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Design, computer aided analysis and construction of bamboo gazebo

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Abstract
Outdoor living spaces have become increasingly popular, offering a welcome escape from the confines of indoor living and fostering a connection with nature. Patios, decks, and gardens provide opportunities for relaxation, entertainment, and social gatherings. Gazebos, freestanding structures with roofs and open sides, add a touch of charm and functionality to these havens. Traditionally constructed from wood or metal, gazebos can be expensive and require significant maintenance, often with a higher environmental footprint. This study explores the design, analysis, and construction of a bamboo gazebo, focusing on its functionality, aesthetics, and structural integrity. The chosen bamboo species, *Dendrocalamus stocksii* (Manga), is known for its well-documented strength and weight balance, making it suitable for load- bearing structures like gazebos.
Computer-aided design (CAD) and computer-aided engineering (CAE) analysis play a crucial role in optimizing the design for functionality and structural integrity. The design process considers factors like occupancy loads, wind directionality, and desired aesthetics. The CAE analysis resulted in improved design modifications to enhance wind load resistance, highlighting the effectiveness of iterative design and these powerful tools. The findings from this research contribute significantly to the development of improved bamboo gazebo designs. The project aims to pave the way for environmentally conscious and user-friendly outdoor structures. A life cycle cost analysis, a potential future exploration, could provide a more comprehensive picture of the long-term economic viability of bamboo gazebos compared to traditional materials.

Keywords: Computer-aided design, computer-aided engineering, bamboo gazebo

Introduction
The desire to extend living spaces beyond the confines of our homes has fueled the growing popularity of outdoor living areas. Patios, decks, and gardens offer a delightful escape for relaxation, entertainment, and a connection with nature. Gazebos, freestanding structures with roofs and open sides, add a touch of charm and functionality to these outdoor havens. Traditionally constructed from wood or metal, gazebos can be expensive, require significant maintenance, and have a higher environmental footprint. However, bamboo, a readily renewable resource with exceptional strength-to-weight ratio and aesthetic appeal, is emerging as a viable alternative building material for these outdoor structures.
This research delves into the design, analysis, and construction of a bamboo gazebo. The primary objective is to create a functional and safe structure that complements outdoor living spaces while offering environmental and economic advantages over traditional materials.

Bamboo: A Sustainable and Functional Alternative
Gazebos have traditionally been constructed from wood or metal. While both materials offer certain advantages, they also come with limitations. Bamboo, a rapidly renewable resource with exceptional strength-to-weight ratio and aesthetic appeal, is emerging as a viable alternative building material for gazebos. Bamboo offers a compelling choice for Sustainability, Strength and Durability, Aesthetics and Cost-Effectiveness. Hence the present study entitled “Design, Computer aided analysis and Construction of Bamboo Gazebo” deals with following objectives:
1. Design and development of Bamboo Gazebo.
2. FEA of the Bamboo Gazebo.

Mosalam *et al.* (2014) [6] developed a design framework for analyzing wind load on bamboo structures. This framework can be helpful for calculating wind load on your gazebo specific to the Dapoli location. Fang *et al.* (2015) [2] explored the use of finite element analysis (FEA) for modeling bamboo structures. This study highlights the importance of considering structural loads during the design phase. Asocian *et al.* (2017) [1] explored the life cycle assessment of bamboo structures, emphasizing their environmental benefits compared to traditional construction materials. This research reinforced the sustainable aspects of using bamboo. Nguyen *et al.* (2017) [7] analyzed the strength and efficiency of different bamboo lashing techniques. The research guided the selection of appropriate lashing methods for the load-bearing components of gazebo. Karaca *et al.* (2017) [3] investigated the mechanical properties of Manga bamboo *(Dendrocalamus stocksii*) and found it to possess good strength and flexibility. However, emphasized the importance of proper treatment for durability, especially in high- humidity environments. Lac *et al.* (2018) [5] presented a case study on the construction of a traditional Vietnamese bamboo gazebo. The study provides valuable insights into the practical application of traditional design principles and construction techniques. Kumar *et al.* (2015) [4] investigated the socio-cultural significance of traditional bamboo architecture in India. Understanding the local context and incorporating traditional design elements can enhance the aesthetic appeal and cultural relevance of gazebo.

Discussed design considerations for optimizing bamboo usage and minimizing waste. Local regulations and certifications for sustainable bamboo construction might exist. Van den Heijden *et al.* (2016) [8] a variety of construction techniques exist for bamboo gazebos. Flooring options include bamboo slats and plywood. Roofing options range from thatched for aesthetics to metal with bamboo support for durability. Mayekar *et al.* (2017) [9] revealed the selecting and preparing bamboo suitable for the Konkan climate is another crucial aspect. The study discussed about factors like age, diameter, and culm quality for selection. Additionally, traditional methods for treating bamboo against pests and moisture are explored. Jain *et al.* (2018) [10] emphasized on the importance of a strong foundation, especially considering the Konkan monsoon season. It explored foundation options based on soil type and wind resistance, recommending stone or laterite block footings with a concrete base for stability.

Materials

Table 1: Construction materials required

S. N	Material	Quantity
1	Bamboo (*Dendrocalamus stocksii*)	25 nos.
2	Plastic sheet (for treatment tank lining)	1 nos. (14'*8')
3	Chemical (Boric acid)	
5	Chemical (Borax)	
6	Bamboo Mat (7'*4')	4 nos.
7	Completely threaded studs (8 mm*2 m)	10 nos.
8	Nut Washer (8 mm)	100 nos.
9	Nut (8 mm)	100 nos.
10	Screw (8*50)	100 nos.
11	Nails (1.5", medium size)	1.5 kg
12	Nylon Rope	2 bundle
13	Grinder paper 60 no.)	10 units
14	Sand paper (220 no.)	20 units
15	Fevicol Marine	2 kg
1	Drill bit (8 mm, 12 in)	2 units
17	Drill bit (3 mm, 4 in)	2 units
18	Other tools (spanner, grinder, stud cutter, cutter, saw cutter, etc.)	1 unit each
19	Workshop Machinery	As required
20	Coconut thatching	As required
21	Ply board (8 by4ft)	2
22	GI pipe frame cost (7by7ft)	1
23	Brushes	2
24	Wood varnish	2
25	Coconut coir rope	1
26	Cement-Sand mixture 20 kg bags	4

Table 2: Software used

Sr. No.	Software	Purpose
1	Solid Works	Preparing CAD Model
2	ANSYS Granta Libraries and Selector	Obtaining Material Properties
3	ANSYS WorkBench SS Module	For Finite Element Analysis

Sustainable Bamboo Gazebos and FEA Analysis

The designing and analysing a bamboo gazebo was carried by using CAD (SolidWorks) and FEA (ANSYS) software. Bamboo's sustainability and impressive strength-to-weight ratio make it an attractive building material. FEA is a valuable tool for evaluating a structure's behaviour under various loads. The objectives were to develop a detailed 3D CAD model of the bamboo gazebo (SolidWorks), to perform static structural FEA (ANSYS) to assess deformation under wind loading and to utilize accurate material properties from ANSYS Granta Libraries for realistic simulations.

Solid Works Modeling

The gazebo design incorporates a modified king truss with a two-sided sloping roof supported by fixed columns and angled rafters. A metal frame supports the plywood floor. The model includes individual bamboo elements, sub-assemblies, and the complete structure.

Modeling assumptions and Simplifications

1. Bolt holes were ignored in favour of bonded connections.
2. All connections were assumed to be fixed.
3. A combination of feet/inches and millimetres were used for modelling.

Importance of Material Properties in FEA

Accurate material properties are crucial for reliable FEA results. ANSYS Granta Libraries were used to obtain material data for all components, including bamboo (with separate properties for longitudinal and transverse directions due to anisotropy).

FEA Analysis Setup in ANSYS Workbench

ANSYS Workbench with ANSYS Mechanical solver was chosen for its static structural analysis capabilities. The complete assembly model from SolidWorks was imported directly into ANSYS Workbench using compatibility add-on. Material properties were assigned based on data from ANSYS Granta Libraries.

Mesh Generation
A balanced meshing approach was adopted. Patch Conforming meshing was used for bamboo culms, while Automatic Linear meshing was used for the metal frame components.

Boundary Conditions and Load Application
1. Fixed boundary conditions were applied at the gazebo's base.
2. Standard gravity was considered.
3. Wind loads were applied in both transverse and longitudinal directions for wind speeds of 100 kmph, 80 kmph, and 50 kmph.
4. Point loads were applied to the floor to simulate occupancy.

Solution Setup and Analysis
An iterative solver was used due to computational resource limitations. Convergence criteria were set to ensure solution accuracy.

Result Analysis
Wind Load Analysis
Maximum deformations occurred in the longitudinal wind direction due to the king truss design's strength against lateral loads. Deformations under wind loads and point load tests (simulating four people) were within safe limits for the gazebo floor and structure.

Stress Analysis
Highest stress concentrations were observed at column bases and king post-rafter connections, but remained within safe limits based on generic bamboo properties. Species-specific data is recommended for future refinements.

Iterative Design Optimization
Adding a slant support from the king post base to the apex bamboo significantly reduced deformations, especially in the longitudinal direction.
Thus, the design and analysis of a bamboo gazebo using CAD and FEA results in incorporating accurate material properties, and refinement of the design to ensure the bamboo gazebo meets structural requirements while maintaining its sustainability and aesthetics.

Development
The construction phase served as a platform to evaluate the effectiveness of various connection methods for the bamboo gazebo design. Here's a breakdown of the findings (Fig. 1):
1. **Stud-nut joints:** These offered ease of construction due to their mechanical fastening nature. However, precisely aligning bent bamboo culms, particularly in the columns, proved challenging. This misalignment resulted in uneven stress distribution and compromised joint strength. While offering ease of use, stud-nut joints might require a selection and preparation process for the bamboo culms to ensure straightness and uniformity. Alternatively, exploring prefabricated connector elements specifically designed for bamboo construction could address alignment challenges associated with stud-nut joints.
2. **Bamboo nails:** Fabricated with 7 mm diameter bamboo and used in 6 mm drilled holes, these emerged as a highly effective connection method. They provided strong and secure joints. However, the process of creating bamboo nails was time- consuming, impacting construction efficiency.
3. **Lashing joints:** A traditional technique in bamboo construction, lashing joints emerged as the most practical and adaptable method. Their effectiveness, particularly with GI wire reinforcement in high-stress areas, validates their suitability for bamboo gazebo construction, especially when considering factors like ease of use, adaptability, and material availability. Lashing joints offer a good balance between ease of construction and structural integrity.

Fig 1: Completed Gazebo

Conclusion
The design of bamboo gazebo using CAD and FEA with a king truss structure made up with *Dendrocalamus stocksii* (Manga) bamboo, ensured that the bamboo gazebo meets structural requirements while maintaining its sustainability and aesthetics.

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