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BAMBOO APPLICATION IN BUILDING DESIGN: CASE STUDY OF GREEN SCHOOL, BALI, INDONESIA

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ABSTRACT

Bamboo has been known widely as a material for buildings since the dawn of the century. Nevertheless, bamboo is often regarded as a low-class building material which has commonly used by low-income people. Since the issue of global warming and sustainability, bamboo became a focus for building material due to its sustenance and fast growth in the natural environment. Architects and builders alike started to choose bamboo as an alternative to wood. Furthermore, it is difficult to get good-quality woods for construction and historically, a vast tract of land has been ruined due to deforestation that caused an adverse effect on the surroundings. This paper attempts to discuss the properties of bamboo and how it is inventively applied in building design. Descriptive-qualitative methods were used in this study to reveal an understanding of the application of bamboo in building design. To further enhance the finding and context of discussing a case study on how bamboo has been used in designing the structure in an innovative organic form. The result from this research found out that bamboo is noble to be considered as an alternative material in building design due to its natural properties, exclusively for curvilinear organic-form building that hardly achieved in steel and concrete.

Disciplinary: Architecture (Green/Sustainable Architecture).

1. INTRODUCTION

The image of bamboo usually reflects the characteristics and context of Asian and tropical countries. Usually, in Indonesia, it is easy to find a bamboo plant with various kinds of species in almost every region of the country. Scientists indicated that 1,250 bamboo species found in all around the world and 11 percent of them are locally endemic to Indonesia. Bamboo plant has a definite property to preserve an environmental balance such as to avoid erosion and to improve

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groundwater quality. Normally, bamboo can grow up 10 to 30 centimeters in a day which is faster than any kind of timber. After 3-5 years, the bamboo plant achieves its maturity and ready to be harvested.

For generations, bamboo is widely known by the people in Indonesia as used as a local material for various purposes in their daily life. Bamboo plants in Indonesia are found in both lowlands and highlands with an altitude of about 300 m above the sea level and are generally grown in open areas and free of puddles (Purwito, 2008). However, bamboo is often regarded as 'a low-income material' because it generally used by the working class in building shelter. This stereotype presumption affects the middle to high-income people to disregard bamboo as a building material in their design. They prefer to suit their architectural design according to the trends leading towards high-end technologies with modern materials, commonly, steel, concrete, glass or brick. Therefore, this study attempts to examine the properties of bamboo and will deliberately apply a case study to elaborate and explore the application of bamboo in building design.

2. METHODOLOGY

This research will employ a descriptive-qualitative technique in conducting the study to reveal an understanding as well as the applications of bamboo as a material in building design. The discussion focuses on the utilization of bamboo in building design and how the creative and innovative way of this humble material can address the current demand for sustainable and green architectural issues. Some factors are taken into account for the analysis, i.e., types of bamboo to generate building form, how the creativity in construction technique can be manipulated and the creativity of local craftsmanship. The case study scrutinizes the building of the Heart of Green School (HGS) inside the Green School Complex in Bali, Indonesia. It was selected to enlighten further the application of bamboo as key building materials, the complexity of the design and the technique of construction. HGS, as the main building in the Green School Complex, shows the ingenuity of the architect to utilize the humble material to its utmost wonder to reveal its aesthetic nature and technique of connections. The case study helps to designate the competence of bamboo as a key building material and construction technique, that respects the environment and fulfill the requirement of sustainable design and green architecture.

3. LITERATURE REVIEW

Bamboo has good properties as construction material, for its splendid characteristics such as strong, flexible, straight, even, hard, flush, easy to split, easy to be fabricated and lightweight material. Moreover, bamboo is relatively cheap compared to other building materials because of its availability and easy to be found in all regions in Indonesia (Purwito, 2012). Bamboo belongs to the grass species, and its tensile strength is better than steel. Bamboo can grow ten to thirty percent faster than other trees which only reach two to five percent per year and the production of fifty to one hundred tons per hectare (depending on species, soil and climate). In each colony bamboo plants consist of sixty to seventy percent stems ten to fifteen percent branches and fifteen to twenty percent leaves. Bamboo plants are good to speed up groundwater recycle processes, even two hundred and forty percent better than a pine forest. It has been used for soil consolidation, where its roots have strong properties to retain soil erosion. On the other hand, bamboo plants absorb CO_2 as much as sixty-two tons per hectare per year, which is four times larger than other forest plant species that can only absorb fifteen tons per hectare each year. Bamboo also releases O_2 thirty-five percent higher than other forest plants during the photosynthesis process (Jansen, 2000).

The bamboo plant grows plentifully in tropical and sub-tropical countries. In recent years, scholars clarify two important characteristics regarding cultivation and engineering properties of bamboo, such as:

1) bamboo can grow faster even in an extreme climatic region (Zhou, 1993),
2) it has good properties and many advantages, especially in bending and tensile. It overtakes other composite materials (Janssen, 1991).

Scholars have evaluated some famous bamboo species regarding their physical and mechanical properties. They indicate the various density of bamboo between 500 to 800 kg/m^3. It also indicates a different density according to the quantity and distribution of its fibre around the culm. Naturally, the density will grow from the centre of the culm to the periphery: from the base until the top of the culm. Usually, after three years, the maximum density will be achieved to a certain level (Espiloy, 1994).

Bamboo has excellent properties in tensile strength depending on the species and the climatic condition where it is planted. The tensile strength also differs according to the lengthwise and course of the stems. The lower part of the stems (stem base) has a higher tensile strength than the upper. However, the upper stems have a higher bending strength than the lower part (Kabir et al., 1993). The strength inside the bamboo stems itself is formed during the third to the fourth year of growing, then it will decrease gradually. Therefore, the maturity period of the bamboo stems can be considered around three to four years in relation to its strength and density. The good quality of the stem maturity is crucial and is a prerequisite for the finest utilization of bamboo in building construction and other structural applications.

Formerly, most buildings in Indonesia and Southeast Asian countries used bamboo straight away as both structural and non-structural materials. The mass application of bamboo is used in traditional buildings and shelters because it is abundant in the region. Besides, it can grow faster than other kinds of plants. However, bamboo is rarely used as a building material is for it signifies the backward rural traditions. Nowadays, many modern builders believe that bamboo has a shabby image and considered it as inexpensive materials and rated it as 'poor-people' material (Lobokivov et al., 2009).

In general, the choice of steel, brick, or concrete is preferable that symbolize modern materials. Currently, in line with the issues of global warming and sustainability, bamboo re-emerges as an alternative material to be used in building construction. Perhaps the difficulty to get them straight and quality timber for building construction as well as mass-deforestation issues become a major concern. Now, the people turn to bamboo and bamboo can be harvested between 3-5 years, meanwhile wood requires a longer time to grow to be utilized as construction materials. In addition, the bamboo plants can release excessive oxygen into the air. This is the advantage of bamboo as compared to mass-industrial materials such as steel, plastic, and concrete. Therefore, bamboo has broadly recognized as a sustainable material for building construction.

4. CASE STUDY: GREEN SCHOOL, BALI, INDONESIA

Green School is sited in Banjar Saren, *Kampung* Sibang Kaja, Abiansemal, Badung, which is about thirty kilometres away from downtown Denpasar, Bali. The school has won the Aga Khan Award for the recycle category in 2010. Green School was operated in May 2009 with a current capacity of 700 students. It is clustered into kindergarten, elementary and junior high school. John Hardy, a Canadian businessman who has lived in Bali for over 30 years, was initiated the school. His devotion and passion for the Balinese culture, education, and environment led him to establish the school. According to him, the earliest idea of the school was to cover an area of 20-hectare land. He was influenced by the traditional philosophy of life in Bali known as *Trihita Karana* which is based on the three principles of nature namely: harmony amongst the people, harmony to environment and nature and harmony to God. In each process, there are no manufactured materials or chemicals were used in the construction of the school. The school complex was built using an organic permaculture system and was designed to adapt in perfect cohesion with soil ecology. All buildings inside the school complex were intended to develop a civilization that respects nature by utilizing organic materials and renewable energy sources, such as micro hydropower, solar power, and bio-diesel. On the contrary, each building was not designed by an architect, instead of by a team of electrical engineers, designers and bamboo artists in Bali (Figure1).

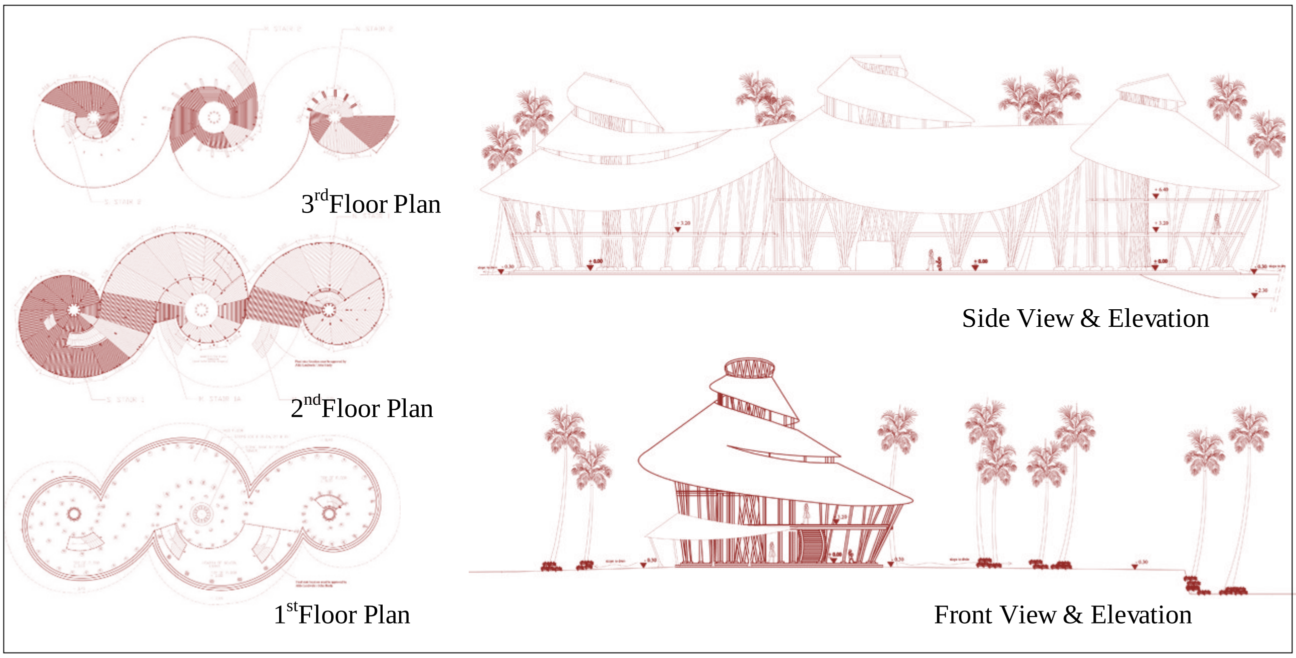

Figure 1: Orthographic drawing of 'Heart of Green School' Building

The layout of the building responses to the natural orientation, consisting of several building masses. The school complex was sited dominantly, among the masses and is used according to the functions as follows: classroom, laboratory, multi-function hall, office, student dormitory, teacher's house, etc. The design of the building form was revised several times to suit its structure and construction system. A two to three storeys building is located at the centre of the site as the main building (HGS) that is dominated by three spherical shapes resemblance the nautilus shell of the complex. This nautilus takes after the roof that linked to the wide envelope below the building, while smaller size nautilus is connected harmoniously in a continuous order of expected nautilus shape (Figure 1).

5. DISCUSSION

The observation from the case study shows that the Heart of the Green School (HGS) functioned as an office is a two to a three-story building surrounded by a double elliptical plan pattern, whereas three spiral-shaped staircases are directed into three core systems of the building to secure and stabilize the building structure. The cores are the highest level which is pragmatically connected to form a single structure building within the spiral organization. Three types of local bamboo were used in the HGS construction system, namely *Dendrocalamus asper* (bamboo *petung*), *Gigantochloa apus* (bamboo rope), and *Bambusa blumeana* (bamboo thorn). The roof structure of each building is covered with bundles of cogon grass (*Imperata cylindrica)*, while an alternate combination of bamboo, clay, mud, and kapok was also used to construct the wall.

It is distinguished that the HGS building is taking an organic shape, where arches, spline, and other curvature profiles have naturally supported the weight above; thus, bamboo is the most appropriate material to achieve these (Figure 2). The lightweight of bamboo enabled the integration of the roof and supporting structure cohesively. Many scholars had characterized two types of techniques in bending the bamboo for construction purposes (Dunkelberg, 1985), i.e., hot and cold method. Hot bending technique acknowledged by dipping the bamboo in lukewarm water to soften the fibres tolerably to be bent by using the clamp accordingly, or by heating up a certain part of the bamboo to a specific heat usually below 150 degrees Celcius. Whereas cold bending technique can be finished by splitting the bamboo into flat strips then tie them together as a wad, another way is by slicing bamboo stems to form a curvature. These two techniques can create smooth or segmented bamboo curvature that may upgrade or reduce the strength of bamboo (Maurina, et al., 2015). The splitting method is applied in the HGS structure system, mainly to support the arches that distribute the structure into spaces for the classrooms. However, this splitting technique may reduce the strength properties of bamboo which have consequences to trigger a structural deformation or deflection (Maurina, et al., 2015). The correct dimension must be equivalent to the span as required to avoid deformation or deflection of the structural system.

Figure 2: Organic-nautilus shape of HGS building.

HGS implemented the active-structure system with its organic-nautilus shape (Maurina, et al., 2014). The organic-nautilus shell shape is generated to tackle the surface structure by using bamboo pillars to support its battens, rafters, and purlins (Figure 3). The system resembles a tensile structure system while the round purlins help to provide a continuous strength to support the shell shape of the roof. In lieu of the main hall space, a wide-span arches structure system helped to stabilize the

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roof by rafters applied along the eaves to produce better protection from tropical wind, sunlight and rain.

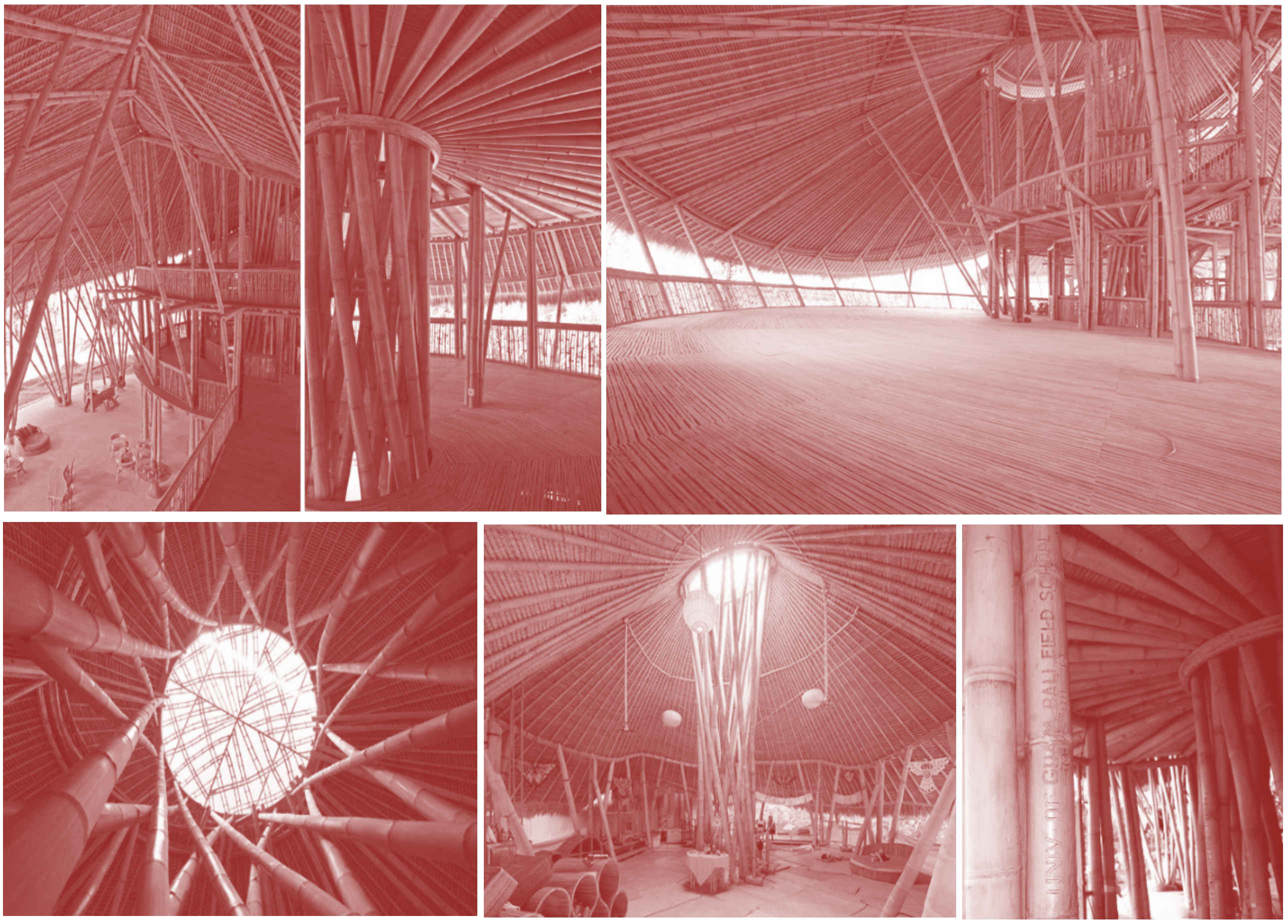

Figure 3: Interior shows the structural system.

In terms of the structure properties, *Dendrocalamus asper* (bamboo *petung*) is stiff, high strength and compressive value are used as columns for it enables to bear the compressive force as well as to sustain deflection risk. On the other hand, *Gigantochloa apus* (bamboo rope) was used for small beam as well as to support floor plate, roof frame, and rafter. It also possesses the same value on flexural, tensile and compressive strength. together, laminated split bamboo was used to bind the vertical core structure.

6. CONCLUSION

The utilization of bamboo for building construction material in creative and innovative ways could create an interesting architectural structure and give a good choice in architectural design. As applied in Green School, the potential of bamboo was explored in the design and construction, which created a good image that fits the purpose and blends with nature harmoniously. Implementation of bamboo for building construction material has to be explored further, especially to promote appropriate technology and create employment among the locals. The skill of the craftsman, as well as the technique of construction, has to be refined.

Although there were several new techniques applied to bend the bamboo to get the preferred shape and form, yet hot and cold bending technique is still popular and commonly used to achieve an interesting organic shape as that of HGS. Therefore, awareness concerning the nature and properties of bamboo is necessary in this case. Correspondingly, the understanding of the appropriate structure system and also bending technique is compulsory. Nevertheless, to classify bamboo as a sustainable material to be used for building construction is still debatable, particularly concerning its chemical treatment preservation method. It is necessary to accomplish further research to find out appropriate and environmentally friendly preservation methods that require natural or non-chemical ingredients to reduce the negative impact on the environment.

7. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

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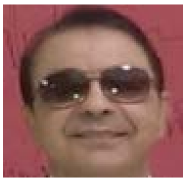

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