Bending Blossom

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Abstract Bending Blossom provides visitors with the feeling of being in a bamboo forest. The structure takes advantage of bamboo's elasticity. Bent bamboo poles of the structure transfer horizontal loads and reduce the risk of buckling under vertical loads. A green roof serves as a thermal buffer that provides a comfortable microclimate with natural ventilation. The bending green roof and bamboo create an elegant form in harmony with nature.

Keywords Bamboo · Bending-active · Gridshell · Sustainable design

1 Background

Due to the speed of its growth and material strength, bamboo culms are widely used in Asian vernacular architecture. But in contemporary architecture they are mostly replaced with concrete and steel. One reason for this replacement is the wide variation in bamboo culms' dimensions and structural properties that are caused by different growing environments. But the unique cellular structure of bamboo culms gives them strength not only in compression and tension but especially when the bamboo culms are bent [1].

The ZCB Bamboo Pavilion is a long-span, bending-active bamboo gridshell that is four floors tall (Fig. 1). A team of researchers from CHUK School of Architecture led by Prof. Kristof Crolla designed the pavilion and, in October 2015, completed

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K. Liu et al. (eds.), *2019 International Bamboo Construction Competition*, Springer Tracts in Civil Engineering, https://doi.org/10.1007/978-3-030-91990-0_14

Fig. 1 ZCB bamboo pavilion [3]

it in Kowloon Bay, Hong Kong, China. Three layers of bamboo culms, 475 in total, were bent and hand-tied into a bending-active, triangulated diagrid onsite.

The pavilion's structure was developed and tested with a series of digital and physical models, including bamboo prototypes [2]. The researchers "flattened" the digital model into straight lines to transfer the culms' intersection points from the digital model onto the physical bamboo culms. The bamboo culms were hand-tied with metal wires because traditional knots are not fireproof [3].

As the ZCB Pavilion demonstrates, active-bending bamboo structures utilize bamboo's natural properties better than pre-bent, curved bamboo structures. But, in practice, there are many more examples of the latter than the former, probably due to the difficulty of designing active-bending structures, especially with an anisotropic, natural material. In other words, the potential of bamboo for efficient and sustainable, active-bending structures still needs to be explored and exploited more fully [4]. For this reason, we designed our pavilion as an active bending structure.

Fig. 2 Concept design sketches

2 Concept Design

The pavilion provides a raised platform to sit and relax on, and from which to observe passers-by. An eye-catching, cantilevered canopy offers shade and rain protection for this platform. The curved shape of the canopy is inspired by an inverted blossom and topped with a green roof to more harmoniously blend into the surrounding horticultural expo (Fig. 2).

3 Design Development

The pavilion consists almost entirely of bamboo. A bolted frame of primary bamboo culms (diameter 10 cm) is filled in with a secondary grid of smaller, tied bamboo culms (diameter 5 cm). The sides of the pavilion are covered with bamboo weave and the raised floor with bamboo laminate (thickness 3 cm). The pavilion's base fits in 3×3 m^2 (Fig. 3b), and the canopy in 4×4 m^2 (Fig. 3a). The pavilion's ceiling is covered with a green roof (Figs. 4 and 5). This green roof helps to maintain the pavilion's shape by weighing down the bending-active structure.

The pavilion is a lightweight, bending-active structure, whose shape and stiffness are created through bending the primary bamboo culms. Bächer et al. [5] state that the bending-active, large-span shell structures of the Mannheim Multihalle were made possible by prefabricated regular grids without shear rigidity that were bent and braced on site. Our pavilion follows a similar approach: the primary bamboo culms are bent by connecting them and loading them with the green roof. We have demonstrated the feasibility of this structural concept with a physical 1:10 prototype (Fig. 6). The secondary culms connect the primary culms into a grid structure.

There are three principles to prevent bamboo from decaying: (1) Shielding from direct sunlight or ultraviolet rays, (2) avoiding exposure to rain and water, and (3) prophylactic treatment to protect from biotic attack [6]. Accordingly, our bamboo structure is covered with a bamboo weave to protect it from UV and humidity.

The pavilion is naturally ventilated, with additional cooling provided by the green roof. The green roof is to be planted with flowers according to the context of the

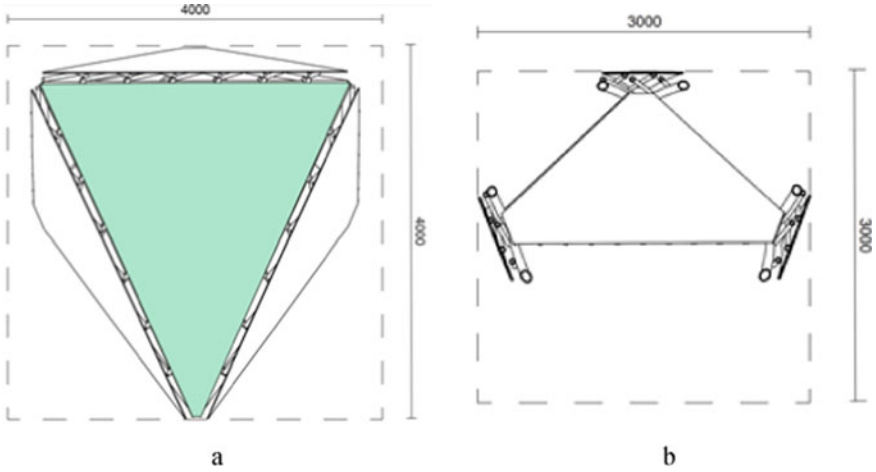

Fig. 3 Roof plan (**a**); Floor plan (**b**)

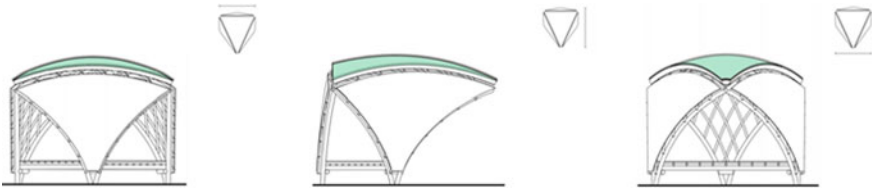

Fig. 4 Elevations

Fig. 5 Section

Fig. 6 Physical model testing

horticultural expo. The canopy's curved shape assists in the drainage of rainwater. The green roof is watered mainly by rainwater. When the green roof needs watering, there is a water pump and hose, integrated into the bamboo culms, to water the grass (Fig. 7).

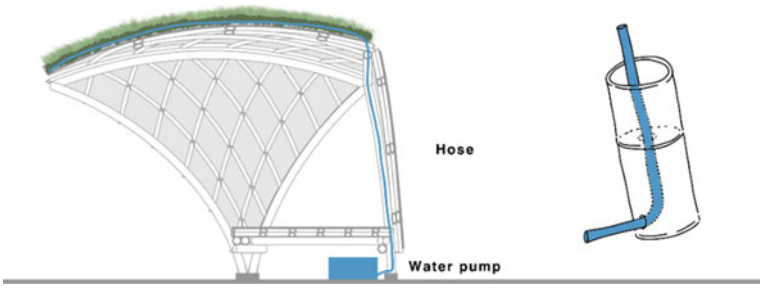

Fig. 7 Irrigation system

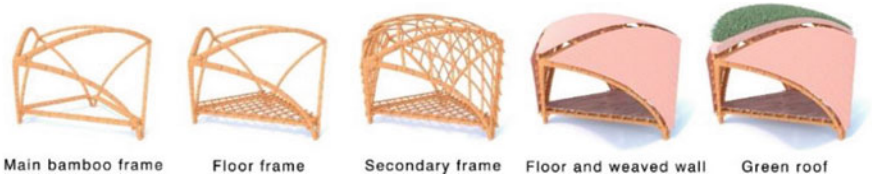

Fig. 8 Construction process

The lightweight pavilion can be moved in one piece, or disassembled by removing the sides' bamboo weave cover, removing the four prices of secondary structure, and disassembling the bolted primary structure (Fig. 8). Figure 9 shows the foundation detail, and Fig. 10 the roof detail.

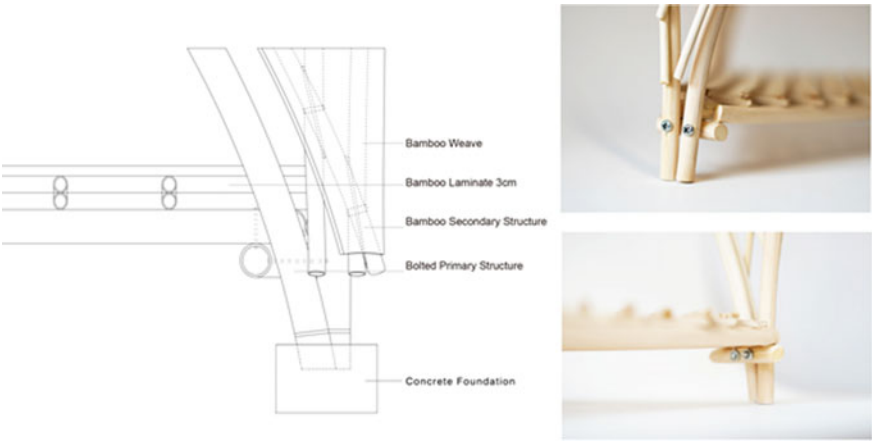

Fig. 9 Foundation construction detail

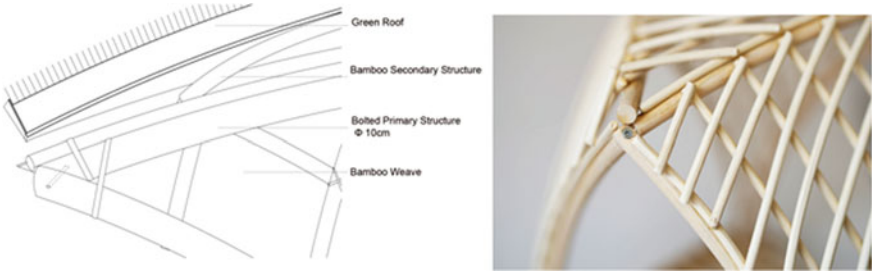

Fig. 10 Roof construction detail

4 Renderings

The renderings in Figs. 11 and 12 show that the bamboo pavilion is a bending-active gridshell. The bolted frame of primary bamboo culms is filled with a grid of smaller, secondary bamboo culms. The structure is covered by bamboo weave to provide shading to visitors. One of the structure's corners is extended, to shelter visitors when they are sitting in the pavilion or standing under the roof (Fig. 12). The bamboo pavilion is suitable to be located in urban and natural environments.

Fig. 11 Rendering of outside view

Fig. 12 Rendering of inside view

5 Conclusions

Our tests with a physical model show that a non-bending structure is not stiff enough and needs additional bracing when dealing with horizontal forces. But the active-bending structure shows a strong ability to prevent buckling and bending from vertical and horizontal forces. Bamboo is good at bending, which provides great potential to create a curved, structural form.

This pavilion design demonstrates that bamboo has multiple advantages as a sustainable building material. Ecologically, for sequestering carbon and providing natural habitat, aesthetically, as a natural material, structurally, due to its strength in active bending, and for construction, since it is easy to build with.

References

1. Crolla, K. 2017. Building indeterminacy modelling—the "ZCB Bamboo Pavilion" as a case study on nonstandard construction from natural materials. *Visualization in Engineering* 5: 15.
2. Crolla, K. 2018. Bending bamboo rules: Beyond century-old typologies. *Journal of Architectural Education* 72 (1): 135–145.
3. Crolla, K., and A. Fingrut. 2016. The design and construction of a bending-active gridshell from natural bamboo.
4. Rockwood, D. 2015. *Bamboo gridshells.* London: Routledge.
5. Bächer, M., B. Burkhardt, and F. Otto. 1978. IL13—Mannheim Multihalle. Stuttgart: Institute for Lightweight Structures, University of Stuttgart.
6. López, O.H. 2003. Bamboo: the gift of the gods. D'VINNI LTDA.