Push and Pull, Varying Tranquility

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Abstract "Push and Pull, Varying Tranquility" is a tea house designed for the 2019 International Bamboo Construction Competition (IBCC 2019). Its form and inner space can be changed by users. We designed the appearance and decoration in light of the characteristics of bamboo. We also want to enhance the relationship between humans and nature by stimulating interactions. To achieve that, we designed a special component and made it to become a part of the building. The space has multiple definitions by using its transparency characteristic to create different experiences and expand the overall space of building in human sensation.

Keywords Bamboo · Variable architecture · Green building

1 Concept Design

Being in harmony has always been an important topic in the field of architecture. The use of natural materials is environmentally friendly which has important social and environmental value. What role natural material plays and how it can inspire people, that are the questions we concern about. Nowadays, participation as an activity has drawn more and more attention from designers and artists [1–4]. People are no longer just viewers in an exhibition, but a part of their artwork. By getting people involved in, artworks and architecture can change their form and appearance, and gain new meanings as well. We want to create opportunities for this kind of involvement and stimulate interactions between people and the building, not only to make people talking to the material which we used but bring them to a new and incredible experience.

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Under the thinking of these ideas, space and materials become the main focuses in this design.

In the aspect of space, we try to create multiple spaces by transparency characteristics, therefore people can experience more than one space in one place.

In the aspect of material, we aim to guide people to experience, understand and appreciate the material by creating a tranquil atmosphere and stimulating interactions. The material we use is bamboo, which has a cylinder shape and slender form as its natural features, and has connotations as one of the "three cold weather friends",[1] and is often praised by Chinese people. Bamboo's natural features and connotations give us the inspiration and ideas of the whole design. We made push–pull sliding doors, the open and close of push–pull sliding parts changes the spatial relationship of the building. The appearance is designed as pure and neat as possible, the distinctive uprightness and hollow-hearted characteristics of bamboo, and vertical arrays of bamboo poles and sheets are used as skin to show the form of bamboo.

We aim to create an interesting connection between architecture and its users, so we designed different spaces with multiple definitions and made them all infiltrated into each other. The architecture has a changeable appearance and special push–pull sliding components. Light and shadow create an incredible experience which also gives users a chance to trigger the change of space.

2 Design Development

2.1 Form Generation

The inspiration of the architectural form is from bamboo which grows in nature. We abstracted the sharp corners from the shape of the bamboo shoot as which of building's roof, and designed two roofs that gradually rise up, symbolizing the blooming and vigorous growth of life. In the design of the building facade and structural form, we adopted the image of bamboo growing vertically in the forest. Part of the wall was designed as a vertical arrangement of bamboo materials to show the vitality of the building. For the design of internal space, we divided the mass into blocks based on its height and created a comparison between empty space and solid masses. Then we added a horizontal structure to form a cubic space, which is nested with other space. Finally, we divided the interior space of the building further by bamboo grill, enriching space layers, and positioning sliding doors (Fig. 1).

[1] "Three cold weather friends": pine, bamboo, and plum blossom. Because these three plants can still maintain tenacious vitality in cold winter, they are the symbol of noble personality in Chinese traditional culture.

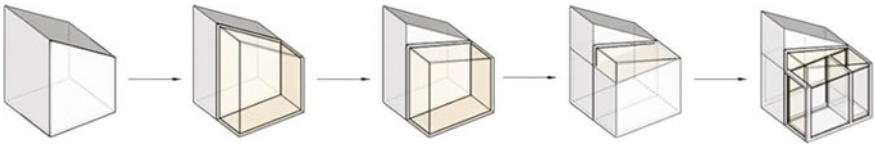

Fig. 1 Form generation

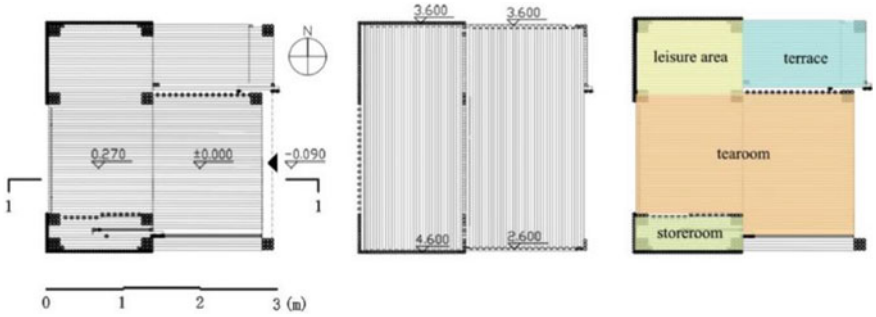

Fig. 2 Floor plan and functional partition

2.2 Floor Plan and Functional Partition

The plan of the building is a regular square. The floor is raised to form a platform where people can stay, sit and enjoy the scenery (Fig. 2). Due to the interactivity and spatial variability of the building, the activities in the space become more varied and enriching. When the sliding doors are not pulled out, the tea house is open to the landscape completely, which could show a clear view. When the doors are pulled out, the tea house is bathed in the light and shadow of the bamboo grill, and the space also becomes more private and quieter than before. In addition, the north and south sides of the building are divided by sliding doors, creating some small space for storage, viewing, and any other purposes (Fig. 3).

2.3 Development of Push–Pull Sliding Component

The change of the spatial interface is achieved through the sliding doors. Considering the human scale and building scale, we finally chose the metal framework of the foldable sofa bed as the inspiration for the design (Fig. 4). Besides, the framework of the door is designed with a uniform spacing and extra space, in case the undulating surface of bamboo ensures smooth sliding and safety [5].

Fig. 3 Space experience and analysis of human activities

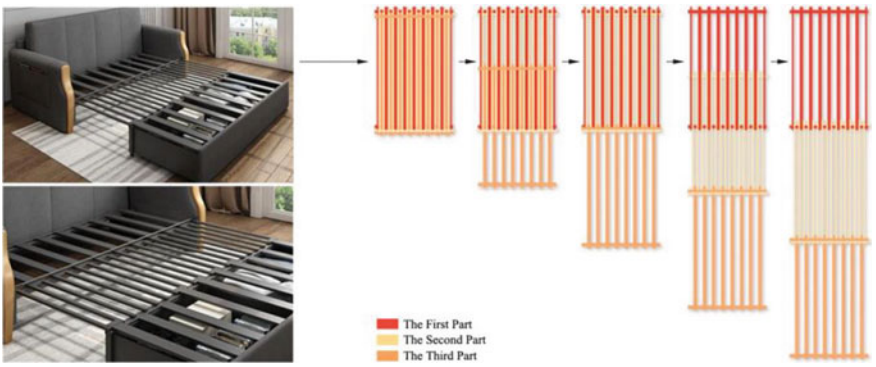

Fig. 4 Inspiration source from furniture. (Left pictures from: https://detail.1688.com/pic/622689974269.html?spm=a261y.8881078.0.0.5d8c6ce2LgLUDx)

The framework is divided into three parts. The first part is installed between the pillars as a fixed part, while the rest has pulleys installed at the grounding points, which ensures that they can be pulled and slid.

The doors on the north side of the building can be pulled out and rotated inward, while the doors on the south side can only be pushed or pulled. By changing the position of the doors, the spatial interface changes between solid and empty, and the privacy level of the space also changes (Fig. 5).

2.4 Sight System Analysis

We analyzed two different states of plans based on the spatial syntax. We converted the virtual reality of the bamboo facade corresponding to the height of human vision

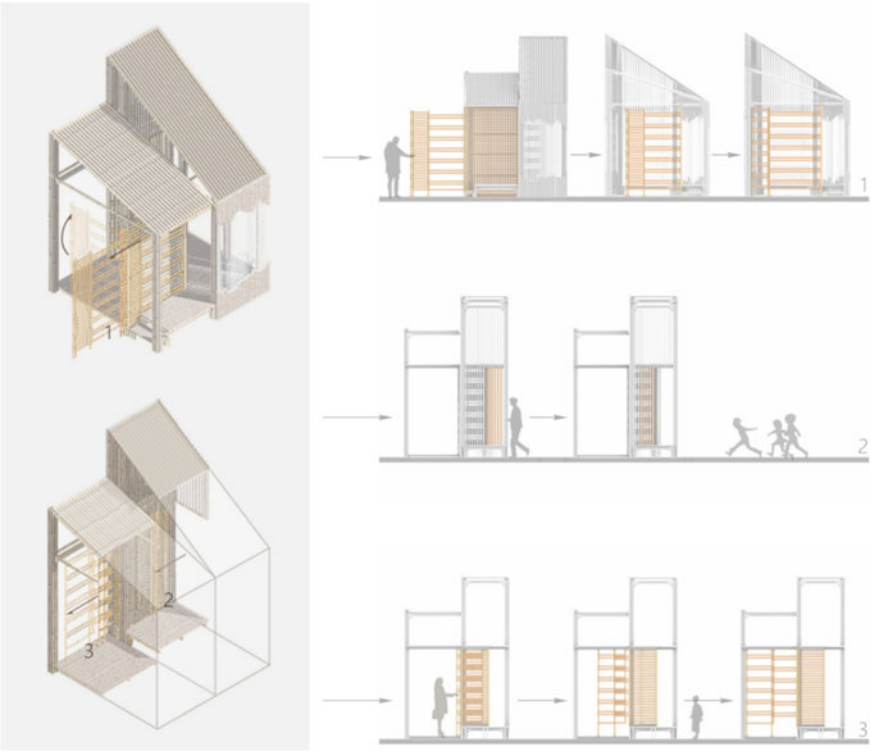

Fig. 5 Analysis of push–pull sliding components

to the building plans and generated distribution color maps based on visual clustering coefficient [6]. We found the results are quite different between the two states, with the door completely open or the door close. Therefore, people can create their ideal space for comfortable by pushing or pulling those components, which is consistent with our original idea to create diverse experiences by promoting interactions between people and buildings (Fig. 6).

2.5 Skin Details: Elevation and Roof

In order to enhance the interaction among building, nature, and human, we made a more in-depth detailed design for the facade and roof skin based on the existing form and frame. For the facades, we placed thin, rotatable bamboo sheets in bamboo tubes of different lengths to form a rhythmic decorative facade. The facade texture formed by bamboo slices was different from which formed by the round bamboos, which added a variety of textures to the building, and also showed the variable forms of bamboo as a building material. In order to increase the feasibility of this idea, we

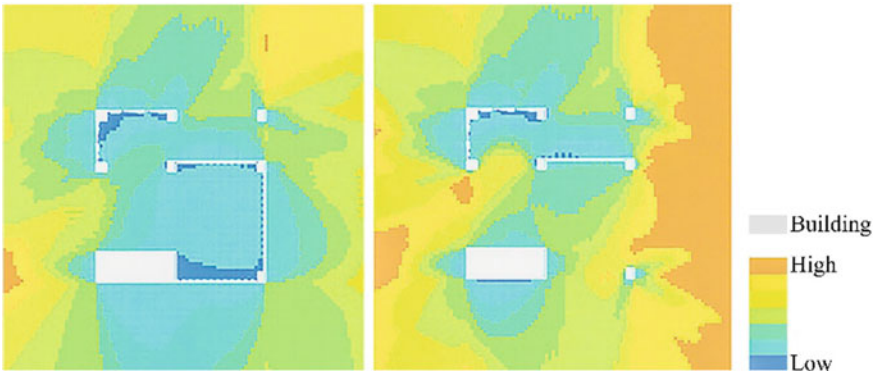

Fig. 6 Distribution color maps based on visual clustering coefficient

used steel pipes to reduce friction at the nodes and guarantee smooth rotation. This facade form also enriched the lighting and shading effect of the building. The rotatable bamboo sheets acted as a sunshade shutter. When the solar radiation intensity changed, people can adjust the amount of light entering the room by rotating the bamboo sheets to ensure a comfortable indoor thermal environment (Fig. 7). When touched by users, the sheets rotated and the light and shadow also flickered, just like the way the wind blew through a bamboo forest. We believe that such a small design stimulates the interaction between people and the building. For the roof, we covered the bamboo frame with a layer of translucent material, so that light can fall through the intervals and make the light and shade effect more magnificent, while at the same time the translucent material can play a role in preventing rains (Fig. 8).

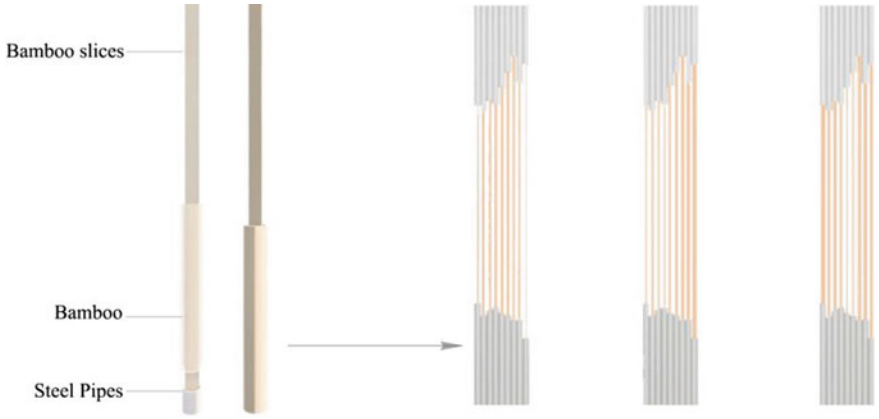

Fig. 7 Rotating the bamboo sheets

Fig. 8 Elevations

2.6 Structure Analysis

The Connection Method of Universal Wheel. When designing the pulley, mobile stability and steering flexibility should be considered. The reasonable structure of the universal wheel largely depends on the stability and the flexibility of the sliding door when it is pushed and pulled. We chose two common connection forms for comparative analysis. One is the shaft-type wheel and the other is the ball-bearing type. By referring to the horizontal speed change and vertical speed change of these two different connecting universal wheels under experimental simulation, it is found that the slope of the speed change curve of the shaft-type wheel is less than which of the ball-bearing type wheel. Under the same level of the horizontal driving force, the ball-bearing type wheel has greater horizontal acceleration and better flexibility, which means under driving force with the same speed, the ball-bearing type wheel is more labor-saving. On a flat road, the speed change of the two types of universal wheels is almost zero, when the universal wheel travels on obstacle roads, the shaft-type universal wheel has a buffer peak while the ball-bearing type wheel travels at a faster speed, showing a cliff-like landing during the landing process without buffering wave crests, which indicates that the axle-type universal wheels are more stable [7].

In order to make the movement of the sliding doors smoother, we lay the guide rails to meet the requirements of a certain level of ground flatness and to meet the smooth performance requirements of the universal wheels. Considering the flexibility of the sliding door movement, we chose the ball-bearing type wheel.

Force analysis of universal wheel. The universal wheel we chose is with a wheel diameter of 100 mm, a wheel width of 5 mm, and a load-bearing capacity of 270 kg.

The density of bamboo was 800 kg/m^3 and the weight of the sliding door was about 3528 N. The relative position between the center of gravity and the universal wheel is shown in the figure as below (Fig. 9).

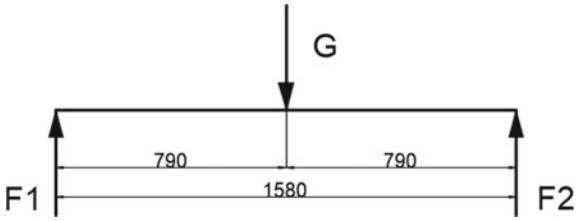

Fig. 9 Schematic diagram of universal wheel forces

According to the vertical force balance equation:

$$\Sigma F_y = 0 \tag{2.1}$$

$$G - F_1 - F_2 = 0 \tag{2.2}$$

The vertical forces on the universal wheel 1 and wheel 2 are:

$$F_1 = F_2 = G/2 = 1,764N \tag{2.3}$$

Design value of load-carrying capacity of universal wheel is:

$$F_{\max} = mg = 270 \times 9.8 = 2,646N \tag{2.4}$$

$$F_1 = 1764N < F_{\max} = 2,646N \tag{2.5}$$

So the selected universal wheel model meets the force requirements.

Stability analysis. The sliding door is moved by the rolling of universal wheels. When the thrust is greater than or equal to the maximum rolling friction, the sliding door moves forward [8]. At this time, the maximum rolling friction couple is:

$$M_{\max} = d \times F_N \tag{2.6}$$

In the formula: d is the rolling friction coefficient. The upper limit of the rolling friction coefficient of the universal wheel and the concrete pavement is 10 mm; F_N is the positive pressure (acting vertically on the supporting surface) of the roller and the supporting surface, which is the weight of the sliding door in the design.

Therefore,

$$M_{\max} = d \times F_N = 10 \times 1.764 = 17.640N \times \text{mm} \tag{2.7}$$

The minimum horizontal thrust F_T required to make the wheel roll can be obtained by the equation:

$$\Sigma M_A(F) = 0 \tag{2.8}$$

$$F_T = M_{\max}/R = 17.640/50 = 352.8N \tag{2.9}$$

Overturning moment produced by horizontal thrust is:

$$M_1 = F_T \times H = 352.8 \times 1.500 = 5.29 \times 10^5 N \times \text{mm} \tag{2.10}$$

Anti-overturning moment of gravity on the sliding door is:

$$M_2 = G \times L/2 = 3.528 \times 1.580/2 = 2.79 \times 10^6 N \times \text{mm} \tag{2.11}$$

As $M_1 < M_2$, so it meets the stability requirements of the mobile process.

2.7 Construction Process and Joints

After the form, function, interactive device, and decorative details were determined, we envisioned the construction process of the building, which provides a clear picture of the design. Once those main components such as foundations, structural columns, beams, and body frames have been constructed, lay the floor and the roof, then install the fixed walls [9–11]. After that, mount the push-and-pull components in the reserved locations [12]. Finally, add the decorative details to complete the whole (Fig. 10).

In order to ensure the feasibility of construction and push–pull components, we consulted a large amount of information about bamboo construction joints, including rope strapping, metal bolts, mortise and tenon joint, and other commonly used construction methods. For push–pull components, we compared various forms of sliding doors and joint connections. We finally decided to use the rail and wheels to reduce friction to ensure that people can move them more easily. One of the wheels is a one-way pulley and the other one is a universal wheel used to cooperate with the rotatable door. The decorative bamboo sheets and tubes of the facades are fixed by round steel pipe to ensure that they are rotatable (Fig. 11).

From form to plan function, from the design of push–pull components to joints connections, from skin details to human activities, we constantly looked up papers and documents, compared varieties of forms to choose the best one, stove to make that every aspect has been detailed considered, to ensure that the original design concept “creating an interesting connection between architecture and its users” is truly realized.

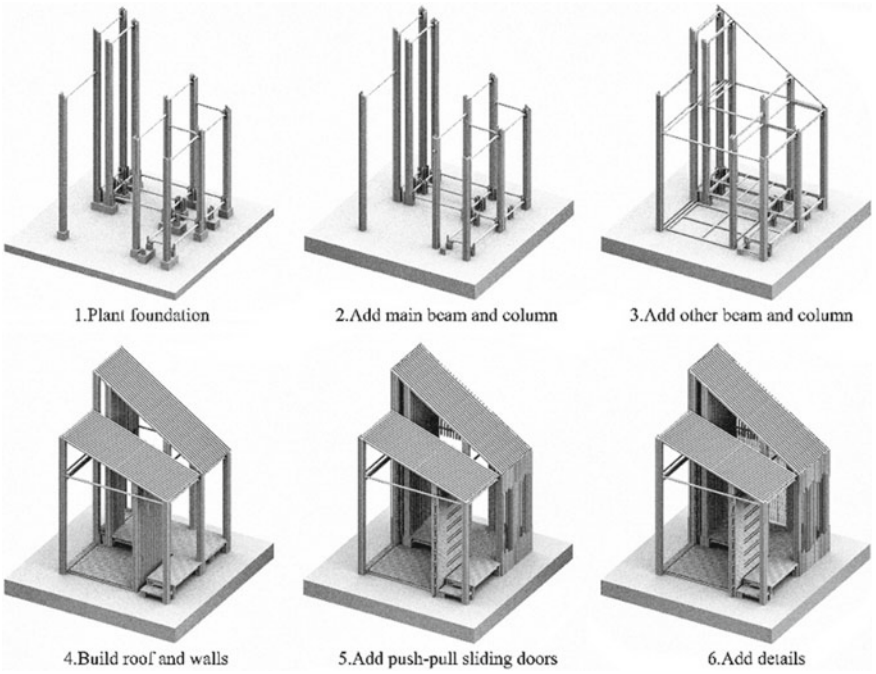

Fig. 10 Construction process

3 Experience

This competition benefited us sufficiently, the team worked closely and made breakthroughs and innovations, our teacher gave us patient guidance and the jury provide us good advice.

As the most important phase of our design, the push–pull sliding components naturally become the focus of the jury. Though the idea is intriguing, it still has shortcomings and there is room for further improvement. The push–pull sliding components work by pure friction, which is simple and can be easily damaged, while there are other forms of force, we can try to improve it. Additionally, we only applied the device to the door and furniture. The door was made as a variable wall that changes the whole space of the building, and the furniture works as a drawer, was made as part of the building. But we didn't expect other parts such as the roof to be variable as well, while a brave attempt just might make the whole design more interesting.

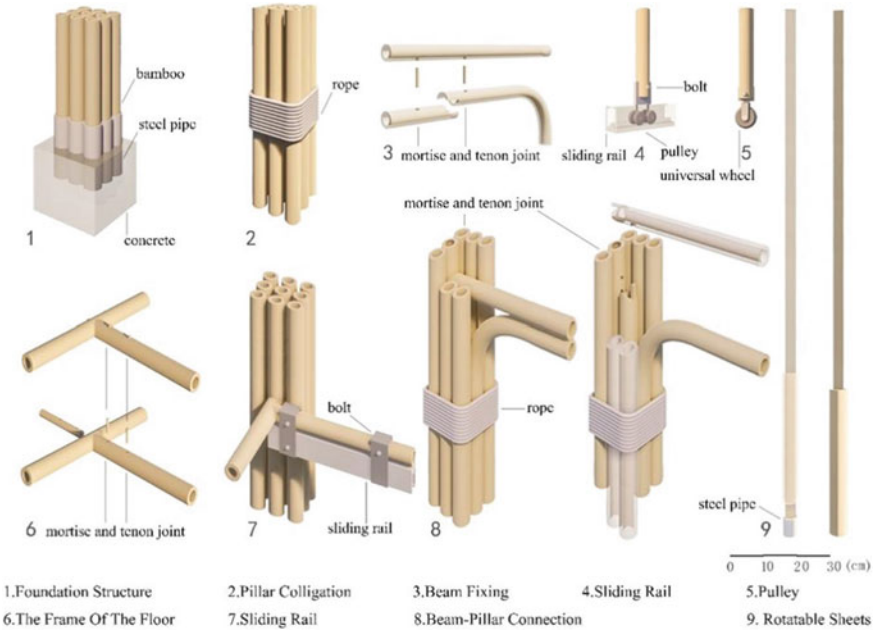

Fig. 11 Joints analysis

4 Renderings

Several renderings of the structure are provided. Figure 2 shows the transparent interface of the building. We designed the blinds, bamboo artifacts that can rotate to show different possibilities of the bamboo material. Figure 3 shows push–pull artifacts formation of the "open" and "close", two different space dialogue with each other, mutual penetration (Fig. 12).

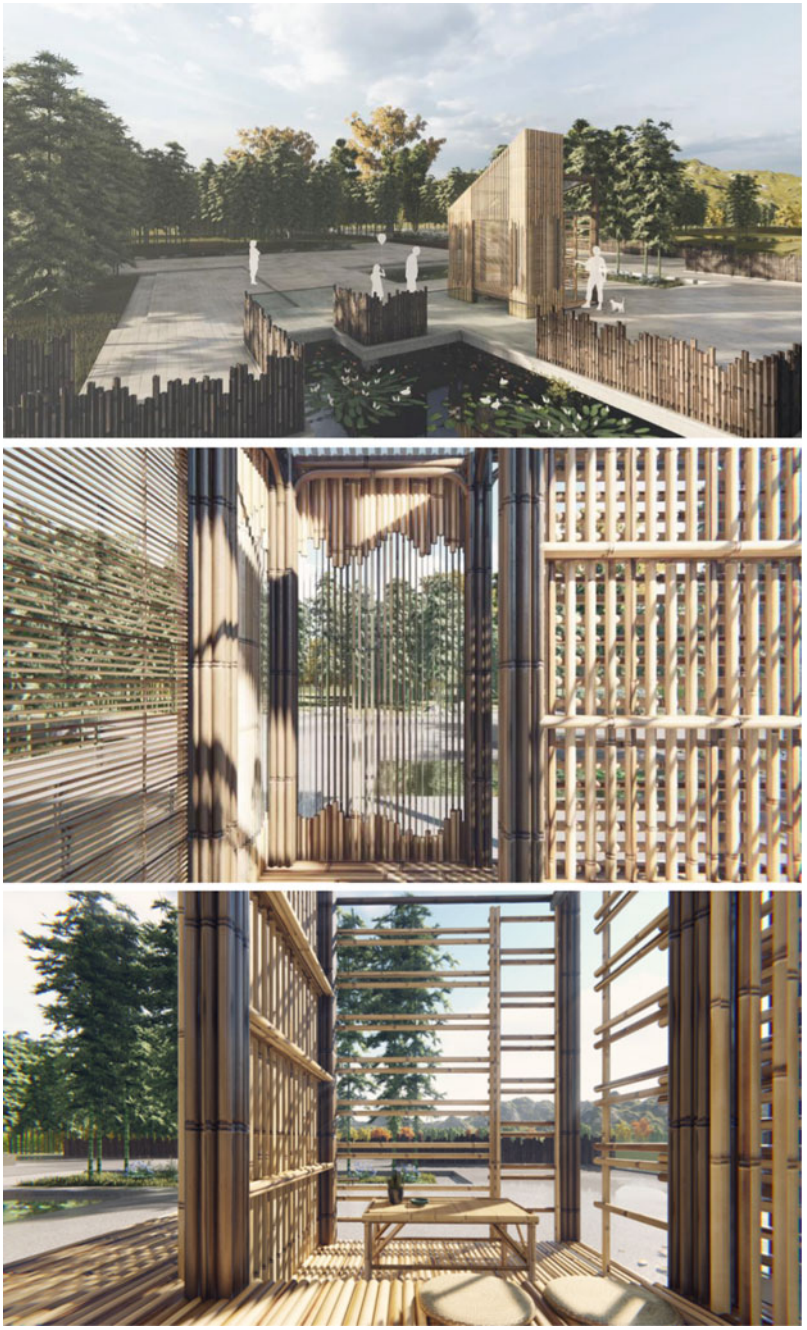

Fig. 12 Renderings of the building

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