



ELSEVIER



Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 216 (2016) 30 – 38

Procedia
Social and Behavioral Sciences

Urban Planning and Architecture Design for Sustainable Development, UPADSD 14- 16 October 2015

The Potential of Bamboo as Building Material in Organic Shaped Buildings

Esti Asih Nurdiah*

Department of Architecture, Petra Christian University, Siwalankerto 121-131, Surabaya, 60236, Indonesia

Abstract

Bamboo has been widely known as a sustainable building material due to some reasons among others are bamboo can be easily cultivated and harvested in a relative short time and can be reused. Bamboo as building materials is easy to bend and lithe. Those characters are very suitable for organic shaped building construction. This paper attempts to discuss how bamboo is being used in organic shaped building. Several case studies are taken to describe the relation between shape, structure, construction and joint system. It will classify how bamboo is formed in curved thus result is an organic form. The paper result will show that bamboo can be a potential building material for organic shaped buildings and become an alternative building material other than steel and concrete.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of IEREK, International experts for Research Enrichment and Knowledge Exchange

Keywords:

1. Introduction

The use of bamboo as building materials has occurred in a long period. Most of traditional houses in Indonesia and Asia use bamboo as building materials, both as structural and non-structural materials. The use of bamboo in traditional houses is due to the fact that bamboo grows abundantly in tropical rain forest. But after industrial era has begun the use of bamboo as building material become obsolete. Bamboo is considered as cheap and non-permanent

* Corresponding author. Tel.: +62-31-8439040; fax: +62-31-8417658.

E-mail address: estian@petra.ac.id

materials. It is also considered as low-class material, even called as “the poor man timber” by many modern builder (Lobokivov, 2009). People tend to choose brick, concrete and steel as structural and construction materials for modern building.

But nowadays, after global warming and sustainability issues are emerged, bamboo as building materials is widely discussed and reviewed. Some architect and builder nowadays tend to choose bamboo for building material. High-quality woods for construction are rarely found nowadays because of deforestation. Wood also takes long time to regrow and ready to use as construction materials. Meanwhile bamboo can be harvested in a short time, which is between 3-5 years. When planting, bamboo also releases oxygen into the air, the ability that cannot be performed by industrial materials like steel, plastic and concrete. For the reasons, bamboo has been widely known as sustainable building materials.

Bamboo naturally grows in the forest but also can be cultivated in plantation. While the largest stock of bamboo grows in forest, it raises some important questions regarding resource ownership and management (Jansen, 2000). Local community in Asia usually plant bamboo around their village. In some remote village, bamboo grove is used as a fence or as boundary layer for the village. In this case, bamboo belongs to the community and it is free to use by the community.

1.1. The Property of Bamboo as Building Construction Material

Bamboo is basically a giant grass that comes from sub family *bambusoideae* and family *Poaceae* or *Gramineae*. Sub family *bambusoideae* comprises both woody and herbaceous bamboos with 1,575 species altogether (Bystriakova, et al, 2003). Bamboo naturally grows in groups. Its growth character can be divided into two types: monopodial and sympodial bamboo. Monopodial bamboo roots spread horizontally in a shallow depth of the soil. A new shoots are produced in a relative long distance from the parents' plant. Monopodial bamboo is mostly found in temperate climate such as Japan, China and Korea. While sympodial bamboo roots grow very close to parents' plant thus form a clump of many stems or canes. It mostly found in tropical climate such as Southeast Asia and South America (Anagal, et al, 2010, Widowijatnoko, 2012).



Fig. 1. (a) Monopodial bamboo; (b) Sympodial Bamboo.

Source: http://nbm.nic.in/types_of_bamboo.html

The characters of bamboo rods are round, segmented, jointed and hollow. Part of bamboo culms or stems consists of segments or internodes which are separated by diaphragm. The length and thickness of the internodes are varied; depend on the species and the environment. The structure anatomy of the internodes is determined by shape, size, and vascular bundles of bamboo culm. In the outer culm (peripheral zone), the vascular bundles are smaller while in the inner are bigger and fewer. The number of vascular bundles in bamboo culm is reduced from top to bottom, while the density is relatively in the same amount. Bamboo culm consists of 50% parenchyma, 40% fiber and 10% conducting tissue (Liese, 1998).

As construction materials, bamboo has a very strong fiber. The compressive strength of bamboo is two times higher than concrete, while the tensile strength is close to steel. Bamboo fiber has a shear stress that is higher than wood. Bamboo has wider span than wood. Bamboo also can be curved without breaking. Bamboo is considered as

one of building materials that are very strong with tensile strength more and less than 28,000 N per square inch, compared to steel which is 23,000 N per square inch (Anagal, et al, 2010).

The use of bamboo as construction material must go through preservation process. It is because bamboo is vulnerable to termites and fungal attack. In construction, bamboo is generally preserved using borax boric acid solution through several techniques, such as immersion, gravitational or vertical soak diffusion, and injection using compressor machine. Borax boric acid has proven effective and able to extend the life span of bamboo (Purwito, 2015). However, the use of chemicals in the preservation process arises various questions and debates about the impact of the waste water to the environment. Therefore, several studies of bamboo preservation using organic ingredients have been conducted in an attempt to find the more environmental friendly preservation method.

1.2. Organic Shaped in Architecture

Term organic architecture is introduced by Frank Lloyd Wright in his essay entitled “*The Language of Organic Architecture*”. Wright’s essay was actually to defend the idea of Louis Sullivan which was known as form follow function. Organic architecture term comprises a literal relation between a building and its environment, a building should integrate itself with its site (Cruz, 2012). While organic shape term may have a slightly different meaning with organic architecture term. Organic form can be described as form that has been generated or created inspired by natural forms in nature. organically inspired structural systems typically exhibit interesting aesthetic qualities which are not necessarily intuitive (Sarkisian, et al, 2008). Adaptation of natural forms usually generates an irregular geometries.

Irregular geometries or by some designer and scholar are called as freeform is not completely irregular or shape without any pattern, but a shape that can be composed by various forms became a spline curve (Veltkam, 2007). Moreover, Veltkam explain that freeform can be developed by transform the primitive geometries. The primitive geometries are elements of zero to three dimensions, such as points, curves, surfaces and volumes. The applied transformation consist of extrusion, scaling and rotating. Geometric shapes then affect the constructive geometry which describe the way the geometry was constructed.

Meanwhile, Materials in architecture is should be use based on its nature. As Sandaker (2008) has mentioned:

“Form ‘resides’ in the material, and is made explicit by respecting the qualities and properties, or the ‘nature’, of that material. Form is conceived irrespective of the material, and is as such free to evolve without preconditions for realisation in a specific material.”

From Sandaker opinion, it can be said that the use of materials in architecture should consider the character and properties of the materials because materials play a role in generate a form.

2. Research Method

In this study, case studies are needed to review the potential of bamboo as building material in organic shaped building. The objects of case studies are Green School, OBI Great Hall, Dodoha Mosintuwu and Bamboe Koenig restaurant. The objects are selected because all of the objects have unique form and organic shape moreover use specific structural system and construction method to obtain the organic shape. Research method is carried out through field study, literature review and by acquiring some information from the architect who designed the case study object. This research is limited to the aspect of form and formgiver, which is defined as structure and construction system to learn and observe the implementation of bamboo in organic shaped building.

3. Analysis and Discussion

3.1. Organic Shaped Buildings with Bamboo

Bamboo as building material is not constantly use into organic shaped building. The reference shape of bamboo building mostly come from wooden building which is generally constructed using simple frame structure. Therefore, the builders tend to construct bamboo into frame structure thus becoming a box, static and, consider as boring,

simple form building. However, the study, research and exploration of bamboo as building material are being conducted by scholars, architects and builders. As a result, the evolution of building shape and form of building with has become more dynamic, moving and flowing. The strength and internal property of bamboo are studied. Bamboo are pushed to the limit to find what bamboo can do in building, what shape and form can be develop using bamboo, and what the suitable system is needed to design a unique bamboo building.

Green School is a school building build using bamboo as main structure materials. Initiated by John Hardy, the school complex building finally won Aga Kahn award in 2010. The school building is located in Bali, Indonesia, designed in 2006 and completed in 2007. It is considered as the originator of bamboo revival in Indonesia. Even though bamboo is common building material in Indonesia, but, as mention before, due to the idea of bamboo as cheap and “poor man timber”, bamboo potential and charm in creating unique building become submerged. Thus when a bamboo building is awarded by international organization and the design is being discussed by experts, people become aware to bamboo.



Fig. 2. Green School (a) Main hall “Mepantigan”; (b) Main building “The heart of Green School”; (c) The bridge

Green School building design has been through various stage of exploration in building form, structure system and construction process. The school complex consist of several masses which each mass accommodate different function such as classroom, laboratory, multifunction hall, office, student and teacher’s dormitory, etc. Roofs are the most noticeable and prominent of the mass, each mass has different roof shape and it is organic shaped. The main hall is using arch shape located near the entrance gate (fig 2.a.). The main building, which is located in the center, is two to three storage building. The building has three circular shapes that resemble nautilus shell. The three nautilus shape roof is lined together formed wide envelope for the space below. While other smaller masses has varies roof shape and form. Not only the masses have organic shape but also the bridge which has hyper structure.

After Green School, various building using bamboo as building material is designed and built. If at first bamboo used in simple frame structure, nowadays bamboo is pushed to the limit and other structure systems are proposed. OBI Great Hall which is located in Jatiluhur, West Java province, Indonesia, is known as one of the phenomenal building using bamboo. Designed by Andry Widyowijatnoko, OBI Great Hall is an example of wide span building structure using bamboo. The oval shape plan is covered by combination of dome and hyper shape roof. The opening at the roof top creates a stunning and striking skylight.



Fig. 3. OBI Great Hall (a) Building form; (b) Interior, show the structural system

Along with the increasing popularity of bamboo to public, especially designer, the use of bamboo as building material began to be implemented in commercial buildings such as exclusive yet expensive resort hotel and restaurant. For example is Bamboe Koenig (yellow bamboo) restaurant in Lodunduh, Bali, which is recently received an award from FuturArc for using local material and worker. Designed by young architect, Effan Adhiwira, the restaurant has a circular plan with a circular stage in the center of the restaurant; therefore, the owner can perform a Balinese traditional dance on the stage. Its roof also has a circular and dynamic shape that make the building looks like a serpent.



Fig. 4. Bamboe Koenig restaurant (a) Building form; (b) Interior, show the organic roof form

Another organic shaped bamboo building designed by Effan Adhiwira which also has an organic shape is a community building for community development project in Poso, Central Sulawesi (Celebes) province, Indonesia, namely as Dodoha Mosintuwu. This unique building is built on land that is flooded every rainy season thus the construction process is conducted on the dry season. It has dynamic and twisting roof shape combination of synclastic and anticlastic curvature. The synclastic curvature roof shape serves as an envelope for multipurpose hall while the anticlastic curvature roof shape is for daily activities space, such as office and library.



Fig. 5. Dodoha Mosintuwu (a) Interior; (b) Exterior; (c) Entrance
Source: courtesy of Effan Adhiwira

3.2. Structural System of Organic Shaped Buildings with Bamboo

Architecture cannot be detached from form and architecture also requires structure to create form, without structure, the form cannot be achieved and only become a mere concepts. Structural system can be divided into form active, semi form active and non-form active structure systems. Form active structure is a structure system that only can withstand the axial forces, tension or compression. While non-form active structure is a structure system that can withstand both tension, compression, and also bending moment (Macdonald, 2001). Considering from the four

buildings that have been mentioned before, organic shape are implemented to the roof. Furthermore, the roof form can be created and developed from spatial or surface structure. Surface structure can be divided into non-rigid shape, such as cables and membranes, and rigid shape, such as grid shell, shell, folded plate, hybrids and freeform (Betchthold, 2008). The four buildings taken as case of study, none are resolved using non-rigid system but some structure systems are tent-like structure.

Building masses in Green School are using form active structure to achieve organic shape for the buildings form. The main hall using wide span arches, that are stabilized by roof rafters, to form the curved shape roof. Long roof eaves provide good protection from sun and rain. The main building, functioned as office, which has nautilus shell shape is resolved using surface structure. The surface structure of the main building, called as the heart of Green School, uses battens, rafters and purlins supported by bamboo pillars. The system resemble to the tent-like structure system. The circular purlins play a role in giving the nautilus shell shape to the roof. Meanwhile other smaller buildings are using combination of arches and surface structure.



Fig. 6. Green School structure system; (a) Arches in main hall “Mepantigan”; (b) Surface structure in main building “The heart of Green School”; (c) Bamboo arches in classroom.

Source of Fig. 6.a.: <http://www.designboom.com/architecture/pt-bamboo-pure-green-school-bali/>

OBI Great Hall which needs a wide span structure for the multipurpose hall is using a semi form active structure system. Trusses frame are arranged in a radially reinforced by braced frame to resist lateral forces. A comparative research of Green School main hall and OBI Great Hall conducted found that OBI Great Hall radial configuration of the trusses are needed compression purlins placed at the outer ring and tension purlins at the inner ring to stabilize the configuration (Maurina, et al, 2014).



Fig. 7. OBI Great Hall structure system; (a) Skylight; (b) Trusses; (c) Details of braced frame.

Synclastic curvature shape of Dodoha Mosintuwu roof is resolved using arches combined with trusses. Arches are spanned to the longitudinal direction while trusses are needed to stabilize the transverse direction (Fig. 8.c.). Meanwhile, the anticlastic curvature roof is resolved using trusses. In this project, straight bamboo rods are used for rafters and trusses while natural curved bamboos are used for the arches. In order to elaborate wide span arches, natural curved bamboo joined in row until the desired length and shape are achieved. Bamboo species that grows abundantly in the location are classified to the sympodial bamboo thus natural curved bamboo is easily found. But

local people tend to choose straight bamboo than natural curved bamboo and dispose the natural curved bamboo; therefore mostly the natural curved bamboos which are used during the construction process are free of charge. In fact, mostly the bamboos that are used for the construction are free or very cheap because local people, at that time, didn't consider bamboo as valuable building material. As a result, construction cost is reduced significantly.



Fig. 8. Dodoha Mosintuwu structure system; (a) structure of the Synclastic roof part; (b) Interior; (c) Structure model.
Source: courtesy of Effan Adhiwira

Utilization of natural curve bamboo is also applied by the architect in the Bamboe Koenig restaurant. The structure system of the building combine trusses system and arches. The arches also play a role to stabilize the structure and to avoid deformation due to lateral force thus the building circular form can be maintained.



Fig. 9. Bamboe Koenig structure system; (a) Bamboo arches; (b) Structural details; (c) Structure model.
Source of Fig. 9.c.: courtesy of Effan Adhiwira

3.3. Construction Techniques of Bamboo for Organic Shaped Buildings

Organic shape buildings generally use arch, spline or other curvature shape. To achieve the form, it needs curve bamboo. There are two methods of bamboo bending according to Dulkenberg: hot bending method and cold bending method. Hot bending method can be done by immersing bamboo in the lukewarm water until the fibers are become soft enough to be curves using clamp; or by heating bamboo section to the desire heat ($>150^{\circ}$) that cause bamboo fibers become soft and easy to bend. To bend bamboo in cold bending method can be done by splitting bamboo into planks then tie it into become a bundle; or by slashing bamboo rods the curved it. Bamboo bending method can produced smooth or segmented bamboo curved as well as can increase or decrease th strength of bamboo, differ to the method that is applied (Maurina, 2015).

Bamboo split technique is used in Green School structure, especially as supporting arches in the smaller masses that are functioned as classrooms. While in Bamboe Koenig restaurant, bamboo splits are installed at the roof eaves to support rafters and form a twisting end of the roof. Bamboo split method is flexible and easy to construct. It can be used to create smooth curve even spline shape. However, bamboo split method can decrease the strength property of bamboo and can cause structural deformation and deflection (Maurina, 2015). To prevent deformation and deflection of structural members, the sufficient dimension proportion to the span is needed.

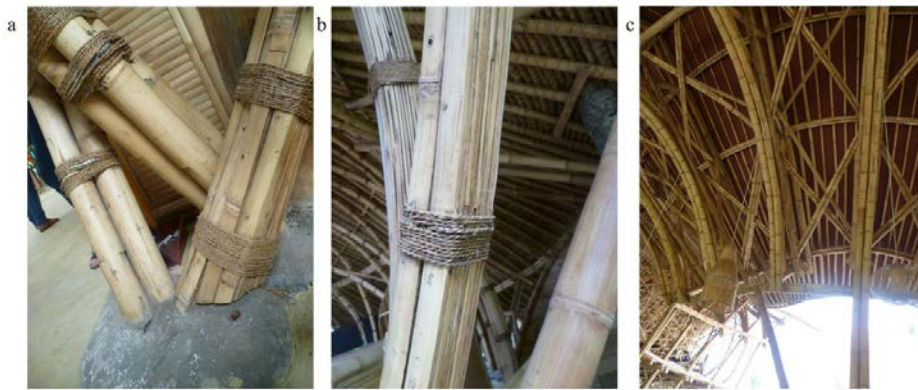


Fig. 10. Structural details; (a) Bamboo split method and bamboo bundling; (b) Bamboo split details; (c) Detail of arches using bamboo bundling.

In addition to these two methods, we can take advantage from natural curve bamboo. Bamboo can grow in curve shape; depend on the species, soil condition and environment. Natural curve bamboo can be joined in a row to create a continuous curve shape. This method can be applied to create arches or spline roof ridge. Joinery can be done by inserting smaller bamboo into the culm, or by inserting other materials, such as resins. This method is applied in Green School, Dodoha Mosintuwu and Bamboe Koenig restaurant. Besides using natural curved bamboo, curved shape, especially for arches, can be crete by bending and bundling smaller bamboos (Fig. 10.c).

4. Conclusion

The use of bamboo as building material in organic shaped building proved vastly potential because the nature and properties of bamboo are capable to accommodate it. Organic shaped building generally develop using form active structure system or semi form active system, although it is also possible to use non-form active structure system, i.e. trusses. There are several method that can be done to curve or bend the bamboo into desired shape, such as hot bending method and cold bending method. Beside hot bending and cold bending, curvature shape also can be generated by connected natural curve bamboo. Beside the understanding about the nature and properties of bamboo, the knowledge about structure system and bending method, the knowledge about joinery system is also needed.

However, the use of bamboo as sustainable building material still arise a question about the preservation method. It is critical to observe and perform continuously research on effective and environmental friendly preservation method using minimal or without chemical ingredient to minimize negative impact to the environment. Therefore we can use bamboo in reliable and responsible manner

Acknowledgements

The author of this paper would like to thank to Petra Christian University of its financial support of the research; to Mr. Effan Adhiwira and Mr. Andry Widjowijatnoko for the knowledge of bamboo in architecture and for the project sharing.

References

- Anagal, V., Darvekar, G., & Gokhale, V. A. (2010). *Bamboo Construction : Learning Through Experience*. ARCHITECTURE - Time Space & People, page 36-43.
- Bystriakova, N., Kapos, V., Stapleton, C., & Lysenko, I. (2003). *Bamboo Biodiversity: Information for Planning Conservation and Management in the Asia-Pacific Region*. Beijing: UNEP-WCMC/INBAR.
- Cruz, C. A. (2012). *Wright's Organic Architecture: From Form Follows Function to Form and Function are One*. *Wolkenkuckucksheim Issue* 32. Vol. 17. 2012.
- Jansen, J.J.A. (2000). *Designing and Building with Bamboo*. Technical Report No. 20. International Network for Bamboo and Rattan (INBAR).
- Liese, W. (1998). *The Anatomy of Bamboo Culm*. Beijing: International Network for Bamboo and Rattan.

- Lobokivov, M., Lou, Y., Schoene, D., Widenoja, R. (2009). *The Poor Man's Carbon Sink: Bamboo in Climate Change and Poverty Alleviation*. Rome: FAO.
- Maurina, A., Sari, W.E., Krisanti, J., Adhisaksana, J. (2014). *Komparasi Penggunaan Material Bambu dalam Struktur 'Form Active' dan 'Semi Form Active' pada Bangunan Lengkung Berbentang Lebar*. Bandung: Universitas Katolik Parahyangan.
- Maurina, A. (2015). *Curved Bamboo Structural Element*. Proceeding of International Construction Workshop and Conference Parahyangan Bamboo Nation 2. Page 81-92. Bandung: Unpar Press.
- Macdonald, A. (2001). *Structure and Architecture - 2nd ed*. Oxford: Architectural Press.
- Purwito. (2015). *Laminated Bamboo: The Future Wood*. Proceeding of International Construction Workshop and Conference Parahyangan Bamboo Nation 2. Page 19-58. Bandung: Unpar Press.
- Sarkisian, M., Lee, P., Long, E., Shook, D. (2008). *Organic and Natural Forms in Building Design*. CTBUH Technical Paper.
- Sandaker, B. N. (2008). *On Span and Space: Exploring Structure in Architecture*. New York: Routledge.
- Veltkam, M. (2007). *Free Form Structural Design: Schemes, Systems, Prototypes of Structures for Irregular Buildings*. Delft: Delft University Press.
- Widyowijatnoko, A. (2012). *Traditional and Innovative Joints in Bamboo Construction*. Aachen: RWTH Aachen University.