Bamboo as a solution for low-cost housing and storage in Pabal (India)

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Abstract

This paper presents the work on bamboo as a structural material that final year MEng students are performing at the University of Strathclyde, Glasgow, in partnership with Engineers Without Borders-UK, engIndia and the Centre for Education 'Vigyan Ashram' in Pabal (India). In those areas of the world (e.g. Africa, South America, India) where concrete or steel housing is very expensive and unattainable for many of the poorest people, bamboo offers a cheap, readily available and sustainable alternative. This project looks to address the challenges of using bamboo as a structural component for low-cost housing and storage places, and to standardise the assembly of novel structures that are fit for purpose in deprived areas such as in Pabal, India. It is our intention to engineer a multi-purpose kit for setting up bamboo structures that includes pre-fabricated connections, tools and instructions. In this way, we will empower population suffering from low-resources and with basic building skills to become more independent providers of housing and storage spaces for their families and community.

Keywords: Bamboo, Structure, Materials, Connections, Habitat, India

1. Introduction

For many years, bamboo has been used as a feasible and sustainable solution as a building component of structures in developing countries in Africa, South America and the Far East. Its widespread availability and rapid growth in areas of China, Japan and India has made this grass an interesting structural material due to its affordability, easy assembly and relatively long durability. In the Far East, bamboo is broadly used in scaffolding structures [1] and, for those who have little, housing and storage solutions have also seen bamboo as a structural component.

Concrete and steel structures for buildings are typically difficult to prepare and assemble, requiring skilled workers and quality materials for any truly successful result. Bamboo offers an easier alternative to that process. However, in developing nations the implementation of bamboo structures seem to be generally quite poor, with poor planning, design and specification being abandoned in favour of 'quick and dirty' building techniques. This project looks to address these issues with superior guidelines and frameworks for building of bamboo structures.

The rest of the paper is divided into 6 sections: in the first one, an overview of the project objectives is presented, followed by a literature review of bamboo mechanical properties and its potential as a structural material, as well as current practice in joining methods and connections. The research challenges that we have encountered in this project will be discussed in the following section, before future work and actions described. Finally, a summary and conclusions on our work up to date will be drawn.

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2. Project overview

After discussions with our partners in the project, Engineers Without Borders-UK, engIndia and the Centre for Education 'Vigyan Ashram' in Pabal (India), it was agreed that the project should have an implementation aspect, in order to complement previous theoretical work (e.g. mechanical properties testing, finite element analysis of the bamboo behaviour). The project's three key objectives are:

1. Research properties and types of bamboo available in Pabal.
2. Review, invent and develop joining methods (i.e. connections) for bamboo structures.
3. Design structural system for wide-scale implementation in Pabal.

If time permits, it is expected to include in the project outcomes the results of physical analysis and simulation of the design structure prototypes to verify the solution.

3. Bamboo as a structural material: a literature survey

In order to align this project's outcomes to previous work done in the area, the project began by reviewing relevant literature of past EWB students [2-5], journal articles on the topic of bamboo mechanical properties [6-8] and articles discussing connection systems [1, 9]. Patent databases were searched with only a few connection system findings, but these do not seem to propose any significant contribution to our problem-solving process.

3.1. Mechanical Properties of the bamboo

The most relevant properties that will impact the design specification and concept selection of the bamboo structures are Young's Modulus (i.e. its flexibility), and tensile strength (i.e. its resistance of a material to a tearing force). As for any natural material, also the bamboo mechanical properties vary from specimen to specimen and the scientific tests are used in this study as guidance for analysis of the designed structure. It has been found that a large number of studies on bamboo properties and its structural design have been conducted at the Hong Kong Polytechnic University, China [1]. Although these studies focus on properties of Chinese bamboo species, such as Mao Jue and Kao Jue, it was concluded, after discussion with our partners and comparison with previous mechanical testing work done on the bamboo species in Pabal, that the values and guidelines for construction and assembly presented in the Hong Kong species were still valid in the Eastern India bamboo species.

Comparing mechanical properties of bamboo fibre with other engineering materials, it can be found that bamboo fibre has equivalent tensile strength of 650MPa with tensile strength of steel (500-1000MPa) and much higher flexibility determined by lower Young's modulus value of ~50GPa compared to steel's ~200GPa [7]. Bamboo fibre material has specific strength comparable with engineering alloys, ceramics, and bone. In terms of weight-cost relation bamboo fibre provides even better value than steel [8] (figure 1).

It is extremely difficult to accurately determine mechanical properties of each bamboo beam. Therefore a consensus on the mechanical property values to be used for our structure analysis was reached. Lower Young's modulus values of 20GPa and lower tensile/compression strength of 60MPa shall be used for a structure analysis.

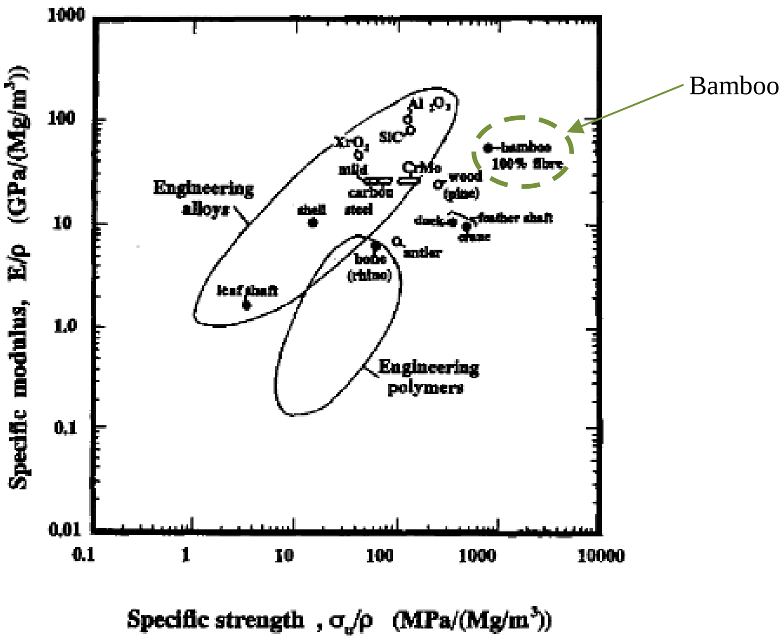

Figure 1: Comparison of engineering materials, strength vs Young's Modulus, as in [8]

The mechanical properties vary significantly depending on the growing conditions, and, most importantly, the moisture content. Moisture impacts compression strength much more than bending strength so is important for design of a structure base where the bamboo columns are subjected to compression stress and high moisture [1] (figure 2).

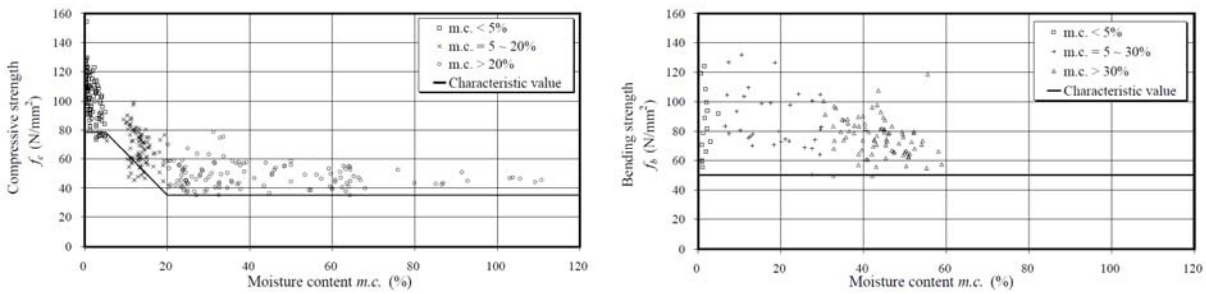

Figure 2: Compressive and bending strength vs moisture content in bamboo stems, as in [1]

With a tensile strength approximately 20% higher than compression strength it can be concluded that bamboo works better when used as a beam with shear forces rather than columns with buckling.

3.2. Connection and Joining Systems

Bamboo has proven to be a very effective structural material. However, connecting culms of bamboo together has long been a problematic issue. The reasons for the difficulty in connecting bamboo culms are listed below:

- Bamboo has a circular profile which is a geometric shape that is inherently difficult to connect with other members.
- Bamboo is hollow which means there is no support in the middle of the culm, so it cannot be subjected to high compressive forces perpendicular to the culms surface.

- As bamboo is a natural material, the culms vary in diameter, wall thickness, length and quality.
- The outer surface of the cane is very slippery which limits the performance of frictional connections such as lashing.

Bamboo has been used as a building material for thousands of years and so numerous connection systems have been developed. All of these connection systems have their advantages and disadvantages depending on: the design of the structure, cost, time-frame, the skill of the builder, the availability of materials and the capabilities of local manufacturing facilities.

When constructing a connection or designing new connection system, several rules have been found in the literature [3] and also are part of the locals' tacit knowledge. To ensure for a good connection, some steps in the good practice are:

1. Avoid openings in culms (e.g. drilling & cutting)
2. Construct joints near nodes, so they are stronger and protects against water percolation and insects
3. Treat the bamboo culms to prevent against rotting
4. Securely fit joints by edge preparation and a correct level of tightening
5. Make durable connections (i.e. consider materials and quality, design solution, etc)
6. Reinforce culms under high point loads (e.g. with wood core inserts and concrete reinforcement)

4. Research challenges

Early in the project, we realised that a successful solution for bamboo structures would come only from a holistic approach to the problem. This new viewpoint brought several challenges that are helping shape the project.

For example, it has been difficult to determine with certainty the bamboo species and types available in Pabal. With more than 1,000 species classified in more than 70 genera [2, 4, 5], the existing literature of bamboo properties and data has required careful consideration. The principles and general behaviour of bamboo remain the same across most of the construction grade bamboo species but specific data found in studies will need to be carefully considered and validated if required in later stages of development.

The focus on mechanical and structural development has also been expanded to include architectural issues and considerations. Current practice in other developing countries, such as in Colombia, has been surveyed, and the bio-inspired work of the architects Simon Vélez and Marcelo Villegas (figure 3) brought to consideration for the development of this project.

As part of the holistic strategy adopted in this project, the socio-cultural reality of the geographic areas in Pabal has been considered. The cultural and social implications of building for the poor have been highlighted by enquiry of suitable structures and its acceptance in consultation with the local partners. In Vigyan Ashram, low cost steel geodesic domes are under development and it has been found that while accessible and cheap, they are poorly accepted due to the negative connotations attached to non square box-shaped housing. In our research of bamboo as an architectural material, we have found similar issues as highlighted by the Institute for Structural Design at RWTH Aachen University in Germany: "*Bamboo has the image of being the building material of the poorer class, for example in Colombia the upper class especially prefers concrete. In India the highest caste builds with stone, the middle castes use wood and only the lowest castes use bamboo*" [10]. These socio-cultural constraints will also be taken into consideration in the development of structures, joining connections and entire aesthetical appearance of our proposed set of solutions.

Figure 3: Examples of Velez and Villegas' work with bamboo, several sources[2]

5. Future work

It is our intention to engineer a cheap, multi-purpose kit for setting up bamboo structures that includes pre-fabricated connections, tools and instructions or guidelines. In this way, we will empower population with low-resources and basic building knowledge and skills to become more independent providers of housing and storage spaces for their families and community.

To do that, our work will continue with the generation of concepts for connection systems, some of which are currently being produced by the team at the time of writing this report (figures 4 and 5), once suitable exploration has been performed using problem-solving tools such as TRIZ, evaluation and selection of our connection solution can be made based on Quality Function Deployment techniques (QFD).

Further research of architectural and structural state of art is required; the conclusions from this research will enable informed generation of structural concepts to be proposed. The social and cultural aspects of architectural design decisions have also been highlighted as important to the successful project and these aspects will have to be considered.

The economics of solutions are known design considerations but with the focus of this project on implementation for poorer members of society, cost justification and value analysis are useful tools.

[2] Web resources (accessed 16th December 2009):
http://www.koolbamboo.com/large_structures.htm | http://www.deboerarchitects.com/BambooThoughts.html

Virtual and physical prototyping will enable detail design and development to be properly considered and justified. Results of these activities should allow solutions to be specified and documented for implemented by Vigyan Ashram in Pabal and across India.

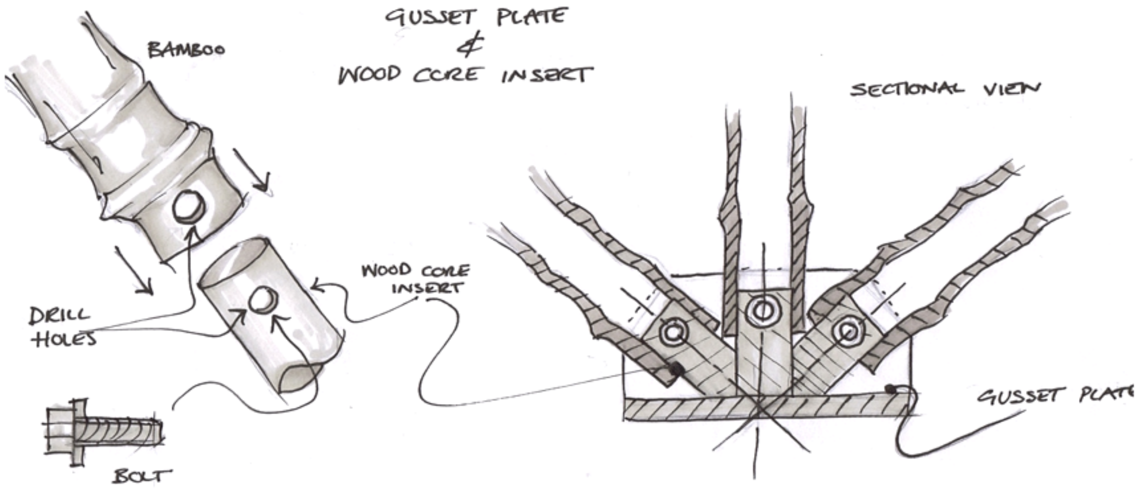

Figure 4: Example of concept generated for connections

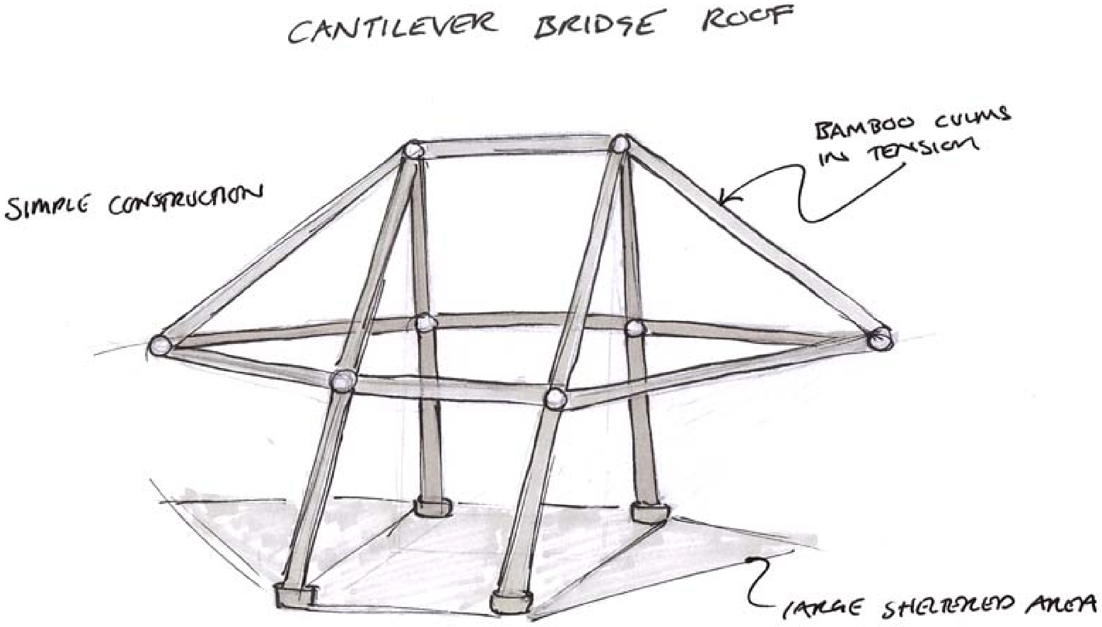

Figure 5: Example of concept generated for structures

6. Conclusions

In nations such as India, bamboo is a well established building component but generally seems quite poorly implemented. Much academic literature has been published on the mechanical properties of bamboo and possible connection systems. Combined studies covering both aspects, mechanical behaviour and suitability of connections, for implementation purposes are rarer and more suitable for a EWB project.

Based on the material properties and economic considerations, bamboo is a very suitable component for cheap architectural implementations in developing nations. The key areas that this project must focus on include connection types and complete structural systems.

We have found the social and cultural aspects of bamboo as an architectural component are just as important as the economic and technical considerations. The solution should be tailored for targeted user groups in provide the most benefit.

Enabling any member of society to build their own structure is a key vision of this project. To do this a cheap kit that includes pre-fabricated connections, tools and instructions or guidelines will be proposed. With access to this kit almost any member of society could purchase bamboo cheaply and instantly improve their living conditions and immediate environment.

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