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Research on the Application of Parametric Morphogenesis in Bamboo Construction Devices - Taking Bamboo Cove as an Example

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Abstract. With the development of digital technology, parametric design has been increasingly and extensively studied and applied in the field of intangible cultural heritage preservation. Regarding digital-based bamboo structure installations, current models face challenges, particularly in the precise virtual-to-physical transition. Considering the versatile nature of bamboo morphology, the implementation of bamboo structures is constrained by factors such as high design complexity and limitations of construction techniques, advocating for the development of a more effective digital-based design methodology for bamboo installations. This paper first discusses and analyzes several effective digital-based bamboo-structured models based on existing cases, followed by a concrete implementation example: Bamboo Cove. Based on the design and construction process of this example, the paper introduces a method with the refined coding of bamboo parameters and the real-time adjustment of model parameters according to the influence of the site environment, which improves the design and construction efficiency of bamboo installations. In sum, the goal of the paper is to make a beneficial exploration of the application and development of parametric design in bamboo installations, specifically discussing the advantages and limitations of digital technology in the design and application of bamboo installations.

Keywords. Bamboo construction, Parametric modeling, Landscape device, Design innovation

1. Introduction

China's bamboo culture has a long history, with records of bamboo processing and application dating back to the Neolithic era [1]. From clothing, food, housing, and transportation to poetry, books, rites, and music, bamboo as a material and culture has long permeated the lives and thinking of Chinese people. Among the national-level representative intangible cultural heritage projects, there are 50 related to bamboo1, and there are hundreds more at the provincial and municipal levels, including silk and bamboo music, bamboo horse dance, bamboo weaving craftsmanship, and bamboo construction techniques. The *Yingzao Fashi* of the Song Dynasty specifically listed the

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Bamboo Works chapter, and bamboo structures such as bamboo halls, bamboo houses, bamboo rooms, bamboo buildings, and bamboo pavilions were widely used before the Northern Song Dynasty [2].

Bamboo grows and produces rapidly and more importantly biodegradable. These characteristics makes bamboo an ideal environmentally friendly green building material that has been widely promoted and applied in China. Currently, China has 5.2 million hectares (12.85 acres) of bamboo forests, with 32 million farmers engaged in the production and processing of bamboo, which is the largest in the world. On the other hand, in recent years, with the continuous upgrading of digital construction and management technologies in the design field, traditional bamboo construction weaving and other craftsmanship have been well inherited and innovated, and the potential for free expression of bamboo morphology has been stimulated. Due to its high compressive and tensile strength alongside the easy bending and shaping characteristics, bamboo can be used in conjunction with parametric algorithms to design more complex and diverse shapes and assist in processing and construction. At the same time, this also brings new problems and challenges.

2. Overview of the Development and Current Situation of Bamboo Construction Devices

Research on bamboo construction design has never stopped at home and abroad. In 2006, Ji Zhengrong proposed in his article to explore the construction essence of bamboo materials and excavate the experimental significance of bamboo construction [3]. In 2013, Liu Jing, Zhang Jialiang, and others proposed that bamboo materials integrate the advantages of mechanics, aesthetics, and other aspects, so bamboo materials are a fast-growing, high-yield, and environmentally friendly *green building material*, which is an inevitable choice in the context of the intensifying global energy crisis [4]. In the same year, Liu Tong explored a construction strategy that combines the *high-tech* nonlinear parametric design method with the *low-tech* construction process, using the *Garden of the Soul* as an example, to deal with the constraints of the construction environment [5]. It can be seen that the path of digital intervention in bamboo construction design has been opened. In 2015, Ren Xiao proposed that in China, the research of contemporary architectural design neglects the thinking of architecture at the level of construction technology [6]. In 2020, Xu Kai, Liu Hui, and others proposed an effective control method for the actual construction difficulties in the process of digital design of original bamboo architecture [7]. In recent years, to better inherit and develop bamboo culture, various design competitions and exhibitions related to bamboo construction have been held in various places, such as the *Beilin International Garden Construction Festival* held by Beijing Forestry University since 2019. Among the winning works of the past four competitions, the number of teams adopting parametric design has gone from sporadic to widespread, and the design thinking and thinking methods of the contestants have undergone drastic changes. It is evident that while domestic research and practice on bamboo construction have become a hot topic, the connection with digital design has become closer.

Foreign research on bamboo as a building material was also not at a standstill. In 2014, Zhao Zhang Rong et al. proposed to establish experimental standards for the comprehensive performance of bamboo materials, which can provide technical support for bamboo structural engineering [8]. In 2017, Kristof Crolla proposed a new digital design practice model to deal with the uncertainty of site and materials through the design and construction of the ZCB Bamboo Pavilion [9].

In summary, domestic and foreign literature has proposed thoughts and suggestions on the research of bamboo architecture from promotion to the intervention of new technologies, but the problem of bamboo construction is still the focus of discussion in related research.

3. Parametric Thinking Intervenes in the Design and Practice of Bamboo Construction Devices

3.1. Bamboo Construction Device Design Process

Taking the bamboo weaving skin design that is commonly used in bamboo construction device design as an example, traditional bamboo weaving makes it difficult to predict the appearance of the finished product at the design stage, and the *design drawing* is often limited to the weaver's conception in mind, which affects the early design and communication; bamboo weaving techniques are usually composed of bamboo silk and bamboo strips in a way of picking and pressing, and the warp and weft are difficult to change, which affects the design modification in the middle and late stages.

Parametric modeling establishes a parametric relationship between digital design software and design form output to generate a computer model that is easy to flexibly control. The parameters that control it can be various information related to the design. Bamboo weaving methods generally have rules to follow, which is convenient for parameter conversion. Its weaving methods, bamboo strip interlacing methods, etc. can all be converted into digital formulas through coding. When designers are designing bamboo structures, they can adjust the width, thickness, overlapping method, and density of bamboo strips by modifying parameters, avoiding the problem of being difficult to adjust in the pre-fabrication process of new products, and eliminating the process of constantly experimenting with real materials, saving time, effort, and materials; parametric design facilitates the free combination and matching of different forms, which is conducive to the innovation of bamboo weaving expression language and form.

The winning work *In Dream with the Butterfly* (Figure 1) of the *Beilin International Garden Construction Festival* in 2020 generated a random matrix of points on the surface using parametric design methods after generating the shell structure at the design stage, and performed tangent circle generation, and finally used tangent circle generation to map it onto the shell structure to form a novel bamboo weaving skin. The design uses random point arrays to create diverse bamboo weaving forms, which is an innovation in bamboo weaving forms and methods; by intervening in the random point arrays to make corresponding adjustments to the form, it demonstrates the solution of digital design methods to the problems of traditional bamboo weaving design being difficult to predict results and inconvenient to timely adjust forms at the design stage.

3.2. Production Process

The manual weaving process of bamboo materials is slow and uncertain; new products and new weaving methods often require apprenticeship-style teaching and considerable time investment. Parametric models can generate standard and clear design drawings according to product requirements, which is convenient for manufacturing facilities to carry out hot bending, weaving, and other procedures in advance according to parameters and drawings. The parametric model in this case is conducive to subsequent production and manufacturing, and is the preferred method for improving production efficiency and process standardization.

The third prize-winning work *A World all its own* takes the mysterious and ever-changing Taihu stone in classical gardens as the design inspiration and uses parametric design methods and standard unit modules to "simulate" the spatial form of Taihu stone using the Gyroid minimal surface as the design prototype. The complex cavity space is condensed into three simple bamboo components, with freely woven bamboo strips as the covering surface. It well integrated parametric morphogenesis with bamboo weaving design, and ultimately created a secret garden from *A World all its own* Due to the shape being based on the minimal surface algorithm, the structure only needs five different components (the U-shaped keel is half of the long S-shaped keel). The entire structure only needs to distinguish three components, which greatly reduces the difficulty of the production process. The construction time is controlled within three and a half days, which is precise and fast, and the finished product of the device is also well presented.

4. Parametric Design Practice: Bamboo Construction Device Bamboo Cove

In the 2020 Beijing International Design Week, the design exhibition *Design for a Healthy Lifestyle* with the theme of *Chinese Traditional Crafts Revival* opened in September 2020 at the China Millennium Monument in Beijing. As the third intangible cultural heritage section of the Beijing International Design Week, this exhibition focuses on the practical significance of traditional crafts from the perspective of life aesthetics and sociology, hoping to lead a healthy lifestyle and establish a healthy view of life. Bamboo weaving, as a traditional Chinese handicraft and a national intangible cultural heritage of China, and with the material characteristics of being green and environmentally friendly, is a highlight of this exhibition - the exhibition plans to set up a bamboo construction device at the entrance.

4.1. Design Concept

Bamboo Cove aims to use the abstract form of the silk and bamboo musical instrument Cauk as the spatial carrier, set up an interactive device in the middle part of the bamboo structure, and hang bamboo curtains on the top surface. Pushing the bamboo curtains makes them collide and emit acoustics, which mimics the sound of bamboo leaves colliding in the wind, and using these bamboo sounds as a creative clue to guide visitors to explore the experience (Figure 1). *The silk strings are gentle and soothing, and the bamboo sounds linger for five thousand years*, With the lingering bamboo sounds, it suddenly becomes clear, neither the bamboo coming into the eyes nor the eyes reaching the bamboo, but only where the heart is, as if there is some realization.

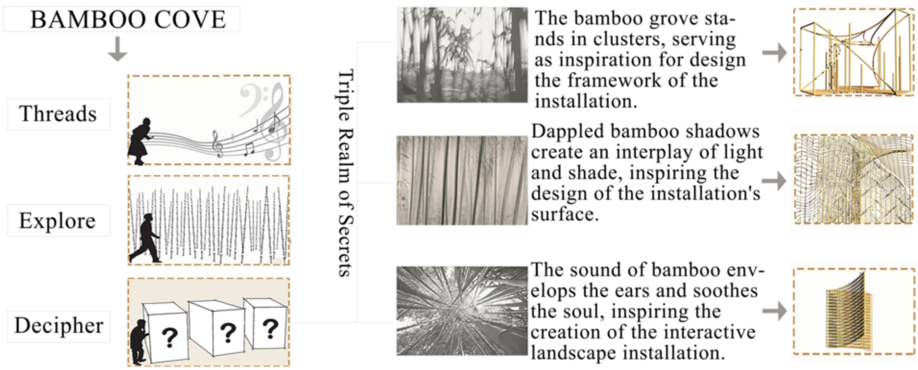

Figure 1. Design Concept (Source: Illustrated by Yujia Zhou)

4.2. Design Process

After determining the theme, the design team turned the idea into form, extracting and abstracting the outer contour of the Cauk (An ancient plucked musical instrument) to obtain the general shape of the device frame, and simulating it in Rhino (Figure2). Later, considering the shape of the device frame and combining it with the theme of *bamboo sound*, a wave-like weaving method referencing to the twisting method was designed. In the early stage of the scheme, the designer could only see the bamboo weaving techniques displayed or applied on the plan and previous bamboo construction devices, and it was difficult to imagine the effect of it being attached to the main frame of the device. The width of the bamboo strips and the distance between the warp and weft strips were also difficult to decide, until the width of the bamboo strips and the interlacing direction were converted into parameters and brought into the Rhino model.

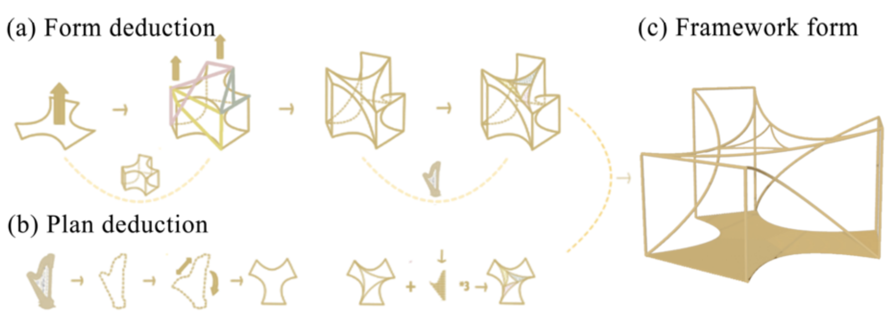

Figure 2. Deduction of the conceptual form of bamboo cove, (a)Form deduction, (b) Plan deduction, (c)Framework form. (Source: Illustrated by Ying Kang)

The surface of this bamboo installation emulates the undulating texture of bamboo material using the sine curve formula, as shown in Equation as below:

$$y = A\sin(\omega x + \varphi) + k \tag{1}$$

In the equation, each variable represents specific attributes of a sinusoidal function. y denotes the function's output value corresponding to the independent variable x.A signifies the amplitude, which measures the peak distance from the function's mean value. ω represents the angular frequency, determining the oscillation rate and period $T = \frac{2\pi}{\omega}$. x serves as the independent variable, indicating the position or time within the function. φ represents the phase angle, dictating the horizontal shift of the function along the x-axis. Lastly, k denotes the vertical shift or offset from the origin along the y-axis. Together, these variables comprehensively define the characteristics and positioning of the sinusoidal function.

The sine wave, often considered the most basic and fundamental unit of sound waves, represents the simplest form of acoustic vibration. Characterized by its symmetric, rhythmic undulations, the sine wave forms an ideal texture for the surface of the installation.By repeatedly adjusting the parameters in Grasshoppers, the shape suitable for building scale can be obtained.

Firstly, a series representing the horizontal range variable x is substituted into the formula, generating a corresponding series for the y direction. This series is then arrayed according to the spacing and staggered distance of the weft strips, resulting in a model of weft strips arranged on a plane. Given that the weft strips form sine waves, the warp spacing is determined to prevent clutter on the woven surface. The array connects the nearest points on the frame at both ends of the weaving surface, thus fixing the sine wave tructure of the weft strips.Subsequently, the model generated in Grasshopper is applied to the framework surface using the "flow along surface" command, creating a solid 3D model.During this process, the parameters A, ω, and φ in the sine curve formula can be adjusted in Grasshopper to control the amplitude of the weft strip undulations. The width and spacing of the warp and weft strips can be fine-tuned at any time, requiring multiple adjustments to fit the overall framework based on the actual dimensions of the construction materials. (Figure 3)

After numerous trials, the final texture of the bamboo installation's woven surface was determined with both warp and weft strips having a thickness of 5 mm, the weft strips a width of 10 mm, and the warp strips a width of 5 mm. The closest spacing of the weft strips is 10 mm, while the widest spacing is 25 mm. The weft strips change staggered direction in groups often. (Figure 4)

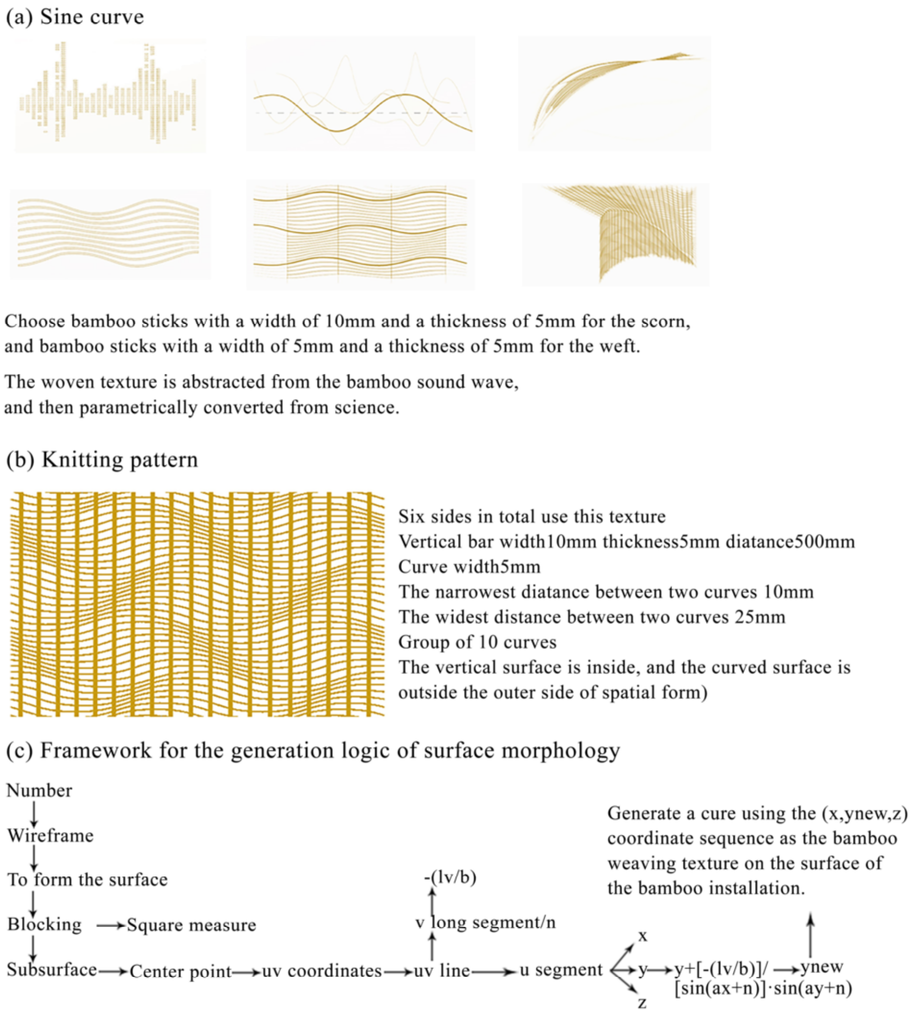

Figure 3. Analysis of the overall structure and skin texture design and construction of bamboo cove, (a)Sine curve, (b)Knitting pattern, (c)Framework for the generation logic of surface morphology (Source: Illustrated by Yujia Zhou, Xiamengwei Zhang)

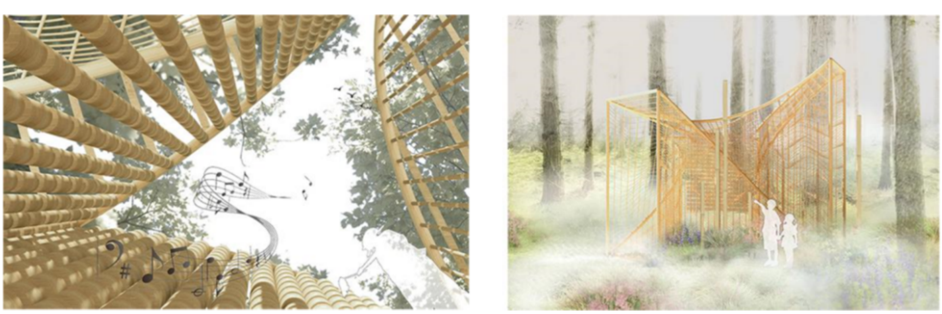

Figure 4. Design renderings (Source: Illustrated by Yujia Zhou)

4.3. Construction Process

In the material preparation stage, the author quickly obtained the data of the required materials through the parametric model and drew the hot bending drawings of the main frame bamboo tubes based on this model, which were used for material selection and production. This method greatly reduces the time for material data collection and estimation. During the on-site construction process, the main frame was hot bent according to the drawings, the device was quickly constructed, and the production of the covering bamboo weaving part began.

Due to cost, technical and other limitations, the materials required for the covering bamboo weaving were not hotbent and were later completed in the form of "manual bending". During the construction process, the design team found that the previously selected bamboo strip spacing had problems that were difficult to weave when placed on the actual device: according to the twisting method, the weft strips need to be twisted between the warp strips for weaving and shaping, but when modeling on the computer, the selected bamboo strip thickness was large and the initial warp strip spacing was close; the weather in Beijing is dry, and the moisture in the bamboo strips evaporates and decreases, making them brittle and more prone to breakage, making it difficult for the weft strips to twist smoothly. Finally, the bamboo weaving masters and the design team modified and adjusted the bamboo strip spacing according to various factors on-site, and built a satisfactory effect. (Figure 5).

Figure 5. The construction achievement of Bamboo Cove (Photographed by Mingyang Xie)

It can be seen that parametric models can quickly provide model data, which is convenient for the preparation of construction materials and the construction of the device. In the process of parametric morphogenesis, it is necessary to consider the properties and seasonal changes of the constituent materials. The elasticity, density, etc. of bamboo should be converted into a language that can be recognized by computers through coding and used as an important reference for morphogenesis.

5. Conclusion

The three cases listed in this paper demonstrate the digitization of bamboo material at different levels. Each step of the leap shows the advantages of the *cooperation* between bamboo materials and digitalization from idea to form to finished product. Parametric morphogenesis has further innovated and developed the design concepts and techniques of bamboo construction devices, effectively improving the possibility, controllability, and design and manufacturing efficiency of bamboo construction design; while bamboo materials provide more opportunities for realizing various parametric models due to their material properties. These achievements have made tremendous contributions to the inheritance and development of bamboo as an intangible cultural heritage. In addition, in this design research, it was also found that the modularization of bamboo construction can reduce the difficulty of construction. Bamboo as a non-standardized material still has the problem of difficulties in handling the nodes; the various new weaving methods generated by digitalization require conditional adjustments for on-site construction, which is prone to errors. Digital models should be finely modeled according to the characteristics of bamboo materials and then adjusted in real-time according to the site conditions to achieve the construction of complex bamboo structures.

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