Sustainable Design Principles for Using Bamboo Stems

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Abstract: This paper sets out to explore possibility of increasing the usage of bamboo stems in product design. The researchers argue that bamboo stem is a sustainable material that provides similar benefits as bamboo sheet materials and represents an untapped resource. Through market research, field study, and interviews with manufacturers, the researchers found that both internal and external constraints prevent bamboo stems to be adapted for mass production. The main internal constraint is the inconsistency of bamboo stems' diameters. The researchers examine several forms of connectors used in bamboo stem products and found two joint types that might help solving this problem. To better understand the external constraints, the researchers conducted a survey and follow-up interviews to reveal the gap between user needs and the capability of manufacturers. In conclusion, several key issues that should be resolved by design are listed to provide design directions.

1. Introduction

Bamboo, as a fast-growing, biodegradable, and renewable material, is an acceptable alternative for wood. It has low negative environmental impact and meets the criteria for sustainable materials recommended by several organizations such as Cradle to Cradle Product Innovation Institute and US Council for Green Building, etc. Bamboo stems retain the natural cylindrical form of bamboo and have been used as a material in traditional craft making as well as in building construction in bamboo-growing regions.

As new materials became available, people are less and less likely to encounter bamboo stem products. But as the movement of sustainable development gains traction around the world, bamboo stems once again gain the attention of designers because they could be a more economical material than plybamboo and fiber board[1].

We argue that there is a great potential in using bamboo stems as a sustainable material in product design if we can find better ways to overcome the internal constraints which are material properties and external constraints which is viability and desirability of the material (Arce, 1993).

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1 Definition of terms:

Bamboo stems: hollow bamboo sticks with nodes.

Bamboo stem products: products made of mainly bamboo stems.

Cultural symbolism: the association users make between certain materials and culture. In this paper, this symbolism specifically means the texture and the grain of bamboo stems often remind users with traditional Eastern/Chinese culture because their extensive presence in traditional Eastern/Chinese paintings, literature, and furniture.

Association with nature: means users commonly associate the material with nature, which provides a sense of comfort, relaxation, and affability.

Material properties: Toughness, pulverability, rigidity, plasticity and elasticity/ductility.

Application of Materials: to maximize the benefits of a particular material to fulfill certain functional requirements or provide superior quality.

2. Theoretical background

Our hypothesis for this research project are: What are the obstacles in the mass-manufacturing of bamboo stems that prevent them from being widely used and what can designers do to help overcome these obstacles?

2.1 Bamboo as a Sustainable Material

Bamboo stem retains the anisotropic property of the original plant and has superior specific strength (Dixon & Gibson, 2014) compared to bamboo boards, which allows it to become a structural component by itself. In architectural design, bamboo stems have been tested and proven to be a viable alternative to steel bars, based on the results of several studies conducted since the 1970s (Janssen & P.M.; Ramanuja Rao, 1991; Ogunbiyi, Olawale, Tudjegbe, & Akinola, 2015). In furniture design, bamboo stems could be seen frequently used as supporting components (Esteve-Sendra, Moreno-Cuesta, Portalés-Mañanós, & Magal-Royo, 2012).

Secondly, bamboo stem's natural and distinct form inspires users to associate Eastern culture with the products made from it. This is because bamboo products and its cultural meaning occupy an important position in the material and spiritual life of the Chinese peopl (Fang & Yan, 2015; Shen & Zhang, 2005). Products made with bamboo stems can also be associated with the enjoyment of nature, which is desirable for city dwellers who would like to incorporate natural elements into their home decor.

In terms of sustainability, it is pointed out that transportation has a large influence on the eco-costs of bamboo stems (Lugt, Vogtländer, and Brezet, 2009). If the production and consumption were completed at the origin, the eco-costs of bamboo would be drastically lower than all other materials including wood materials and steel.

Based on life cycle assessment, bamboo stems have the potential to have less environmental impact than bamboo boards because bamboo stems do not require additional manufacturing procedures such as gluing or pressing the bamboo strips as does plybamboo(Lugt et al., 2009, Ogawa, Hirogaki, Aoyama, Taniguchi, & Ogawa, 2010). Thus, it has the potential to reduce overall energy consumption, which makes promoting the use of this material worth pursuing.

2.2 Physical Structure for Contemporary Bamboo Stem Product

To understand the current usage of bamboo stems in products, we created a database of current products using bamboo stems. These products were widely collected and categorized, documented and compared. In this paper, we focus on categorizing and analyzing three groups of bamboo stem products (Table 1). They are: Traditionally processed or structured bamboo stem products, Contemporary bamboo stem product designed for mass production, Contemporary bamboo stem product design based on computer-aided manufacturing.

Table 1 Three Categories of Contemporary Bamboo Stem Product Design

Traditionally processed or structured bamboo stem products	
Contemporary bamboo stem product designed for mass production	
Contemporary bamboo stem product design based on computer-aided manufacturing	

As for Contemporary bamboo stem product designed for mass production, we have some Discussions:

Some of them borrow joint design of bamboo stems in architecture. We argue that the scale of design must be taken into account. Users are usually sufficiently far away from joints of building materials to ignore their complexity or irregularity. But people interact with products closely. Joints that are overly complicated or coarse will negatively impact user experience. We conclude that minimalizing complex joints should be a goal in product design using bamboo stems.

Second, some of contemporary bamboo stem products designed for mass production borrow joggle way and design from wood. It is supposed that Bamboo fibers absorb moisture in the air like wood. However, it is pointed out by a bamboo stem product producer that bamboo and wood have vastly different expansion rate with temperature and moisture absorption rate, which might affect the durability of products made of them.

The third but very important, it is likely that bamboo stems will be used with other materials such as plyboard, glass, or metals in mass processed products, we argue the joint design for bamboo stems is very important. They must be able to accommodate other materials to allow for easy assembly and disassembly.

2.3 Joint Design of Bamboo Stems for Standardization of Production

From research, we conclude the following typical joint design most possibly be used in bamboo stem products for mass production (Fig. 1-3):

- Hoop plate joint: two bamboo stems are connected through a round wood part collinearly, then tightened by a hoop plate.
- Mortise and Tenon joint: shouldered joint, through and wedged joint, plastic joint, etc.
- Pull and screw rod joint.
- Embedded metal and plastic joints: metal parts are embedded into the bamboo stems and then connected into other parts.
- Rod and screw joint: a rod goes through several stacked bamboo stems vertically, then it is screwed down on both ends.
- Multi-connector joint: using multiple connectors to fit into bamboo stems.

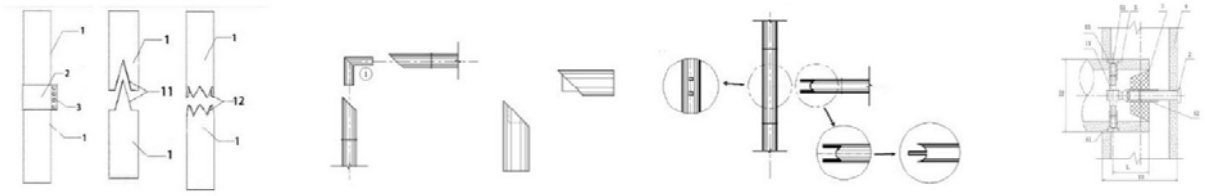
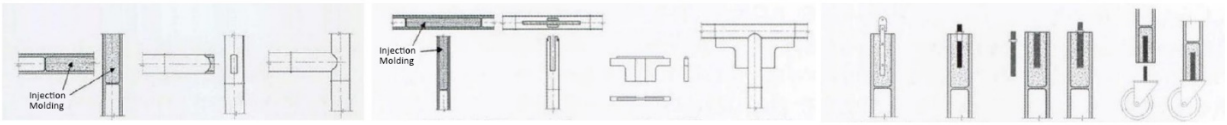


Figure 1. (L)Hoop plate joint, (M) Mortise and Tenon joint, (R) Pull and screw rod joint



a b c

Figure 2. Embedded metal and plastic joints

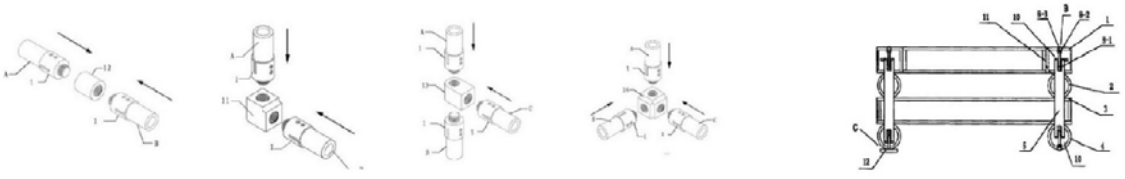


Figure 3. (L) Multi-connector joint, (R) Rod and screw joint

And this is our Discussions on the above listed joins design:

Bamboo stems are hollow, have many nodes and variances in diameters, which make standardization of production difficult. The joints shown above require a high level of consistency of bamboo stems. During our field study of the bamboo forest, we observed that the consistency of the diameter of bamboo stems is difficult to guarantee.

Another problem is that as joint parts can only be fit into a certain diameter of bamboo stems, to reach the required structural integrity, the ends of the stems must be inspected and modified by hand. This procedure increases the labour cost and prolongs the production time.

One direction to solve this problem is to design joints that can accommodate variance of diameters as much as possible, we found the solution might lies in the following joint design: part of the embedded metal and plastic joints (Fig. 2: c), the rod and screw joints (Fig. 3: R). These two joints, especially the latter, have the potential to connect bamboo stems of various diameters with standardized joints.

3. Research Method

In this study, two research methodologies were employed. First, we conducted multiple field studies in China to interview manufacturer and designers to discover problems they encountered while attempting to use bamboo stems in mass production. These field studies provided us with a general understanding of the current manufacturing and marketing practices using bamboo.

3.1 Survey and Analysis of Consumer Perception of Products Made with Bamboo Stems

To understand the current consumers' perception of bamboo stem products, we distributed a survey in January, 2019 via WeChat to Chinese respondents. Responses were voluntary and 280 responses were received. (Because the distribution was done through various chat groups of designers and friends of the researchers, the sampling cannot be stated as completely random and skewed towards design professionals.)

Analysis show that respondents' age affects their preference for the bamboo stem products' cultural symbolism and association with nature (Fig. 4): As their age increases, the respondents care more about the practicality and association with nature of bamboo stem products, and care less about the cultural symbolism. Respondents who have not experienced bamboo stem products prefer the unique style of bamboo stems, while respondents with experience in using these products tend to pay more attention to the value of these products.

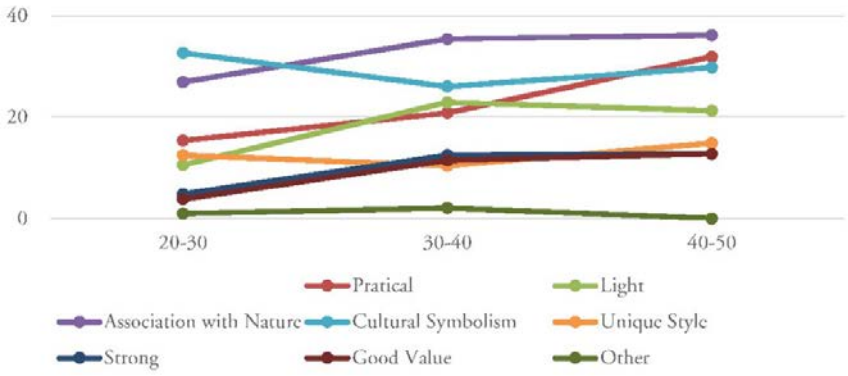


Figure 4. Reasons on age

We selected 18 images of bamboo stem products (Fig. 5) to show to the respondents and they were asked to rate the products in terms of their preference and their cultural and natural values. Our survey found that there was a strong positive correlation between the respondents' preference and the product's cultural and natural values (Fig. 6).

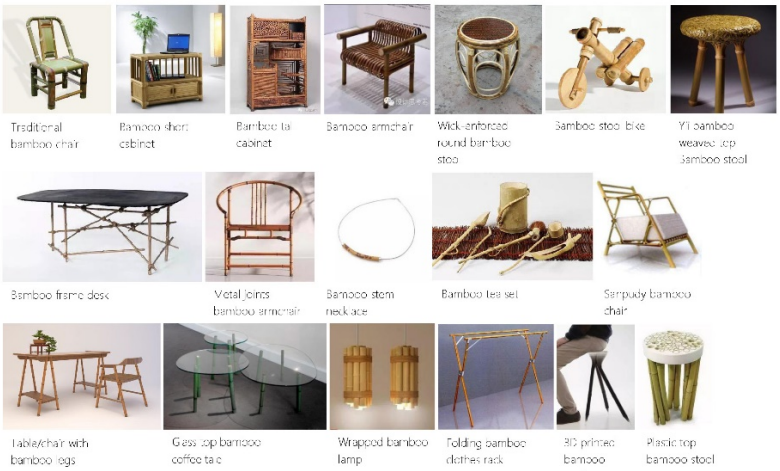


Figure 5. 18 images of bamboo stem products

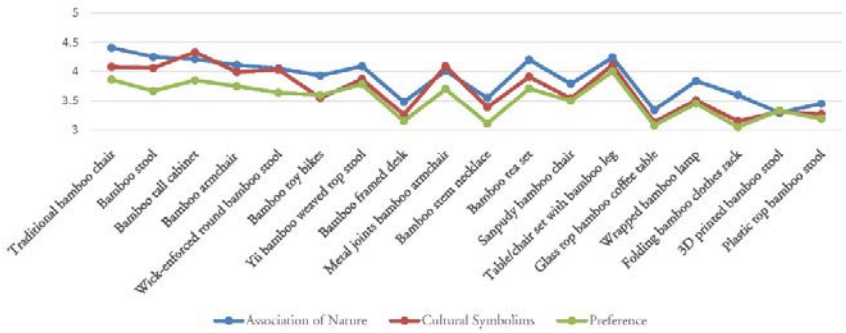


Figure 6. Comparison of Association of Nature, Cultural Symbolism & Consumer Preference

The main problems of bamboo stem products that we found is that they tend to split after a while, which deters users from choosing these products. One of our interviewees, a craftsman in Zhejiang Anji, said that the nodes and sheath can protect bamboo stems from splitting. He suggested keeping the sheath and nodes. If the ends of the stems have no nodes, then they should be wrapped with ropes or rattan skins to imitate the nodes' function. Research in preventing stem splitting has been conducted by various researchers (ZOU, Yi-jia, CHEN, Yu-he, WU, Zai-xing, CHEN, and Zhang-min. 2012). But more efficient and standardized methods need to be developed in the future.

3.2 Follow-up Interviews with Bamboo Product Manufacturers

Besides the survey, we also conducted follow-up interviews with several companies that either manufacture or sell bamboo products. We presented images of bamboo stem products that our respondents preferred in our survey to these interviewees[2]. They categorically rejected bamboo stems as suitable materials because the difficulty in manufacturing. They suggested to retain the forms of bamboo stems but replace them with plybamboo. Furthermore, we interviewed a design/build company in Beijing that specializes in hand-made bamboo stem furniture. They also pointed out that bamboo stems have different characteristics than wood, therefore they might not offer the same stability. They do not use bamboo stems together with wood or plybamboo in their furniture making.

4. Research and Analysis

4.1 Conclusions from research

We can draw these conclusions from the above research:

2 The identities of these interviewees are confidential. The companies are located in Fujian, Jiangxi, as well as Guangdong provinces.

Internal Constraints: Bamboo stems' natural differences and variation in form and sizes makes standardized and mechanized production of them difficult. The manufacturing process still heavily relies on experienced workers who can select, cut down, clean, strengthen, and dry the materials by hand; We identify the design of connecting components as an important factor, which must accommodate the differences in shapes and sizes of bamboo stems. These connecting components greatly impact the production and assembly effectiveness, storage and transport costs, as well as the performance of various attributes of products using bamboo stems; currently, large products made of bamboo stems cannot be easily dissembled. Thus, the storage and transportation costs remain high;

External Constraints: The cultural meaning and association of nature of bamboo stems are important factors in choosing them for consumers; Manufacturers for plybamboo and bamboo stem products have little experience collaborating with manufacturers of other materials. In general, small manufacturers do not have the capacity to work with multiple materials;

4.2 Sustainable design principles for using bamboo stems

Based on the above results and analysis, we suggest these principles for designing products using bamboo stems: Designers must understand the internal constraints of the material and design around them by accommodating the natural variance of the material in their design; The nodes, joints, and the connections of bamboo stems should be the focus of the design, which might reduce production costs and increase production efficiency; designers should take advantage of the high specific strength property of the bamboo stem and design accordingly. Structural components using bamboo stems is a possibility to explore; Designers should investigate the modularity possibility of bamboo stems because the material is generally round and hollow. This might help reducing the storage and transportation costs. Because untreated bamboo has a natural durability of less than two years (Boran, Cavdar, & Barbu, 2013) and can be quickly biodegraded, designers should focus on designing products with shorter life expectancy that do not require long-term and repetitive uses;

5. Summary

Bamboo has a long history in craft making and has been proven to be a sustainable material. By reducing manufacturing procedures and waste, bamboo stems could be a viable alternative to replace other materials that might have higher eco-costs such as steel and plastics. While plybamboo is used widely, bamboo stems' potential in product design is largely untapped due to a multitude of internal and external constraints. As designers, we must work with the internal constraints to make bamboo stem products more desirable. By showcasing the beauty of bamboo stems, designers could encourage more economically viable manufacturing technology to be developed for bamboo stems.

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