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Compression and tension forces in bamboo truss with curved model

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Enhancing the strength performance of bamboo truss. This paper discusses the performance of a customize bamboo truss and emphasizing how stress forces interact under vertical loads. The customize truss with a span 4 meters and a height with 2 meters, comprises three components; the base, truss legs and bracing. At the base of the truss underneath, whole bamboo is utilized. In contrast, the bracing section employs curved stacks of split bamboo. The design variation allows for structural support while incorporating the flexibility and strength of bamboo in different parts of the truss. It's essential to ensure the structural integrity and load-bearing capacity in bamboo trusses. The aim of this study to investigate how the customize truss respond to the stress forces, focusing on the ability to withstand vertical loads. This research collecting data by using a quantitative method after customizing a unique model of bamboo truss with curved stacks then conducting an experiment under hydraulic test. As a result, the curved stacks model in the customize truss successes to withstand 4.78 KN vertical load.

Introduction

Bamboo is the building material of the past and future. it highly adaptable for numerous applications, particularly in construction (Adier et al. 2023). Bamboo is a lifeline for source of livelihood. Bamboo is a type of grass belonging to the family grasses (Hogarth and Belcher 2013). It is classified as a monocotyledonous flowering plant, characterized by its woody stems' "culms" and jointed segments. There are over 1,500 species of bamboo found in diverse climates around the world, with varying sizes, colors and uses. Bamboo plants produce a lot of oxygen. The roots of bamboo plants store water and strengthen the soil to prevent erosion, especially in the slope of a steep cliff.

It is one of the fastest-growing plants on Earth (Tia et al. 2017). Bamboo's remarkable strength-to-weight ratio rivals that of steel. making it a versatile and durable material for various applications (Tambunan et al. 2022). It's super strong but lightweight. Bamboo plant is essential for human life, offering food from its shoots and leaves. Fibers for clothing, and versatile building material for homes. It meets up the basic needs for food, clothing, and housing. Bamboo's natural fibers are tightly packed, giving it excellent structural integrity (Kumar et al. 2021; Ghavami 2005). This allows bamboo to withstand heavy loads and forces, making it suitable for use in construction. Bamboo trusses facing many challenges to make sure they can support weights and coming up with new designs. Bamboo, often referred to as "green steel," has captured the interest of structural engineers and designers due to its remarkable blend of strength, flexibility, and rapid renewability (Sil 2024).

Bamboo segment space and fibers provide extra strength which could be adjusted in its use even in the form of an arch (Rambe and Nasution 2023). Bamboo has a tensile property that are very rarely found in other construction materials. The tensile system refers to the ability of a material withstand pulling or stretching forces, Tensile strength is a crucial property, especially for materials used in applications, where they are subjected to tension such as members and braces in bamboo trusses (Xie et al. 2020). Trusses are very well known as very crucial construction points and require to be in a strong condition, it is not hindered if bamboo is the construction material for trusses. The flexibility that can be created from bamboo material certainly cannot be used in a state of intact bamboo material, due to bamboo segments that block the bending properties created from bamboo fibers. Generally, every part of the bamboo plant is significant in the process of propagation (Johar et al. 2023).

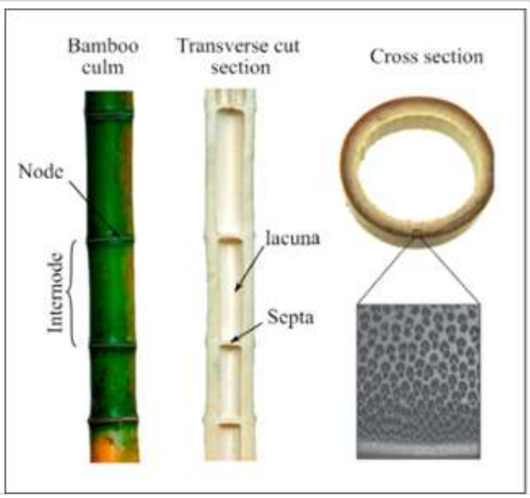

Figure 1. Macroscale anatomy of a bamboo culm
Source: (Gangwar and Schillinger 2019)

Characterization of bamboo through microimaging, Bamboo, a significant member of the grass family Poaceae, features a cylindrical and hollow culm (stem) that is segmented by nodes and internodes, as depicted in figure 1. At each node, a transverse diaphragm (*septa*) is present, which helps to prevent Brazier buckling caused by the ovalization of the cross-section during bending. Unlike wood, bamboo lacks secondary growth, limiting its ability to adapt geometrically and thereby necessitating structural optimization at the material level (Gangwar and Schillinger 2019).

Bamboo trusses with curved models are gaining attention in sustainable architecture due to their strength, flexibility, and aesthetic appeal, it's known that curving and shaping hollow bamboo poles within its natural form is difficult and challenging because of its cylindrical profile. but in case of using Techniques such as splitting bamboo, using U-brackets at critical nodes, and optimizing joint placement then it can enhance the stability and performance of these curved trusses.

The aim of this research is to explore the structural capabilities and enhancements of bamboo trusses with curved designs, focusing on their ability to withstand vertical loads and improve overall stability. Bamboo, known for its impressive strength-to-weight ratio and rapid renewability, offers significant potential as a sustainable building material. This study seeks to provide a comprehensive analysis of customized bamboo trusses, examining how modifications such as joint optimization and reinforcement techniques can enhance their performance. By conducting hydraulic tests and collecting quantitative data, the research aims to validate the efficacy of these designs under stress. Additionally, the study will address existing gaps in the literature, particularly regarding the long-term durability and load-bearing capacity of curved bamboo trusses in contemporary architecture. The ultimate goal is to promote the use of bamboo in innovative architectural applications, highlighting its benefits for sustainable and aesthetically pleasing design.

The hypothesis of this study is to evaluate how bamboo trusses can enhance the sustainability and aesthetic quality of architectural designs. It is hypothesized that the integration of bamboo trusses into modern architecture can significantly improve its integrity. the research predicts that these enhanced bamboo trusses will contribute positively to sustainable architectural practices by providing a robust, renewable alternative to conventional building materials.

Despite the promising attributes of bamboo trusses with curved models, there is a significant gap in comprehensive research that delves into their long-term performance and optimization within contemporary architecture. Current studies predominantly focus on the basic structural properties of bamboo and its conventional applications. This limited scope overlooks critical aspects such as the durability, load-bearing capacity, and resilience of bamboo trusses, particularly in curved configurations, when subjected to various environmental conditions. Furthermore, the existing body of work lacks a thorough empirical analysis and theoretical framework that address how these curved bamboo trusses behave over extended periods and under diverse stress factors. This oversight is particularly crucial as it leaves questions unanswered about the practical viability and sustainability of using bamboo in modern, complex architectural designs. Understanding these dimensions is essential for advancing the use of bamboo as a reliable, eco-friendly construction material and for ensuring its integration into innovative architectural practices.

One of the most common problems encountered in using bamboo for curved models is the difficulty in bending and shaping the material without compromising its structural integrity. Bamboo's natural cylindrical and segmented structure makes it challenging to create curves without causing fractures or weakening the bamboo fibers. This issue is particularly significant when the curved bamboo needs to bear loads, as improper bending can lead to stress concentrations and potential failure points.

Methods

This study used a qualitative method for collecting data which is taken through out an experimental design process during workshop. The reason of choosing qualitative methods in the research to be used for solving problems is intended to make accurate measurements of a variable (Creswell and Creswell 2018). The experimental design process was stablished at the beginning, before conducting the experiment. The design followed the standard formula which is (m=2j-r), where m refers to the number of members and j refers to the number of joints, using this equation to confirm that the truss was perfectly balanced. also applying the Cremona diagrams system to evaluate the strength generated by the design and to determine the function of each truss member, identifying whether they were under tensile or compressive loads. So, by integrating workshop with hydraulic press test, this research provides a comprehensive approach to understanding and improving the stability and strength of bamboo truss structures. The iterative design process informed by practical testing ensures that the final design is both strong and optimized for real-world applications.

Workshop

During the group workshop, three distinct truss designs were developed and iteratively refined to reach the final, optimal design. Throughout this process, each design stage revealed specific weaknesses and areas for improvement, which were subsequently addressed based on detailed feedback from the lecturers. The primary focus during this iterative process was on enhancing the tension and pressure distribution across the trusses to ensure greater structural integrity and performance. The design process was methodically approached by creating scaled models at progressively larger scales. Initially, a 1:10 scale model was constructed to explore the basic design concepts and identify any fundamental issues. Following this, a more detailed and slightly larger 1:2 scale model was developed, allowing for a more thorough examination of the design's performance and further refinement based on the initial findings and lecturer feedback. Finally, the culmination of this iterative process was the creation of a full-scale 1:1 model, which incorporated all the improvements and adjustments made throughout the previous stages. This comprehensive approach ensured that the final design was robust, well-balanced, and capable of effectively handling tension and pressure distribution. The purpose of this project is to construct a lightweight bamboo Truss with a bamboo frame using straightforward connections in a short period of time. The design principle for the structures involved the easy connection of bamboo culms using accessible materials such as nails and rings (Dauletbek et al. 2023).

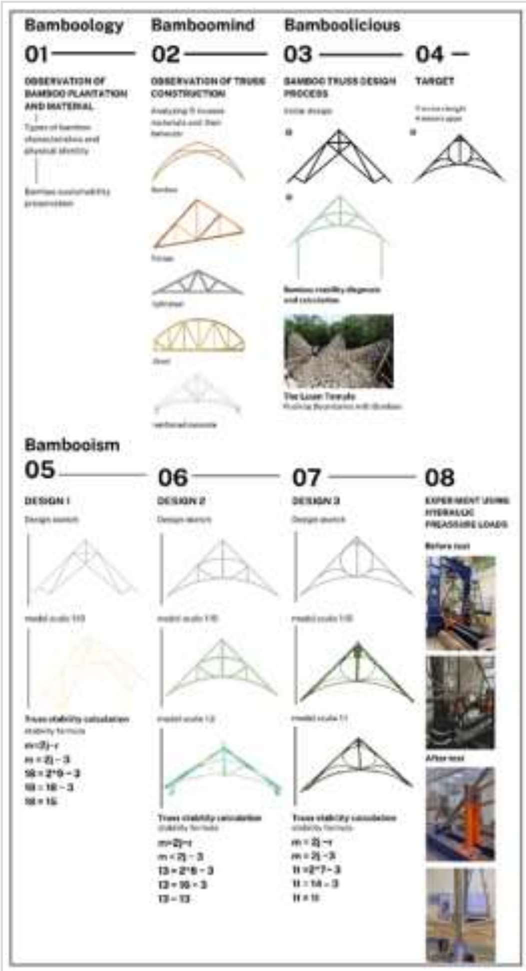

Figure 2. Diagram methodology

The schematic diagram outlines a structured approach to researching bamboo trusses in modern architecture. This methodical progression aims to explore bamboo's potential fully, from foundational understanding to real-world application in sustainable building practices.

Figure 3. Evaluation of truss design stability

To test the stability for each design into a scale 1:10 here is the equation for testing the stability, (m=2j−r), where:
m = Number of members
j = Number of joints
r = Number of reactions

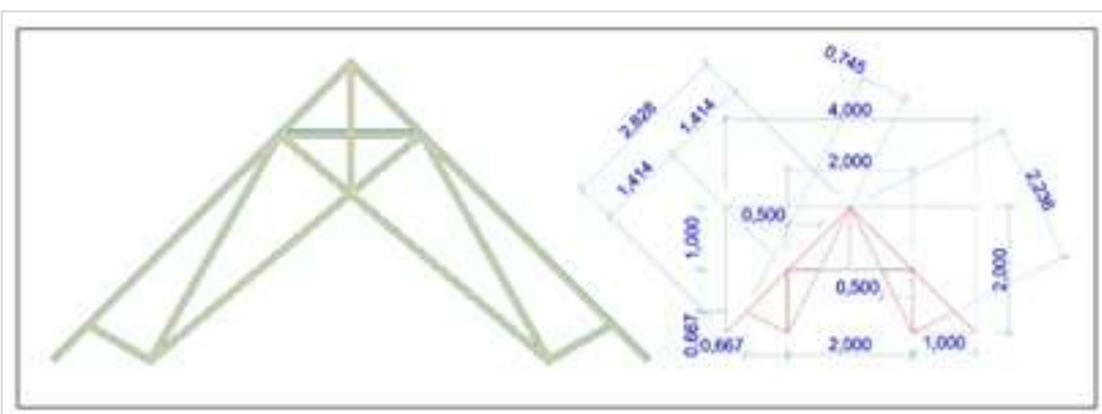

Figure 4. Testing the stability for the first alternative

$m=2j-r$
$m = 2j - 3$
$18 = 2*9 - 3$
$18 = 18 - 3$
$18 = 15$

In the case of the first design truss not stable as the number of joints is less than the number of the whole members. Calculations using the stability configuration formula revealed that the original plan, which consisted of triangular piles, was still considered insecure. due to the disparity in the number of bamboo members and the number of recruits already present. In such designs, it is necessary to review the number of members and joins, adding or removing, or swapping places with one another, until a balanced outcome is achieved in line with the design standards for truss structures. The original design still uses whole bamboo throughout, which reduces stability and unevenly distributes vertical loads due to the three joints in a single bamboo member that will cause the member to overload and become unable to support the applied load.

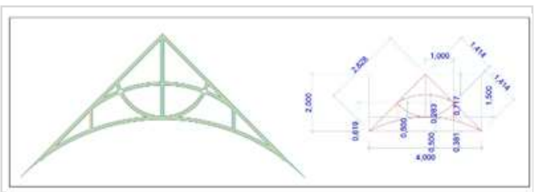

Figure 5. Testing the stability for the second alternative

$m = 2j - r$
$m = 2j - 3$
$13 = 2*8 - 3$
$13 = 16 - 3$
$13 = 13$

Based on the equation of the stability, the second alternative design truss is stable. The second truss design, initially developed at a scale of 1:10, was later scaled up to 1:2 as part of the iterative design process aimed at enhancing stability. This revised design was incorporated into the entrance structure of Bamboo Land. The design featured a modified bent system aimed at improving the compressive strength of bamboo. Tensile forces were applied to the curved sections to transform the previous design into a curved system. Key structural components, including the understructure and other members, were strategically positioned to distribute tensile and compressive forces effectively. Fasteners were inserted at 10-centimeter intervals to secure the bamboo strands and provide additional tensile support from underneath. The initial design evaluation did not account for the use of divided or whole bamboo elements, which significantly impacts the truss's strength behavior. Consequently, divided bamboo, converted into laminated bamboo, replaced the curved components in the design. Laminated divided bamboo was selectively used in specific members to optimize the performance of the curved systems.

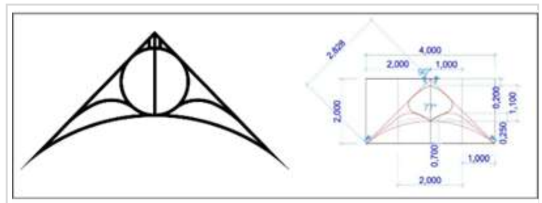

Figure 6. Testing the stability for the third alternative

$m = 2j - r$
$m = 2j - 3$
$11 = 2*7 - 3$
$11 = 14 - 3$
$11 = 11$

Based on the equation of stability the third design truss is stable When looking at the finished design from the perspective of a bamboo truss, it is clear that not all materials can be handled like the above design with a curved system as the primary framework because bamboo naturally becomes a tensile load. The triangular structure gains stability and strength by channeling the vertical weight through the bamboo, which is left undamaged. The curved structure will be very simple to stretch inward and outward, which will reduce the truss's strength (Maurina 2015). Members are joined by a U-shaped iron bracket that can sustain the tensile weight. Accordingly, if the connection with the iron bracket separates, the truss will no longer be able to resist vertical pressures, according to the analysis that has been done. As a result, the axle or under is crucial in maintaining the bent structure on the member so that none of the members deviates from their axes or becomes straight again.

Figure 7. Team collaboration: Bamboo truss Workshop in action "manufacturing process"

The workshop on bamboo truss construction provided invaluable insights into the structural behavior of bamboo under compression and tension forces. Through hands-on experiments with participants, learned about the importance of prototyping and testing at various scales to optimize design. Key takeaways included understanding the tensile properties of bamboo, the significance of proper attachment techniques, and the benefits of using split bamboo for curved structures (Bhardwaj, Stoner, and Pang 2023).

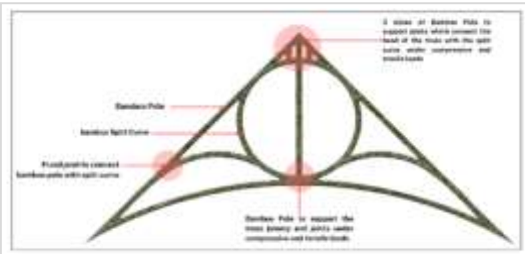

Figure 8. Final design and its components

Displaying the team's workshop activities, including bamboo cutting, joint fabrication for assembling whole and splatted bamboo layers, machine operations for cutting or drilling holes in the bamboo, and daily planning to achieve workshop objectives.

Figure 9. Final truss assembly in bamboo land at 1:1 scale

The significant accomplishment of the workshop's final phase. It represents the culmination of extensive efforts as the last version of the third truss design is fully assembled at a 1:1 scale in Bamboo Land. This milestone marks the conclusion of the design process before the truss undergoes testing at the UII laboratory under the Hydraulic Press Test. It serves as a testament to the group's collaborative work and signifies a noteworthy progression in the project.

Hydraulic press test

The hydraulic pressure test serves as a critical phase in assessing the integrity and reliability of hydraulic systems, evaluating their ability to withstand operational demands under high-pressure conditions. However, despite meticulous planning, unforeseen incidents can arise, necessitating swift remedial actions to maintain system functionality. This report focuses on an incident encountered during the initial hydraulic pressure test, wherein the destruction of the vertical component responsible for gathering tensile strength occurred. Subsequently, the damaged part was effectively repaired by reinforcing it with a steel joint (Ahmad, Alam, and Alam 2020).

The formula for hydraulic pressure (P) is P = F / A; where: P is the pressure, measured in units like pounds per square inch or newtons per square meter. F is the force applied, measured in pounds or newtons. A is the area over which the force is spread, measured in square inches or square meters. To find the area (A) of the piston, measure its diameter (d) in meters, then use the formula A = π*(d/2) ^2, where π (pi) is about 3.14.

Once you have the diameter and area, plug them into the hydraulic pressure formula to calculate the pressure needed to produce a specific force. Additional Load: The Load deflection curve for the truss. The load-deflection curve can give important information about the behavior of the truss under load. For example, the slope of the curve at any point represents the stiffness of the truss at that load point.

The point where the curve starts to deviate from a straight line indicates the yield point of the truss, where it begins to deform permanently. The point where the curve drops sharply indicates the ultimate load, where the truss fails completely.

Hydraulic press machine components

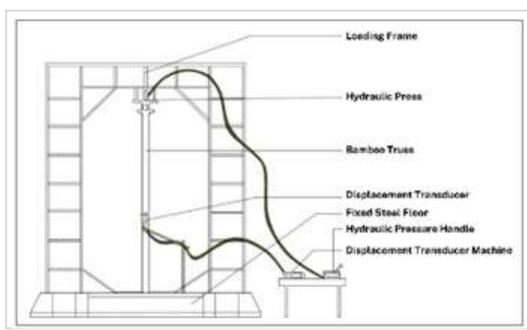

Figure 10. Set up the Truss for hydraulic pressure testing

1) Loading frame;
2) Head of the hydraulic pressure;
3) Displacement transducer;
4) Steel base;
5) Hydraulic pressure hand pump;
6) Displacement transducer machine.

Set up preparation

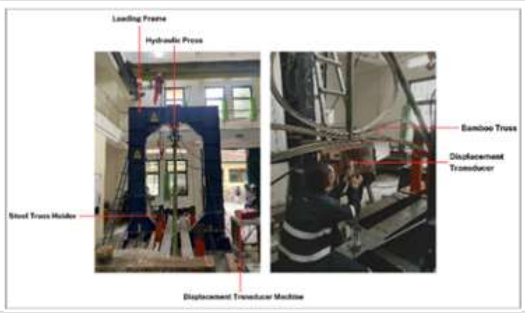

Figure 11. Setting up the truss for hydraulic pressure testing

Test setup and strain gauge detail (Deng et al. 2023). The setup process involves securely positioning the truss within the hydraulic test apparatus, ensuring proper alignment and stability. Careful attention is given to securing the truss at key anchor points to withstand the anticipated hydraulic forces. Additionally, any necessary instrumentation for data collection and monitoring is installed to accurately measure the truss's response during testing. Quality assurance checks are conducted to verify the integrity of the setup before initiating the hydraulic pressure test.

Figure 12. Front and Side Set Up View

The setup involved securing the bamboo truss in a hydraulic press, with displacement transducers positioned to accurately measure deformation under applied loads (Awaludin and Andriani 2014).

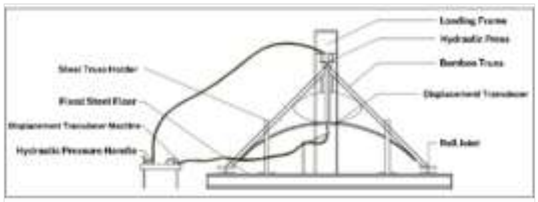

Figure 13. Side View of the set-up preparation

The laminated split bamboo curved system comprises four layers of split bamboo, enabling a maximum stack height of eight split bamboo at the pivot. Five separate bamboo members are interconnected at different joint locations to distribute loads evenly and prevent overloading of any single member. Varied joint positions are crucial for maintaining structural integrity and strength, ensuring robust connections between members.

Figure 14. Experimental set up for bamboo truss compression testing using hydraulic press

Steel holder: In order to see how the bamboo truss reacts after being compressed, the model or tools required for installation are meant to keep the bamboo out of the shaft after it has been subjected to pressure from the hydraulic pressure machine. With the current equipment, the pressure generated by the hydraulic machine can then be documented along with the depth attained. Side and peak joint view before the test under the hydraulic pressure.

Figure 15. Experimental set up for bamboo truss compression testing using hydraulic pressure

Steel clamping configurations for bamboo culm truss connections (Lucena and Cruz 2023). Supporting joint and peak view preparing for the test under hydraulic pressure, general design of the vehicle following testing.

The stresses impacting the component can be used to illustrate a number of concepts. The extent of the shift at the fulcrum is indicated by the shift at the roll joint's fulcrum and the measurement next to it. This shift is crucial for understanding the overall performance and structural integrity of the bamboo truss under load. Furthermore, the iron pedestal that serves as an intermediary and a foundation for the hydraulic pressure with the bamboo truss is only tilted; no major damage is encountered. This lack of significant damage indicates that the pedestal provides adequate support and stability, maintaining the integrity of the structure. It can be inferred that the u-bracket used to link the curved component above it with the underside of the bamboo truss becomes the primary structure and component. This inference is based on the fact that all tensile systems are centralized at this junction, making the u-bracket a critical element in the overall design. The response at the joint in the midsection of the bamboo truss was quite important, highlighting its role in distributing stresses and ensuring thestructural performance of the entire truss system.

Results and discussion

Bamboo trusses have gained attention in sustainable construction due to their mechanical properties, especially their ability to handle tensile and compressive forces. Studies have shown that bamboo exhibits high tensile strength and sufficient compressive strength, the theory of the tensile and bending properties of bamboo are critical to understanding its behavior in curved applications. Bamboo is known for its high tensile strength, which allows it to withstand significant stretching forces. However, its bending properties are influenced by its natural structure, including the presence of nodes and internodes, which can act as points of weakness if not properly managed (Janssen 2020). While bamboo's tensile strength is advantageous, its hollow, segmented nature poses challenges for creating curves. Proper treatment methods, joint techniques, and the use of reinforcing elements are essential to maintaining bamboo's structural integrity when used in curved forms. making it suitable for truss structures.

Recent research, such as that has analyzed the strength of bamboo fibers, highlighting their effectiveness in managing these forces (Lo 2004). Curved bamboo trusses, however, require careful consideration of joint techniques and auxiliary components like U-brackets to enhance performance and prevent failure. Despite these advances, gaps remain in understanding the long-term durability of these structures. Future research should focus on advanced joint techniques and protective treatments to optimize the use of bamboo in curved truss designs.

Test result

The experimental evaluation of bamboo truss models under compression and tension forces entailed a rigorous series of hydraulic press tests aimed at comprehensively assessing their structural integrity and performance. These tests, conducted systematically, involved subjecting each truss to increasing loads until failure occurred, with meticulous monitoring of deformation using a displacement transducer positioned strategically at the base of each truss. The resulting dataset provided invaluable insights into the pressure exerted and the corresponding displacement experienced by the trusses, allowing for a nuanced understanding of their behavior under varying loads. Notably, the observed deformation patterns varied significantly across the tested models, highlighting the intricate interplay between design factors, material properties, and applied forces. Models equipped with advanced joint techniques and reinforced with auxiliary components, such as U-brackets, exhibited superior resilience to deformation, suggesting the pivotal role of optimized design strategies in bolstering structural robustness. These findings underscore the imperative for future bamboo truss designs to prioritize the integration of sophisticated joint techniques and auxiliary components, thereby fostering enhanced structural integrity and longevity.

Figure 16. Apparatus result from bamboo truss compression using a hidraulic pressure

A displacement transducer device in a hydraulic press test is used to measure the amount of displacement or deformation that occurs in the material or structure being tested. This device accurately records the changes in position or length as the hydraulic press applies force, providing essential data on the material's or structure's response to compression or tension forces. it shows the result from the Hydraulic Pressure Handle after the test in the laboratory.

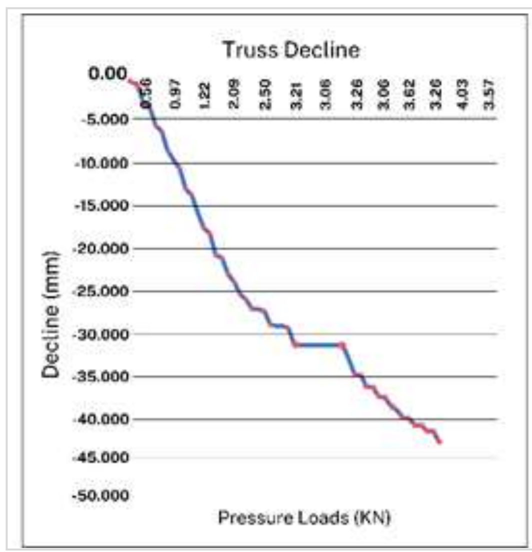

Figure 17. Table 1 Truss decline to pressure load chart

So, at the end of the test under hydraulic pressure, the bamboo truss can withstand loads up to 4.74 KN, with a downward displacement of 4.4101 cm. This limit was reached when some bamboo components failed, preventing the structure from supporting additional load. These findings suggest that bamboo trusses with curved designs need further consideration. To maximize the tensile strength of bamboo, auxiliary components like U-brackets can be used to counteract the pulling forces in curved sections. Applying pressure to curved bamboo sections to ensure they pull against each other can enhance the overall strength and stability of the structure.

Figure 18. Bamboo truss center's response to compressive loads after test

The saddle should be positioned near a node to minimize the risk of splitting. An alternative approach involves cutting a long, integral tongue that is bent completely over the transverse member and secured back in place (Satish et al. 1979).

Figure 19. Response of split curved sections under vertical loads

The impact on the split curve with a roll joint is minimal (Widyowijatnoko and Harries 2020).

Figure 20. Compressive load reaction to bamboo truss support (roll joint)

The hydraulic test revealed that the roll joint of the bamboo truss support experienced noticeable movement under compressive load, indicating potential points of failure that require further investigation and design optimization.

Figure 21. Compressive load reaction to bamboo truss support (fixed joint)

After the first experimental test some damages and breakage happen into the roll joint so it supported by steel truss holder.

Figure 22. Test examination of peak performance in bamboo trusses

Following the initial experiment, the truss head sustained damage. To prepare for the second stage of testing, it was reinforced with a wooden stand and secured with ties.

Figure 23. Shift of support (roll joint) after test

Figure 24. Before and after the experiment of the truss

Before the first experiment, the truss was not supported by a steel truss holder or metal fastener from bellow, even at the peak point. However, after the test, it was reinforced by supporting the weak points of the bamboo.

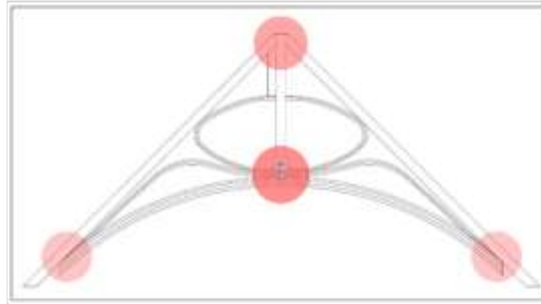

Figure 25. Points of breakage post-experiment

The most effected part in the truss after the hydraulic press test is the Fulcrum member so after the first test it supported by metal fastener to check the stability in the second round of experimental test.

Conclusions

The results of the study indicate several points on waterfront public space quality. The IPA approach helps to identify which criteria need to be improved or given a specific strategy. Quadrant IV (focus here) is where you will discover the availability of shade-giving vegetation, good drainage and clean water, and accessible facilities for the disabled. This implies that these requirements represent fundamental flaws. The stakeholders ought to concentrate more of their efforts on raising the standard for the comfort and happiness of the visitors. The results also indicate that since quadrant I, which indicates both high performance and a high importance score, pertains to security, environmental cleanliness, pedestrian paths, recreational facilities, informal sectors, lighting facilities, and transportation, these aspects of the economy should be preserved. The outcomes of the IPA support Tirtonadi Dam Park's development as a waterfront public area with both tourism and economic value. As a result, enhancing waterfront facilities holds the potential to attract more visitors due to their comforting and recreational attributes. Urban redevelopment and increasing community involvement are essential. Cities' public spaces may encourage local businesses and economic growth when they are vibrant and bustling with positive activities. Future research needs to investigate what factors make public spaces appealing and how they contribute to the well-being and prosperity of communities.

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Author(s) contribution

Omar Khaled Farouk Ahmed Khalil contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Yulianto Purwono Prihatmaji contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

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