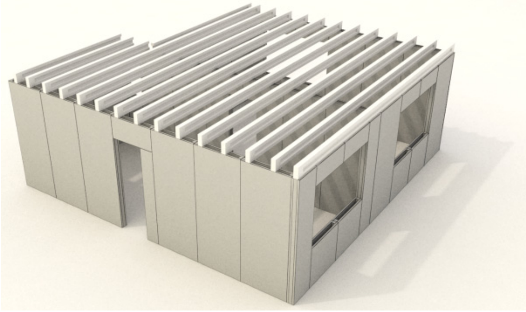

Figure 7: structure of one apartment – System 5

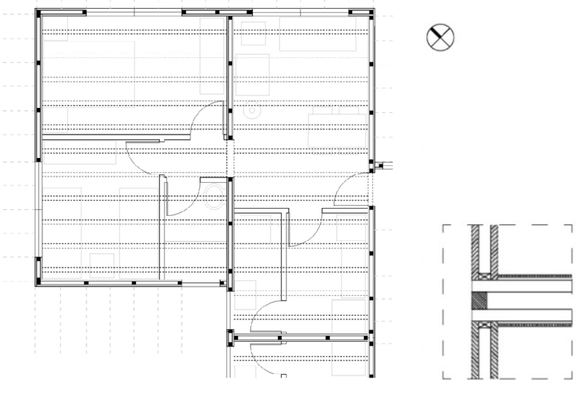

Figure 8: apartment plan with Sandwich Panel System (5) (section detail of wall-slab connection) – no scale drawing

Systems 4 and 5 enable a higher industrialization level than systems 2 and 3, since besides the elements, entire parts of the building are also prefabricated.

Environmental Impact Analysis – Comparison between Bamboo Systems

The results of environmental impact concerning the weight, embodied energy and CO_2 emissions calculated for each system are presented on table 1 and figure 9:

	Weight [Kg/m²]	Energy [MJ/m²]	Emissions [Kg CO_2/m²]
System 1	75,69	209,38	11,59
System 2	75,84	253,30	15,35
System 3	63,51	218,85	13,48
System 4	120,67	402,65	24,39
System 5	115,49	385,99	23,41

Table 1: Numeric results of the Environmental Impact of the five Bamboo Systems

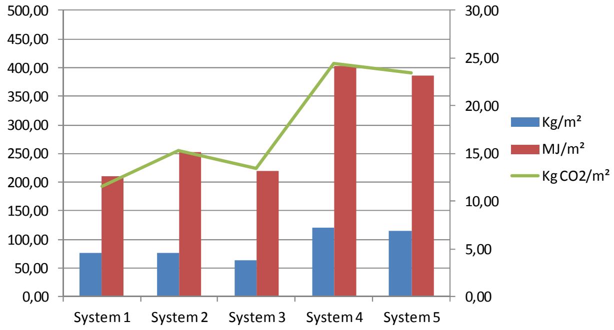

Figure 9: Graphic results of the Environmental Impact of the five Bamboo Systems

The analysis shows that the **System 1**, despite being mostly organic (natural bamboo), needs a large amount of material, besides the necessity of a high amount of steel connectors and some laminated panels. Thus, the environmental impact becomes similar to the laminated bamboo systems 2 and 3. The **System 2** presents relatively low environmental impact, but other disadvantages already explained. The **System 3** has the lowest environmental impact among the laminated systems, being very similar to the reference System 1. Although it uses much less laminated material than the others, the quantity of steel to connect its elements is much higher than the 2, 4 and 5, which raises its impact to the level of the systems 1 and 2. The **Systems 4 and 5** present the highest environmental impact levels among the bamboo systems, as they require larger amount of laminated material.

It is also seen that, despite **Systems 4 and 5** being the ones with higher environmental impact level, they are more stable systems, thus would not need the reinforced concrete core to stabilize the whole building and consequently would not present this extra environmental load coming from this material (not taken into account on table 1 and fig. 9). **Systems 4 and 5** also present the advantages of being faster to put up, because of a higher level of prefabrication and industrialization.

The results demonstrate that the environmental impact depends basically on the quantity of laminated bamboo used and consequently on the glue content of the system. The metallic content is responsible for a small but also relevant percentage of the impact.

Environmental Impact Analysis – Comparison with Conventional Materials

The three conventional systems used for comparison with bamboo are **concrete** (reinforced concrete pillars and lattice slab), **steel** (steel pillars, beams and joists, and decking slab) and **mixed** (reinforced concrete pillars, steel beams, steel joists and decking slab). The bamboo system 1 is not considered in this comparison for not being recognized as an urban system. Two kinds of comparison are made: **(A)** in which steel elements of all systems have 85% recycled content (Table 2, Figure 10) and **(B)** in which steel elements of all systems have 1st fusion content (Table 3, Fig. 11).

	Weight [Kg/m²]	Energy [MJ/m²]	Emissions [Kg CO_2/m²]
Concrete	450,72	318,45	48,02
Steel	244,87	403,59	42,69
Mixed	300,19	363,53	42,88
System 2	75,84	253,30	15,35
System 3	63,52	218,85	13,48
System 4	120,67	402,65	24,39
System 5	115,49	385,99	23,41

Table 2: Numeric results of the Environmental Impact of bamboo and conventional material systems (A)

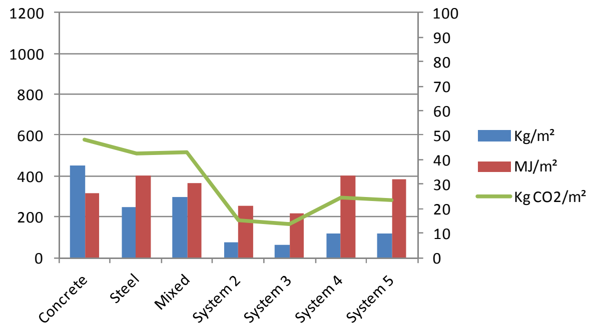

Figure 10: Graphic results of the Environmental Impact of bamboo and conventional material systems (A)

In the case A (Table 2, Fig. 10), it is noted that the concrete system can present less embodied energy (MJ/m^2) than the bamboo systems 4 and 5. However, the weight (Kg/m^2) and CO_2 emissions ($Kg\ CO_2/m^2$) are much lower for the bamboo systems. As a result, the small amount of higher embodied energy of the concrete system in relation to Systems 4 and 5 should not be the deciding factor in this case, also because bamboo presents other advantages, as of being highly renewable, local and of storing CO_2.

	Weight	Energy	Emissions
	[Kg/m²]	[MJ/m²]	[Kg CO_2/m²]
Concrete	450,72	541,43	62,97
Steel	244,87	1121,57	90,84
Mixed	300,19	904,02	79,13
System 2	75,84	253,83	15,39
System 3	63,52	229,02	14,08
System 4	120,67	402,93	24,41
System 5	115,49	387,15	23,47

Table 3: Numeric results of the Environmental Impact of bamboo and conventional material systems (B)

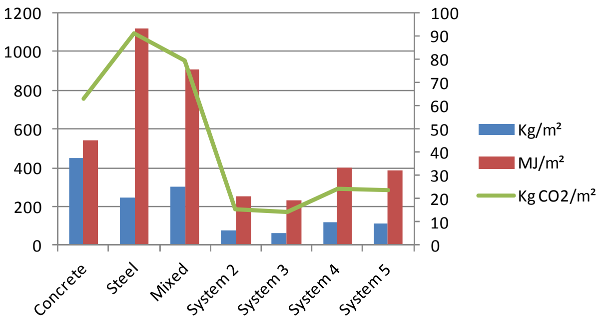

Figure 11: Graphic results of the Environmental Impact of bamboo and conventional material systems (B)

In the case B, with 1st fusion steel (Tab. 3, Fig. 11), it is clear that the traditional materials present higher environmental impact for the three aspects analyzed. It can also be said that even though the concrete system does not present such a high difference compared to the bamboo ones as the steel and mixed systems do, again the CO_2 emissions and weight are much higher.

CONCLUSION

This paper demonstrates the feasibility of using bamboo as a structural material, to decrease the environmental impact in the construction phase of buildings, showing it as a viable alternative to other widely used structural materials in urban settings. With its rapid growth and other economic, environmental and social advantages, the use of bamboo as an industrialized material brings many benefits. The Brazilian example could be spread to many other countries, with adaptation to local climate, local technology and building demand.

The analysis of the best bamboo system applied depends on its environmental impact, existence of local raw material, local technology, industrialization level and the possibilities of reusing and recycling, conditions that would change depending on the location of the application. This work reinforces the credibility on the development of the bamboo industry; technology and companies that process bamboo exist in the world; a transfer of technology from other countries would be necessary to spread the know-how of producing industrialized bamboo. Further research should focus on larger harvesting based on a sustainable management of bamboo forests, besides the standards and norms for these new products.

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