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Learning by Making with Bamboo: A Design-Build Approach to Low-Carbon and Sustainable Architectural Practice in Pakistan

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ABSTRACT

This research delves into the potential of engaging academia for introducing the concept of bamboo construction and use of indigenous building materials through sustainable pavilion design studio exercises at under-grad level students of Architecture under the title of "Learning by Making: Bamboo Pavilion Design as a Pedagogy for Sustainable architectural Education." It primarily encourages to introduce the use of bamboo, hailed as green steel of the 21st century, for its rapid growth, structural stability, and wide availability within the construction industry at the early stage of architectural education. The study aims to inculcate in students the value of ecological design, indigenous materials and sustainable design practice within urban landscapes. The research methodology involves design-studio exercises engaging students for pavilion designs along with physical execution while exploring bamboo as indigenous material, employing traditional techniques of joinery and lashing. Two architectural schools in Pakistan, located in Abbottabad and Karachi, served as practical sites for implementation of pavilion designs with bamboo. Undergraduate students in their second year of architecture were tasked with designing pavilions spanning 100-200 sq.[L6.1] Ft area, emphasizing contextual sensitivity, innovation, and functionality. Different site selections such as under tree shadows, in parking lot and within a courtyard, emerged as stimulating aspects, inspiring creative conceptualization and execution. Each student's design and model underwent individual assessment whereas selected models were executed at full-scale within campuses. The conclusion underscores the critical importance of hands on practice, learning by making and do it yourself approach and the integration of ecological considerations into architectural endeavors at early stage of architectural education. This research significantly contributes to fostering community engagement and accessibility within architectural design, particularly in South Asian countries. Furthermore, the design execution serves as a blueprint for the revival of indigenous materials and techniques, providing a pathway towards low-carbon emission[L7.1] shelters and setting a benchmark for future sustainable architectural practices.

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1. Introduction

Bamboo is an environmentally friendly and widely used as a construction material due to its mechanical behavior, Ahmad and Kamke (2011); Li et al. (2019) renewability and fast growing characteristics (Li et al., 2018; Van Der Lugt et al., 2006). Comparatively to conventional construction materials, like concrete, steel and aluminum alloy, its strength to weight is relatively high (Li et al., 2016; Porras & Maranon, 2012).

When it comes to making choices of green building materials for sustainable construction, bamboo offers many properties in comparison with concrete and steel. It's easy and fast growth with less energy not only restrain the soil from erosion by creating a barrier for water but also produce more oxygen than other plants and traps more carbon dioxide (Sharma, 1980), thus help in restoring the adverse effects of climate change (Shafiq et al., 2021). Given that bamboo can be used as an alternative to conventional building materials, its application in daily life in our local context is reduced to its usage for making scaffolding at construction sites, temporary shades on roadsides, gazebos in parks, moveable ladders and fencing with straight-line geometry. The design potential of using bamboos in curved geometry, making bridges and creating hyperbolas need to be explored at architectural schools in Pakistan, giving enough confidence to under-grad students to explore the endless design possibilities, experimenting with bamboos in the field of architectural practice.

This paper is based on the learning and outcomes from such experiments carried out from 2016-2018 at two schools of Architecture in Pakistan, one in mountainous region in north and other in a city by the sea in south. Initiated by the 2nd year design studio faculty at Department of Architecture and Planning, NED University, Karachi, two workshops were organized in two consecutive years engaging 2nd year students to design and build pavilions with bamboo during 3-week design studios. The author of this paper from University of Engineering and Technology, Peshawar (Abbottabad Campus) designed the workshop and joined the team in Karachi for steering the process of execution, employing traditional techniques of splitting bamboos, its bending, cutting and joinery details with lashing and jute weaving. The experiment was repeated with the students at Abbottabad Campus in subsequent years. During the process students were taught about bamboo as building material and its usage in creative pavilion design having different structural approaches such as free-standing structure and cantilevered structure. Students who were given this opportunity, graduated in the year 2018, 2019 and 2020. It was heartening to note that few of those students opted bamboo as an ultimate choice for their architectural practice and set their office to promote use of bamboo as green material for designing and building structures for under-privileged schools, roadside multi-level restaurants and shelters in flood affected areas during massive floods in Pakistan in 2020, 2021 and 2022.

This paper records the need of introducing hands-on practice with non-conventional green materials at architectural schools to inculcate the importance of using such materials for enhancing urban ecology and bringing communities together with 'Do it Yourself-DIY approach. It also emphasizes the importance of translating present day design vocabulary into life-scale project within the potential and constraints of material properties and employing traditional techniques while building structure with indigenous materials for a better future. The environmental, structural, and sustainable construction benefits of bamboo have been demonstrated by previous research, but its "design-build application in architectural education," especially in Pakistan, has received less attention. The documented evidence in Pakistan architectural academia is lacking on how hands-on experimentation can help architecture students regarding understanding of bamboo's structural potential, material limitations, and conventional construction techniques. This study addresses the gap by documenting bamboo design-build workshops conducted at two architecture schools in Pakistan, where students explore pavilion designs, transformation of conceptual ideas into design and then its full-scale execution, while using and learning bending, splitting, lashing, weaving, joinery and structural systems, and to promote bamboo as a sustainable architectural material and encourage its wider application in contemporary practice.

2. Literature Review
2.1. Overview of Bamboo

Bamboo is an ever green and fastest growing plant Liese and Kohl (2015), the word bamboo came from Kannada term bamboo, which was introduced to English through Malay (Bain, 2020). Bamboo is a giant grass Liese (1998), As tropical grass, bamboo grows quickly with strong fibers mostly in Asia, Africa, South America and parts of North America in tropical and subtropical environments with temperature ranging between 18°C (64°F) to 38°C (100°F) (Wang, 2002). At present, Asian regions from east to south hold a large proportion of the bamboo's forest in the world with approx. 80% species of world bamboos (Sharma, 1980).

It is a kind of bio material Liu et al. (2019), While improving the durability of bamboo, it has been described that it could be used for above than 50 years without performance degradation after proper treatment. The treatments are chemical and physical (Gauss et al., 2021), rosin (Su et al., 2021). Heat treatment is a physical technique where bamboos can immerse into hot water, hot air, saturated steam for a period (Yu et al., 2018). Bamboo can save the planet: it is a renewable resource, we can use it in substitute of concrete and steel. It protects soil, prevent erosion and help retain nutrients for other crops (Chen et al., 2022; El Bassam, 2010). Use of bamboo reinforced concrete structures date backs a century in Southeast Asia (Glenn, 1950), design approaches and recognize that poor bamboo to concrete bond will typically govern design (Agarwal et al., 2014; Archila et al., 2018).

Bamboo products include boards, plywood's, artificial silk, charcoal, and Glubam is on its way to be in market (Mohanan, 2023). 1.5 million Human beings life is based on bamboos (Schmidt et al., 2013). Bamboos include 1670 species in 123 genera belongs to three tribes (Soreng et al., 2015), According to FAO report 1642 species, Vorontsova et al. (2016), 751 species, 56 varieties, 134 forms belong to China while four hybrids belonging to 43 genera, with the highest bio diversity in Asia Yi (2008), followed by India, japan, Indonesia, Myanmar and Malaysia (Mohanan, 2023). the major bamboo growing countries in Asia are India (16 million ha) (Fan et al., 2021; Lobovikov et al., 2007), China (6.4 million ha), and Malaysia (5 million ha) as shown in figure 1 and 2 (Lopez, 2016; Vorontsova et al., 2016).

Figure 1: Locations of Bamboo Grown Around the World
Source: Mohan et al. (2022)

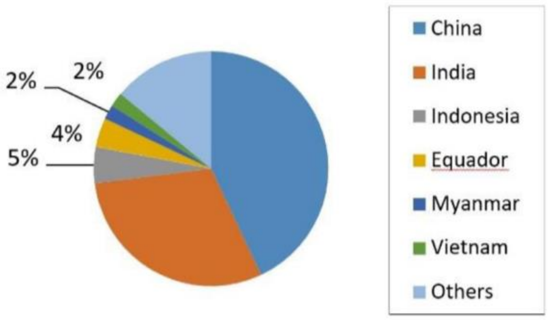


Figure 2: Distribution and contribution of Bamboo grown in Asia
Source: Mohan et al. (2022)

2.2. Bamboo as a Sustainable Construction Material

Due to its advantageous characteristics, bamboo is becoming more widely acknowledged as a sustainable building material, in contrast to may wood species bamboo may reach maturity in a matter of years and be harvested without killing other plants, allowing for ongoing regrowth. Where we can apply it anywhere in construction. Bamboo is appropriate for ecologically aware architecture since, it has a lower embodied energy than some traditional building materials. Guaranteed endurance and shield it from decay treatment are required. (Liese & Kohl, 2015). Bamboo is used as material for poor, and yes, it is less expensive, being cultivated to become more and easily renewed (Manandhar et al., 2019).

2.3. Environmental Performance of Bamboo

Bamboo can generate biomass with comparatively little resource consumption, bamboo exhibit great environmental performance, due to its fast growth it improves soil quality, minimizes the need for planting, and permits frequent harvesting, while preserving the plants root structure. When responsibly maintained and utilized in durable items, it can also store carbon throughout growth, helping to mitigate climate change. As construction material, its relatively low embodied energy can help reduce environmental impacts compared with conventional materials (Liese & Kohl, 2015). As far as Pakistan construction industry it has been witnessed that bamboo is used as a main structural component while building traditional desi Dhaba's, restaurants, roof top seating areas, and some time it is used as a fence for privacy, shading and articulation.

2.4. Structural Characteristics of Bamboo

Due to Bamboo's effectiveness for structural applications and its excellent strength to weight ratio, its hollow, tubular shape it reduces material weight and providing strength. Its flexibility enables it to tolerate bending and dynamic loads, and the longitudinal fibers offer excellent tensile strength. However, species, age, moisture content, and fiber direction all affect strength (Janssen, 2000). Structural characteristics in terms of rigidity and density it is strong, while its tensile strength is same throughout the ages; the plant fiber strength increases as it gets older (Liese, 1998). Some example of structure would be: Walls, Bridges, roofs, shelters, pavilions, flooring and landscaping (Hone et al., 2020). As a building material its hard and durable product from a renewable resource, this material becoming more popular with eco aware consumers and environmentally responsible designers (Gillani et al., 2026; Hone et al., 2020). The findings for the five Chinese cities indicates that using bamboo as a replacement of conventional reinforced concrete structures will result in a 3%-5% reduction in energy consumption and a 7%-20% reduction in CO_2 emissions (Zhao et al., 2024).

2.5. Vernacular Construction

Bamboo is easily available, light weight, flexible and simple to work with using conventional equipment's, it has been employed extensively in vernacular construction. Structural frames, columns, beams, roof trusses, walls floors, ceilings. Doors and makeshift shelters are all made of bamboo in numerous areas. Because of its adaptability, structures can react to wind and with the right design, seismic forces. To make it cost effective, climatic responsive structures, traditional methods frequently combine bamboo with materials like mud, thatch, wood, and dirt. These techniques save construction and shipping costs, while utilizing local resources and expertise. To increase its durability and shield bamboo from moisture and termites, proper finishing and treatment are crucial (Janssen, 2000).

2.6. Sustainable Architectural Design

Additionally, promoting energy efficiency, resource conservation, occupant well-being, and long-term resilience, sustainable architecture design seeks to reduce its negative effects on environment. It includes tactics like building orientation, natural ventilation, day lighting, shading, insulation, renewable energy and careful material selection. Passive design can reduce reliance on mechanical heating, cooling and lighting, while life-cycle considerations help minimize operational and embodied carbon (Oloukoi & Babalola, 2026). While in such cases bamboo is an excellent sustainable material within this approach because it grows rapidly, can be harvested without replanting, and has high strength to weight ratio. It can be used a structural frame, walls, roofs, ceiling, cladding. Its renewable nature and relatively low embodied energy make it an attractive alternative to conventional materials. It is durable, environmentally responsible and resilient architectural design (Janssen, 2000). In Pakistan we can grow it on mass level and can help to improve economy.

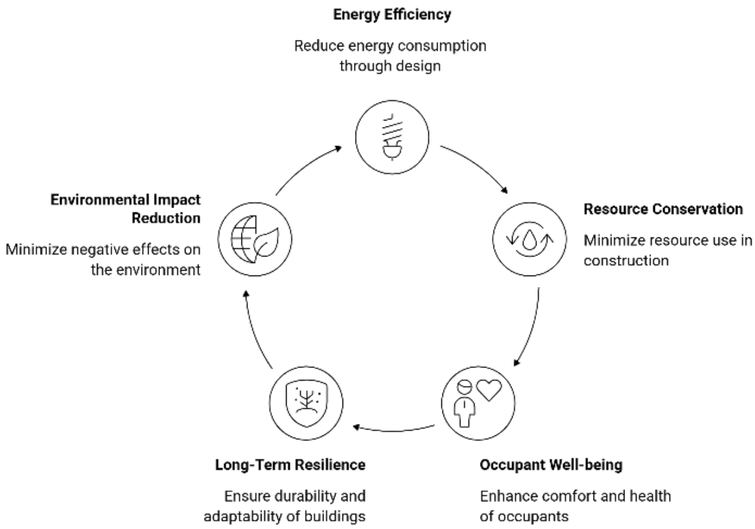


Figure 3: Sustainable Architecture Design Cycle
Source: (Author)

2.7. Relevant Examples of Bamboo constructed shelters

In figure 4, The Structure is developed at Vietnam, the low-cost housing project is in a flood-stricken region that receives extreme temperature around the year, the structure will be strong enough to float in flood due to its mechanism (Habibi, 2019). Which has been added to this research to take an inspiration that how we can use the technique of raising the platforms of the bamboo structures to meet extreme weather especially in rain and flood. In terms of contextual linkages, we can refer the work of Ar. Yasmeen Lari, at interior Sindh Pakistan. In figure 4, Three conical bamboo structures in the lawn of national museum of Singapore. The immersive installation beckons viewer's inside its mysterious interior Habibi (2019), the example has been taken as without any nut, bolt and nails that how we can produce conical and huge roof structures, while using the techniques of lashing and ropes. Which should be an inspiration to create any thematical structures.

Figure 4 (a) and (b): Vietnamese Low-cost Housing by H&P Architects Six-member Family House, having Raised Platform and Wormhole, 2013 Bamboo Installation, Dimensions Variable Artist Collection, Singapore 2013 Commission
Source: (Wikipedia)

3. Methodology
3.1. Research Approach and Context

A qualitative, practice based, and design-build research approach was adopted in the study. Where it examines that how hands-on bamboo pavilion design and construction can be used as pedagogical method for teaching sustainable architecture and indigenous construction techniques. This study was conducted and concluded between 2016-2018 at two architectural schools in Pakistan in different climatic conditions, i.e.: located in north and south (Abbottabad and Karachi). Second year undergraduate architecture students participated in three-week design studio, more than 50 students were divided in 10 groups and were trained accordingly.

3.2. Project Brief and Design Build Process

A 100-200 sq. Ft. bamboo pavilion within the university campus premises were assigned to design, which must be respond to the site as per requirements, i.e.: function and existing landscape while demonstrating creativity and appropriate use of bamboo material while controlling the wastage of material. The overall process includes: material, site selection, conceptual process, innovative structure designing, and then jury assessment, selection of designs, full scale construction, where students, explored the conventional cutting, splitting, bending, lashing and traditional joinery without using and nut bolt, or nails, using local ally available tools and materials.

3.3. Data Collection

For understanding of materials, literature and lectures were given to students, then data were collected through students designs, physical models, photographs, construction observations of the completed pavilions. Students learning, and design outcomes were assessed according to contextual response, functionality, innovation, material use, structural feasibility and construction potential.

3.4. Data Analysis

The collected data and material were analyzed qualitatively to highlight students learning regarding indigenous bamboo materials, its construction techniques, sustainability and structural understanding to build a team work for design and making. The two relevant case studies have been studied for inspiration, understanding and compared with the local context in terms of applicability of bamboo design-build education in Pakistan.

The methodological framework for qualitative practice-based, design-build approach for sustainable architectural education follows a "learning by making" process, in which all students were assigned to learn about techniques, uses and characteristics of bamboo, and to explore the strategies of transformation of bamboo from design to full scale execution, the process follows, conceptual process, physical models, designing drawings and construction. Then the overall process has been evaluated regarding learning, creativity, technical aspects and sustainability awareness.

Significance of Proposed Research are totally based upon understanding of indigenous building materials bamboos, its vernacular behavior in terms of the south Asian climatic conditions, the challenges faces to the below average communities, specially will help for the transformation of slums, will use as a shading devices and cladding in public, recreational buildings, development of landscaping inside urban fabric and open spaces to control carbon emission due its sustainable aspect, and will also help to students while incorporating their conceptual/abstract ideas into reality.

4. Results and Discussion
4.1. Project Brief and Targets

The second-year students of architecture on undergraduate level, has been instructed to design a shelter/pavilion at university campus premises having an area of 100-200 Sq. Ft, to keep in mind the contextual and climatic sensitivity, which must be innovative in term of its design and fulfill the functional requirements as well, where one can sit, read informally, used for eatery and gossips in a break.

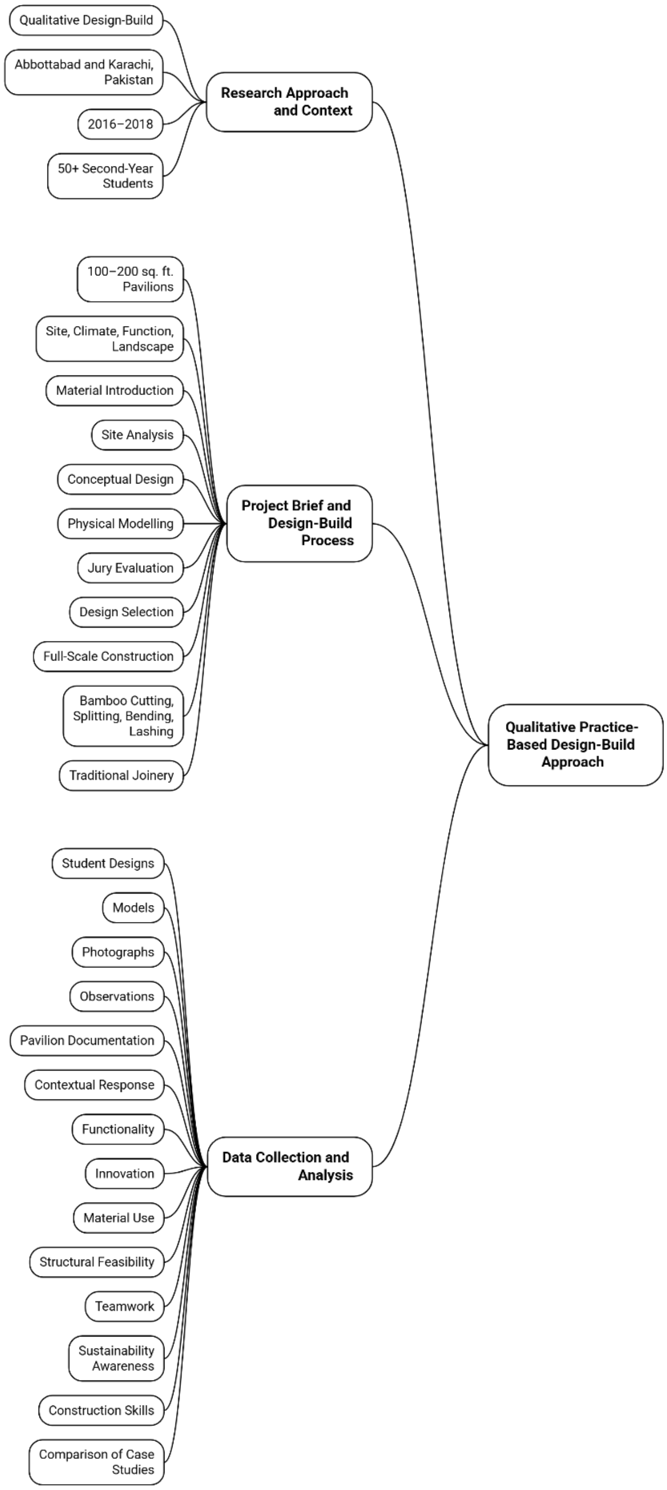


Figure 5: Methodological Framework for Qualitative Practice-Based, Design-Build Approach for Sustainable Architectural Education
Source: (Author)

The interesting flexibility in design and its site selection is to select it may be under tree or near a greenery or existing landscape to not deteriorate its real shape. The conceptualization process must be inspired innovatively, may be an abstract idea which might be difficult to execute as it was the main objective. Almost above than 50 students were divided into 10 groups and given the task to design student pavilion to keep in mind the research done in studio and has given a demonstration on the uses of bamboos and designing of bamboos structures, it was a second year design studio, students produced 10 designs and 2 design has been selected during assessment by jurors and instructors as per the require execution, The student's designs and physical small scale models has been individually assessed and realized them that selected two designs design will be executed physically while looking at the below targets which should be achieved in final product.

4.2. Materials Selection, Measurements and technical calculation

The next step was selection of materials which must be indigenous, and bamboos were already been decided to work on it, due its material flexibility, bending, cutting and molding. On a broad level the project was based on the use of indigenous materials like bamboos its techniques of construction. The intention is to help in the understanding of its joinery details, how to bend, cut, use and how to work with bamboos. And to understand the importance of bamboo's as a traditional material of construction. Through these techniques' students should understand its importance like it is a sustainable material and to understand its techniques through which we developed/produced 3 structures in 2 different Universities/Architectural Schools in Pakistan, in campus premises. In this Project, students were supposed to focuses on the target and project brief which should be achieved.

Figure 6 (a), (b), (c): Organic Jute Ropes, Bamboo Poles and Stone Boulders used as Primary Material for Shelter
Source: (Author)

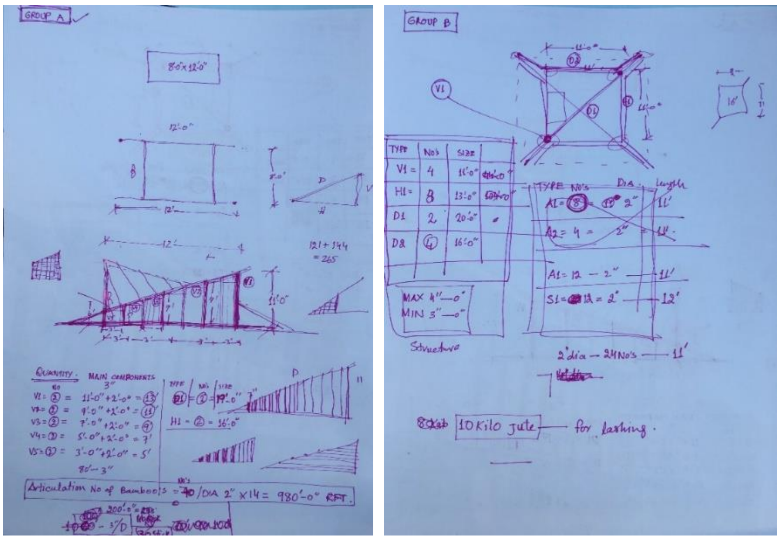


Figure 7 (a), (b): Manual Calculation and Measurements for no of Bamboo Poles and its Length on RFT Basis
Source: (Author)

As already decided and defined materials was bamboos for the execution and jute ropes which are totally organic and made in local shops for lashing and joints has been selected as shown in figure 6, calculations of materials were based on the area of structure, its number of vertical and horizontal structure elements and then the cladding where split bamboos were used. The restriction was that it will be totally zero carbon footprint, no nail, steel or things were not allowed only organic materials were decided to use. The calculation for number of bamboos its diameter and posts are shown in figure 7 (a), (b) and then finalized it in table 1.

Table 1
Calculation of Vertical, Horizontal and diagonal Structural Members/Bamboos for Each Shelter on RFT Basis

S. No	Vertical Member (V)				Horizontal Member (H)				Diagonal Member (D)			
	Type	**No of Bamboos**	**Diameter**	**Length on RFT**	**Type**	**No of Bamboos**	**Diameter**	**Length on RFT**	**Type**	**No of Bamboos**	**Diameter**	**Length on RFT**
1	V1	2	2 inches	13 Ft	H1	2	2 inches	16 Ft	D1	2 inches	2	19 Ft
2	V2	2	2 inches	11 Ft	H2	8	2 inches	13 Ft	D2	2 inches	4	16 Ft
3	V3	2	2 inches	9 Ft								
4	V4	2	2 inches	7 Ft								
5	V5	2	2 inches	5 Ft								
Total		10		45RFT		10		29RFT			6	25RFT

Where V= Vertical Post, H = Horizontal Post and D = Diagonal post, Cladding is depending on number of Sq. Ft area of elevation and roofing.

Table 1 is the calculation and measurement for a 100 and 200 sq. Ft modular pavilion as installed and executed physically, where we calculated number of different poles/posts used in the structure, I-e: V1 is vertical post 1, which are require 2 numbers of vertical posts having diameter 2 inches and length 13 feet. Where V2 is vertical post 2 and so on. H1 are horizontal posts having 2 numbers, where its diameter is 2 inches having 16 feet length and D1 is a diagonal post, having 2 inches diameter and 19 feet length, while keeping in mind that these V= Vertical posts, H= horizontal posts and D= diagonal post used in the shelter are structural skeleton and rest of the cladding bamboos were split and calculated on the basis of per Sq.-ft and structural skeleton were calculated on the basis of running feet. All the posts/poles were joined and connected through lashing techniques while using three basic types of lashing, i-e: Pole lashing, T-lashing and triangular or tripod lashing.

4.3. Transportation of material from market to site

Like the project zero carbon foot print the materials has been transported from 5km distance from market to site on donkey cart, to avoid the vehicles smoke and disturbance at the premises, which was totally a traditional way of transportation and environmentally friendly, where we can call it sustainable transportation to avoid vehicular smokes and noise pollution as shown in figure 8.

Figure 8: Transportation of Bamboo Poles from Market to site through a Sustainable and Traditional Transportation
Source: (Author)

4.4. Bamboo Joints, Cutting, Lashing and Split Technique

Do not use fresh bamboo. It must be completely dry before using it in construction. Use mature bamboo up to 4-6 years. While joining bamboos do not try to use nail etc. it will split the bamboo in parts (Syidanova et al., 2021). In this research as explained earlier we are focusing on lashing techniques to join bamboos and to avoid nails, nut and bolts.

Figure 9 (a) (b): Bamboo Poles on Site and Student Discussion to Devise Strategy for Cutting on Measurement
Source: (Author)

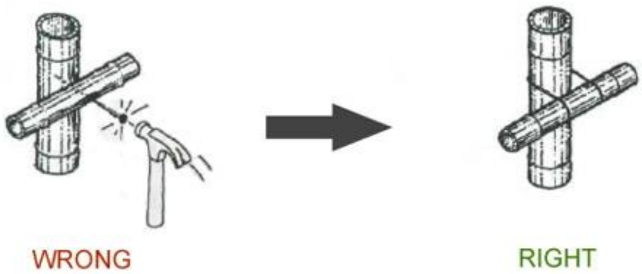


Figure 10: Joining of Bamboos Through Right Lashing Techniques
Source: Syidanova et al. (2021)

Basic cuts do not require power tools are machinery, only need traditional hand tools as shown in figure 11 (a) and (b).

Figure 11 (a) (b): Cutting Techniques of B
Source: (Author)

Joining bamboos with the unique lashing techniques, by using the right poles, lashing rope, & few pegs can start making thousands of different items such as bamboo structures, cages, towers etc (Ward, 2008).

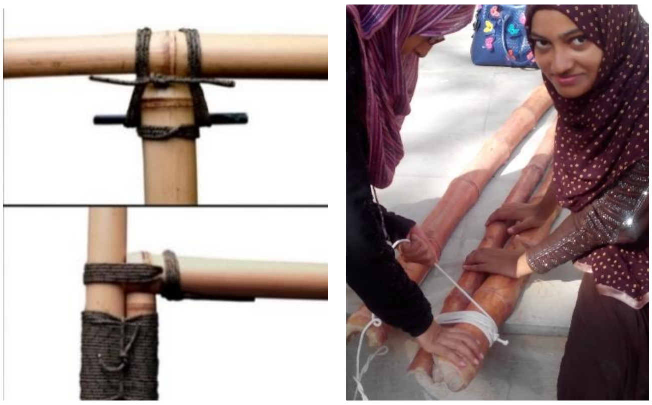


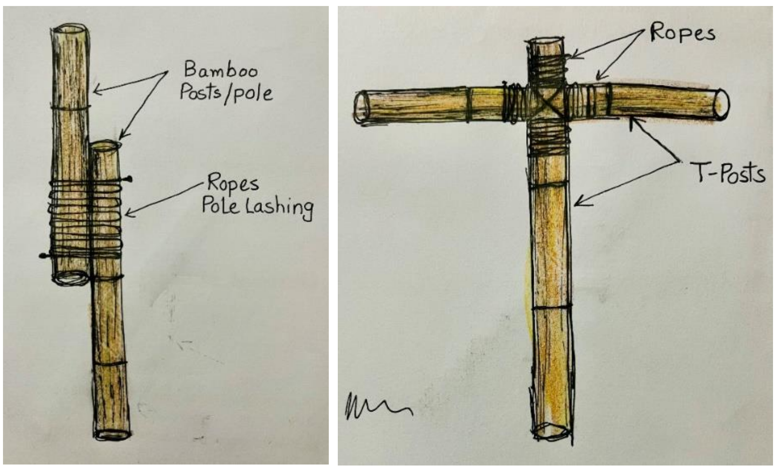
Figure 12 (a) (b): Basic Technique of T-Lashing in Bamboo, Basic Technique of Pole Lashing in Bamboo
Source: (Author)

Splitting bamboo is an important technique, where split bamboo can use in cladding and fencing etc. while bending can be accomplished in its green and dried form as shown in figure 13 (Kumar et al., 1994).

Figure 13 (a) (b): Basic Technique of Split Bamboo
Source: (Author)

4.5. Process of Lashing Technique Used in the Project

Process of Lashing and its different techniques along with different Knots, a lecture was given to the students in studio along with some visuals and then later on I myself the instructor of the project, I teaches them on site about the knots, lashing, joineries', bending cutting of the material and how to deal with, to keep in mind the calculated measurements and proposed design and its execution. There are different types of Lashing techniques used in this project and research work, i-e: Pole lashing, T-Lashing, triangular lashing shown in figure 14.



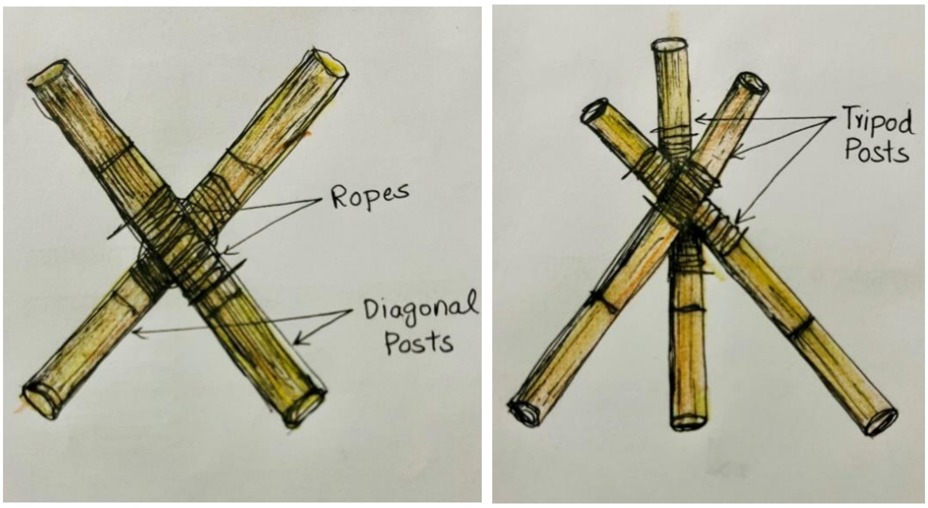


Figure 14 (a)(b)(c)(d): Four Major Lashing Techniques to Join/Connect Bamboos, i-e: Pole Lashing, T-lashing, Triangular Lashing and Tripod Lashing
Source: (Author)

Figure 15 (a)(b)(c): Important Technique of Joining Bamboos through Different Knots and Lashing with Ropes
Source: (Author)

4.6. Execution

Excavation for main posts and vertical structural elements has been done by students and interestingly enjoyed and the whole process I-e: the layout, excavation and later vertical structural posts has been erected in foundation along with stone boulders and treated the posts with lime powder, a conventional and indigenous technique to protect them from termites. the plastic shoppers were re used in the bottom of vertical posts.

Figure 16 (a)(b): Site Layouts and Excavation for Bamboo Posts Foundation
Source: (Author)

4.6.1.Product/Result 1

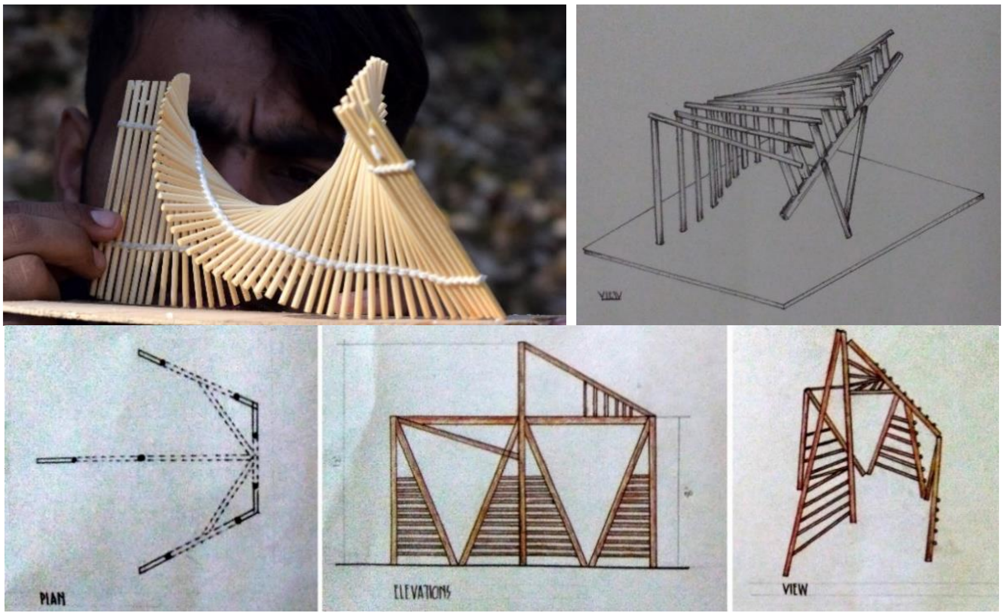


Figure 17 (a)(b)(c)(d)(e): Students Conceptual Models made of sticks While Experimenting the Abstract Ideas, Student's Manual Idea Drawings
Source: (Author)

Figure 18 (a)(b)(c)(d)(e): Students Pavilion has been Erected under the Tree Shade, Highlighting the Bamboo Joineries, Lashing and the Clay Tiles used for Flooring
Source: (Author)

4.6.2.Product/Result 2

Figure 19 (a)(b)(c): Students Pavilion has been Erected, Highlighting the Bamboo Structure, its Joineries, Lashing, Landscape Features, Benches and Final Group Photo Along with the Author/Instructor of the Project
Source: (Author)

5. Conclusions and Recommendations

This study demonstrates that a practice-based “learning by making” approach can effectively integrate bamboo construction, indigenous materials, and sustainable design principles into undergraduate architecture education. The findings indicate that hands-on engagement enhanced students understanding of bamboos material, creativity in design, behavior, structural feasibility, contextual response, joinery, lashing, bending, splitting, weaving, and construction sequencing. The use of locally available bamboos, jute, without nails, bolts and steel connections, encouraged the students regarding exploration of traditional construction techniques and translation of conceptual ideas into buildable structure. Experiences across the contrasting contexts of Abbottabad and Karachi demonstrated the adaptability of bamboo pavilion design. The study establishes the deign-build experimentation as a viable pedagogical model for experiential sustainability education while identifying the need for further quantitative assessment of structural, environmental and long-term performance. Furthermore, the design execution serves as a blueprint for the revival of indigenous materials and techniques, providing a pathway towards low-carbon emission shelters and setting a benchmark for future sustainable architectural practices.

Future research should quantitively assess bamboo pavilion performance through energy simulation, Life Cycle Assessment (LCA), and structural analysis. Tools such as Design Builder, energy Plus, and SAP 2000 can evaluate thermal comfort, embodied energy, carbon emissions, structural stability and material efficiency under different climatic conditions.

Authors Contribution
Habib Ullah: Conceptualization, writing-original draft, visualization, writing-review & editing
Farida Abdul Ghaffar: Conceptualization, writing-review & editing
Shabbir U Qureshi: Writing-review & editing
Salman jamil: Writing-review & editing

Conflict of Interests/Disclosures
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