Bamboo Field

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Abstract The design is inspired by the ancient rattan ball for sports. Through researches on its material and structure, the beautiful shape and solid characteristics of the rattan ball help us deepen the design. Combined with traditional Chinese bamboo weaving technologies, a simple and stable structure is designed. The design uses the good flexibility of bamboo to form a spherical grid structure. Woven bamboo strips restrict each other to ensure the firmness of the structure. The spherical grid structure allows the air in and out, with changing light and shadow. A membrane is used to shield sun and rain. Structural analysis was also carried out to check the deformation of the structure and the stress strength of components.

Keywords Spherical grid structure · Rattan ball for sports · Bamboo weaving technologies

1 Concept Design

Bamboo, as a fast-growing renewable material, is expected to be a sustainable alternative for some traditional structural materials, such as concrete, steel, and timber [1]. Meanwhile, bamboo is the main structural material required by the competition. Combined with the theme for which we want to express, "build a house in a bustling settlement but I can still not be bothered by the clatter of the traffic, and keep a heart away from the worldly world is the secret of my peace", we carried out the design. The concept design of our pavilion is to be introduced from the following three aspects: spherical grid structure, rattan ball for sports and bamboo weaving technologies.

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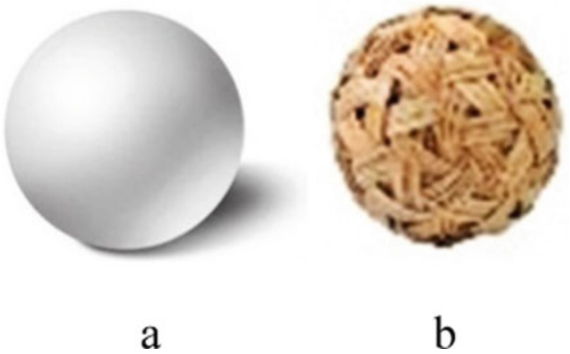

Fig. 1 Sphere (**a**); Rattan ball for sports (**b**)

1.1 Spherical Grid Structure

The sphere (Fig. 1a) is a very solid structure that gives people a feeling of comfortable and pure that is consistent with one of the targeted functions of our pavilion. The purpose of our design is to explore how to construct a spherical grid structure by using bamboo. The characteristics of bamboo could be also fully applied to the structure at the same time.

1.2 Rattan Ball for Sports

Based on the idea of constructing a spherical structure, an ancient Chinese rattan ball for sports came to our eyes after studying a series of different materials. To imitate the structure of the rattan ball became the object of our design and research. The rattan ball is a Chinese ancient handicraft, which is easy to make and its structure is very stable. It was introduced to Southeast Asia and became a popular sport in the 1940s, known as "sepak takraw" (in Malaysian) [2]. The ball is woven by rattan strips, with uniform stress and gaps between different strips, as shown in Fig. 1b. We can imagine that the rattan ball is a building with a good structural performance, and it also meets the ventilation and light requirements of the building.

1.3 Bamboo Weaving Technologies

Traditional bamboo weaving technology has a long history and bamboo woven products are closely related to people's daily life. Weaving is also one of the basic forms of construction in ancient times [3]. Therefore, on the one hand, we aim to use traditional weaving skills to reflect the good characteristics of bamboo in a small-scale structure. On the other hand, we also hope to spread this great Chinese craft to the

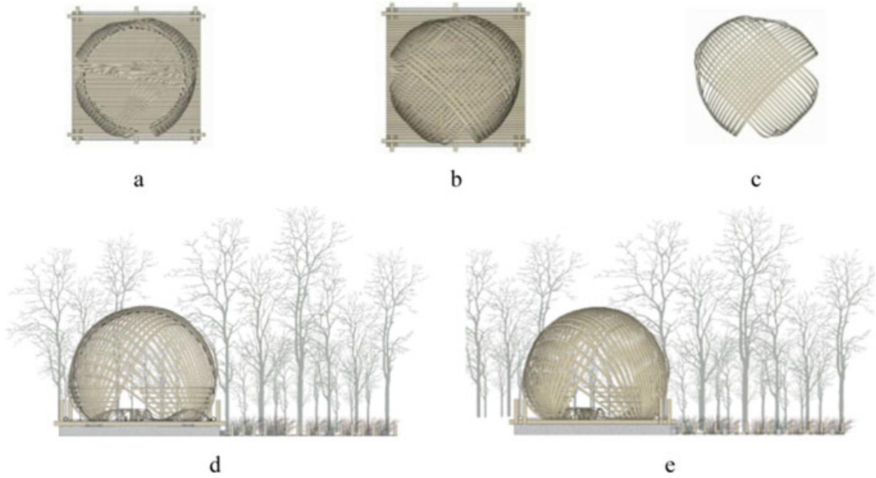

Fig. 2 Plan (**a**); Top view (**b**); Upward view (**c**); East elevation (**d**); West elevation (**e**)

world. The biggest challenge for us is how to scale up a small woven object into a real functional structure.

2 Design Development

2.1 Profile of the Pavilion

The planned building area is about 7.06 m^2 and the whole site area is 9 m^2. The plan of the structure, its top and upward views, as well as its elevations, are shown in Fig. 2. The structure is assembled by prefabricated bamboo strips through metal connections. We consider to use a membrane to form an external façade and use round bamboo culms to pave the ground.

2.2 Function Analysis

This structure can achieve two functions: if we do not cover any material outside of the bamboo structure, then the pavilion can become a completely open leisure space; if we tie the membrane to the bamboo strips, the pavilion can be rain-proof, sun shading and with other functions.

Fig. 3 Sunlight analysis chart

2.3 Light Analysis

By using bamboo weaving technologies, the structure can present different light and shadow effects when the sunlight passes through the building at different time points of the day (Fig. 3).

2.4 Processing of Construction

After studying a series of references, we plan to construct it in several steps as follows: Firstly, choose bamboo species with good toughness, such as Moso bamboo, then split the whole bamboo culm into strips with certain width; Secondly, weaving bamboo strips to form a spherical grid structure; Thirdly, insert ends of bamboo strips into four foundations and pour concrete to fix them.

The structure is smooth and continuous with coherent external lines to form a space with shelter function, presenting bamboo's natural tension and beauty. The space can subtly reflect the color of the sky as time goes on. The sunshine in the day and the light at night create delicate light and shadow. The external membrane makes the edge of the bamboo structure blurred, presenting the flexibility and permeability of the structure, as well as the beauty of bamboo's soft and rigid.

2.5 Nodes

In the construction of modern bamboo structures, metal bolts are usually used for connections. However, to match bamboo's natural simplicity, we choose the way of lashing rather than bolts, while maintaining the organic overall characteristics of the structure. Lashing by hemp rope (Fig. 4) not only highlights the natural characteristics of bamboo architecture but also inherits the aesthetics of traditional bamboo construction technologies.

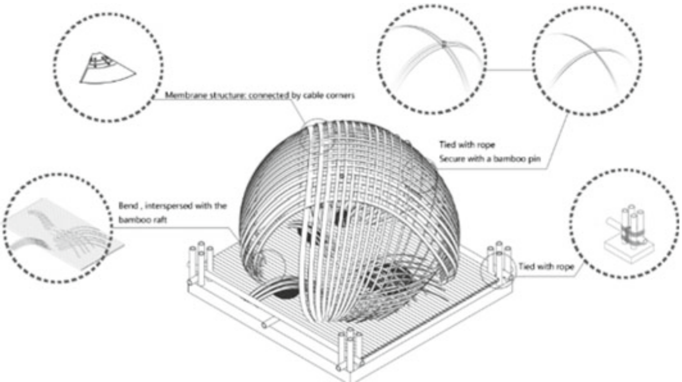

Fig. 4 Nodes and other details

2.6 Modeling and Analysis for Structure

Bamboo has high tensile strength along the fibre, which is about 2 times of wood. Its compressive strength is about 1.5–2 times of wood, and its tensile strength per unit weight is about 3–4 times of steel. Therefore, bamboo is a very good structural material. Through weaving technologies, bamboo can create curved structures with large spans.

The parameters of bamboo used in the calculation are shown as follows: the density of bamboo is 800 kg/m^3; the modulus of elasticity is 9500 MPa and the Poisson's ratio is 0.3. The cross-sectional area of bamboo strips was 50 mm $\times$ 9 mm. We used Ansys to analyze the structure and the results are shown in the following paragraphs. ANSYS software is a large general finite element analysis software. Can carry out structural analysis, static analysis, load analysis and so on.

Deformation: According to Fig. 5, the deformation of the structure in the X, Y, Z directions are −0.018 m~0.019 m, −0.021 m~0.01 m, and −0.025 m~0.002 m respectively. Deformations in three directions are all within the controllable range, which satisfy the deformation control conditions.

Strength: the maximum compressive stress, the maximum tensile stress, and the maximum shear stress of the structure are 7.79 MPa, 10.1 MPa, and 1.7 MPa respectively, which are lower than the allowable stress of selected bamboo materials.

3 Experience

IBCC 2019 aims to invite global students who are learning architecture, civil engineering, landscape, and other related majors to show the potentials of bamboo as a construction material. Thus, we had such a wonderful opportunity to compete with many other students from around the world. During the competition, we learned a

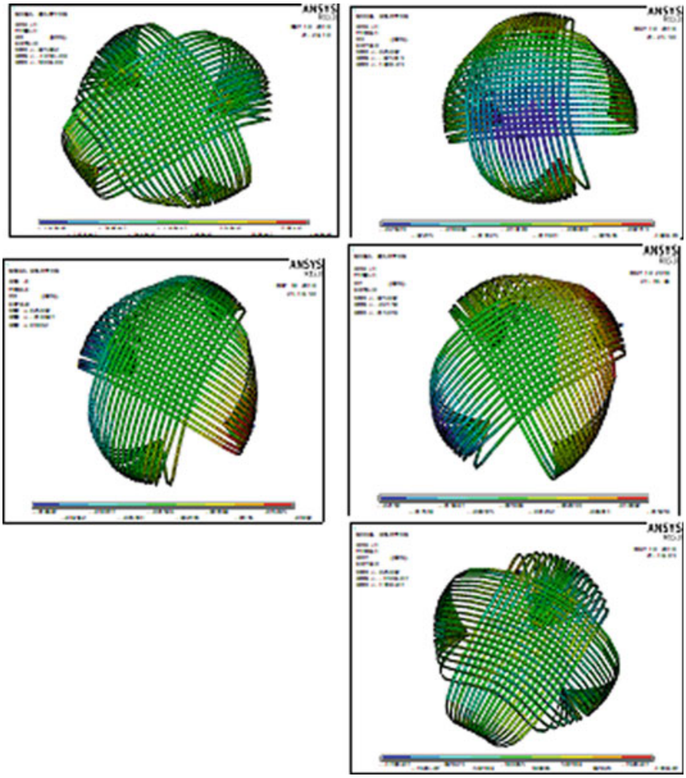

Fig. 5 Structural analysis diagram

lot which we wouldn't normally touch with. Our team, consisting of three students, Yin Zhang, Qing Gong, and Runan Qin, from the architecture department, was led by Mr. Lin Yuxin. From the initial design to the final submission, all the members cooperated very well. We learned how to help each other and how to overcome the difficulties, which were extremely valuable experiences for us.

3.1 Preparation for Presentation in Beijing

One month after submitting the design, we received the good news that our project was shortlisted as one of the top 15 finalists. This result was the best reward for our efforts in the past several months. However, we cannot relax, because the final result was to be decided during the Jury Review Meeting in the coming month in Beijing. Therefore, do our best to prepare the presentation had become a top priority for us. As time was so limited, we almost spent all of our spare time on the discussion of how to show our design concept as well as how to prepare a small model required by the Organizing Committee. As shown in Fig. 6 of the construction flow chart, we made a 1:50 scale model, for which we used hemp rope to strengthen the stability of the structure. Meanwhile, we purchased some little lamps with knitting elements to decorate it. After several days and nights, a realistic model (Fig. 7) was created.

Finally, Zhang Yin and Qin Ruonan represented the team to go to Beijing, and Gong Qing gave supports from Xiamen. When we spoke English fluently to introduce our design to the jury, we were very excited and felt so proud of ourselves.

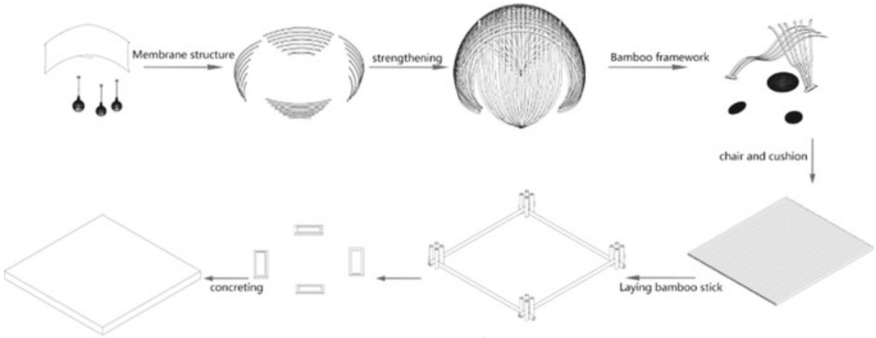

Fig. 6 Construction flow chart for model

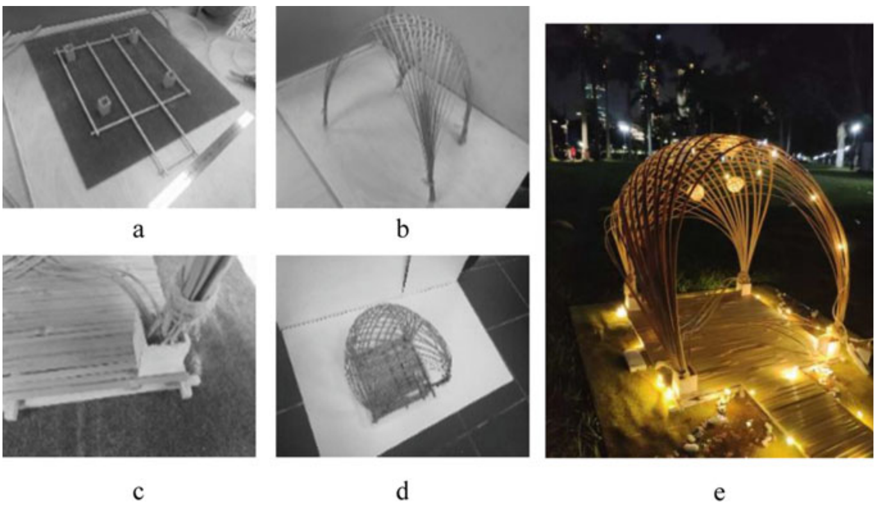

Fig. 7 Photo of the model

3.2 Ideas for the Future

For this design, we paid too much attention to the concept and pavilion's shape, but we didn't give enough consideration for bamboo's performances, such as whether bamboo could really help us to complete the complex weaving to form a building, or whether the space formed by bamboo can accommodate more activities. In Beijing, we saw four structures in 1:1 scale at INBAR garden which were completed by other teams. One of them even accomplished a two-floor structure, for which we think their idea is really a breakthrough to realize a small space with multiple functions. We learned a lot from others through this competition and we hope we could be better in the future.

4 Renderings

Several renderings of the pavilion are provided as below, shown in Fig. 8. The architectural style of bamboo pavilion is unified as a whole, and the seats inside are also woven with bamboo strips, bringing people a comfortable feeling.

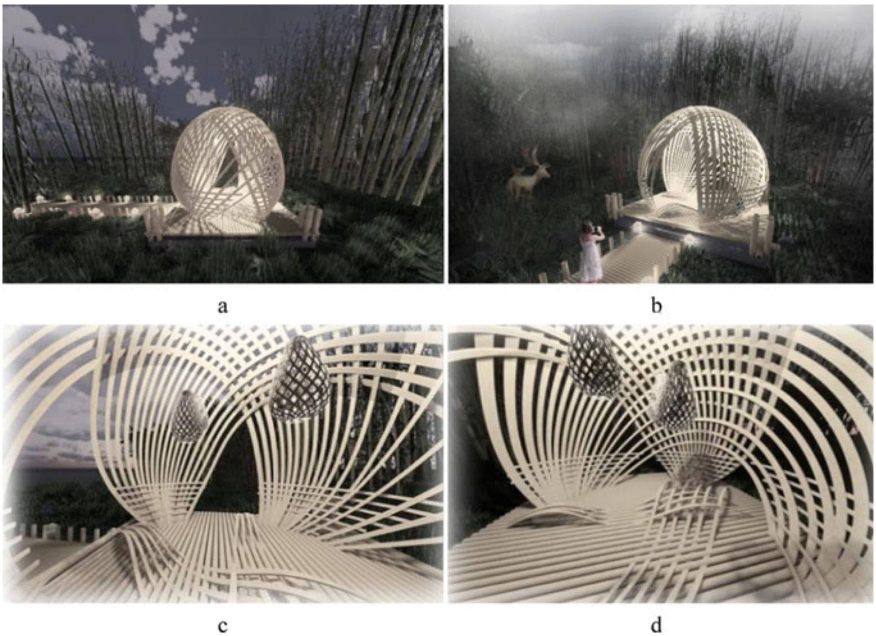

Fig. 8 Renderings: Side perspective (**a**, **b**); Interior space (**c**, **d**)

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