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'HOUSING NOW': INVESTIGATING REAL-WORLD SMALL DIAMETER BUNDLED BAMBOO APPLICATIONS FOR LOW-COST HOUSING

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ABSTRACT

This research investigates unconventional bamboo construction techniques aimed at addressing the affordable housing problem in Myanmar by leveraging on an untapped and abundant resource in the local market: small diameter bamboo. The investigation was developed through a series of real-world prototypes, incrementally optimizing the tectonics and design in order to achieve a scalable and prefabricated standardized structural frame system for building houses.

KEYWORDS
Composite material; prefabrication; modular design; affordable housing

INTRODUCTION

In recent years, bamboo architecture has witnessed significant development in South East Asia as well as in South America. The material shifted from being employed in vernacular and traditional construction techniques to more sophisticated, engineered, and modern ones. This transition shifted the public's perception of bamboo from being a 'poor man's timber' to a high-end material. This research looks at ways to utilize new design tools, treatment processes, and unconventional construction techniques in order to tackle low-cost housing, the other end of the commonly researched spectrum of applications for bamboo.

Very few bamboo species are used for construction because their natural internal structure allows them to bear a load. There are more than 350 species of bamboo in Myanmar, only 7 of which are used in construction because of their load-bearing capacities such as *Dendrocalamus Giganteus Munro* or *Asper*. They grow in particular areas in Myanmar and are in high demand; therefore the cost per pole is relatively high. The supply of bamboo is inconsistent; even though bamboo grows everywhere in the country, the species used for construction are not that abundant, in reality. Looking at *Bambusa tulda Roxbo* for example, this species is widely used in scaffolding construction for Buddhist pagoda renovation projects in Myanmar; however, only the bottom part of the bamboo is collected during the harvest. The top part of the plant is usually discarded, as waste, due to its slenderness and fragility. By upcycling this natural waste that is usually burned during the harvest, it already contains a negative carbon footprint.

This market research showed that the natural waste within the bamboo harvesting industry as well as the unconventionally utilized bamboo species within the construction industry are of great abundance on the local market. This research investigates ways to utilize the researched resource to build affordable houses.

Design process

Smaller diameter bamboo has a high bending capacity that allows for more complex designs. Bundling together sets of bamboo subsequently makes the structure more resilient to damage compared to a structure made from single large diameter bamboo poles. The structure's integrity is therefore no longer subjected to its weakest link, it is a composite material within a monolithic structure. In order to create a design that can use commonly non-structurally performing materials in a structurally performing way, advanced computational design tools such as 2D topology optimization was needed to generate a structurally optimized overall shape. This shape was generated using Millipede, a Grasshopper plugin that operates on Rhinoceros. Kangaroo 2 collider component, a live physics engine on Grasshopper, was then used to model the actual bamboo within the generated shape. Interpreting the results through a series of simplications was important to make the design practically easier to fabricate with local workers. Computational design tools can therefore be used to reassess materials that are commonly non-commodifiable, create a new utility, and mobilize abundant and untapped resources that are often beyond the realm of marketization.

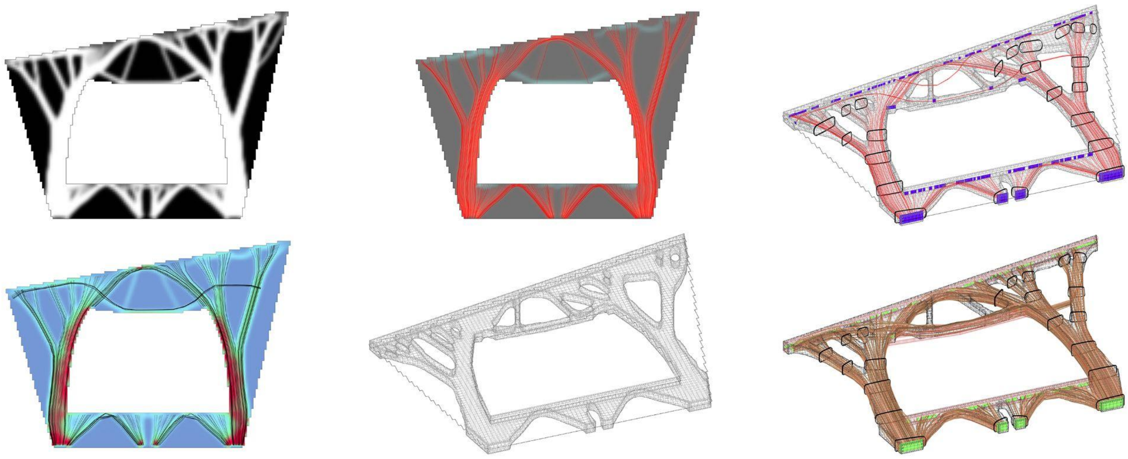

Figure 1: 2D topology optimization by Blue Temple Co., Ltd.

Prototyping process

The final design is a prefabricated modular structural frame system that can be assembled on-site for low-cost housing in rural areas. The prototyping phase of this research included; the construction of four 1:1 scale models; the fabrication of numerous metal molds to be used to form the overall shape of the frame to standardized modular dimensions; and, the optimization of the construction process. The modularity of the design allows for prefabrication where quality control of the whole assembly chain is more easily monitored. The final design consists of small diameter bamboo prefabricated modular structural frames that can easily be transported and assembled on site. The rest of the house, which includes the walls, floor, and roof is then built together with the local community.

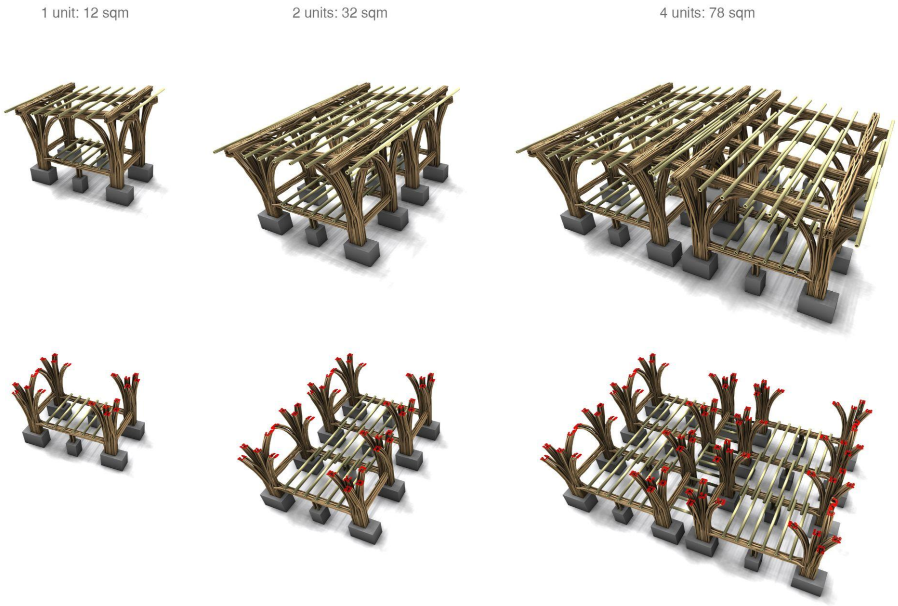

Figure 2: Modular design

Mockup prototype

The prototyping phase of this project was crucial in order to optimize not only the structure, by looking at each individual joint, but also the general shape of the frame. The first mockup prototype shown in figure 3 was built using the top part of *Bambusa Tulda Roxbo* which was bought in Rhakine Yoma, The Arakan Mountains, which is a mountain range in western Myanmar. One pack of 50 culms cost 2500 kyats, which at that time was the equivalent of 1.5 USD. An overall budget of 3 USD was spent to buy the main construction material for this first prototype; this price was a success of its own in proving the affordability of this construction technique.

Different types of strapping techniques were tested to bundle the bamboo together (coconut rope, post mounting straps, galvanized steel strap, and galvanized tie wires); the steel strap revealed itself to be the most suitable candidate. Coconut rope would have been the most affordable option, as it is widely used in bamboo scaffolding construction projects, however, this organic material is not considered permanent, it can loosen up after several years due to the change of humidity throughout the year and is highly flammable. The metal straps were purchased at the local electrical store, they are usually employed by electrician workers to hold equipment onto concrete electrical pillars in the city. To further reduce the price of the metal straps, therefore reducing the price of the construction, larger scale quantities would need to be ordered at a local metal factory.

This first mockup was used for roofing support in a local tea shop in a middle-class residential neighborhood in Yankin township, north of Yangon. Three years later, the structure is still standing with no traces of damage and insect bites on the untreated bamboo. *Bambusa Tulda Roxbo* has a low cellulose/starch content, which naturally protects it against beetles and termites. This natural condition represents a big potential during prefabrication because the treatment process can be achieved faster and at a much lower cost.

Looking closer at the bundle itself, whenever the length of the structural element was longer than the actual size of the bamboo, overlapping was necessary to reach the required size. A couple of ideas helped the structural elements composed of several bundles to act as a continuous piece within the frame, mitigating any extra bending that isn't due to the elasticity of the bamboo but to the looseness of the overlap. Firstly, the overlap is composed of two separate straps with a minimum of a foot between them. Secondly, the bamboo isn't well arranged in a straight formation along the bundle, the culms are purposely randomized, the entanglement within the bundle but also within the overlap of two bundles together further improves the structural element to act as a single composite material rather than single pieces acting individually. This means that a single culm of bamboo located on one side of the bundle isn't necessarily stressed evenly throughout its length, by entangling the culms together, the culm can navigate throughout the section of the bundle; a single piece of bamboo within the bundle can therefore be in tension at one part and in compression at another. Furthermore, the direction of the culm is important to consider, whenever the structural element is horizontal, the bundle is composed of half the culms going in one direction and half in the other direction; this allowed the bundle to have a better dispersed stiffness, both ends of the bundle having similar strength and size in diameter. Moreover, whenever the bundle is vertical within the frame, the bamboo is oriented in its original direction when growing, thicker part at the bottom, thinner at the top.

The main difficulty we encountered was controlling the bending of the bundles and following precisely the measurements drawn from the tea shop. This kind of freestyle construction needed to be much more controlled. The idea of building a steel framework on top of which the bundles could be attached and positioned in the right place seemed like the next logical step in this prototyping phase.

Figure 3: Mockup prototype construction process

1:1 scale prototypes of houses
Following up on the learnings acquired from the mockup prototype, actual 1:1 scale houses were needed to step up the research. The construction of these 1:1 scale models was done in the industrial zone of Mingaladon Township, north of Yangon, in a warehouse that was partially rented. The bamboo was bought in Bago city, from a local supplier, the species we decided on using was *Oxytenanthera albocialiata Munro*, shown in figure 4. The culm has a 5-centimeter diameter and when it is freshly cut, the green bamboo has a high bending capacity before its breaking point. The stem is thick-walled, almost full, which makes the bamboo relatively strong to use in a bundle. Furthermore, *Bambusa nigrociliata Munro* was used for the floor beams, and *Bambusa polymorpha Munra* for the roof beam; all of which can be easily found on the local market at a very low price.

Figure 4: Oxytenanthera albocialiata Munro supply

The first steel framework that was built to guide the fabrication of the structural frames of the prototype house was made out of circular hollow section iron. Not only was the welding not strong enough to resist and control the bending by locking the bundles in place once they reached their final target curvature, but the metal pipes also started deforming and bending because the pressure created by the bending of the bundles was too great. Moreover, reinforcement with the use of bracing wasn't enough; a second steel framework was needed. The second version was built using 1.2 mm thick 2 inch wide Square Hollow Section (SHS). This material was much easier to work with and precise, however, the bamboo was still bending the steel. For the third version, we bought the thickest Square Hollow Section that can be found on the local market in Saw Bwar Gyi Kone, north of Yangon, which is 1.8 mm thick. The welding was done differently as well, the parts weren't directly welded together but with the use of a Mild Steel Angle to make the connection. The framework was also raised 1 meter high so that the workers wouldn't need to fabricate the frames sitting on the floor, but standing. In order to guarantee the precision of the overall shape of the frames, the actual thickness of the bundles wasn't taken into account when building the framework, as it might vary due to possible changes in the number of culms per bundle in order to optimize the structure and the varying sizes of bundles which have the same numbers of culms. The framework was designed to guide only one side of the bundle which needs to be precise, the upper side for the flooring, the lower side for the roofing, the upper side for the ceiling, etc... The design of the frame was done as a way to reduce the number of steel frameworks required to build all the frames of the house. The design consists of 3 different types of structural frames as shown in figure 5, however, only 2 steel frameworks were needed to fabricate them.

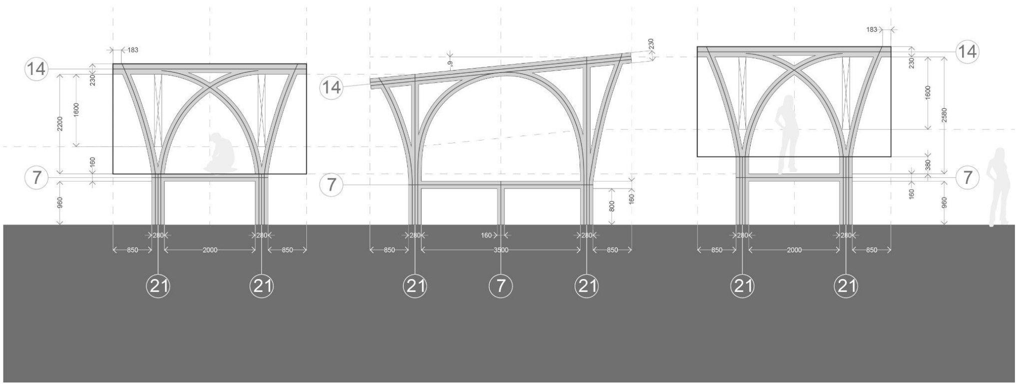

Figure 5: Design of the frames

Figure 6: Fabrication of the frame on the metal framework

Macro topological optimizations

The findings from prototypes #2 and #3, shown in figure 8, have led to different topological optimizations such as the elongation of the stilts, the need for proper bracing to support the floor beam, the two-point strapping technique to hold the bracing onto the structure. Furthermore, the design of the two side frames shown in figure 5 includes the crossing of the two internal bracing elements, this connection adds more complexity to the structure and helps the frame to behave in a more wholesome way, increasing the overall stiffness of the structure.

The structural properties of bending-active structures come from the elasticity of the material that allows deformations while keeping a constant pressure to return to its original shape. In order to reach the maximum stiffness of this elastic composite material, the bundles need to be bent as much as possible without cracking. This pressure allows the bent bamboo bundles to resist further deformations when applying loads. Therefore, the bundles become structurally performing and load-bearing. Additionally to the design of the bracing that supports the floor beam, the floor beam itself was modified to slightly bend upwards in the middle of its span. This small modification allows for a more comfortable living space inside the house because it prevents the trampoline effect. When applying live loads, the pre-strained floor beam deforms slightly, becoming flatter. This intended deformation was also designed to mitigate possible bamboo fatigue after a long period of time.

Other documented failures in these first prototypes led to a change in material selection in components such as flooring, for which bamboo shingles, also called “Wa Te” in Burmese, showed better potential in comparison to plywood or plasterboard because of the flexibility needed when adapting to irregularities. In terms of fabrication optimization, more efficient tools were employed such as pneumatic bundling tensioners powered by an air compressor which replaced the manual strapper. This technology showed great potential in accelerating prefabrication by making it less labor-intensive and time-consuming. A simple change of tools can improve productivity and allow to build an entire frame per steel framework in one single day with only two construction workers.

Figure 7: Pneumatic strapping with galvanized steel straps

Micro optimizations at a tectonic level

Looking at the actual tectonics of the structure, shown in figure 9, the intricate interweaving located at the meeting point of two bundles, such as the column and roof beam, for example, was an opportunity to explore different sequences of interweaving bamboo and optimize the structural performance of the frame at a micro-level. Depending on the nature of the load upon the joint, the section of that bundle at an interweaving point would change, either by having the depth longer than the width to support weight, or the opposite to reduce shearing forces.

The more the sequence singles out culms instead of grouping them, the wider the interweaving joint of bundles are. Also, the steel straps are tied on both sides of the joint, meaning that each bundle crossing would need 4 straps to become strong. At every crossing, at least one culm would crack under the pressure of the strap, however, this cracking didn't show any signs that it was weakening the overall structural performance of the frame, on the contrary, the cracking was a sign that the strapping is tight enough to secure the connection and immobilize the bundles in place. At a molecular level, bamboo is made out of elongated fibers within the stem wall, which means that even if it cracks, the bamboo is still functioning structurally speaking. The observed cracks would always be along the length of the culm, never across it.

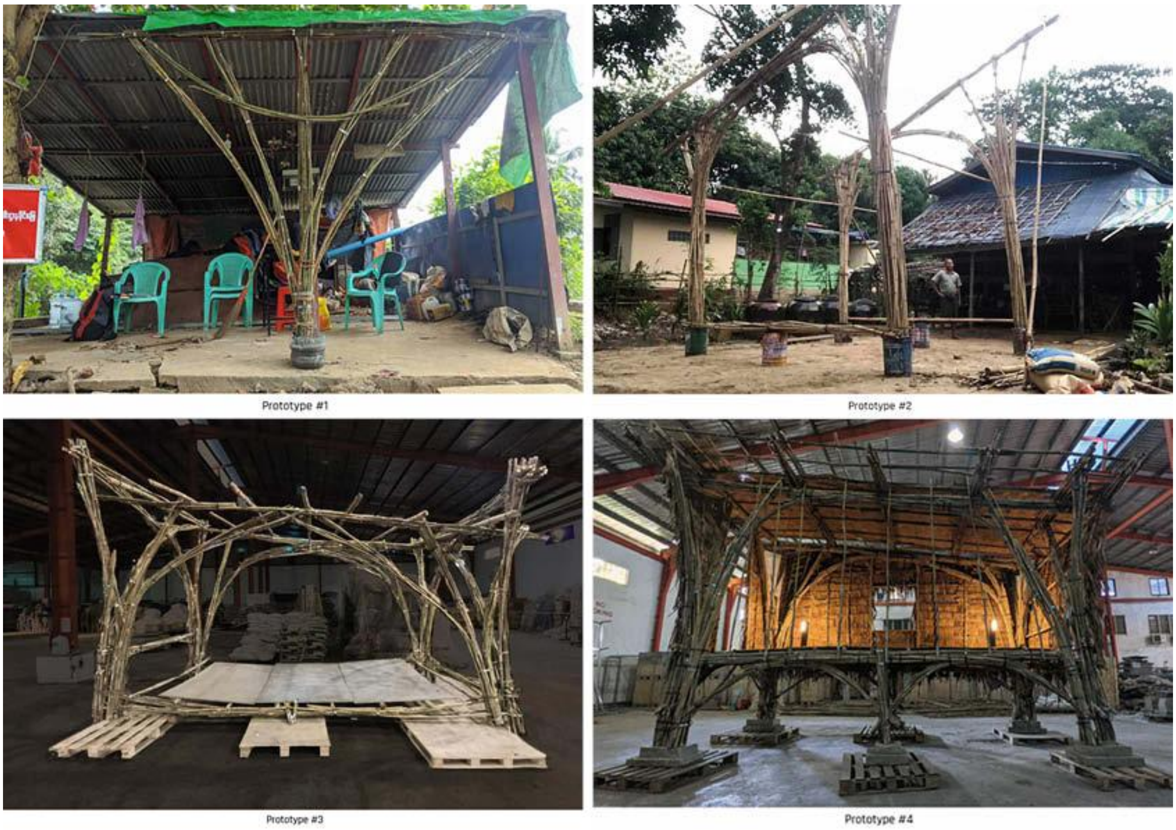

Figure 8: Prototype iterations

Figure 9: Sequencing of the interweaving

Real-world applications

After successfully raising funds during a crowdfunding campaign, the project is now planning to scale up the production. Together with local implementing partners, a first pilot project will be carried out, it will consist of donating 6 houses to family in need of decent shelter.

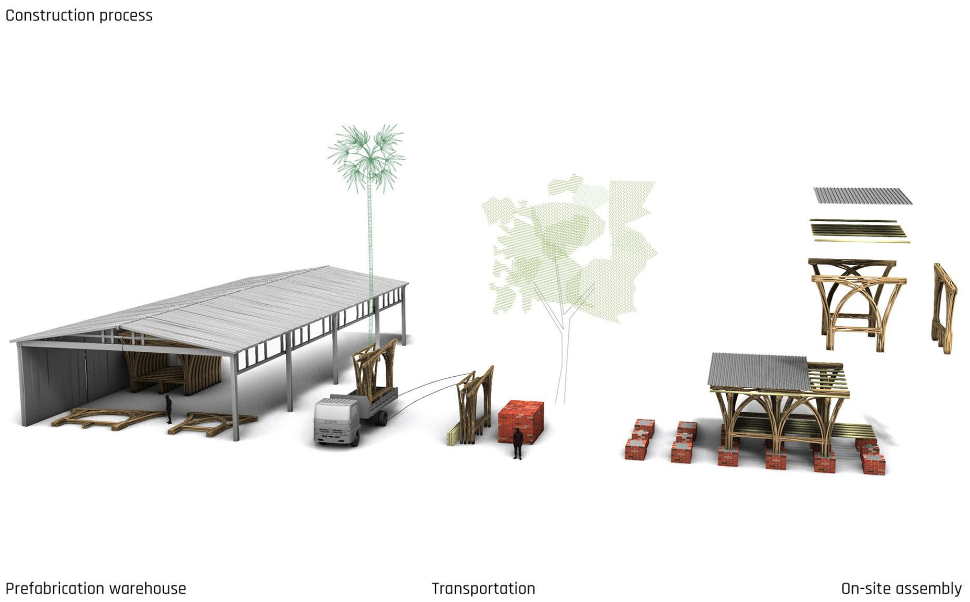

Figure 10: Construction process

Figure 11: Prefabrication warehouse

Figure 12: Transportation

Figure 13: Prototype #5 on-site assembly

References

Ascoli, R. (2021). Augmenting Computational Design Agency in Emerging Economies. PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 2, 639-648. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

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Data on which this paper is based is available from the authors upon reasonable request.