Lessons from India: Bamboo as a solution for low-cost housing in India

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Abstract

This paper summarises the work done over a span of 18 months on bamboo as a structural material for low-cost housing solutions in Pabal, in the province of Pune, in India. The start of the project takes us to the University of Strathclyde in Glasgow, where the first designs and process methodology for building these DIY structures were conceived. After initial testing done in Scotland with 1:2 scale prototypes, a group from the University of Bath deployed in Ambajogai (Maharastra, India) built the full scale structure and reported back on the process and the difficulties encountered when erecting this structure in India along with the locals. The current work is focused on including the feedback obtained from the full scale construction, sorting out the major difficulties encountered, and adopting new solutions to counteract the setbacks that took place when the initial construction took place. Further work in the acoustics of the structures, as well as energy efficiency analyses are being carried out at present. The intention is to have another opportunity at building the new improved structure this coming summer, taking the advantage of EWB-affiliated students going to India for work placements or study trips.

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

1. Introduction

This work sees its continuity in the work carried out in three Higher Education UK Institutions, the University of Strathclyde, in Glasgow, the University of Bath, and Heriot-Watt University, in Edinburgh. For the last 18 months, students from these institutions have contributed to the overall project ‘Bamboo as a structural material for low-cost housing in Pabal’. This has been possible thanks to the partnership with Engineers Without Borders-UK, engIndia and the Centre for Education ‘Vigyan Ashram’ in Pabal (India).

In 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. The overall 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 or Maharastra, India. The main motivation that drives this project is to empower populations suffering from low-resources and with basic building skills to become more independent providers of housing and storage spaces for their families and community.

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Initial work done by Leake et al. at the University of Strathclyde in 2009-2010 set the basis for engineering a multi-purpose kit to erect bamboo structures in economically challenged areas by low-skilled labour. This kit included pre-fabricated connections, tools and instructions. This work was presented in the Engineers without Borders UK Research Conference in 2010 [1]. The full report compiling the instructions to fabricate the connections, the necessary tools for the job and a set of instructions to proceed with the construction of the bamboo huts can be found elsewhere [2].

In summer 2010, two undergraduate students from the University of Bath (Ms. Rebecca Drake & Mr. Daniel Miles) attempted the construction of the bamboo huts following the instructions in the material developed by Leake et al. These students were in the Ambajogai area on a volunteering placement. The experience of the construction was documented in a report [3] that is used as a basis for the optimisation in the jointing method and to set the basis of further research in the acoustics and energy field.

This paper will be mainly focussed on the lessons learnt from the construction of the full scale bamboo structure in India, and how that feeds back to current work done on improving the user-friendliness of the procedure for low-skilled builders in the Maharastra region.

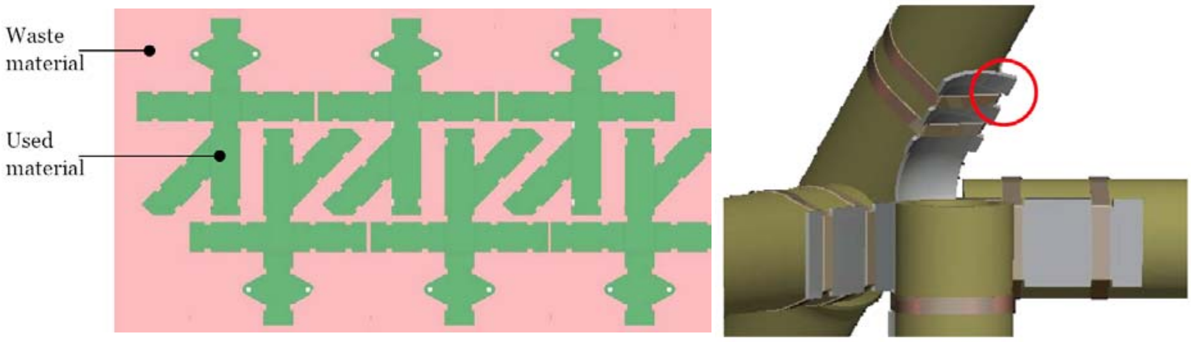
The rest of the paper is divided into 5 sections: in the one that follows, an overview of the construction method created for these structures is presented, which includes the main reasoning behind why certain design criteria such as aesthetics and 'design for assembly' had to be taken into account for the final product. This is followed by a summary on the main points that arose from the actual building of the structure in India. The next section focuses on the current work being done at Heriot-Watt in order to improve upon those points. Finally, a summary of the main points of action in the next few months will be drawn.

2. Methodology

2.1. Design for assembly

The concept of a 'kit' which includes pre-fabricated connections, tools and instructions to provide locals with, so they are empowered to build their own structures, was an idea broadly accepted by all the partners involved in this project. The design relies on the fabrication of a universal joint made from steel (i.e. mild steel, if this is more broadly used locally) attached with cable ties. In this way, bamboo culm, connection plate and cable will form the joints (figure 1b). These connections could be fabricated using the local manufacturing capabilities at the Centre for Education 'Vigyan Ashram' in Pabal. The objective here is twofold: on the one hand, the connections for the bamboo huts that will be erected are sourced locally, and on the other hand pupils at the 'Vigyan Ashram' can have a hands-on learning experience by being trained to cut and finish these connections.

The two main advantages of the connection fabrication as proposed by Leake et al. are the possibility to use a 'stamping' process for its semi-mass production in an universal formal (figure 1a). During the stamping process, material utilisation is important for efficient manufacturing and to minimise excess. Each individual part has to fit on the blank and leave minimum waste after the stamping process. The second advantage of the plate connection design is the slots being placed at the edge of the plate, as shown in Figure 1b. The metal strap that wraps the bamboo culm and the metal plate does not have to be fed through a slot but wound around these two components.

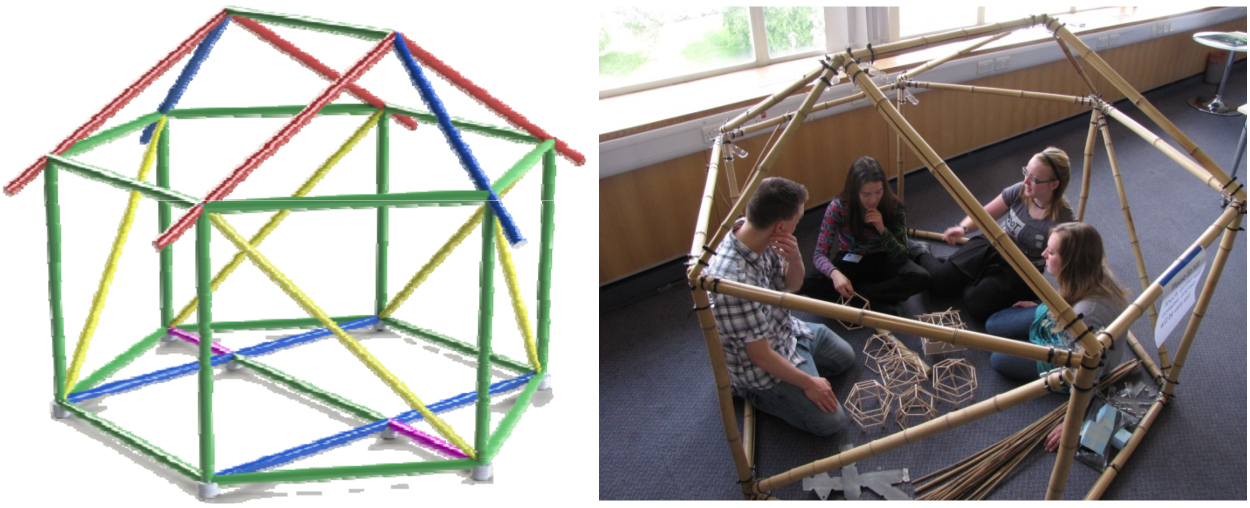


(a) (b)

Figure 1: (a) Distribution of connection plates for stamping to minimise waste; (b) Model of the jointing approach. The strap is wound around the bamboo culm and the metal plate (circled)

2.2. Aesthetics

It was identified early in the project that building with bamboo in developing nations has a significant cultural aspect; the type of house reflects the occupant wealth with traditional concrete and steel box-shaped buildings represents affluence while domes and bamboo have connotations of poverty. The structure developed has a hexagonal plan that has several structural advantages for bamboo and can be later connected in modules and in combination with the sheet metal and strapping connections provides a cheap housing solution for India. While the hexagonal style is not quite a concrete box it is aesthetically closer to this configuration than a geodesic dome and also masks the structural bamboo. The connections, tools and instructions for the house are to be produced as a kit so once the customer has the kit can purchase their bamboo, cladding and roofing cheaply and locally. The kit also allows minimal cost by offering a low-skill do-it-yourself solution that can be built within one day by two unskilled workers with pictorial instructions to follow (figure 2a). A 1:2 scale prototype was built for testing in Scotland (figure 2b) before the full scale structure was erected in India.



(a) (b)

Figure 2: (a) Model of the bamboo hut, coloured scheme for the different parts; (b) 1:2 scale prototype built in Scotland being shown to EWB in June 2010

3. Testing: Construction in India

The remarkable work accomplished by Drake et al [3] in India during the summer of 2010 has made possible the continuation of this work in a meaningful way.

Ms Drake and her team visited the rural area of Maharashtra as part of an engineering teaching placement. They built the bamboo structure shown in figure 3a assisted with pupils from an impoverished village (figure 3b). The school to which these pupils belong will use the hut as an extra space for its normal educational activities. Although the full scale structure was built using the original assembly instructions by Leake et al [2] as a guideline, these were however adapted in the field to suit local conditions and availability of materials and skills.

(a) (b) (c)

Figure 3: (a) bamboo hut in Pabal, summer 2010; (b) School pupils in the hut; (c) Detail of the 5-point metal plate connection

The lifetime of other similar bamboo structures in the local area (mainly used as shelters for livestock) were approximated to up to 5 years, according to locals. It is thus hoped that with maintenance of the joints, roof and walls the structure built in the summer of 2010 will also have a lifespan of at least 5 years before overall decay occurs and thus a need for replacement of the bamboo develops. This structure is however the first of its kind in the area and is thus acting as a prototype to determine the actual lifetime. The main points risen as feedback after the construction of this first full-scale structure were:

- Jointing points becoming loose due to movement of the structure during construction of remaining sections. Thus, careful drilling and bolting of the joint and bamboo in some key positions were advised. In this way, bamboo should be directly bolted to the joint twice on each column and likewise twice on each end of the roof beam to give further stability and rotational prevention (figure 3c)
- It was important to ensure that the ground was slightly raised above surrounding area to allow water to drain away from house and create a flat/levelled square surface ready for preparing the foundation. A foundation is advised in all cases, though detailing of the foundation joint should be tested in a more thorough way and other methods for anchoring the structure to the floor proposed.
- The roof and wall covering used in this case was a combination of tarpaulin sheet and bamboo sheet sewn together and attached to all bamboo members. This material should always remain tight in order to prevent sagging, and if after a particularly heavy period of rainfall there are apparent areas of weakness or failure, it would be advised to cut through the

stitching and re-sew. This will however weaken the tarpaulin material over time so it may need replacing before the 5 year expected life span of the bamboo culms.

4. Proposed improvements to the original structure

The work continues in 2011 at Heriot-Watt University at present and is carried out by Mr Robert Morton. His work is addressing the weaknesses in the design and construction highlighted by Drake et al [3]. In addition to the hexagonal-base hut, he is also studying the square-base formation. The first objective is to minimise the buckling that was featured in the corners in the structure erected in India. In this section, computer simulations and further calculations are presented as part of the analysis on the effect that using multiple pieces of bamboo will have in the corners and jointing zones.

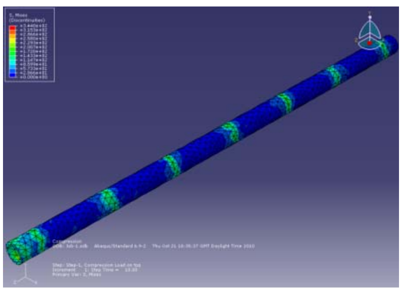
4.1. Culm arrangement

A comparison between different arrangements of bamboo culms is presented here by looking at the compression stresses and the bending stress when a load is applied at the top end of the culm. The geometric parameters of the bamboo culms were kept constant (i.e. overall length = 2m; thickness = 8.5mm; overall width = 84.5mm; node thickness = 8.5mm; internode length = 30.5mm; length from end to end node = 85mm). The material parameters were [4]: Young's Modulus E = 19.6GPa, stress σ = 274MPa, Poisson's Ratio v = 0.35, density ρ = 866kg/m^3

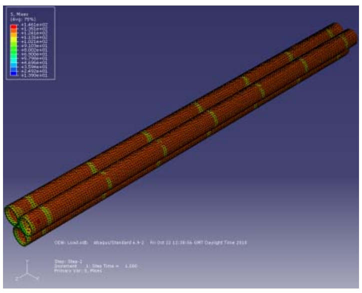
Several culm arrangements were considered for testing. These included: single culm, two culms, three culms in triangle formation, four culms in square formation, and four culms in zigzag formation. The culms and their multiple arrangements were mapped out in a FEA program (Abaqus). The results of a constant compression force on the top of the culms are shown in figures 4(a-c). The variations of bending forces across the top of the culm for the different culm arrangements can be seen in figures 4(d-f). Only forces that would seem typical to happen in the hut were tested. Full details on the simulations are not the scope of this paper and can be made available upon request.

4.2. Results

After consideration of the cost, stresses and maximum deflection of the pole formations, it was decided that the 4-culm arrangements (i.e. four culms in square formation and four culms in zigzag formation) will be taken forward for the optimised design of the bamboo huts. For instance, for a hexagonal-base hut, the zigzag formation is recommended, and for a square-base hut the square formation instead. The reasoning behind this is the angle that the shapes are set in, which in a hexagon it is 120° and in a square it is 90°.



(a)



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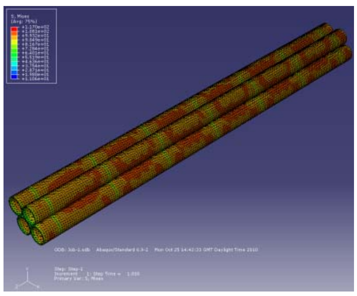
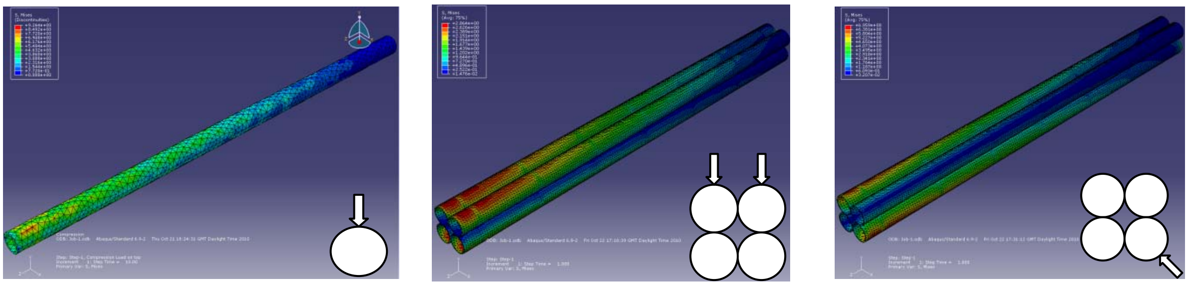


(c)

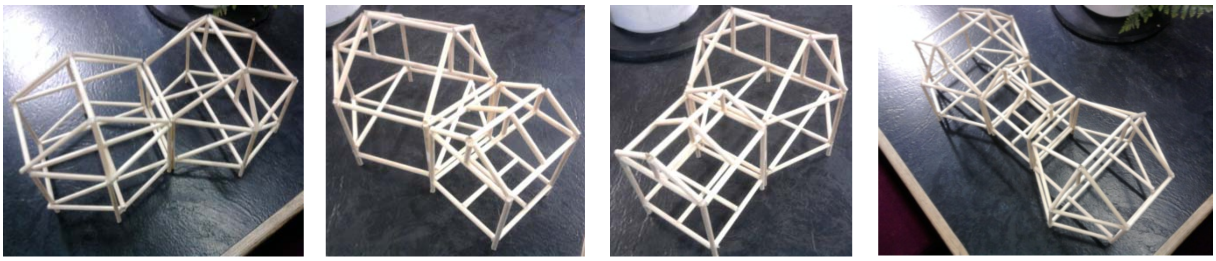


(d) (e) (f)

Figure 4: (a-c) Stress distributions when culms are under compression loading at top of the culm for the configurations: single culm, three culms in triangle formation, and four culms in zigzag formation; (d-f) stress distributions of different culms arrangements after variations in bending force parameters. The directions and positions of the forces are noted in the figures

4.3. Prototype construction

A 1:2 scale prototype is currently being built at Heriot-Watt using bamboo of a species similar to the one locally sourced in Ambajogai, India. The bamboo (supplied by UK Bamboo Supplies Ltd, Washington, Tyne & Wear, UK) is a dried yellow bamboo, a mosso bamboo (*phyllostachys pubescens*). The intention is to test the connections that have been commissioned recently and that have an improved profile with respect to those originally used in the construction of the full scale model in India. The real novelty in this new set of joining connections is the addition of those used for joining more than one modular structure. Different layouts using a hexagonal-base layout and a square one have been considered (figure 5a-c) and the layout presented in figure5c will be the one taken forward. This is because its special distribution is symmetrical, so the study on one of the halves can be scaled up to its whole (figure 5d).



(a) (b) (c) (d)

Figure 5: Spatial location of connected modules for an expanded bamboo hut structure

5. Future work

5.1. Acoustics, Energy Efficiency, and walls and roofing

Considerations on the bamboo structure performance in terms of acoustics and energy efficiency are currently under study. For example, a full CFD model analysis to determine its performance in terms of energy and comfort is going to be performed by Heriot-Watt colleagues based in the Dubai campus.

5.2. Perception surveys

In order to identify any barriers in the implementation of these designs and the 'kit' concept in rural areas of India, it is important to conduct perception surveys from the general public about what they think of the structure, the construction methodology and its feasibility to be undertaken by low-skilled people, even families where the father carries out most of the work solely helped by his children or the elderly in the house. We hope our colleagues the Centre for Education ‘Vigyan Ashram’ in Pabal or students travelling to that area for work/study placements can carry out these.

6. Conclusions

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 nations such as India, bamboo is a well established building component but generally seems quite poorly implemented.

This project intends to enable low-skilled low-resourced people to build their own structure using a ‘kit’ that includes pre-fabricated connections, tools and instructions or guidelines.

The initial set of construction guidelines and the initial design for the metal plate connections for the bamboo culms was developed at the University of Strathclyde in 2010. A 1:2 scale prototype was built to show the concept and test its user-friendliness with the intention to deploy this idea in rural areas of Pabal, in Pune (India). A group of researchers from University of Bath implemented this design in summer 2010 assisted by pupils from a local school. The feedback from that activity has been instrumental for the optimisation of the jointing system (i.e. the design of the connection plates), the considerations taken forward in the selection of walls and roofing material and other characteristics such as acoustics and energy efficiency, as this original structure is going to be used by the current educational activities in the school.

Current work is focused on enhancing the initial structure by the introduction of multi-pole culms (i.e. columns and beams for the hut) and the generation of a strategy to join more than one modular structure in order to expand the hut and provide a feeling of a residential space.

References

1. Leake G., Toole K., Divis P., Torres-Sanchez C., “Bamboo as a solution for low-cost housing and storage in Papal (India)”, the Engineers Without Borders-UK Research Conference “From small steps to giant leaps. Putting research into practice”, in partnership with the Royal Academy of Engineering, 19th February 2010, London, UK.
2. Leake G., Toole K., Divis P., 2010, “Bamboo as a Structural Material”. Product Development Partnership (PDP 2) - 56 502, Final year MEng, folio and report, University of Strathclyde, Glasgow, Scotland, UK
3. Drake R., 2010, “Adapted Bamboo House Assembly Instructions”, post-experience internal report to Engineer Without Borders (September 2010)
4. Amada and Untao, 2001 S. Amada and S. Untao, Fracture properties of bamboo, Compos. Part B Eng. **32** (2001), pp. 449–457.