SUSTAINABLE DESIGN PRINCIPLES FOR USING BAMBOO STEMS

Ping Wu
Collage of Fashion and Design, Donghua University, 1882 West Yanan Road, Shanghai 200051, China, E-mail: wuping@dhu.edu.cn, snilsong@163.com
Tao Huang
School of Art and Design, Southern Illinois University, 1100 South Normal Avenue, Carbondale, Illinois 62901, E-mail: thuang@siu.edu

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.

Key Words: Sustainability, Bamboo Stem, Product Design, Structure Design

1. INTRODUCTION

Bamboo, as a fast-growing, biodegradable, and renewable material, has long been used in building construction and product design in many parts of the world. Bamboo is an acceptable alternative for wood because it offers similar physical-mechanical properties while having low negative environmental impact that 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. Presently, bamboo plywood (also known as plybamboo) and fiber board[1], both sheet materials, are two main forms for utilizing bamboo in design and construction.

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 such as Eastern Asia, Africa, and South America for centuries. It shares many of the same environmental advantages as the sheet bamboo materials. However, as new materials and became available and industrialization of manufacturing became a norm, the market for bamboo products shrank. People are less and less likely to encounter bamboo products, including products made with bamboo stems.

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. Designers hope to increase the use of bamboo stems to save resources as well as investment. There are many award-winning designs utilize bamboo stems, including some appearing in international awards such as the Red Dot and i.F. design competitions. But according to our observation, bamboo stem products are still largely absent in our daily life. There are also no established and well-known brands of such products. Innovative bamboo stem products are even rarer.

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 (material properties) and external constraints (viability and desirability) of the material (Arce, 1993). Due to the internal constraints, bamboo stems can only be used in specific scenarios. What are these scenarios? Can these scenarios be expanded? We also understand that sustainability is only one of many factors in product design. Designers choose materials mainly based on the products' functional, economical, and aesthetic needs. How do we market the full potential of bamboo stems to designers? What are the obstacles in the mass-manufacturing of bamboo stems that prevent them from being widely used? To answer these questions, a list of guidelines for using bamboo stems in design needs to be created. By interviewing designers and manufacturers of bamboo stems and analyzing the current usage of this material in design, our study intends to improve the understanding of this material and its use in product design.

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 stems and plybamboo/bamboo fiber board share an origin but their usage in design are quite different due to their manufacturing process. First of all, 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 available 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, Portales-Mananos, & Magal-Royo, 2012). Their lightness also makes bamboo stems a good option in the case when weight is an important factor in design.

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 people (Fang & Yan, 2015; Shen & Zhang, 2005). Bamboo has been widely used in traditional Chinese art forms such as calligraphy and painting. Products made with bamboo stems can also be associated with the enjoyment of nature. Therefore, the use of bamboo stems might be desirable for city dwellers who would like to incorporate natural elements into their home decor.

In terms of sustainability, Lugt, Vogtlander, and Brezet (2009)pointed out that transportation has a large influence on the eco-costs of bamboo stems: due to their hollow shape, smaller quantities of the stems can be shipped in a shipping container compared to sheet materials. In their report, 94.5% the eco-costs of bamboo stems were caused

[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.

by the sea transportation from China (the material's origin) to the Netherlands where the study was conducted. But if the production and consumption were completed at the origin, the eco-costs of bamboo would be drastically lower than all other materials they had calculated, including various wood materials and steel. In the era of globalization, these transportation costs might be inherently associated with many products that utilize materials from around the world. Therefore, we can argue that bamboo remains a viable option for sustainable design.

Based on life cycle assessment, bamboo stems have the potential to have less environmental impact than bamboo boards because the manufacturing processes of these materials have significant differences. Bamboo stems do not require additional manufacturing procedures such as gluing and pressing the bamboo strips as does plybamboo (Lugt et al., 2009). A common alternative to this method is to extract the fibers of bamboo and then hot press them into fiber boards without any adhesives (Ogawa, Hirogaki, Aoyama, Taniguchi, & Ogawa, 2010). The processing of bamboo stems also omits these procedures, 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 products using bamboo stems currently in the market. These products were categorized into furniture, building construction products, household products, and heritage-based products. These products' material use, sizes, component numbers/complexity, nodes design, cultural attributes, functionality, costs/prices, etc. were documented and compared. In this paper, we focus on categorizing and analyzing three groups of bamboo stem products by structure: Traditionally structured bamboo stem products; Contemporary product designed for mass production; Contemporary bamboo stem product design based on computer-aided manufacturing[2].

Discussions

When considering borrowing joint design of bamboo stems in architecture, 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 made of bamboo stems 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.

Bamboo stems are hollow like plastic or metal pipes. Bamboo fibers absorbs moisture in the air like wood. These characteristics led us to contemplate the possibility of borrowing joggle way and design from wood. However, we found that bamboo and wood have vastly different expansion rate with temperature and moisture absorption rate, which affect the durability of products made of them.

Since 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 must be able to also accommodate other materials to allow for easy assembly and disassembly.

2.3 Joint Design of Bamboo Stems for Standardization of Production

Bamboo stems might need to be joined with other materials to create products. We conclude there are these possible joint design to use bamboo stems in products[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.

Discussions

Bamboo stems are hollow, have many nodes and variances in diameters, which make standardization of production difficult. The joints shown above are commonly produced and widely available. However, they still require a high level of consistency of the material. During our field study of the bamboo forest, we observed that the harvesting of bamboo stems ishighly mechanized and non-discriminatory. Artificial intelligence in the near future might allow us to be more selective in this process. Nonetheless, currently we have to rely on people to select bamboo stems to ensure consistency in forms, which is an undesirable job for most. Consequently, 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 re-

[2] Images available in presentation and upon requests.

[3] The stability and weight bearing capabilities of these joints need to be studied further. This paper only discusses the possibility of utilizing these joints in mass production of bamboo stem products.

quired structural integrity, the ends of the stems must be inspected and modified by hand. This procedure increases the labor cost and prolongs the production time.

Since 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, the embedded metal and plastic joints and the rod and screw joint. 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 manufacturers and designers to discover problems they encountered while attempting to use bamboo stems in mass production. Our interviewees included: sellers at bamboo product markets; competitors and organizers at design competitions; technicians and owners at bamboo manufacturing factories; bamboo growers and sellers; bamboo wholesalers. These interviews were conducted at several locations over a period of several years, usually in informal and unstructured settings. 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[4] 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.

Our analysis of the data collected from the survey shows, 50.71% of the respondents have not used bamboo stem products, and however, most reported they have seen images of such products. 48.57% reported that they have little to no knowledge of such products, yet 70% claimed that they like the form of bamboo stems.

Analysis show that respondents' age affects their preference for the bamboo stem products' cultural symbolism and association with nature: 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. Another surprising finding from our analysis is that 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.

We selected 18 images of bamboo stem products 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.

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. Though research in preventing stem splitting has been conducted by various researchers (ZOU, Yi-jia,CHEN, Yu-he,WU, Zai-xing, CHEN, Zhang-min. 2012),designer must understand that because the hollow form and moisture retaining quality of bamboo stems, the stems must be treated when close to the ground. There are two ways to achieve this: 1, strengthen the ends with bamboo nodes or similar structures; 2,avoid absorbing moisture from the ground. 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[5]. 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. RESULT AND ANALYSIS

We can draw these conclusions from the above research:

- 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

[4] The survey and analysis charts are available upon request and in the presentation.

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

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.

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. IMPACTS ON SUSTAINABILITY

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.

BIBLIOGRAPHY

1. Arce, O. A. (1993). *Fundamentals ofthe design of bamboo structures.* (PhD), Technische Universiteit Eindhoven Eindhoven.
2. Boran, S., Cavdar, A. D., & Barbu, M. C. (2013). *Evaluation of Bamboo As Furniture Material and Its Furniture Designs*. PRO LIGNO, 9(4), 9.
3. Dixon, P. G., & Gibson, L. J. (2014). *The Structure and Mechanics of Moso Bamboo Material.* Journal of The Royal Society Inerface, 11. doi:10.1098/rsif.2014.0321
4. Esteve-Sendra, C., Moreno-Cuesta, R., Portales-Mananos, A., & Magal-Royo, T. (2012). *Bamboo, from Traditional Crafts to Contemporary Design and Architecture.* Procedia -Social and Behavioral Sciences, 51, 5.
5. Fang, H., & Yan, Y. (2015). *The Design of Chinese Bamboo in Ancient Graphs*. Decoration, 265(05), 4.
6. Janssen, J. J. A. B., G.; Adkoli, N.S.; Ranjan, M.P.; Sastry, Cherla B.; Ganapathy,, & P.M.; Ramanuja Rao, I. V. G., K.; Ravindran, K. (1991). *Bamboo as an engineering material: an annotated bibliography.* . Singapore: International Development Research Centre.
7. Lugt, P. v. d., Vogtlander, J., & Brezet, H. (2009). *Bamboo, a Sustainable Solution for Western Europe Design Cases*, LCAs and Land-use. Retrieved from http://www.bambooteam.com/
8. Ogawa, K., Hirogaki, T., Aoyama, E., Taniguchi, M., & Ogawa, S. (2010). *Sustainable Manufacturing System Focusing on the Natural Growth of Bamboo.* Journal of Advanced Mechanical Design, Systems, and Manufacturing, 4(2), 12. doi:10.1299/jamdsm.4.531
9. Ogunbiyi, M. A., Olawale, S. O., Tudjegbe, O. E., & Akinola, S. R. (2015). *Comparitive Analysis of the Tensile Strength of Bamboo and Reinforcement Steelbars as Structural Members in Building Construction.* International Journal of Scientific & Technology Research, 4(11), 6.
10. Shen, F., & Zhang, F. (2005). *The Characteristics of BambooCrafts Forms and Its Foundation in Chinese Philosophy*. Journal of Bamboo Research, 24(04), 9.
11. Zou, Yi-jia,Chen, Yu-he,Wu, Zai-xing,Chen, Zhang-min. (2012). *Advance of Research on Bamboo Cracking Prevention.* Journal of Zhejiang Forestry Science and Technology, 32(05)85.
12. Yang, Ling-yun.(2015). *The Design of the Joint Structure of Raw Bamboo Furniture. Journal of Bamboo Research*. Hangzhou, China.34(01),26.
13. He, Rui-lin.(2016). *Research on the Design of Bamboo-culm Furniture Based on Structural Innovation.* Master's Thesis, Central South University Forestry and Technology, Hunan, China.
14. He, Rui-lin, Zhou, Zi-yun, Zhang, Zhong-feng. (2016). *The Innovative Design of the Round-bamboo Furniture's Structure.* China Forest Products Industry, Beijing, China. 43(04),52.
15. Yao, Li-hong, Xu, Wei-tao, You,Xi, Fei, Ben-hua, SONG, Sha-sha. (2018). *Study on the Design of Round Bamboo Furniture.* China Forest Products Industry, Beijing, China. 45(03),26.