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Exploring bundle bamboo split technique in bending *dendrocalamus asper* for landscape structure

Meor Abdullah Zaidi Meor Razali[1], Sapura Mohamad[1], Lee, L. Y.[1], Mohd Sabrizaa Abd Rashid[2], Ahmad Mazlan Othman[3]

[1]Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor, Malaysia
[2]Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, Seri Iskandar, Perak, Malaysia
[3]Bamboo Jungle Adventure, Sungai Siput (Utara), Perak, Malaysia

E-mail: meorabdullahzaidi@graduate.utm.my

Abstract. Bamboo is one of the fastest-growing natural construction materials and is locally available in most developing countries, including South America, Africa, and Asia. Bamboo is a “green gold” plant in the tropical forest. It is a fast-growing monocotyledon species belonging to the Gramineae family (Bambusoideae) and requires a short time for re-production. Bamboo’s physical strength provides builders from ancient times until today an opportunity to use bamboo as a natural and sustainable construction material for building houses and structures. Due to its capability to bend, bamboo is the most preferred material in vernacular construction and lately in Southeast Asia countries which borne new trend in building design. The built-environment professionals, namely landscape architects, architects, and engineers in Malaysia, still lack knowledge of bamboo, especially on bending capabilities, as one of the sustainable construction materials. Less concern was given to researching the capabilities of bamboo’s ability to bend, even though its strength is more than steel and provides various design opportunities compared to other sustainable materials. Different types of bamboo present different strength capacities. Therefore, the aims of this research is to compare and determine their strength capacity, bending criteria and species suitability for design and construction in Malaysia. This paper collects published literature on experimental studies on the different methods of Hot and Cold Bending Methods which allow bamboo to bend to suit designer needs and concentrate on Malaysian *Dendrocalamus asper* (Buluh Betung), which considered as tough and durable species, as the primary construction material for landscape structures. Bundle Bamboo Split (BBS), identified as one of the bending techniques adopted for an experimental project, using BBS of 0.8m radius, produces a prototype for a landscape structure. The findings indicate observation of works by a team of craftsmen trained by an expert in bamboo construction who used to produce bamboo structures from Bali, Indonesia, highlighted tools and procedures in bamboo construction. In short, this paper will also enhance the use of bamboo as an accessible, durable, creative and sustainable construction material that represents the local identity of Tropical Malaysia Landscape Architecture.

1. Introduction

Bamboo, a member of the Gramineae family (Bambusoideae), exhibits a diverse range of species that can be categorized into two main groups: monopodial, which thrives in temperate regions, and sympodial, which flourishes in tropical areas. This resilient plant is particularly well-suited for growth in semi-tropical and tropical climates, with the largest diversity of bamboo species found in China, boasting an impressive 500 native species [1]. India follows closely behind with 130 species documented [2], while Indonesia is home to 143 bamboo species [3]. In Malaysia, there are a total of 80 bamboo species, with 20 of them possessing significant commercial value [4].

Bamboo's physical characteristics make it a highly sought-after material. It is renowned for its flexibility, as it is capable of bending without breaking.[5] Additionally, bamboo exhibits remarkable strength, comparable to that of steel [6]. Its elegant and organic shape further adds to its aesthetic appeal.[7] Furthermore, bamboo has been recognized as a sustainable material, aligning with the principles of environmental conservation and sustainability [8]. The current interest in bamboo extends beyond its physical attributes. Various projects around the world highlight bamboo's versatility and potential for innovation. For instance, the Sustainable Design and Architecture Firm in Bali (Ibuku project) showcases the elegance of bamboo in its architectural designs, embellishing the landscapes of Bali as well the Bamboo Pavilion in China demonstrates the architectural possibilities that bamboo offers. Nurdiah [9] concurs, where in Indonesia, bamboo helps in establishing settlement, and also been utilized in housing projects in Manila and sustainable ecological villages in Brazil, further exemplifying its diverse applications [10] .

Where in Malaysia, researchers have surveyed the traditional use of bamboo, finding that it has been historically used by indigenous people for building settlements and decorating palaces of the Sultan [11]. Additionally, it has been observed that bamboo is utilized as functional tools in Malay kampungs. These findings categorize bamboo under the field of ethnobotany, specifically in relation to its importance for local communities [12] [13] [14]. Bamboo has been widely utilized by past and possibly present communities because of its abundant availability and ease of use for construction, which has been passed down through generations. It is necessary to implement new techniques and uses for bamboo as a sustainable material in order to solidify its status as such. Therefore, the aim of this research is to compare and determine their strength capacity, bending criteria and species suitability for design and construction in Malaysia.

1.1 Bamboo as Sustainable Material

Bamboo, an incredibly versatile plant, has garnered attention for its ability to thrive in unfavorable soil conditions, requires fewer pesticides and fertilizers and endure low water availability. This exceptional adaptability makes bamboo an appealing option for cultivation in regions characterized by arid climates or limited access to water resources. With a modest water requirement of less than 200mm, bamboo has proven its resilience in environments where other plant species struggle to survive.

One of the most notable attributes of bamboo is its remarkable growth rate, which contributes to its reputation as a valuable resource. Within a few months, bamboo can reach a height of 3–30 m with a diameter up to 30 cm and is ready for harvest in 3–4 years [15].

Overall, the adaptability and rapid growth rate of bamboo make it a promising candidate for cultivation in regions with challenging environmental conditions. Its ability to thrive in poor soil and withstand limited water availability positions bamboo as an attractive solution for areas facing arid climates or water scarcity. Furthermore, the substantial biomass yield achieved during harvests highlights the economic and ecological value of bamboo as a sustainable resource. During the initial harvest, bamboo can yield a dry biomass of approximately 30 tonnes, and subsequent crops of bamboo have the potential to produce even higher biomass, ranging from 40 to 50 tonnes [16]. It is a significant output considering its relatively short growth period.

Additionally, bamboo biomass holds promise in the manufacturing sector. Its fibrous nature and strength make it an ideal material for the production of paper, textiles, and composite materials. The versatility of bamboo biomass extends to the construction industry, where it can be utilized for the production of structural elements, such as beams and columns. The lightweight and high strength-to-weight ratio of bamboo make it an attractive alternative to traditional building materials, contributing to sustainable construction practices. Due to this aspect, bamboo has become a material that reproduce biomass with high capacity and reproduce in shorter time compared to timber which takes 10-30 years, whereas it takes just 4-5 years to grow [17].

Figure 1. Bamboo under Sustainable Development Goals (Source: International Bamboo and Rattan Organization (INBAR).

Figure 1 description derived from International Bamboo and Rattan Organization website clearly demonstrate how bamboo plays a crucial role in achieving the goals set forth in the SDG frameworks.

In his study, Zhao [18] emphasizes that bamboo can effectively contribute to achieving seven of the 17 Sustainable Development Goals (SDGs) identified by the United Nations, as it is a suitable material for fulfilling these goals in:

i. SDG 1: No Poverty
Bamboo and rattan provide an important source of livelihood for millions of people, particularly in rural areas.

ii. SDG 7: Affordable and Clean Energy
Bamboo can be a sustainable, scalable, and renewable source of energy, which takes pressure off other forest resources.

iii. SDG 11: Sustainable Cities and Communities
Bamboo is strong, flexible, widely available and affordable, and has been used as a construction material for thousands of years.

iv. SDG 12: Responsible Consumption & Production
Bamboo and rattan can be transformed into a wide range of low-carbon products and commodities, replacing everything from single-use plastics to steel.

v. SDG 13: Climate Action
Over time, bamboo plants and products can store more carbon than certain species of trees. Bamboo and rattan are also a resilient source of income for climate-vulnerable communities.

vi. SDG 15: Life on Land
Bamboo and rattan are an important part of biodiverse ecosystems and can help protect the forests in which they grow.

vii. SDG 17: Partnership for the Goals
With a network of Member States spread across the world, INBAR plays a strong role in promoting bamboo and rattan for sustainable development.

1.2 Bamboo as Construction Material

Bamboo, known for its exceptional strength, rapid growth, and versatility, has been employed as a building material for centuries across various cultures as discussed by Hidelgo [19] and De Araujo [20] Its character which similar to steel; strength-to-weight ratio, sustainability in term of sourcing and tensile strength offers builders whom looking for material that are sustainable for their construction[21].

As a grass, bamboo is a highly renewable resource. Following its harvest, the plant has the remarkable ability to regenerate from its pre-existing root system, thereby eliminating the necessity of replanting. This creates a significantly different production of construction supplies compared to timber, which takes years to regrow [22]. In recent years, bamboo has garnered considerable interest in the field of architecture, owing to its sustainable qualities and potential for creating visually striking structures, [7] thanks to works of family of Hardy based in Bali, Indonesia. One notable technique in bamboo construction is the Bundle Bamboo Split (BBS) method, which involves splitting bamboo poles into slender strips and reassembling them to form composite elements.

The environmental benefits of bamboo are widely acknowledged in the academic community due to its remarkable growth rate and sustainability. Bamboo, being one of the fastest-growing plants on Earth, possesses the unique ability to grow several feet within a mere 24-hour period. This rapid growth allows for more frequent harvesting compared to traditional trees commonly used in wood product manufacturing. Consequently, bamboo cultivation requires fewer pesticides and fertilizers, resulting in a reduced environmental impact.

One of the significant advantages of bamboo is its excellent carbon sequestration capabilities. It surpasses most trees in absorbing carbon dioxide (CO2) and releasing oxygen, making it an effective tool for mitigating climate change. This quality makes bamboo an environmentally friendly alternative to other materials that have a higher carbon footprint.

Furthermore, bamboo's versatility makes it suitable for various applications, including construction, furniture, flooring, and textiles. Its wide range of uses allows it to replace materials that may have a more significant environmental impact, thereby contributing to sustainable practices.

Nevertheless, it is crucial to consider responsible sourcing and proper management practices when utilizing bamboo. Concerns have arisen in certain regions regarding the expansion of bamboo plantations leading to habitat destruction and displacement of native vegetation. To maintain the ecological benefits of bamboo, it is imperative to promote sustainable cultivation and ensure responsible harvesting practices.

In conclusion, bamboo stands out as a viable alternative that promotes ecological balance and sustainability in various industries. Its rapid growth, minimal need for pesticides and fertilizers, and carbon sequestration capabilities make it an environmentally friendly material. However, it is essential to address concerns related to responsible sourcing and management practices to fully realize the ecological benefits of bamboo.

1.3 Bending Dendrocalamus asper for Landscape Structures

Dendrocalamus asper, also known as Buluh Betong, is a widely recognized species in Southeast Asia that is highly valued for its durability and strength in construction [23] [25] [26]. According to Awaluddin [24], *Dendrocalamus asper* has impressive compression and tensile strength. Malamit [27] also found that this species is a superior substitute for wood because it shares a similar pH value with wood species used for making composite lumber.

Architect and engineer duo Eleena Jamil Arkitek [28] and Mazlan Othman [29] in Malaysia have taken on the challenge of incorporating bamboo, particularly this specific species, into their innovative projects throughout the country. Bamboo is widely utilized for primary structures in their designs. In Indonesia, particularly in Bali, the species is employed as a key component in creating organic-shaped structures [25] [26]. Above research suggest that bamboo, especially *Dendrocalamus asper* is a sustainable, strong, and lightweight material with potential for use in organic shaped buildings, especially when treated for durability and considering its geometry and mechanical properties.

2. Method

This qualitative paper aims to explore the Bundle Bamboo Split (BBS) technique for landscape structures, with a specific focus on the use of *Dendrocalamus asper*. Comparison of species was discussed during a Focus Group Discussion and the species was chosen specifically to produce bending part of a Bamboo Pavilion. The BBS method which consists of bundling bamboo poles (for large structure) or bundling bamboo splits (for small, light structures) helps bamboo designer and builder creating 'organic style structures' as described by researchers. [5] [7] [25] [26] [30] The following is the workflow (Figure 2) depicting the method employed in this paper, which utilizes Bundle Bamboo Spit (BBS) derived from China and Indonesia as the frameworks for producing bamboo structures.

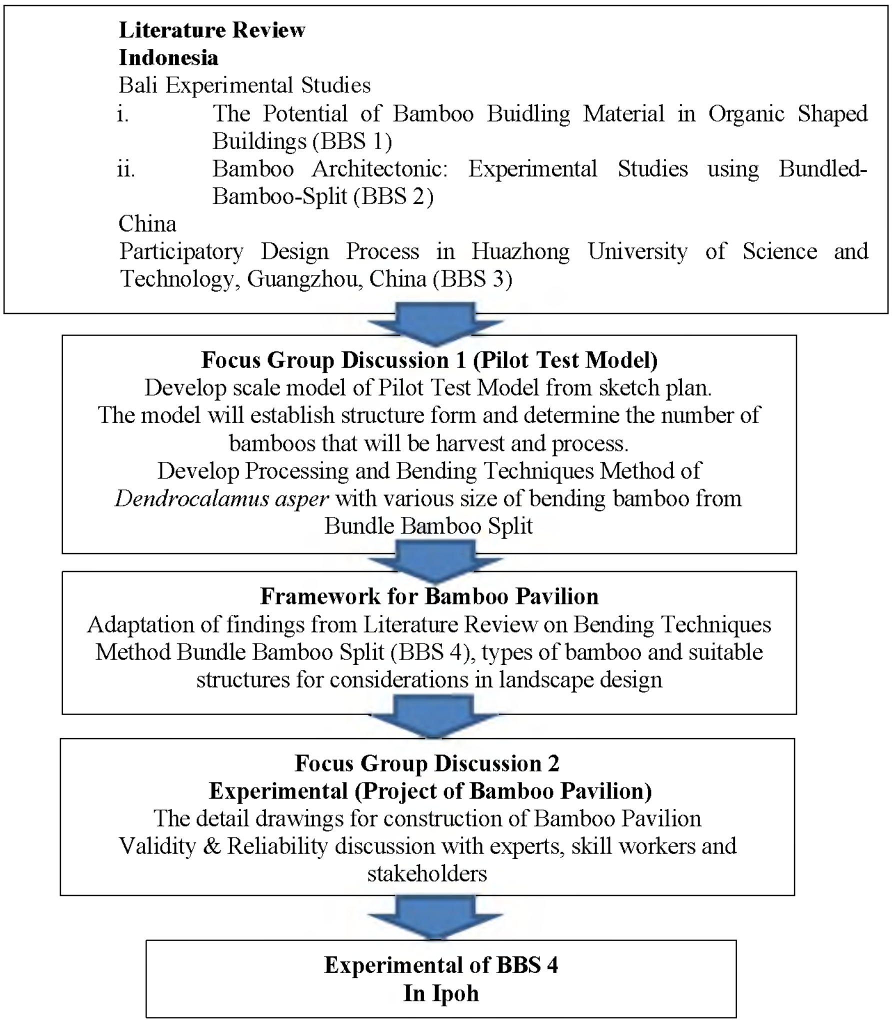


Figure 2. Study of Bundle Bamboo Split and Its Application in Producing Bamboo Structure.

3. Method for Bending Bamboo

In the context of bamboo bending for construction, there are generally two main categories or approaches:

i. Cold Bending Method (CBM): Cold bending refers to bending bamboo without the application of heat. It involves using techniques like bundling and lashing to shape the bamboo into the desired curvature. This method relies on the inherent flexibility of bamboo and the use of mechanical forces to create the desired shape. Cold bending is often used for smaller-scale projects, in this context for landscape structure or when a gentler bend is required.

ii. Hot Bending Method (HBM): Hot bending involves applying heat to bamboo to make it more pliable and easier to bend. The application of heat softens the bamboo fibers, allowing it to be shaped into more extreme or complex curves. Methods like steam bending, boiling, or using a heat gun fall under the hot bending category. Hot bending is typically used when a greater degree of curvature or specific shapes are desired.

Both methods have their advantages and considerations. Cold bending is simpler and requires fewer tools, while hot bending allows for more dramatic curves and precise shaping. The choice between the two methods depends on the project requirements, the desired curvature, and the available tools and expertise shown in Table 1.

Table 1. Comparisons of Bending Method[a]

Aspect	**Hot Bending Method**			**Cold Bending Method**		
	Immersion Technique		Combustion Technique	Slashing Technique	Bundling Technique with bamboo split	Bundling Technique with bamboo poles
Aesthetic Aspect						
Curvature	Smooth	Smooth	Not Smooth	Smooth	Smooth	
Texture	Smooth	Smooth	Smooth	Roughest	Rougher	
Color	Not Change	Change	Not Change	Not Change	Not Change	
Construction Aspect						
Tools	Big Tub & heater	Heater	Knife	Clave or splitter	-	
Time	Long	Long	Short	Short	Short	

[a] Table shows the comparison of method in bending bamboo; Cold and Hot Method [31]

Above comparison shows variety of aspects highlighting bamboo bending techniques. It notes on:

i. Hot Bending Method produce bamboo with smooth and not smooth curvature, depending on immersion or combustion techniques but will takes longer time and variety of tools to achieve the desired curvature.

ii. Cold Bending Method, it notes smooth curvature, minimum tools or none and with short time span.

The evidence clearly demonstrates that CBM is the preferred method for constructing landscape structures, particularly when BBS is used as the primary component.

3.1 Selecting Bending Method for Landscape Structure

After conducting a literature review based on the experiences of Indonesia [23] and China [24] a fundamental framework in creating a bamboo pavilion has been established. This framework has resulted in the development of three Bending Technique Methods (BTM) known as BBS 1, BBS 2, and BBS 3 (refer to Table 2).

Table 2. Comparison of Bundle Bamboo Split (BBS) Techniques.

No	Learning Outcome	Application of Bending Techniques	Advantages	Disadvantages
BBS 1	The Potential of Bamboo Buidling Material in Organic Shaped Buildings	Mixed of Single Poles and Bundle Bamboo Split for main structural elements	BBS allow better flexibility	Deformities of shape detected
BBS 2	Bamboo Architectonic: Experimental Studies using Bundled-Bamboo-Split (BBS)	Bundle Bamboo split for structural element. Natural curve bamboo also serves as main structural element	BBS allows variety of radial sizes that suit in many aspects of structural design in a structure that need organic shapes	Decrease the strength property of bamboo and can cause structural deformation and deflection
BBS 3	Case Study on Participatory Design Process in Huazhong University of Science and Technology, Guangzhou, China	Single pole in early stage, change to split bamboo which allow better flexibility and suit to pre-determine arch	constant dialogue between traditional craftsmanship of local expert and digital tools by the students	Single pole may break during bending process

Source: Meor Razali et al. (32)

3.2 Focus Group Discussion on Selecting Bending Techniques Method

Two (2) Focus Group Discussions (FGD) was held to determine.

i. FGD 1-With craftsmen with previous experience in designing simple bamboo structures and construction from Landscape Department of Ipoh City Council. This discussion aims to understand the best Bending Techniques Method that suits their workflow, availability of types of equipment and knowledge set that they already acquired.
This group discussions resulted in BBS 4 or Ipoh Result (Appendix A) which incorporating strength and weakness of BBS 1, BBS 2 and BBS 3.

ii. FGD 2-The respondents come from Malaysian Bamboo Society, the Building Department of Ipoh City Council and Bamboo Jungle Adventure with experience in bamboo handling and construction. This focus group discussion of the experimental method of *Dendrocalamus asper* involves a series of observations, analysis, and recording technical bamboo works done by workmen of the Landscape Department, Ipoh City Council.

Table 3. Design Process under FGD 2 which resulting design of Bamboo Pavilion.

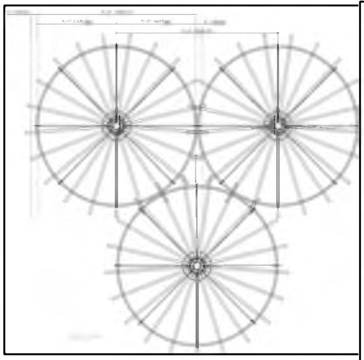
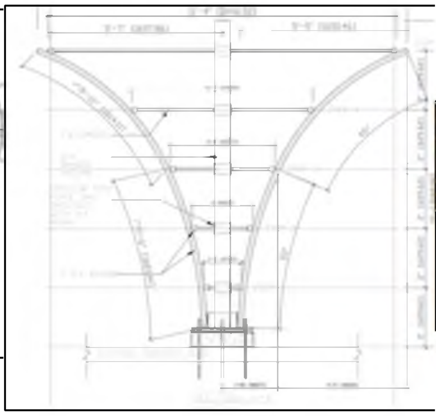
Plan	Section	Axonometric View
		
The plan of Bamboo Pavilion was formulated in genting best result for experimental stage of this research. Three structures of similar components were planed and combines a sculpture look in form of bamboo structure	The section highlights the application of Pilot Test Model in form of radial design of rings various from sizes. The rings were constructed while testing the capabilities of *Dendrocalamus asper* to bend	The axonometric view of structures reveals corresponding structures; the rings and main pole, comprises of *Dendrocalamus asper*. Other component of structures comprises of *Gigantochloa ligulata* (Buluh Tumpat)

Figure 3. Proposed Bamboo Pavilion at Dataran Bandaraya.

The discussion outcome consists of a sketch plan, detailed design, and Experimental Model of Bamboo Pavilion (Table 3 & Figure 3). It helps plan work to carry on identifying quantities of bamboo involved in the construction stage.

3.3 Discussion

A comparison of three reference studies, a probable fundamental framework for designing and constructing a bamboo pavilion can be summarized which define:

i. Bundle Bamboo Split applicable for various sizes of arch or radial design.
ii. Application of BBS may cause deformed shape of structures.
iii. Participatory design process may benefit parties involved in design and construction stage.
iv. The appropriate size of bamboo split will prevent excessive flexibility and deformity of structure.

As conclusion, a possible fundamental framework is developed and further elaborate as below:

Table 4. Fundamental Framework of Bending Bamboo for Landscape Structure[a].

Study of Structures		
Non-Form Active	Semi Form Active	Active Form
Time Saver Standard has outlined several structures that best criteria in designing bamboo for landscape architectural work		
Garden Wall	Site Furniture - Shelter - Foot Bridge - Trellis/Pergola	Special Element - Sculpture - Playground

Table 4a

Bamboo Species	**Characteristics**	
	Strong Physical	Good Mechanical Properties
Bambusa blumeana		
Bambusa heterostachya		
Bambusa vulgaris	/	/
Bambusa vulgaris var.striata		
Dendrocalamus asper	/	/
Gigantochloa levis		
Gigantochloa ligulate		
Gigantochloa scortechinii	/	/
Gigantochloa wrayi		
Schizostachyum brachycladum		
Schizostachyum grande		
Schizostachyum zollingeri		

Table 4b

Bending Technique Method		
Hot Bending Method		Cold Bending Method
Immersion Technique	Combustion Technique	Slashing Technique
Bundling Technique (split & pole) i. The most preferable techniques are Bundling Technique which produce smooth character of bamboo and has shortest time of construction. ii. It also requires less tools and less expertise required compared to slashing technique which need certain level of craftsmanship iii. Researchers notes the need to have a preservation process before splitting and bundling to preserve the bamboo		

Table 4c

[a] Analysis of Literature Review with relation to landscape structures, types of bamboo and bending method. [32]

According to Table 4, the study focuses on analyzing the bending method suitable for *Dendrocalamus asper*, which will be used as the main component in landscape structures. Additional research and FGDs emphasized the significance of the design and construction method for bamboo structures. These findings confirmed the limited bending capabilities of *Dendrocalamus asper* and will help determine the best BBS for the most effective bending techniques. The FGD is expected to provide potential outcomes for identifying the best BTM of BBS to be used in constructing landscape structures.

Table 5. Result & Findings from FGD 1.

Bamboo Species	Use in Structure	Bending Technique Method	Size of Split (cm)	Other Application
Buluh Tumpat	Member of Roof Structure	Pole[a] / Notching/Slashing	-	Furniture
Buluh Semeliang	Floor, Panel	BBS[b]	4-5(width) 3-5(thick)	Furniture, Landscape Structure
Buluh Semantan	Main structure, Post	BBS/Pole-Notching/Slashing	4-5(width) 3-5(thick)	Landscape Structure
Buluh Betong	Main structure, Post	BBS/Pole/ Notching/Slashing	4-5(width) 3-5(thick)	Landscape Structure

[a] single culm bamboo
[b] Bundle Bamboo Split

Source: Meor Razali et al., 2022

As shown in above table, comparisons of bamboo species were discussed and eloberate. The species which commonly used in Malaysian bamboo industry[4] were identitified and referred in the discussion.

Species such as Buluh Tumpat (*Gigantochloa ligulate*), Buluh Semeliang (*Schizostachyum grande),* and Buluh Semantan (*Gigantochloa scortechinil*), were deliberated upon during the discussion. Consensus was reached regarding the superiority of Buluh Semeliang in terms of flexibility, making it highly desirable for various bamboo products when compared to Buluh Betong. However, it should be noted that the latter exhibits exceptional hardness [32], rendering it more suitable for outdoor construction purposes. [6] [20] [24]

The discussion also aims to determine the most appropriate BTM (Bamboo Treatment Method) that can be utilized to achieve the desired curvature, as previously mentioned. Various techniques, such as employing a bamboo slash with a 'V' notch on its culm, are being explored as potential methods for bending bamboo. Additionally, the feasibility of incorporating single-pole bamboo as a component of the proposed bamboo pavilion is also being considered.

Table 6. Framework of Ipoh Result (BBS 4) for *Dendrocalamus asper*.

	Radius (m)	**Bamboo Span Per Split (m)**	**Bamboo Curvature Character**	**Advantage**	**Disadvantage**
A	0.8	Single (3m) This radius is the minimal size applicable for this bbs dimension. Lesser size will not be possible due to stiffness and after several attempt its break	Irregular	Strength -Smaller size have more strength Durability -with small radius it will be much stronger	Aesthetic -closer interval of cable will not be good due to irregular shape, it will not portray smooth character of bamboo
B	1.2	Single (3m but overlap into double)	Irregular	Strength -Smaller size have more strength Durability -with small radius it will be much stronger	Aesthetic -closer interval of cable will not be good due to irregular shape, it will not portray smooth character of bamboo
C	2.2	Double (3m but overlap into double)	Smooth	Aesthetic -With smooth curvature it will be feature for the structure Strength -moderate level of strength with curvature of ring still in good shape Durability -ring component double and triple layer provide enough rigidity to stay in shape	
D	4.0	Double (3m but overlap into double)	Smooth		
E	6.3	Triple (3m but overlap into triple) This ring display the bbs have shear effect due to its long span and wider span	Smooth	Aesthetic -With smooth curvature it will be feature for the structure Strength -moderate level of strength with curvature of ring still in good shape Durability	

		-ring component double and triple layer provide enough rigidity to stay in shape

Focus Group Discussion 2 on 21 November 2019 with a bamboo expert who produces detailed design and workable construction methods. The participants consist of civil engineer, landscape architect and assistant architect from private sector and government agency.

The second round of discussion established protocol to create a member of a pavilion of various sizes of radial design using Bundle Bamboo Split (BBS) that are more flexible and easier to construct when constructing with this species. The proposal initially wants to use *Dendrocalamus asper*, which is the sturdiest Malaysian Bamboo species. FGD 1 had to identify the best BTM using BBS to construct the proposed bamboo pavilion using *Dendrocalamus asper*. The FGD 2 also produces an idea sketch for a bamboo pavilion to test the bending capabilities of *Dendrocalamus asper*.

Figure 5. Section and Model of Bamboo Pavilion, red color indicates proposed rings (Pilot Test Model) and a central post from Buloh Betong.

The following process includes a model construction produced for the structure to study the best construction method before an actual Experimental Model can commence on site. This model production is also in line with typical bamboo construction that has been a practice in China as described by Stamatis [30] and in Indonesia, as mentioned by Elora Hardy:

07:08

So we design in real 3D, making scale structural models out of the same material that we'll later use to build the house. And bamboo model making 's an art, as well as some hardcore engineering. [33]

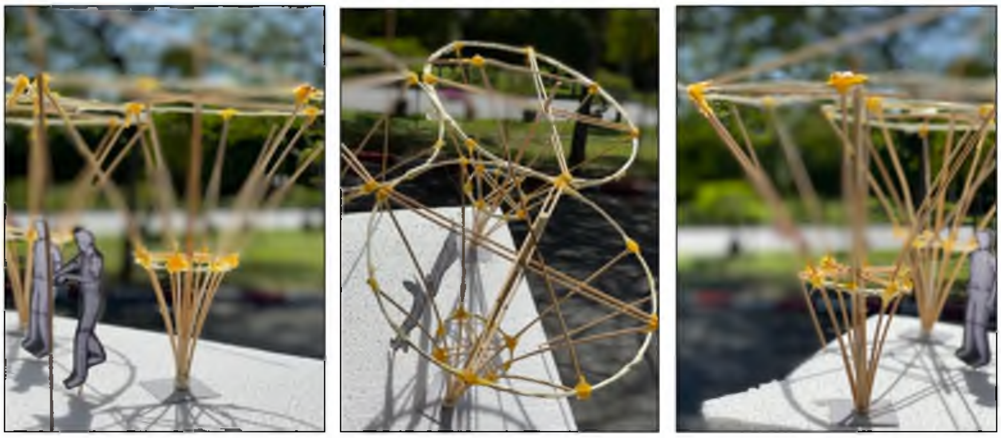


Figure 6. Model of Bamboo Pavilion.

i. The construction method was finalised based on Fundamental Framework from Bali on BBS 1 with split bamboo of *Dendrocalamus asper* together with expert discussion during Focus Group Discussion.
ii. The early intention of building Experimental Model is to have all structure of pavilion using *Dendrocalamus asper*. However, discussion in FGD 1 and 2 have informed the researcher that there is a need to use other possible species as part of the pavilion structure.
iii. In this experimental case, ring with radius of 0.8m is the minimum size for *Dendrocalamus asper* to bend using BBS techniques.

Figure 7. Construction of Bamboo Pavilion.

Figure 7 shows the building of Bamboo Pavilion at Dataran Bandaraya, Ipoh in which 'A' shows BBS 4 was used in creating a radial bamboo ring as per photo 'B', formed on the ground using jigs. Photo 'C' shows a complete bamboo ring constructed and transferred to the site meanwhile, photo 'D' illustrates on the constructed rings being assembled to form a structure. Lastly, a complete Bamboo Pavilion at Dataran Bandaraya is shown in Photo 'E".

The utilization of various bamboo species in the production of this bamboo material presents several advantages, including the facilitation of work and the potential to explore alternative bamboo species throughout the construction process. These changes entail incorporating bamboo species such as Buluh Tumpat for a number of compelling reasons namely, availability of species, ease of construction and ability to bend.

The team from the Landscape Department of Ipoh City Council has further involved themselves with other landscape structures after gaining experience with BBS. They have produced a series of structures that adorn Ipoh city parks and open spaces, as described in Table 7.

Table 7. Bamboo Application in Creating Landscape Structures.

Landscape Structures	Model	Remarks
a. Trellis 		The landscape structures are made up of bamboo rings built using the BBS technique. This method allows for a structure without a central column, enhancing its distinctiveness and providing a framework for climbers to grow on.
b. Pavilion 		The construction of the structure involved using BBS that utilized freshly harvested bamboo from the site. This technique allowed for the creation of in-situ structures, resulting in a reduced carbon footprint while enhancing its purpose celebrating Earth Day 2021 at Ipoh, Perak.
c. Pergola 		The BBS technique was utilized to construct the structure, symbolizing the nearby river. The designer took advantage of the bamboo's flexibility, testing its ability to bend, and used this to create a unique pattern on top of the structure.

Source: (Author, 2023)

4. Conclusion

Bamboo presents a promising opportunity for the construction of sustainable structures, owing to its distinctive attributes: rapid growth, renewable resource, and versatile uses. This resilient plant stands as one of the fastest-growing species on the planet. Consequently, bamboo can be harvested at shorter intervals compared to conventional trees utilized in the production of wood-based products. Moreover, bamboo boasts a broad spectrum of applications, encompassing construction, furniture, flooring, textiles, and various other fields. Its remarkable versatility allows it to serve as a substitute for materials that may have a more detrimental impact on the environment.

This paper has emphasized the inherent flexibility of bamboo as a construction material, particularly in the creation of landscape structures. The potential for replicating these structures in various forms and functions holds promise for landscape architectural design. It is hoped that the utilization of bamboo will elevate its status as a sustainable material, thereby assisting designers and landscape architects in expanding their design palette. By incorporating bamboo into their construction practices, these professionals can both enhance their creative options and contribute to environmental sustainability.

Acknowledgement

I would like to express my heartfelt gratitude to my exceptional crew, the Response Unit, whose unwavering dedication, and commitment have consistently exceeded expectations. Their unwavering response to every job task entrusted to them is truly commendable, and their fervor to go above and beyond the ordinary job scope is truly inspiring.

Furthermore, I would like to extend my gratitude to Majlis Bandaraya Ipoh and Universiti Teknologi Malaysia for providing me with invaluable opportunities to explore the realm of bamboo constructions. It is through their support and encouragement that I have been able to delve deeper into this field, with the aim of benefiting the city of Ipoh in the long run.

I am hopeful that our endeavours in bamboo construction will contribute significantly to achieving our vision of a low carbon city and minimizing our carbon footprint. By embracing sustainable and eco-friendly practices, we can pave the way for a brighter and greener future for Ipoh.

Once again, I express my sincere appreciation to my dedicated crew and the organizations that have supported me on this journey. It is through their collective efforts that we can make a positive and lasting impact on the city and its inhabitants.

This is a beginning of a journey.

Appendices

Appendix A

Focus Group Discussion 1

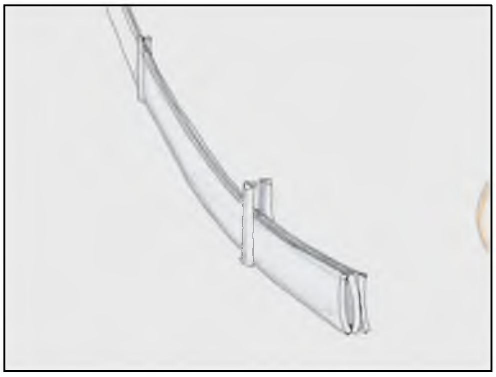
Date: 1 November 2019
Venue: Taman Rekreasi Gunung Lang, Ipoh Perak

The Discussion was conducted between 7 Bamboo Craftsmen who trained and works in bamboo works. This discussion aims to understand the best Bending Techniques Method that suits their workflow, availability of types of equipment and knowledge set that they already acquired.

Result & Findings from FGD 1

Bamboo Species	Use in Structure	Bending Technique Method	Size of Split (cm)	Other Application
Buluh Tumpat	Member of Roof Structure	Pole/ Notching/Slashing	-	Furniture
Buluh Semeliang	Floor, Panel	BBS	4-5(width) 3-5(thick)	Furniture, Landscape Structure
Buluh Semantan	Main structure, Post	BBS/Pole-Notching/Slashing	4-5(width) 3-5(thick)	Landscape Structure
Buluh Betong	**Main structure, Post**	**BBS/Pole/ Notching/Slashing**	**4-5(width) 3-5(thick)**	**Landscape Structure**

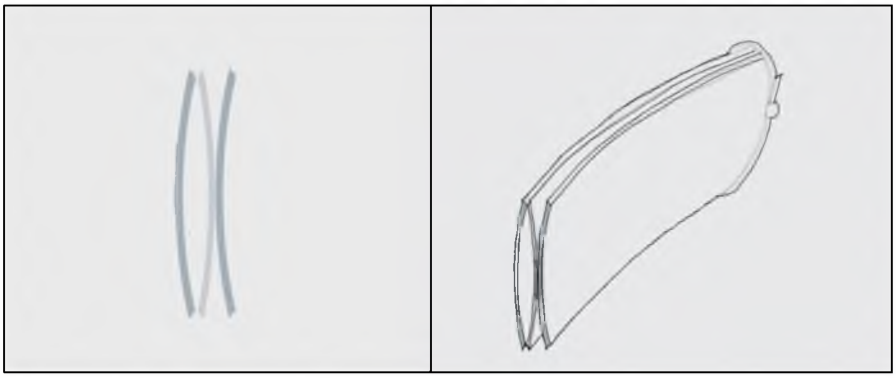
Note: BBS – Bundle Bamboo Split
Pole – single culm bamboo



The splint are arranged on ground and fixed with jigs to retain its curvature.

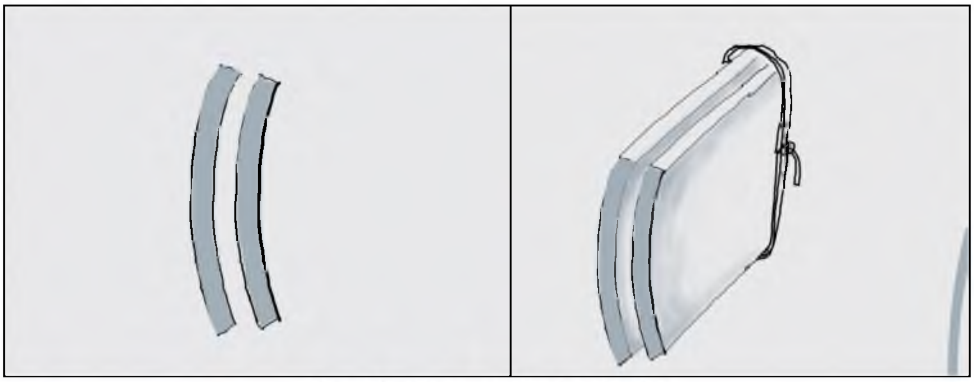
Figure I. The Split	Figure II. The Split in 3 layer	Figure III. The Split in 5 layer

The researcher has experimented with three BBS techniques, as presented in the above figure. Figures I, II and III were built with alternate sides to hinder the rings from deforming as suggested from FGD 1 and with reference from BBS 1 and 2.



Detail of Bundle Bamboo Split in Three Layer
Source: Meor Razali et al, 2022

As shown in the above figure, the split was set in alternate side to enhance its strength as discovered by the worker and also to minimize structural deformation and deflection, as highlighted previously by Nurdiah (26). The layer rises from 3 layers to 5 layers for suitability and strength. However, it is harder to bend due to the stiffness of bamboo and impossible to achieve the desired curvature for a ring. The design was later converted back into three layers of split as shown in Figure I, which is more manageable to construct rather than using detail as shown in Figure III.



Bundle Bamboo Split (BBS 4)
Source: Meor Razali et al 2022

Large-size Radial Ring of Bamboo Pavilion
Source: Meor Razali et al 2022

Middle-size Radial Ring of Bamboo Pavilion
Source: Meor Razali et al 2022

Small-size Radial Ring of Bamboo Pavilion
Source: Meor Razali et al 2022

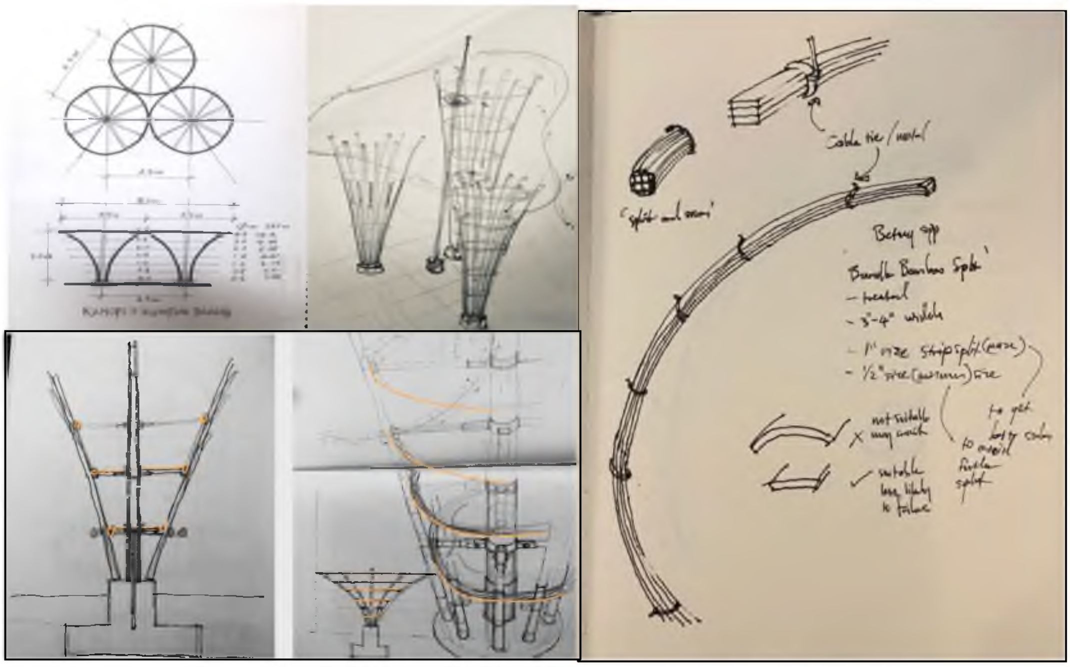
Appendix B

Focus Group Discussion 2

Date: 21 November 2019
Venue: Bamboo Jungle Adventure Adventure, Sungai Siput Utara Perak

Focus Group Discussion 2 on 21 November 2019 with a bamboo expert who produces detailed design and workable construction methods. The participants consist of civil engineer, landscape architect and assistant architect from private sector and government agency.

The second round of discussion established protocol to create a member of a pavilion of various sizes of radial design using Bundle Bamboo Split (BBS) that are more flexible and easier to construct when constructing with this species. The proposal initially wants to use Buluh Betong, which is the most sturdy Malaysian Bamboo species. FGD 1 had to identify the best BTM using BBS to construct the proposed bamboo pavilion using Buluh Betong. The FGD 2 also produces an idea sketch for a bamboo pavilion to test the bending capabilities of Buluh Betong.



Composite Picture of Earlier Design Sketch from The Discussion

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