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## The Research of Curve Elements Used in Original Bamboo Architecture Design

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### Abstract

Bamboo features abundance, short growth cycle, low carbon and low cost, which has a broad prospect in the background of sustainable development. The original bamboo building has a long history in China and forms its unique local culture in the long time of social production and traditional life. This paper is based on a large number of original bamboo building design cases. First of all, bamboo's mechanical property, natural property and spirit connotation are analyzed to find out the co-existence relation between bamboo and curve. Then the curved shape design method in original bamboo building is concluded and classified by means of line, surface and body form. Last but not least, modern design strategy of the curve elements adapted to original bamboo building is proposed from three aspects as shape design, structure logic and the spirit of space. The result of this research will instruct the modern original bamboo building design and promote bamboo, the traditional building material, to revitalize in modern architecture design.

**Keywords:** curve elements; co-existence relation; original bamboo; manifestation mode; modernism

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### 1. Introduction

China is rich in bamboo resources and the bamboo forest area, bamboo species and bamboo resource utilization all rank the first place in the world so that China is called "the Kingdom of bamboo". There are about 1200 species of 100 genera bamboo all over the world among which China has over 500 species of 39 genera. As its practicability, bamboo has a long history to be used as a building material. "Ganlan" was once a traditional building mode widely used in South China whose basic components were bamboo completely.

Compared with straight line, curves have more varieties so as to increase the uncertainty for architecture space as an active element. People's visual and psychological needs could also be met by curves to some extent. Groceries made of bamboo such as utensil, handicrafts, furniture are endowed with curve forms, indicating the close correlation between curves and original bamboo to some degree.

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Formal research put much emphasis on the technical aspect of bamboo's physical property, bamboo buildings' node connection pattern and so forth. However, research for modern architecture constructed by original bamboo are scarce. Based on the intrinsic links between bamboo and curves, this paper takes curve elements as an evoked factor applied into original bamboo design. 130 bamboo design cases with curve elements have been studied and abstract diagrams method has been utilized. The aim of this paper is to find out how to make full use of bamboo properties and make a breakthrough in traditional bamboo architecture design by means of applying curve elements properly. As a result, the implication and character of original bamboo architecture could be expressed more desirably in the new era of time, in order to promote its sustainable development.

## **2. The Co-existence Relation Between Bamboo and Curve**

### **2.1. On the Basis of the Mechanical Properties of Original Bamboo**

Bamboo is low weight and has a high tensile strength and compressive strength with fibers and Vascular tissue running axial so as to be called "botanical steel". Besides, hollow tube structure is beneficial to form strong bending toughness and flexibility. However, the traditional frame structure did not take full advantage of bamboo performance. Incorporating curve elements into structure could cover this shortage very well. For instance, arch is a fine form to develop bamboo's high elasticity and high compressive strength. Woven bamboo curved surface is conducive to develop bamboo's tensile force, providing an ingenious resolution to the weak load-bearing capacity and poor standardization of a single bamboo. Weaving method transforms rod piece into surface, rendering the whole structure lightweight and high strength.

### **2.2 On the Basis of the Natural Properties of Original Bamboo**

As a raw material, original bamboo come from nature, remaining natural building material's property. Due to its fresh color, pleasant scent, soft and elegant shape, original bamboo is always connected with nature by people unconsciously, arousing a sense of intimacy and belonging. Similarly, curve elements are the motif of nature. Rivers and mountains, birds and beasts all feature curved shape so that curves are treated as a bond linking human beings to nature in architecture design. Applying curve to the original bamboo architecture to emphasize its natural feature rather than extraordinary form is an effective way to combine human, architecture and nature perfectly.

### **2.3 On the Basis of the Spiritual Connotation of Original Bamboo**

In China, bamboo has been used in people's daily life for a long time. The irreplaceable sentimental value is cherished by Chinese no matter poets, artists or ordinary people. The Ming emperor Zhu Yuanzhang has complimented bamboo's spirit with the poem: "Despite being pressed by heavy snow, bamboo will not approach the ground. When the sun emerges tomorrow, it will rebound to its original state." Braving snow and forest, bamboo will stand upright despite being bent over by heavy snow, which shows the poet's admiration for its resilience. Incorporating curve elements into original bamboo building design is an embodiment of bamboo's spiritual connotation of flexibility and toughness.

## **3. The Manifestation Mode of Curved Elements in Original Bamboo Architecture Design**

### **3.1 Line Forms**

(1) Arch. When heated above 150°C, the freshly cut bamboo could be bent and keep this shape after



drying. Arch is the most common shape and can be lengthened by binding several arch sections together. Various deformations of arch were also designed in order to create fascinating images. By adding one node on top of the arch symmetrical forms like pointed arch and onion arch can be achieved.

Arch's Deformations. A variety of space like dome surface or polymerised images can be created with several archs by means of arraying, crossing and rotating. (Fig.1.)

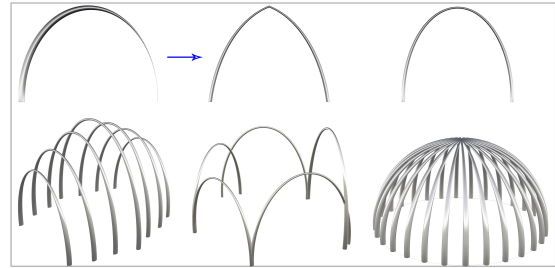


Fig.1. Arch and Arch's Deformations

### 3.2 Surface Forms

(1) Bamboo Weaving Surface. Evolved from traditional hand-woven skill, a lot of knitting methods were created to make living appliance, demonstrating the great intelligence of laboring people. By means of simplifying these knitting methods, three types of curved surface can be woven by bamboo canes or strips.

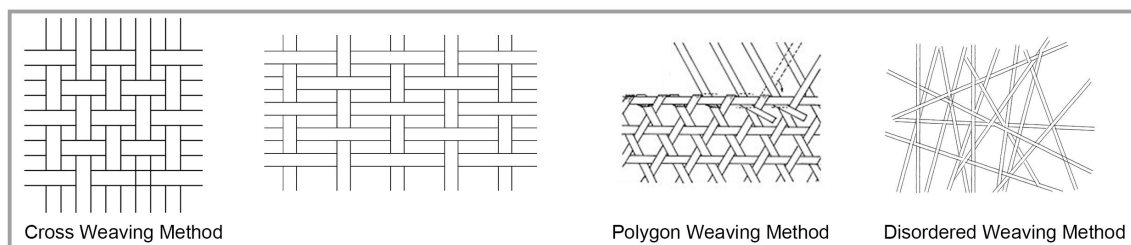


Fig.2. Bamboo Weaving Surface

Fig2 shows three bamboo weaving method. First is the cross weaving method. The lines of longitude and latitude are twined, which can be distributed evenly just as the exhibition hall in Taiwan horticultural expo, or emphasized along one direction to create peaceful and serene atmosphere. Second is polygon weaving method. The lines of longitude and latitude are intersected to form triangle, quadrilateral or hexagon grid. Hyperboloid can also be created. Third is disordered weaving method which features random and freedom. Many innovative images with ever-changing shadows could be created by using this method.

(2) Linear Surface (Fig.3). It is a desirable way to make full advantage of bamboo tube. The curved surface can be formed by arraying bamboo canes to construct buildings' skin. A dome surface which consists of triangle polygon meshes can be formed as well. The original bamboo canes should be accurately cut to form a uniform shape. As sliding deformation will be produced if nodes are too simple, this method provides chances for the creation of innovative nodes' form.

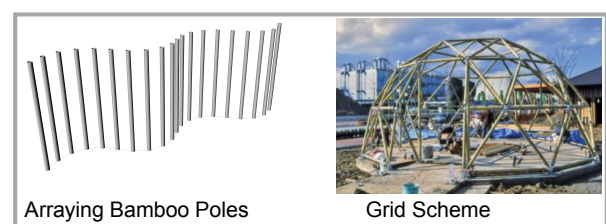


Fig.3. Linear Surface

### 3.3 Body Forms

Bamboo poles are crossed or interwoven in three-dimensional space orderly or disorderly with a curved profile. The temporary leisure facility in Peru (Fig.4.1) was constructed with head-to-tail connected bamboo poles in a logical



Fig.4.1 Leisure Facility in Peru



Fig.4.2 Assembly

order. Connections were designed thoroughly with CNC cutting machine to form an ideal shape. Another fantastic bamboo assembly space was constructed in Black Rock City (Fig.4.2). Bamboo poles were interwoven randomly to create a huge and rough image.

#### 4. The Modern Application of Curve Elements in Original Bamboo Building Design

##### 4.1 Introducing Nonlinear Mode to Create Complex Forms with Low Technology

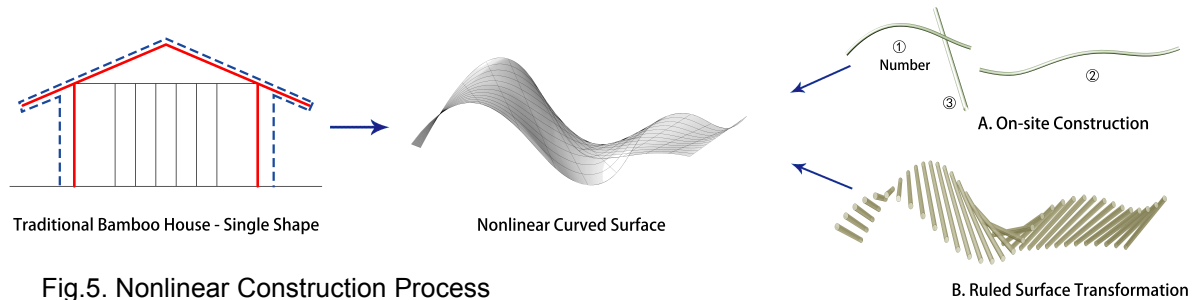


Fig.5. Nonlinear Construction Process

As for the limitation of technology and aesthetic value, traditional bamboo buildings can merely show simple shapes such as cone and dome. In modern bamboo architecture design, however, innovative form, unique space and implication are essential despite adopting low-tech construction measures. Thanks to computer technology, the nonlinear variation such as rotation, distortion and irradiation can be realized to create innovative bamboo building image and revolutionize traditional architecture space. Fig.5 shows two methods. One is to construct on-site on the basis of computer simulation. The position and curvature of each bamboo cane are ensured and numbered precisely. Another is to transform complicated form into ruled surface so as to simplify the process and reduce the restriction of bamboo's irregularity.

##### 4.2 Utilizing Curved Structure to Optimize the Space

The traditional frame structure of bamboo building exposes bamboo's weak transverse resistance, restraining creation of bamboo buildings' space and image. Nevertheless, curved bamboo structure is a desirable way to explore original bamboo's potential, simplifying the logic of force delivering process. Fig.6 shows the optimized bamboo building's space in terms of space expansion and aesthetic expression.

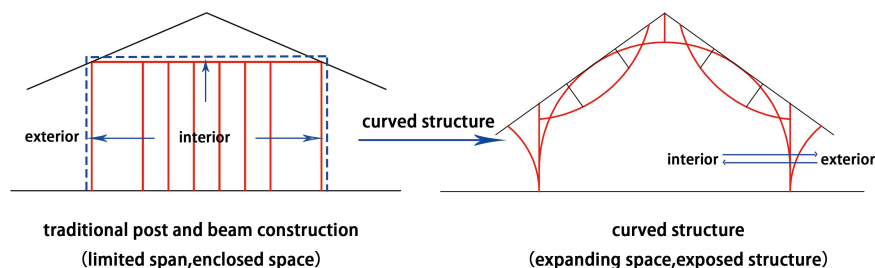


Fig.6. Curved Bamboo Structure

(1) Expanding Space with Curved Bamboo Structure (Fig.7): Firstly, combining bamboo arch with truss system, which comes from steel structure aiming to accommodate a greater span. Secondly, combining bamboo arch with tensile structure system, which can replace the beam and column along the roof in order to create an open space without columns all around or on one side. Thirdly, combining bamboo arch with cantilever structure, which is used to form open and flowing space with light, elegant and large-scale cantilever.

(2) Showing Aesthetic Interest with Curved Bamboo Structure: Fig.8 shows two means to expose curved





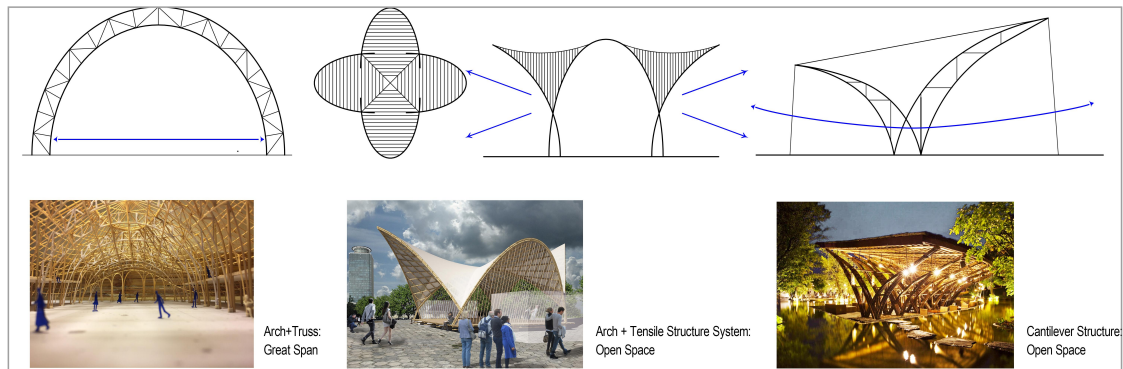


Fig.7. Strategies and Cases to Expand Space

structure so as to reinforce its unique character. One method is imitating natural organisms' form. It is a brand-new way to design curved bamboo structure, endowing vitality to the whole building. Another is to expose complex structure, highlighting the curved structure as visual focus by combining and transforming bamboo poles in three-dimensional space.



Fig.8. Strategies and Cases to Show Aesthetic Interest

#### 4.3 Reconstruct the spirit of place

Modern architecture ought to surpass the former functionalism, putting emphasis on the spirit of place. (Fig.9.)

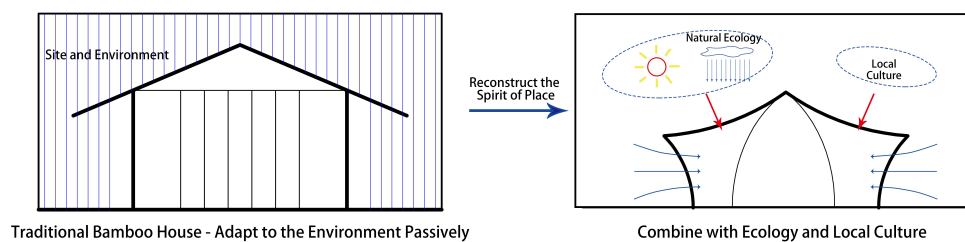


Fig.9. Reconstruct the Spirit of Place

(1) Combining Curve Elements with Ecology. To be a part of nature by means of imitating shapes in nature is not enough for modern bamboo building design, as long as the ecological function is taken into consideration the harmony between human and nature can be achieved at a higher level. Fig.10. shows the following three methods. The first is to bring in natural light by setting several free-form daylighting window on the curved surface which is beneficial to reflex the light evenly. The second is to operate natural ventilation with

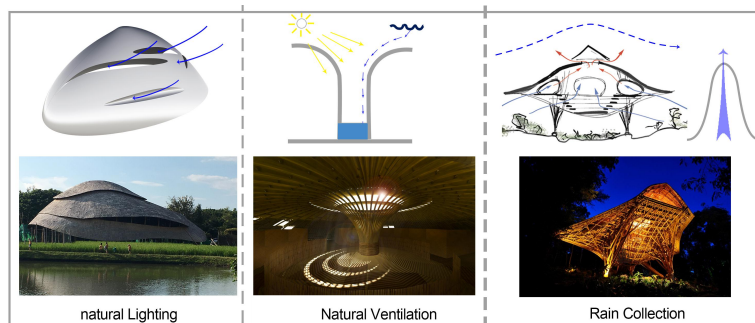


Fig.10. Combining Curve Elements with Ecology

the shape of “人”, high and narrow vertical space, which is an efficient shape to enhance chimney effects, achieving natural ventilation. Thirdly, Funnel shape is effective to collect rain water and also conducive to create an elegant image for bamboo buildings.

(2) Giving Abstract Expression to the Local Culture. Architecture is distinguished from other things so that the most advisable method is to express cultural implications in an abstract way. Differing from specific description, to abstract curved elements means to extract, exaggerate, transform and deform so as to deliver

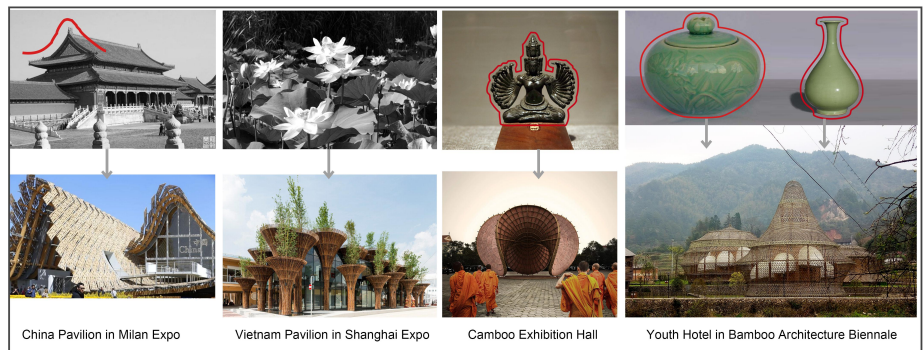


Fig.11. Strategies and Cases to Express Local Culture

deep culture connotation. China pavilion in Milan expo, Vietnam pavilion in Shanghai expo, youth hotel in Bamboo Architecture Biennale and Camboo exhibition hall all extract curved elements from specific objects. Chinese traditional irimoya-zukuri, Vietnam's national flower lotus, celadon made in Zhejiang province and the goddess of prajnaparamita serve as the source of design ideas respectively to embody local culture. (Fig.11)

## 5. Conclusion

As a kind of green, environmentally friendly, fast growing and humanistic material, the original bamboo has been paid more and more attention in the field of Architecture. But the traditional way to construct bamboo buildings has many limitations, which can not fit into the development of modern bamboo architecture. It is significant to treat original bamboo in a developing view. This paper creatively introduces curve elements into the original bamboo architecture design, and then put forward three modern design and construction strategies from the perspective of shape design, structure logic and the spirit of space. In this way, the original bamboo architecture is able to be more innovative and in line with the new era's demand.

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