Sustainable Structures
ISSN: 2789-3111 (Print); ISSN: 2789-312X (Online)
http://www.sustain-dpl.com/journal/sust
DOI: 10.54113/j.sust.2023.000025.

CASE REPORT

Lightweight bamboo structures - Report on 2021 International Collaboration on Bamboo Construction

Assima Dauletbek[a,b], Xin Xue[a,b], Xinqi Shen[a,b], Haitao Li[a,b,*], Zixian Feng[a,b], Rodolfo Lorenzo[c], Kewei Liu[d,f], Edwin Zea Escamilla[e], Lianshu Yao[g], Xiaoyan Zheng[a,b]

[a]College of Civil Engineering, Nanjing Forestry University, Nanjing, 210037, China.
[b]Joint International Research Laboratory for Bio-composite Building Materials and Structures, Nanjing Forestry University, Nanjing, 210037, China.
[c]University College London, Gower Street, London, UK, WC1E 6BT.
[d]International Bamboo and Rattan Organisation (INBAR), Beijing 100102, China.
[e]Swiss Federal Institute of Technology in Zurich (ETH Zurich), Zürich, ZH, Switzerland
[f]School of Civil Engineering, Tsinghua University, Beijing 100084, China.
[g]Guizhou Xinjin Bamboo and Wood Products Co. LTD , Chishui 564799, China
[*]Corresponding Author: Haitao Li. Email: lhaitao1982@126.com.

Abstract: 2021 International Collaboration on Bamboo Construction was held from September 1 to December 1, 2021. The practice was held by the College of Civil Engineering of Nanjing Forestry University, University College London, International Bamboo and Rattan Organisation (INBAR) and co-organized by 6 international institutions and national companies of China. Two main bamboo structures were setup by the teachers and students in the campus of Nanjing Forestry University. More than 50 students attended the practice, including international students from different countries. The practice was held to deliver the feasibility and applicability of bamboo in various geometries and different spans, and different areas. Innovative technologies like BIM Revit Architecture and Sketchup were used for the design of bamboo structures. The main principle of the practice was that the raising of bamboo structures should be simple using a minimum of materials aside from bamboo. The results of the project contributed to the popularization of the use of bamboo in the architecture, engineering and construction sectors.

Keywords: Bamboo practice; bamboo structure; bridge; frame

1 Introduction

In 2019, the 1st International Collaboration on Bamboo Construction (named as China-UK International Collaboration in Bamboo Structure Practice originally) was held by the College of Civil Engineering of Nanjing Forestry University with University College London, International Bamboo and Rattan Organization (INBAR) and other international institutions and companies. The practice was conducted to contribute to the development of the research in the field of bamboo applications in the architecture, engineering and construction sectors. Since ancient times, bamboo has been a material used both for making household utensils and for building houses and bridges in places of its rich abundance. Over the past decade, more than 300 studies have been conducted on the structural application of bamboo in modern realities [1, 2]. Based on obtained results, affordable and lightweight bamboo can be used in its original and engineered forms for various structures, including residential and public buildings, social housing, traditional housing and post-disaster homes [2-8].

Received: 9 August 2022; Received in revised form: 2 December 2022; Accepted: 12 December 2022

The original bamboo has a long history as a building material in China. Traditional bamboo structure houses are more common in Yunnan, Sichuan, Fujian and other ethnic minority residential areas in China, such as Dai bamboo building. With the development of bamboo connection technology [9-12] and the bold imagination of architects, the modern original bamboo architecture is more beautiful and unique, such as the India Pavilion of the Shanghai World Expo [13]. In Southeast Asia, bamboo architecture is also a favorite of architects, such as Thailand 's Neder School and Vietnam 's mountaintop restaurants, have made full use of bamboo [5].

The main goal of the 2019 Bamboo Structure Practice was to deliver the feasibility and applicability of bamboo in various geometries, in different systems, for different spans, and as inspiration for a bio-design. In addition, any innovative method can be used for modelling and realization such as Building Information Modelling (BIM), 3D scanning, parametric design or robotic fabrication. A future bamboo housing was the case study of the practice proposed by Lorenzo et al. [14]. The design of the house was a self-supporting modular system made of short bamboo culms with minimal two-pole connections for long spans (Fig. 1).

Fig. 1. Future bamboo housing – case study of 2019 China-UK international collaboration in bamboo structure practice (*credit: Haitao Li, Rodolfo Lorenzo*).

The 2nd International Collaboration on Bamboo Construction was organized from September 1 to December 2, 2021. The practice was held by the College of Civil Engineering of Nanjing Forestry University and University College London, International Bamboo and Rattan Organization (INBAR) and co-organized by other international institutions and national companies of China. More than 50 students attended the practice, including international students from different countries. The purpose of this project was to create a lightweight bamboo bridge and a bamboo frame with simple connections in a short time. The design principle of the structures included the simple connection of bamboo culms with handy materials like nails, rings and wires. For the lifting of structures, only a human force of a small number of people was provided. The maximum construction time was considered as 5-6 hours for each structure. The main idea of the practice was to demonstrate the simplicity of constructing lightweight bamboo structures using a minimum of materials aside from bamboo and a human force.

2 Why bamboo?

In the last decade, the demand for bamboo has significantly increased since sustainable building materials have become a key to resilient cities [15, 16. Bamboo in its original and engineered form can be a good alternative to conventional building materials due to its sustainability and strength [5-6,14]. Similar to wood, the mechanical characteristics of bamboo change depending on the species, age, moisture content, and grain direction. According to previous studies, bamboo in its original form is comparable to hardwoods, mild steel, cast iron, and aluminium alloys [15-20]. Architects and practitioners choose bamboo for its sustainable characteristics and corresponding low environmental impact. Moreover, its excellent mechanical properties, light weight, and ductility enable the creation of strong, earthquake-resistant and bionic architectural structures that fit into the natural environment [17]. Tab. 1 shows the selected mechanical properties of bamboo- and wood-based materials.

Bamboo in its original and engineered forms was used as the main building material of multiple famous structures all over the world. INBAR Fish-Shaped Bamboo Pavilion was first presented at the 2021 Yangzhou Horticultural Expo. A lightweight and semi-open space with the largest possible span was achieved through the creative use of a minimum number of round bamboo culms (Fig. 2 a).

Table 1. Selected mechanical properties of bamboo- and wood-based materials

Property, MPa	LBL [18-23]	LVL [18, 24-26]	Glulam [25, 27, 28]	WPC [29]	Douglas Fir [24]	Teak [24, 30]
f_b	63.87–128.4	54.2–71.7	48.74	26.1	85	80
E_b	8320–10912	15400–19300	15370	4100	13400	9400
f_t	90–124	88.5	16.5–26	11.6	107.6	95–155
E_t	10700	13790	9400–11900	3000	11600–14800	-
f_c	29.55–72.60	36	24–31	28.1	49.9	41.1
E_c	8396–11022	-	8600	3700	-	-
f_s	7.15–17.5	7.34	2.7–4.3	8.1	7.8	8.9
Species	Phyllostachys Pubescens, Dendrocalamus strictus	Douglas-fir	Douglas-fir	Pine	-	-

Note: LBL – laminated bamboo lumber; LVL – laminated veneer lumber; Glulam – glued laminated timber; WPC – wood plastic composite; f_b, f_t, f_c, f_s – strength parallel to the grain in bending, tension, compression, and shear; E_b, E_t, E_c – MOE parallel to the grain in bending, tension, and compression.

Round bamboo culms are also successfully used in bionic architecture. The shapes of the Baizhishan Tourist Reception Center, in Chongqing, China, achieved with the help of tall bamboo arches, not only perform supporting functions but also beautifully repeat the mountain ranges, which make the architectural complex part of the natural landscape (Fig. 2 b). Gatoo et al. [3] and Wagemann et al. [6] proposed a low-cost emergency housing unit for the Roxas, the region in the Philippines, which was hit by a typhoon in November 2013. The researchers proposed a transitional bamboo house based on the traditional Filipino house called Bahay Kubo (Fig. 2 c). The principle of the emergency house included the construction of a modular system, connections without nails and screws, and resistance to earthquakes and strong winds. The use of engineered versions of bamboo has also increased in the construction of buildings and structures. Fig. 2 c shows an example of the world gardening exposition in Beijing, which was made of laminated bamboo members. As can be seen, bamboo in its original and engineered forms can be used in various systems, shapes and spans, and is a good material for any bionic forms in the architecture.

3 Lightweight bamboo structures

From September 1 to December 1, 2021, the College of Civil Engineering of Nanjing Forestry University together with University College London, International Bamboo and Rattan Organization (INBAR) and other institutions held the 2nd International Collaboration on Bamboo Construction. The cases of the practice were two lightweight structures made of round bamboo culms - a bamboo bridge and a bamboo frame. The main goal of the practice was to demonstrate the simplicity of lightweight bamboo structures' construction. The practice had the following innovations: the design of structures based on the Chinese traditional bridges and frames, the simple connection of bamboo culms with handy materials like nails, rings and wires, and the short time of construction which required only a human force of a small number of people.

(a) Fish-Shaped Bamboo Pavilion

(b) Baizhishan Tourist Reception Center

(c) Emergency house Bahay Kawayan

(d) The world gardening art exposition in Beijing

Fig. 2. INBAR Fish-shaped Pavilion in China [3, 6, 17].

For practice, 100 round Moso bamboo (Phyllostachys pubescens) culms were adopted. The age of the culms was 3-4 years old. Tab. 2 shows the mechanical properties of these Moso bamboo culms. For the design of structures, BIM Revit Architecture 2021 and SketchUp computer programs were used. In total, 50 students attended the practice online and offline, and 2 teams with 12 students in each were designed to construct each structure. According to the design, the construction of each structure should have taken no more than 5-6 hours.

Table 2. Mechanical properties of Moso bamboo culms

Category	f_b (MPa)	E_b (MPa)	f_t (MPa)	E_t (MPa)	F_c (MPa)	E_c (MPa)	F_s (MPa)
With node	98.15	17359	125.97	9759	64.64	12790	8.86
Without node	-	-	162.74	13201	64.41	13942	8.35

3.1 Bamboo bridge

A traditional Chinese bridge was adopted as an analogue of the bamboo bridge (Fig. 3 a) [31]. BIM Revit Architecture 2021 with the material take-off option was used to design the structure and calculate the amount of material for the construction of the bridge. Tab. 3 shows the geometric information of bamboo bridge. Round Moso bamboo culms of 4 m and 2 m long with a diameter of 100 mm were adopted for the construction. Connection type: steel rings (Fig. 3 b). The size of the connecting piece can be adjusted through the bolts at its end, and its diameter can be adjusted freely within the range of 91-114mm to solve the problem of inaccurate diameter of the original bamboo tube. In the construction process, the steel ring is first adjusted to the maximum diameter so that it can fit into the bamboo tube at the predetermined position. Then put in another throat hoop, and tighten the bolt, complete the first bamboo tube fixed. Finally, extend another bamboo tube into the second throat hoop, and tighten the bolt at the predetermined position to complete the connection between the two bamboo tubes.

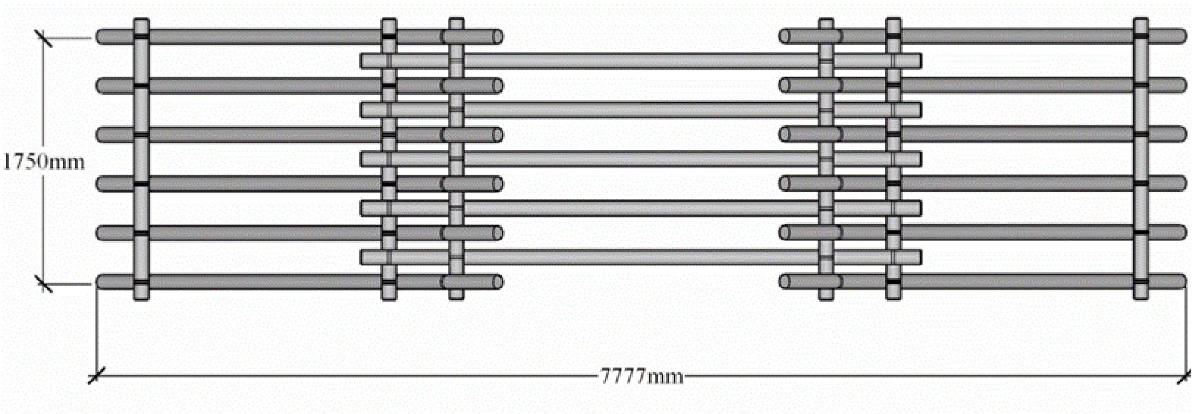
Table 3. Geometric information of bamboo bridge

Length (m)	Width (m)	Height (m)	Angle of grounding (°)
7.777	1.750	1.800	45

According to the design, the construction of the bamboo bridge was divided into 3 parts: the construction of 2 wings and the top. In total, 12 students were involved in the construction, 4 students for each wing and the top. The construction of the bamboo bridge was completed in the following steps. Fig. 5 shows the flowchart of this setup.

(a) Traditional Chinese bridge [31]

(b) Connection rings



(c) Size of the bridge

Fig. 3. Bamboo bridge.

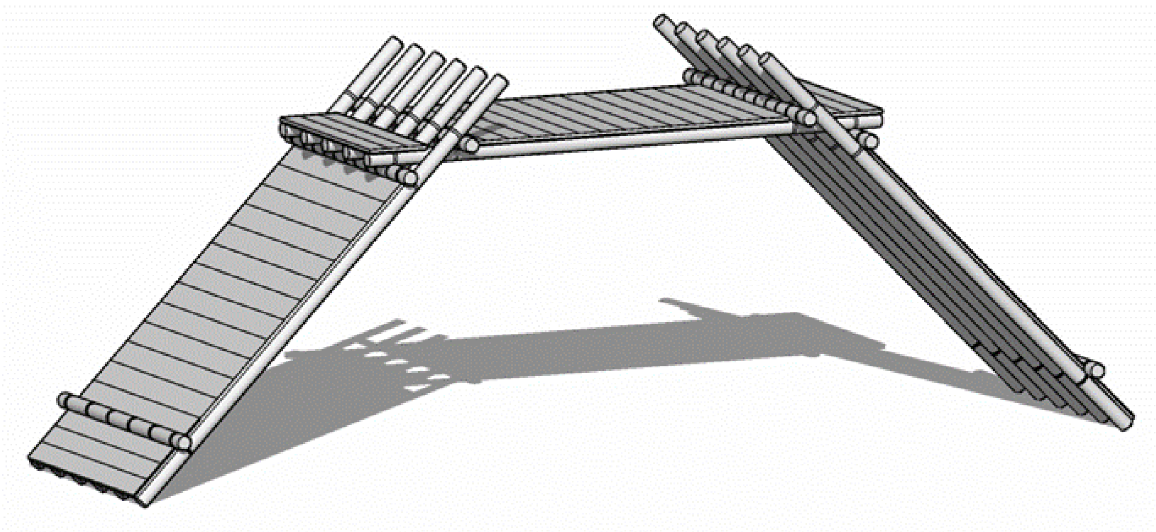


Fig. 4. BIM Revit model of the bamboo bridge.

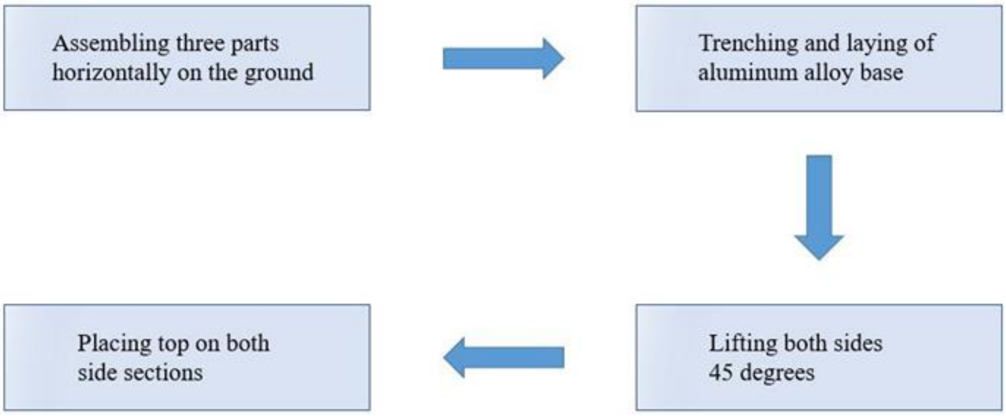
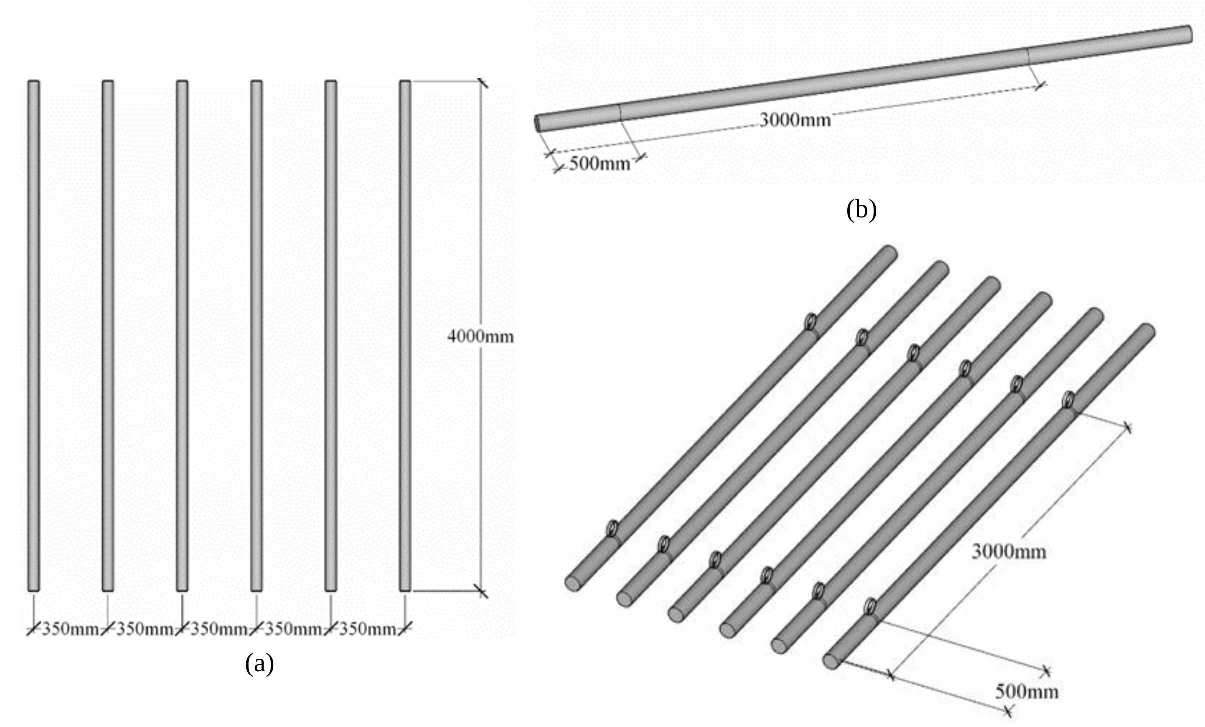


Fig. 5. Flowchart of bamboo bridge construction.

For the bridge wings, 6 culms of 4 m long were chosen and placed on the ground with a step of 350 mm between the cross-sections of each culm, Fig. 6 a. From the edges of each culm distances of 500 mm and 3000 mm were measured and marked, Fig. 6 b. The pair of connection rings were fastened on the culms, over the distances that were just measured and marked, Fig. 6 c.



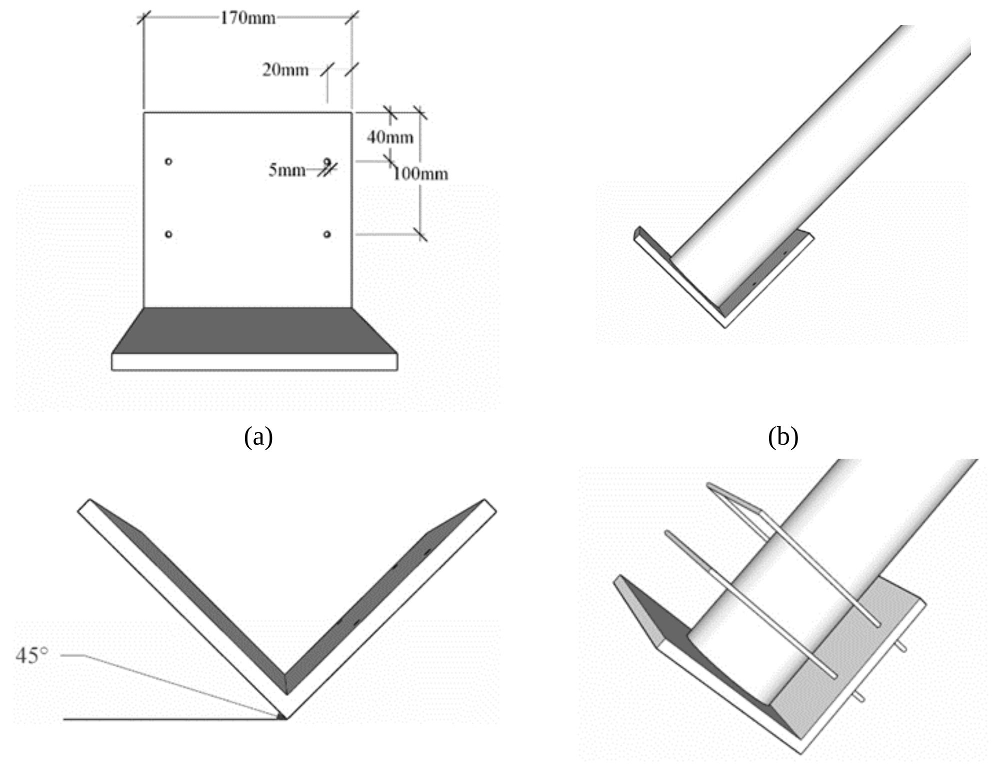
(c)

Fig. 6. Construction steps of the bamboo bridge.

Each wing consisted of 6 round bamboo culms, 6 steel basements were chosen per wing, Fig. 7 a. Iron wires were connected to the basements through the holes at a distance of 130 mm, Fig. 7 b. The basements were adopted to secure the bridge wings to the ground. The basements with wires were put on each bamboo culm of the bridge wings. Fig. 7 c, d.

To fix the wings at measured positions, 2 bamboo culms of 2 m long were selected, and the distances of 125 mm from each edge of the culm were measured and marked, Fig. 8 a. The remaining space between these 2 marks was divided into 5 equal parts with a step of 350 mm.

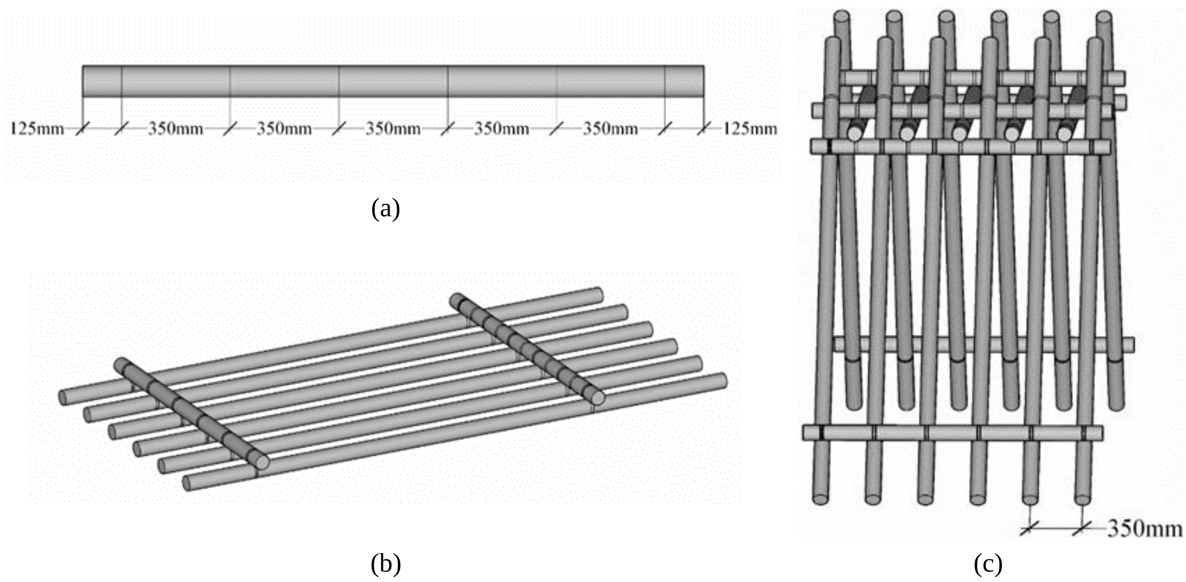
Then, 2 m culms were put into connecting rings so that both ends of the culms protruded 125 mm beyond the cross-section line of the outermost wing culms and the distance between the cross sections of culms was 350 mm, Fig. 8 b.



(a) (b)

(c) (d)

Fig. 7. Construction steps of the bamboo bridge.



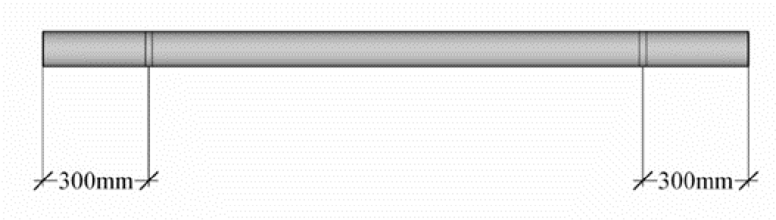
(a)

(b) (c)

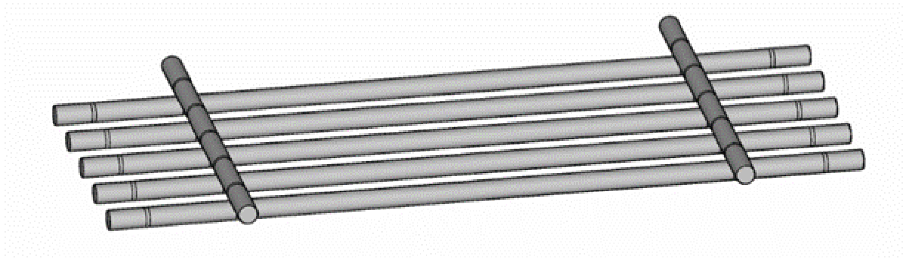
Fig. 8. Construction steps of the bamboo bridge.

The culm located at a distance of 500 mm is the lower horizontal culm; the culm located at a distance of 3000 mm is the upper horizontal culm, Fig. 8 c. The second wing of the bridge was done following the same steps.

For the top of the bridge, 5 round bamboo culms were selected and placed on the ground at a step of 350 mm between the cross-sections of each culm. From the edges of the culms, the distances of 200 mm and 480 mm were measured and marked, and 10 pairs of connection rings were placed at the marks of 480 mm. Then, 2 culms of 2 m long were selected, and the distances of 300 mm from each end of the culms were marked, Fig. 9 a. The 2 m culms were put into the rings so that the marks of 300 mm coincided with the cross-sectional line of the outermost top culms, Fig. 9 b.



(a)



(b)

Fig. 9. Construction steps of the bamboo bridge.

The bridge wings, that were prepared before, were placed 45 degrees on the ground, and the top part was placed on the top of the wings, Fig. 10.

(a) Lifting the left wing of the bridge

(b) Lifting the right wing of the bridge

(c) Placing the top of the bridge

(d) Finished bamboo bridge

Fig. 10. Construction steps of the bamboo bridge.

It should be noted that an additional horizontal bamboo culm with two tilted bamboo culms was added to each side of the bridge wings in order to ensure the stability of the structure. Overall, the construction of the bamboo bridge required 12 students and 6 hours of work. After the installation of the bridge, the parts of the structure were covered with a water-resistant coating.

3.2 Bamboo frame

SketchUp computer software was used for the design of the lightweight bamboo frame. The size of the structure constituted 2900×2000×3867 mm (height, width, length). According to the design, the construction of the frame consisted of 2 parts. Similar to the bamboo bridge, the frame consisted of 2 wings and 4 students were involved in the construction of each side. The following materials were prepared per side: 72 connection rings, 2 handsaws, 1 ladder, bamboo strips, and construction foam. Fig. 11 shows the SketchUp model of the bamboo frame. Fig. 12 shows the process of the bamboo frame.

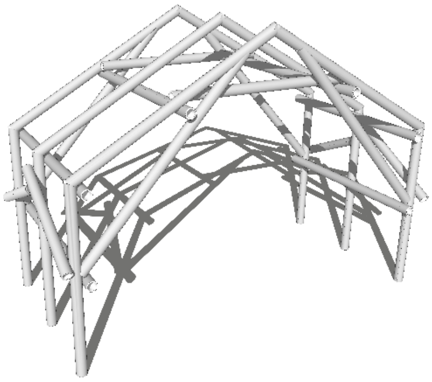


Fig. 11. SketchUp model of the bamboo frame.

For each side of the frame, 6 bamboo tubes of 4 m long, 7 culms of 2 m long and 4 culms of 2.4 m long were chosen and placed on the ground. The culms of 4 m and 2 m long were marked according to Fig. 13 a, b. Then, the basements were fixed to the edges of the culms in the same way as in the bamboo bridge.

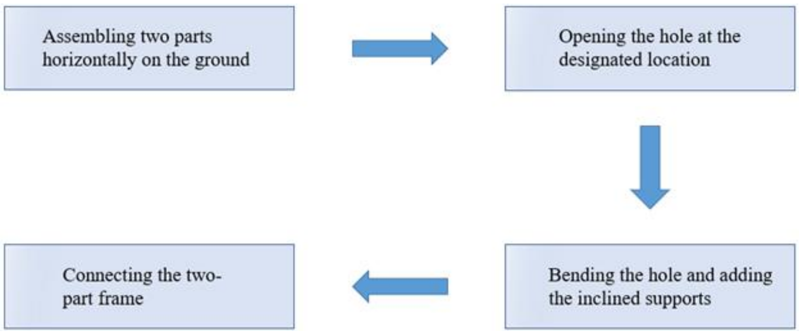
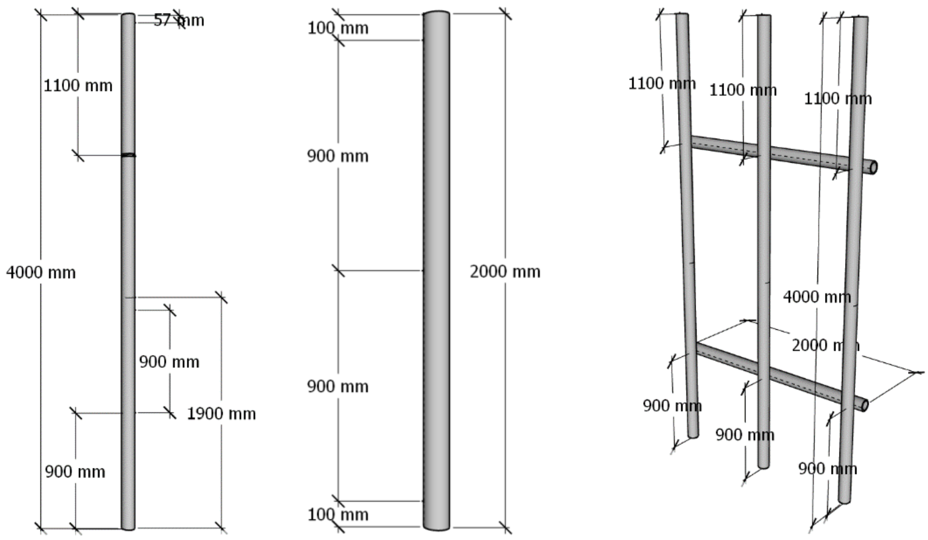


Fig. 12. Flowchart of bamboo frame construction



(a) (b) (c)

Fig. 13. Construction steps of the bamboo frame.

Bamboo tubes of 4 m and 2 m long should be assembled on the ground (by connection rings) according to Fig. 13 c. Each side of the frame has 3 openings. Opening 1 (middle opening) was made at the position of 1.8 m away from the bottom of the bamboo tube according to Fig. 14.

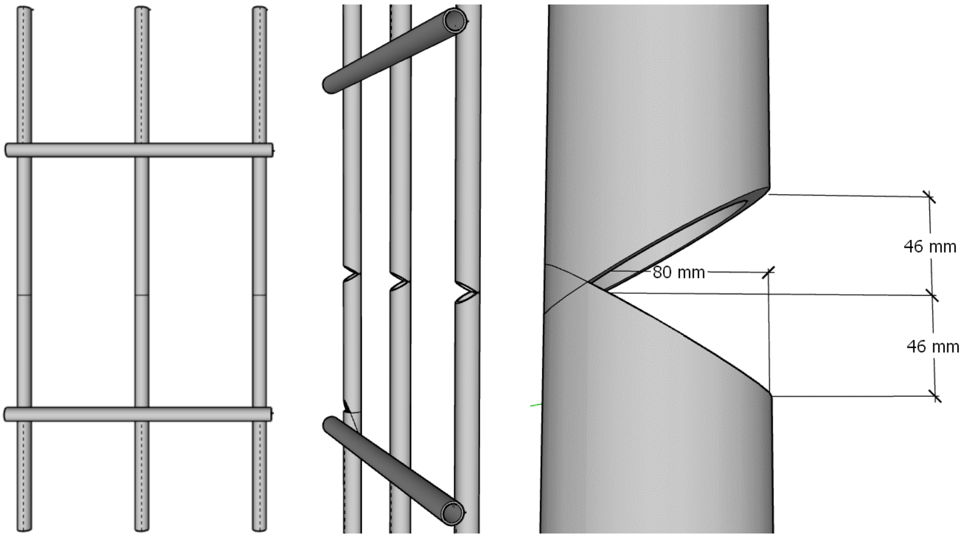
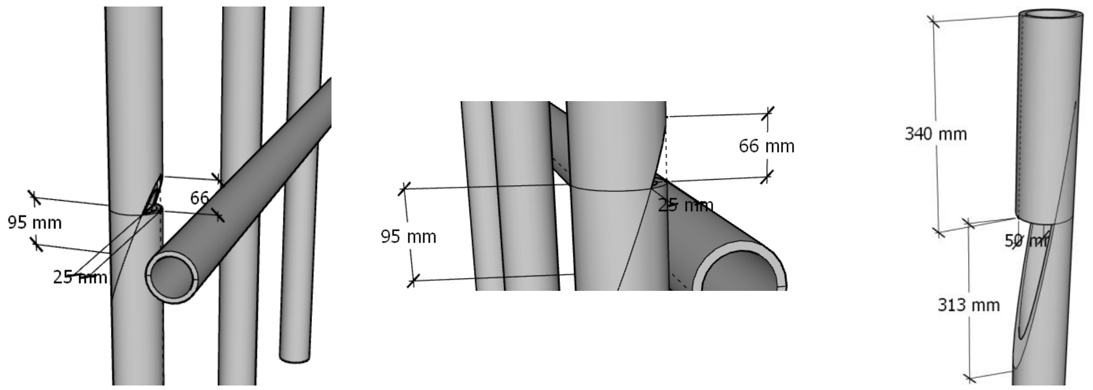


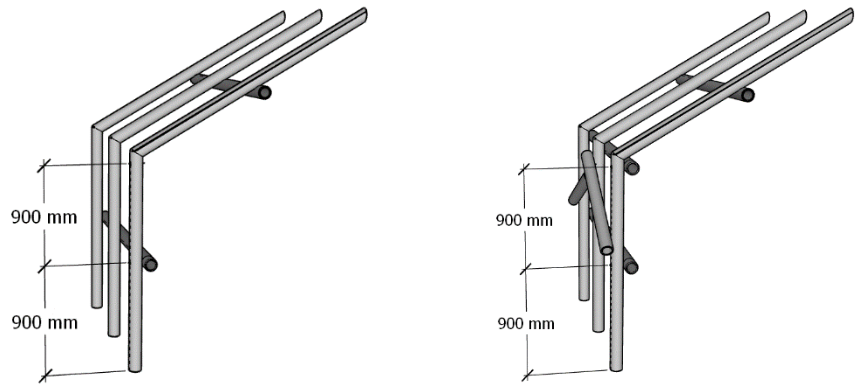
Fig. 14. Dimensions of Opening 1 of the bamboo frame.

Opening 2 (bottom opening) was done on the 1st and 3rd bamboo culms, 95 mm away from the first transverse connection according to the Fig. 15 a, b. And Opening 3 (top opening) was made on 1st and 3rd bamboo culms, 340 mm from the top of the bamboo tube, as shown in Fig. 15 c.



(a) Opening 2 (b)Opening 2 (c) Opening 3

Fig. 15. Dimensions of Openings 2 and 3 of the bamboo frame.



(a) (b)

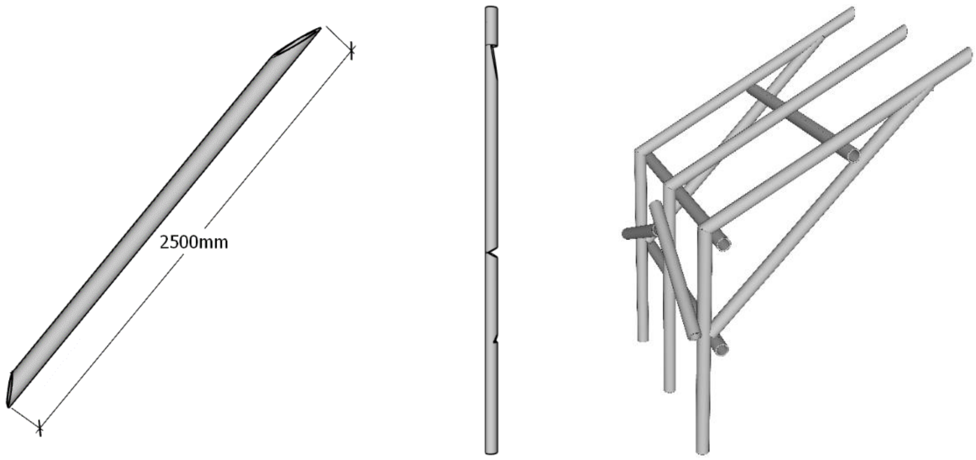
Fig. 16. Construction steps of the bamboo frame.

On the ground, the connected structure was bent at the point of Opening 1. The bamboo strips were placed inside Opening 1 and construction foam was added. The structure was bent and the bending results are shown in Fig. 16 a (the Opening 1 is no longer seen). On the ground, using the connection rings, the additional bamboo culm was fixed at the position below the bent point and use two 1.5 m long bamboo culms as inclined supports as shown in Fig. 16 b. The structure was supported with inclined culms-connectors at the positions of the remaining top and bottom openings, Fig. 17. In order to ensure the reliability of the support, both ends are connected with screws and reinforced with CFRP.

The second wing of the frame was constructed following the same steps. When both sides of the bamboo frame were prepared, each wing was placed on the ground vertically and the tops of the wings were connected using a 2 m long bamboo culm, bamboo strips, iron wire and foam, Fig. 18. To ensure the stability of the structure, the top connections were covered by CFRP sheet and The Sanyou Resin adhesive L500 series with a tensile strength of 30 MPa. Overall, 8 students completed the construction of the bamboo frame in 8 hours. After the installation of the structure, each opening was covered by CFRP, and the parts of the frame were covered with a water-resistant coating. Fig. 19 shows the completed lightweight bamboo frame.

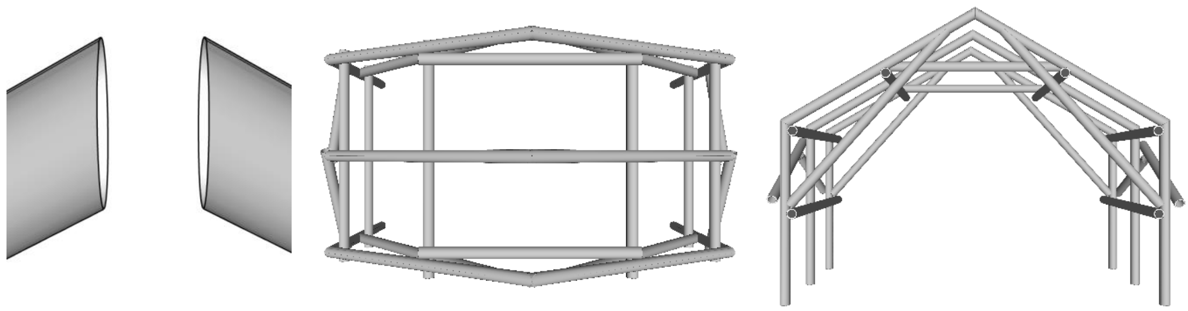
The main lesson learned from the practice was that bamboo is a convenient material for lightweight structures that require speedy construction. Despite its round shape, which to some extent complicates the use of bamboo in structural applications, the construction of the lightweight bamboo bridge and bamboo frame turned out to be easy, not requiring a lot of human force and time, provided the correct design. The use of BIM Revit Architecture 2021 and SketchUp computer software made it possible to quickly and efficiently calculate the number of necessary materials, as well as design the simplest ways to connect the culms.

However, the bamboo culms have different diameters along the length of the bamboo. Therefore, students spent more time choosing and preparing culms of similar sizes. Moreover, when designing in BIM Revit Architecture 2021, the slipping of bamboo culms from connecting rings was not taken into account, which in turn affected the stability of the bridge structure. Therefore, during the construction of the bridge, it was decided to add additional culms to stabilize the structure, which was not considered during the design of the bridge and, accordingly, during the purchase of material.



(a) Inclined culm-connectors (b) Openings 2-3 (c) Connected wing

Fig. 17. Construction steps of the bamboo frame.



(a) Top connection (b) Finished structure

Fig. 18. Construction steps of the bamboo frame.

(a) Connecting the top of the frame (b) Finished bamboo frame

Fig. 19. Construction steps of the bamboo frame.

It took 12 and 8 people, respectively, to build the bamboo bridge and frame, without the use of machinery and other equipment. Due to the light weight of bamboo, it was easy for students to work with it. The construction of both structures took 2 working days.

4 Conclusions

From September 1 to December 1, 2021, the 2nd International Collaboration on Bamboo Construction (named as China-UK International Collaboration in Bamboo Structure Practice originally) was organized by the College of Civil Engineering of Nanjing Forestry University, University College London, International Bamboo and Rattan Organization (INBAR) and other international institutions and national companies of China. The purpose of the practice was to demonstrate the feasibility of bamboo for the construction of lightweight small-scale structures. The practice cases were a bamboo bridge and bamboo frame designed using BIM Revit Architecture 2021 and SketchUp tools. The use of computer programs demonstrated the possibility of fast and accurate design of lightweight small-scale structures made of round bamboo culms. When designing, it is necessary to consider the variation of the diameters of the bamboo culm to ensure the stability of the structure. The practice had the following innovations: the design of structures based on the Chinese traditional bridges and frames, the simple connection of bamboo culms with handy materials like nails, rings and wires, and the short time of construction which required only a human force of a small number of people. The results of the practice demonstrated that bamboo is a suitable natural building material for the construction of strong and stable lightweight structures with simple joints, the construction of which requires 5-6 hours and a human force. The installation of the objects involved worldwide students who got acquainted with the structural properties of round bamboo culms and learned how to build small-scale architectural structures in a short time.

Acknowledgement

The writers gratefully acknowledge Usama Sayed, Ziang Wang, Jinglong Zhang, Patrick Adjei Mahdi Hosseini, Ben Chen and others from the Nanjing Forestry University for helping. Thank for the support from Joint International Research Laboratory of Bio-composite Building Materials and Structures (JIRLBBMS), Ganzhou Sentai bamboo Co. LTD, Guizhou Xinjin Bamboo and Wood Products Co. LTD, Guangxi Lvjing Bamboo Industry Co., LTD, Jiangxi Feiyu Bamboo Stock Co. LTD and so on.

Funding Statement

The research work presented in this paper is supported by the National Natural Science Foundation of China (Nos. 51878354 & 51308301), the Ministry of Housing and Urban-Rural science project of Jiangsu Province under Grant No. 2021ZD10, 333 Talent High-Level Project of Jiangsu Province, and Qinglan Project of Jiangsu Higher Education Institutions. Any research results expressed in this paper

are those of the writers and do not necessarily reflect the views of the foundations.

CRediT authorship contribution statement

Assima Dauletbek: Project leader for the practice, Investigation, Formal analysis, Writing – original draft. **Xin Xue**: Practice member, Investigation, Writing – original draft. **Xinqi Shen**: Practice member, Investigation, Writing – original draft. **Haitao Li**: Conceptualization, Funding acquisition, Supervision, Investigation, Formal analysis, Writing – review & editing. **Zixian Feng**: Practice member, Investigation. **Rodolfo Lorenzo**: Supervision, Writing – review & editing. **Kewei Liu**: Supervision, Writing – review & editing. **Edwin Zea Escamilla**: Supervision, Writing – review & editing. **Lianshu Yao**: Supervision, offering bamboo tubes. **Xiaoyan Zheng**: Supervision, Writing – review & editing.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

References

[1] Dauletbek A, Li H, Lorenzo R, Corbi I, Corbi O, Ashraf M. A review of basic mechanical behavior of laminated bamboo lumber. Journal of Renewable Materials 2022; 10: 273–300. https://doi.org/10.32604/jrm.2022.017805.

[2] Dauletbek A, Li H, Xiong Z; Lorenzo R. A review of mechanical behavior of structural laminated bamboo lumber. Sustainable Structures 2021; 1(1): 000004. https://doi.org/10.54113/j.sust.2021.000004.

[3] Gatóo A, Wagemann E, Ramage M. Bahay Kawayan. 2015. Bahay Kawayan. A Transitional House for the Philippines.

[4] Lei T, Lorenzo R, Mimendi L. 2021. Numerical analysis of a reciprocal bamboo structure with bolt-steel pipe connections.

[5] Mimendi L, Lorenzo R, Li H T. An innovative digital workflow to design, build and manage bamboo structures. Sustainable Structures 2022; 2(1): 000011. https://doi.org/10.54113/j.sust.2022.000011.

[6] Wagemann E, Gatóo A, Ramage M. 2015. Post-disaster housing in bamboo.

[7] Haitao Li, Wei Xu, Chen Chen, Lianshu Yao, Rodolfo Lorenzo. Temperatures influencing on the bending performance of laminated bamboo lumber. Journal of Materials in Civil Engineering ASCE 2022; https://doi.org/10.1061/(ASCE)MT.1943-5533.0004730.

[8] Haitao Li, Ben Chen, Benhua Fei, Hang Li, Zhenhua Xiong, Rodolfo Lorenzo, Changhua Fang, Mahmud Ashraf. Mechanical properties of aramid fiber reinforced polymer confined laminated bamboo lumber column under cyclic loading. European Journal of Wood and Wood Products 2022; 80: 1057-1070. https://doi.org/10.1007/s00107-022-01816-4

[9] Villegas L, Morán R, García J J. A new joint to assemble light structures of bamboo slats. Construction and Building Materials 2015; 98: 61-68. https://doi.org/10.1016/j.conbuildmat.2015.08.113.

[10] Oka G M, Triwiyono A, Awaludin A, Siswosukarto S. Experimental and theoretical investigation of bolted bamboo joints without void filled material. Applied Mechanics and Materials 2015; 776: 59-65. https://doi.org/ 10.4028/www.scientific.net/AMM.776.59.

[11] Hu H, Yang J, Wang F, Zhang Y. Mechanical properties of bolted joints in prefabricated round bamboo structures. Journal of Forestry Engineering 2018; 3(5): 128-135. https://doi.org/10.13360/j.issn.2096-1359.2018.05.020.

[12] Hong C, Li H, Lorenzo R, Wu G, Corbi L, Corbi O, Xiong Z, Yang D, Zhang H. Review on connections for original bamboo structures. Journal of Renewable Materials 2019; 7(8): 713-730. https://doi.org/10.32604/jrm.2019.07647.

[13] Naidu D R, Kewei L. India pavilion, Expo 2010 Shanghai, China, 2010. Industrial Construction 2013; 12: 81-85. https://doi.org/10.16414/j.wa.2013.12.016.

[14] Lorenzo R, Mimendi L. Digitisation of bamboo culms for structural applications. Journal of Building Engineering 2020; 29:101193. https://doi.org/10.1016/j.jobe.2020.101193.

[15] U. Sayed AD, H. Li, X. Xue, R. Lorenzo. A review on the mechanical behaviour of bamboo reinforced concrete beams. Journal of Renewable Materials 2022; 10(12): 3629–3657. https://doi.org/10.32604/jrm.2022.022624.

[16] Dauletbek A, Zhou P. BIM-based LCA as a comprehensive method for the refurbishment of existing dwellings considering environmental compatibility, energy efficiency, and profitability: a case study in China. Journal of Building Engineering 2022; 46:103852. https://doi.org/10.1016/j.jobe.2021.103852.

[17] Liu K, Shi Y, Harries K, Yang J, Jin W, Shi Y, Wu J, Jacome P, Trujillo D. Bamboo: a very sustainable construction material - 2021 international online seminar summary report. Sustainable Structures 2022; 2

(1): 000015. https://doi.org/10.54113/j.sust.2022.000015.
[18] Chen G, Yu YF, Li X, He B. Mechanical behavior of laminated bamboo lumber for structural application: an experimental investigation. European Journal of Wood and Wood Products 2020; 78: 53–63. https://doi.org/10.1007/s00107-019-01486-9.
[19] Li H, Wu G, Xiong Z, Corbi I, Corbi O, Xiong X, Zhang, H, Qiu, Z. Length and orientation direction effect on static bending properties of laminated Moso bamboo. European Journal of Wood and Wood Products 2019; 77: 547–57. https://doi.org/10.1007/s00107-019-01419-6.
[20] Li H, Deeks A, Zhang Q, Wu G. Flexural performance of laminated bamboo lumber beams. Bioresources. 2016; 11: 929–43. https://doi.org/10.15376/biores.11.1.929-943.
[21] Jorissen A, Voermans J, Jansen M. Glued-laminated bamboo: node and joint failure in bamboo laminations in tension. Journal of Bamboo and Rattan 2007; 6: 137–44.
[22] Ni L, Zhang X, Liu H, Sun Z, Song G, Yang L, Jiang, Z. Manufacture and mechanical properties of glued bamboo laminates. Bioresources 2016; 11: 4459-71. https://doi.org/10.15376/biores.11.2.4459-4471.
[23] Sharma B, Gatoo A, Ramage M. Effect of processing methods on the mechanical properties of engineered bamboo. Construction and Building Materials. 2015; 83: 95–101. https://doi.org/10.1016/j.conbuildmat.2015.02.048.
[24] Wood Handbook, Wood as an Engineering Material. Madison WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory 2010.
[25] Zhang X, Que Y, Wang X, Li Z, Zhang L, Que Z, Komatsu K. Experimental behavior of laminated veneer lumber with round holes, with and without reinforcement. Bioresources 2018; 13: 8899–8910. https://doi.org/10.15376/biores.13.4.8899-8910.
[26] Huang Y, Ji Y, Yu W. Development of bamboo scrimber: a literature review. Journal of Wood Science. 2019; 65 (25): 1–10. https://doi.org/10.1186/s10086-019-1806-4.
[27] Marx C, Moody R. Bending strength of shallow glued-laminated beams of a uniform grade. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory 1981. https://doi.org/10.2737/fpl-rp-380.
[28] Sousa H, Branco J, Lourenco P. Glulam mechanical characterization. Advanced Materials Forum VI, 1–2 2013; 730–732: 994–999. https://doi.org/10.4028/www.scientific.net/MSF.730-732.994.
[29] Hugot F, Cazaurang G. Mechanical properties of an extruded wood plastic composite. Mecanique & Industries 2009; 10: 519–24. https://doi.org/10.1051/meca/2010010.
[30] Verma C, Chariar V. Development of layered laminate bamboo composite and their mechanical properties. Composites Part B-Engineering 2012; 43: 1063–1069. https://doi.org/10.1016/j.compositesb.2011.11.065.
[31] China Culture Daily. https://nepaper.ccdy.cn/html/2017-12/27/content_219726.htm, 2017 (accessed 27 December 2017).