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Bamboo shelter structural design optimization: toward sustainable disaster relief housing

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ABSTRACT

This study explores the optimization of bamboo shelter design for emergency housing by integrating technical, implementation, and sustainability aspects in Karangasem Regency, Bali. Using a literature review approach combined with comparative and evaluative analysis, the research examines the structural properties of bamboo compared to conventional materials, assesses joint systems, and evaluates the proposed shelter design from a sustainability perspective. The findings highlight bamboo's key advantages, including rapid construction time (approximately one week per unit) and cost efficiency (Rp1,500,000–Rp4,500,000 per shelter). The proposed design results in a low carbon footprint of 22 kg CO_2/year/m^2 and demonstrates a CO_2 absorption capacity of 3,260 kg/year. Sustainability assessment indicates strong performance in technical reliability (score 4) and shelter habitability (score 4), moderate results in CO_2 emission mitigation and affordability (score 3), and room for improvement in material efficiency (score 2) and tree protection (score 1). This research provides a foundation for developing sustainable bamboo shelters that balance structural performance, environmental impact, and socio-economic feasibility in post-disaster contexts.

Keywords: bamboo shelter; emergency housing; sustainable construction; disaster mitigation

1 Introduction

In recent decades, the frequency and severity of natural disasters have intensified globally, leading to a growing demand for emergency shelters that are not only rapidly deployable but also environmentally sustainable and socially inclusive [1], [2]. In disaster-prone regions like Karangasem Regency, frequently affected by volcanic eruptions such as those from Mount Agung, there is an urgent need to develop resilient housing models that can serve as effective transitional shelters [2]. However, conventional shelter solutions often fall short due to high environmental footprints, long construction times, and limited adaptability to local resources and culture [3], [4].

Bamboo has emerged as a compelling material candidate for sustainable construction, particularly in tropical regions. It is lightweight, fast-growing, and exhibits a high strength-to-weight ratio [5], [6]. When appropriately treated, bamboo structures can achieve lifespans of over 30 years, demonstrating strong performance in seismic zones [1], [6], [7]. Moreover, bamboo cultivation aligns with global climate action goals; its rapid biomass accumulation and high carbon sequestration potential have positioned it as a key nature-based solution (NbS) in climate mitigation strategies [7], [8]. Products derived from engineered bamboo such as laminated panels and strand-woven composites also contribute to long-term carbon storage and reduced embodied energy compared to conventional materials like concrete and steel [6], [8].

Despite these advantages, bamboo-based construction especially in emergency housing, still faces significant challenges, particularly in the design of structural joints [9], [10], [11]. The anisotropic geometry of bamboo culms, combined with variability in culm wall thickness and diameter, complicates the standardization of connection techniques [11]. Traditional lashing methods, while culturally embedded, often fail under cyclic loading conditions such as earthquakes or wind events [10], [12]. Recent innovations in hybrid connections, including bolt-gusset systems, fish-mouth joints, and FRP-enhanced couplings, have shown promise in enhancing joint stiffness and ductility [9], [10], [11], yet empirical validations under full-scale testing remain limited

Several field studies and prototypes developed after major disasters, including the 2018 Lombok earthquake and 2010 Merapi eruption, underscore the potential of bamboo shelters that integrate modular prefabrication, local participation, and ecological sensitivity [3], [4]. For instance, the SHEMINA shelter project employed galvanized pipe joints in a modular bamboo frame to improve lateral load resistance [12], while the Lombok bamboo shelter prototype demonstrated the viability of prefabricated panel systems for rapid deployment [4]. Nevertheless, assessments from these projects reveal gaps in thermal comfort, joint durability, and lifecycle planning particularly regarding reuse, recyclability, and material loops [3].

Moreover, indigenous architectural knowledge from traditional settlements such as Dasan Beleq in North Lombok provides insights into seismic resilience achieved through low-tech, locally derived construction methods using bamboo and timber [13]. These vernacular systems prioritize symmetrical geometry, lightweight roofing, and elastic joints—strategies that align well with modern performance-based design principles. Similarly, conservation-oriented bamboo ecosystems like Penglipuran Village in Bali exemplify how architectural design and socio-environmental stewardship can coexist through regulated forest use and eco-tourism [14].

To address the aforementioned challenges and leverage bamboo's full potential, this study proposes an integrated framework for optimizing bamboo shelter structural design. The approach involves a comprehensive literature review followed by comparative analysis of material properties [3], joint systems [9],[10], and shelter design configuration [4], [15], [16], culminating in a sustainability-based evaluation across environmental, social, and technical criteria [7], [8], [6]. The research flow is structured around three key assessments, material comparison, joint system analysis, and shelter configuration leading to optimization and final design recommendations.

This study contributes to the development of structural engineering approaches for emergency housing by presenting an optimized bamboo shelter design model that integrates structural resilience, material efficiency, and environmental sustainability. Furthermore, the research is intended to serve as a technical and scientific reference for the planning and construction of safe, adaptive, and eco-friendly transitional shelters in disaster-prone tropical regions.

2 Data and Methods

This research adopts a descriptive and evaluative methodology with a strong foundation in literature-based data analysis. The primary objective is to develop an optimized structural design for bamboo shelters that responds effectively to the urgent demands of post-disaster housing, particularly in tropical, disaster-prone regions. The entire process was designed to integrate structural performance assessment with environmental and socio-economic considerations, ensuring the resulting design is not only technically viable but also contextually appropriate and sustainable.

The research process begins with the collection of secondary data related to bamboo as a building material. This includes mechanical properties such as compressive strength, tensile strength, modulus of elasticity, and shear resistance. These technical parameters are essential in evaluating bamboo's feasibility as a primary structural material, especially in comparison to conventional materials like wood, steel, and concrete. In addition to technical characteristics, the study also gathers data on construction time, labour requirements, material availability, environmental footprint, and carbon storage potential of bamboo. This comprehensive data collection serves as the groundwork for multi-dimensional analysis. The research methodology flowchart is shown in Figure 1.

A critical focus of the study lies in the analysis of bamboo connection systems. Since joint performance plays a pivotal role in the safety and durability of any bamboo structure, the study compares various connection techniques, ranging from traditional lashings and pinned joints to modern bolted and hybrid systems. Each type is examined in terms of its structural behaviour under lateral and axial loading, ease of fabrication and installation, material compatibility, and vulnerability to failure. This step is vital to ensure that the proposed shelter design can withstand environmental forces such as wind and seismic activity while remaining feasible for local implementation.

The study further explores shelter configuration through the evaluation of various architectural and structural layouts. The analysis includes considerations of geometric form, modularity, ease of assembly, foundation strategy, ventilation, and space efficiency. These parameters are assessed based on their suitability for emergency deployment, scalability, and adaptability to different disaster scenarios. In this regard, modular prefabrication and local construction capacity are prioritized to ensure practical field application.

To guide the decision-making process, all findings are consolidated into a comparative scoring system that allows for structured evaluation across multiple sustainability indicators. Six key criteria are used: structural reliability, material efficiency, carbon emission mitigation, shelter habitability, economic affordability, and environmental impact. Each criterion is rated on a qualitative scale ranging from 1 (very poor) to 5 (excellent), enabling a balanced analysis that takes into account both technical and contextual performance.

Ultimately, the methodology is designed not only to evaluate existing bamboo shelter solutions, but also to generate a refined structural design that aligns with sustainable development goals. The process ensures that the final recommendation addresses the urgent needs of post-disaster housing while promoting the broader adoption of bamboo as a resilient, eco-friendly construction material.

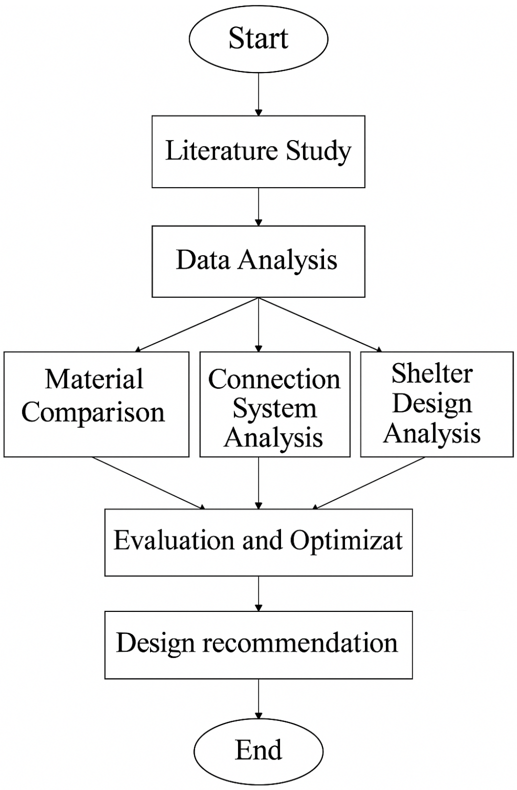

Figure 1. Research methodology flowchart

3 Results and Discussion

3.1 Material Performance Comparison

Table 1 presents a qualitative comparison of four common construction materials bamboo, wood, steel, and brick based on structural performance, construction practicality, and cost-effectiveness. The data emphasize bamboo's distinct advantages in emergency shelter construction, particularly in tropical, disaster-prone regions.

In terms of strength, bamboo exhibits tensile performance comparable to light steel, though it is weaker in lateral compression. While steel leads in both tensile and compressive strength, bamboo offers sufficient structural capability for lightweight shelters. Brick, on the other hand, is notably poor in tension, though strong in compression, making it more suitable for permanent, rigid structures than for modular, rapid-deployment applications.

Durability is one of bamboo's main limitations if untreated, lasting only 1–2 years. However, with appropriate treatment, its lifespan can extend up to 25 years comparable to some types of treated wood. Steel and brick remain the most durable materials, with potential service lives exceeding 30 years, but often come at higher environmental and financial costs. In addition to treatment, proper detailing and joint protection can significantly improve bamboo's long-term performance under outdoor conditions.

In terms of flexibility, bamboo stands out as the most adaptable material, particularly in split form. This characteristic enhances its seismic performance and ease of handling in irregular terrain. In contrast, brick is completely rigid, and wood is limited in bending capacity unless processed into smaller, shaped components. Steel is also flexible and highly formable, though this often requires advanced tools and skilled labour.

Joinery and construction speed further highlight bamboo's practicality. Bamboo allows for simple, low-tech joinery using lashings or basic mechanical connections, enabling rapid on-site assembly. It typically requires only one week to construct a complete shelter. This speed advantage is shared with steel-based prefabricated systems but contrasts sharply with brick structures, which demand up to six weeks for completion.

From a logistical perspective, bamboo is abundant in tropical disaster-prone areas, reducing reliance on long supply chains. In contrast, wood faces declining global supply and environmental regulation, while steel often needs to be imported and brick requires heavy transportation and on-site labour. This makes bamboo not only a material choice, but also a logistical solution in emergency contexts where mobilization speed is critical.

Cost considerations reinforce bamboo's advantage. For a 24 m^2 shelter, bamboo offers the lowest construction cost, ranging from Rp1.5 million to Rp4.5 million. In comparison, wood costs range from Rp7.5 million to Rp15 million, while steel and brick systems are significantly more expensive, potentially exceeding Rp75 million depending on specifications and logistics.

Overall, bamboo combines sufficient strength, speed, flexibility, and affordability to position itself as a leading material for transitional shelters. Despite its limitations in durability and long-term stiffness, its benefits in emergency contexts where speed, cost, and local availability are crucial make it a viable and strategic option for post-disaster housing.

Table 1. Comparative characteristics of common construction materials

Characteristic	Bamboo	Wood	Steel	Brick
Strength	Tensile strength similar to light steel; weak in lateral compression	Strong in lateral, tensile, and longitudinal compression	High tensile and compressive strength	Low tensile strength; high compressive strength
Durability	Low (1–2 years); with treatment: 10–25 years	Depends on wood type and exposure (2–30 years)	Very durable (10–30 years)	Very durable (20–50 years)
Flexibility	Very flexible, especially in split form	Limited to small pieces or complex bending processes	Highly flexible, formable as needed	Not flexible; rigid structure
Joinery	Low-tech: bindings or lashings	Nails or dowels; medium-tech	Screws, bolts, welding; high-tech	Mortar joints
Technology Level	Low	Medium	High	Low
Construction Speed	Very fast, 1 week per shelter	Medium, 1–3 weeks per shelter	Fast, 1 week per shelter	Slow, 4–6 weeks
Availability	Abundant in tropical disaster-prone areas	Diminishing global supply; environmental concerns	Often must be imported; limited in affected areas	Widely available; various sources
Cost (for 24 m^2)	Very low (Rp1,500,000 – Rp4,500,000)	Medium (Rp7,500,000 – Rp15,000,000)	High (Rp30,000,000 – Rp75,000,000)	Medium to high (Rp15,000,000 – Rp75,000,000)

Table 2. Relative advantages of bamboo joint systems

		Strength *				Usability*		Cost*		
Joint Type	**Notes**	**Durability**	**Rigidity**	**Strength**	**Flexibility**	**Ease of Use**	**Across Joints**	**Low Labour**	**Cheap Material**	**Few Tools**
Bolt	Avoid crushing the bamboo during bolt installation. Strength is limited to the bamboo section penetrated. Best when supported from all directions.	5	5	5	2	3	4	2	2	2
Mortar & Bolt	Creates extremely solid joints. Suitable for foundations and industrial loads.	5	5	5	2	2	3	1	1	1
Adhesive	Outer bamboo layer resists glue, inner layer adheres better. Suitable for longitudinal joints.	4	4	4	1	2	1	2	3	3
Rubber Tie	Uses recycled rubber such as inner tubes. Susceptible to UV damage. Performance depends on attachment method.	3	2	2	5	4	4	4	4	4
Nail	Prone to cracking, especially in long-fibered bamboo. Pre-drilling or chiselling reduces cracking. Best for temporary structures.	2	1	2	3	5	4	5	5	5
Peg & Rope	Traditional, strong, and low-cost technique. Ideal for pegged and tied joints.	4	3	4	4	2	5	2	3	2
Peg (Dowel)	Requires pre-drilling. Strength depends on node positioning and joint fit.	3	2	3	3	3	4	3	4	3
Plywood & Bolt	Common for frames or structural loads. Bolt placement must align with nodes.	5	5	5	3	2	4	2	1	1
Rope or Rattan	Common in rural settings. Best results when using local, traditional materials.	3	2	3	5	3	4	4	5	5
Screw	Prone to cracking—requires pre-drilling. Best for bamboo-to-wood connections.	2	2	2	2	3	4	4	4	4
Wire	Prone to rust at ends and knots. Can be treated with protective coating. Tends to degrade under heavy load.	3	3	3	4	4	5	5	5	4

*Note: Scale 1 = Worst, 5 = Best

3.2 Joint System Evaluation

Table 2 presents a comparative evaluation of various bamboo joint systems commonly applied in shelter construction. Each type is assessed based on durability, rigidity, strength, flexibility, ease of use, labour and material efficiency, and required tools using a qualitative scale from 1 (worst) to 5 (best).

Bolt-based joints appear to offer the highest structural performance, scoring 5 in durability, rigidity, and strength. However, their usability is limited, especially in terms of flexibility and ease of use, which could hinder their application in fast, community-based shelter assembly. Plywood and bolt systems provide similar advantages, with high scores in rigidity and strength, making them suitable for structural frames when node alignment is ensured.

Mortar and bolt joints are also structurally strong and highly rigid, but they score lower in labour and tool efficiency, indicating that they are more suitable for industrial applications or permanent structures rather than emergency shelters.

Among traditional systems, the peg-and-rope joint provides a good balance between strength, usability, and moderate cost, scoring well in ease of use and low labour requirements. Adhesive joints also perform moderately across most parameters but are better suited to longitudinal connections where bonding is consistent.

Rubber ties, nails, and pegs (dowel-type) represent medium-performance options. Rubber based joints score high in flexibility and usability, but they are vulnerable to UV degradation. Nail connections are simple and fast to assemble but prone to cracking, particularly in long-fibered bamboo, unless pre-drilled. Dowel joints require careful placement at nodes and have moderate performance in most categories.

Rope/rattan and wire-based joints are the most accessible and locally adaptable options. They excel in low-cost construction and require minimal tools, though they may degrade under heavy load or long-term use. Screws, while structurally weak, are still viable for bamboo-to-wood assemblies and offer average usability.

Overall, the selection of joint type must consider the trade-off between structural integrity and construction practicality. For post-disaster shelter construction, where speed, cost, and local skills are essential, peg-and-rope or wire-based joints may provide the best balance, while bolt and plywood combinations can be reserved for main structural elements

3.3 Sustainability-Oriented Shelter Design Analysis

Figure 2 illustrates the proposed bamboo shelter design, featuring a preserved bamboo frame as its main structural component. The design adopts a stilt house configuration with precast reinforced concrete column foundations, woven bamboo walls, and a corrugated metal sheet roof. Ventilation is integrated through openings such as doors, windows, and bamboo vents located beneath the roof, all aimed at optimizing air circulation and thermal comfort. The joint technique, where bamboo elements are connected using dowels and reinforced with natural rope lashings to ensure structural integrity and accommodate flexibility under dynamic loads. To ensure structural integrity, the shelter incorporates parallel connections between columns and beams to form continuous frames that distribute vertical loads effectively. In addition, diagonal bracing is recommended between columns, especially at the sub-floor level and along wall planes, to enhance lateral stiffness and resist wind or seismic forces. The combination of these jointing methods—horizontal, diagonal, and lashing-based joints—provides a balance between strength, flexibility, and simplicity, making the design highly suitable for post-disaster applications.

According to Table 3, the specifications and performance of the proposed bamboo shelter design cover several critical aspects. In terms of the basic structure, the design employs a balanced combination of natural and manufactured materials. The total use of bamboo as the main structural material amounts to 7.9 m^2, supported by additional materials such as plastic rope (20 kg), steel/nails/wire (105 kg), and cement (210 kg).

From an environmental impact standpoint, the design demonstrates a relatively low carbon footprint, with total CO_2 emissions of 3,823 kg or 22 kg CO_2/year/m^2. Interestingly, the design also features a carbon offset capacity through bamboo's ability to absorb CO_2, amounting to 3,260 kg/year, indicating significant environmental mitigation potential.

The technical performance of the shelter meets various required standards, including wind resistance, flood mitigation, and minimum ventilation requirements. The design also considers liveability by providing adequate space for five occupants, along with features that meet basic needs such as minimum privacy and natural lighting. Additional specifications reveal that the shelter is designed to function in temperatures ranging from +35°C to +10°C, can be built by 8 workers in 7 days, and has a service life of 10 years.

Figure 3 presents a comprehensive sustainability assessment of the proposed bamboo shelter. The evaluation shows strong technical performance (score 4) and habitability (score 4), indicating the shelter's reliability and liveability in emergency contexts. Moderate scores are achieved in CO_2 emission mitigation (score 3) and affordability (score 3), reflecting balanced but improvable environmental and economic aspects.

In contrast, material efficiency receives a relatively low score (score 2), suggesting a need for optimization in resource usage. Tree protection ranks the lowest (score 1), highlighting the environmental trade-off of large-scale bamboo use.

Overall, the proposed bamboo shelter demonstrates a well-rounded performance across key criteria while identifying specific areas for future improvement, particularly in ecological impact and material management.

a. Bamboo shelter structure b. Housing prototype c. Detail of connection

Figure 2. Design and Construction Elements of the Proposed Bamboo Shelter

Table 3. Specifications and Performance of the Proposed Bamboo Shelter

Aspect	Component	Specification
Basic Structure	Structure	Preserved bamboo frame
	Wall	Woven bamboo panels
	Roof	Corrugated galvanized iron sheets
	Foundation	Precast reinforced concrete columns
	Floor	Woven bamboo panels over bamboo beams
	Openings	1 door (90 × 200 cm), 3 windows (60 × 100 cm), bamboo ventilation under the roof
Environmental Impact	Raw Materials	Bamboo (7.9 m^2), Water (74,100 liters)
	Manufactured Materials	Plastic rope (20 kg), Steel/nails/wire (105 kg), Cement (210 kg), Sand (0.32 m^3)
	CO_2 Emissions	Material production (508 kg), Transportation (55 kg)
	CO_2 Absorption	Deforestation offset (3,260 kg/year)
	Total CO_2	3,823 kg (22 kg CO_2/year/m^2)
	Recycling	CGI sheets reusable; bamboo structural elements and tarpaulins recyclable
Technical Performance	Wind Resistance	Meets standard requirements
	Flood Mitigation	Fulfills mitigation measures
	Ventilation	Meets minimum ventilation requirements
	Fire Resistance	Complies with fire resistance criteria
	Thermal Comfort	Reduces extreme temperature impacts
	Safety	Ensures personal safety
	Accessibility	Requires adjustments
Habitability	Floor Area	Suitable for 5 occupants
	Privacy	Provides minimum privacy
	Natural Lighting	Meets minimum lighting requirements
	Artificial Lighting	No available access
	Materials	Adjusted to local practices
	Facilities	Communal facilities provided onsite

Figure 3. Comprehensive sustainability assessment of the proposed bamboo shelter

4 Conclusion

Based on the analysis and discussion, the development of a bamboo shelter design demonstrates strong potential as a sustainable solution for emergency housing. Bamboo, as the primary material, offers key advantages in terms of tensile strength comparable to light steel, rapid construction time (approximately one week per unit), and cost-effectiveness (ranging from Rp1,500,000 to Rp4,500,000 per shelter).

An optimal joint system can be achieved through a strategic combination of high-strength connections (such as bolts or mortar) at critical load-bearing points and simpler joints in low-stress areas, ensuring a balance between structural integrity and practical implementation. From a sustainability standpoint, the proposed design yields a low carbon footprint of 22 kg CO_2/year/m^2 and a CO_2 absorption capacity of 3,260 kg/year. However, material efficiency remains a notable limitation that must be addressed to further reduce environmental impact.

Future research should explore improved bamboo preservation techniques that are both effective and environmentally friendly to extend the material's lifespan. Additionally, efforts to optimize the design for greater material efficiency—without compromising structural performance—are essential. Large-scale pilot implementations are also recommended to assess the design's practicality across diverse geographic, climatic, and socio-cultural settings.

References

[1] S. Das and P. Mukhopadhyay, "Multi-hazard disaster resilient housing with bamboo-based system," Procedia Engineering, vol. 212, pp. 937–945, 2018, doi: 10.1016/j.proeng.2018.01.121.

[2] I. G. A. Irawan, I. W. Diara, and I. B. P. Bhayunagiri, "Pemetaan Potensi Lokasi Pengungsian Akibat Bencana Letusan Gunung Agung di Kabupaten Karangasem Berbasis Sistem Informasi Geografis (SIG)," J. Agroekoteknologi Tropika, vol. 8, no. 4, pp. 371–380, 2019.

[3] Widyarko et al., "Material loops potential in post-disaster transitional shelter: Learning from 2010 Merapi eruption," Architecture & Environment, vol. 20, no. 1, pp. 13–30, Apr. 2021.

[4] J. Fajrin et al., "Bamboo-based temporary house for post disaster relief: A conceptual design and prototype built after Lombok Earthquake 2018," IOP Conf. Ser.: Earth Environ. Sci., vol. 708, p. 012076, 2021, doi: 10.1088/1755-1315/708/1/012076.

[5] J. Bredenoord, "Bamboo as a Sustainable Building Material for Innovative, Low-Cost Housing Construction," Sustainability, vol. 16, no. 6, p. 2347, 2024, doi: 10.3390/su16062347.

[6] R. Manandhar, J.-H. Kim, and J.-T. Kim, "Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings," J. Asian Archit. Build. Eng., vol. 18, no. 2, pp. 49–59, 2019, doi: 10.1080/13467581.2019.1595629.

[7] C. Pan et al., "Bamboo as a nature-based solution (NbS) for climate change mitigation: Biomass, products, and carbon credits," Climate, vol. 11, no. 9, p. 175, 2023, doi: 10.3390/cli11090175.

[8] H. R. Patel et al., "Sustainable bamboo: Technological innovations and patent insights for a greener future," Advances in Bamboo Science, vol. 10, p. 100127, 2025, doi: 10.1016/j.bamboo.2025.100127.

[9] A. Widyowijatnoko and K. A. Harries, "Joints in bamboo construction," in Nonconventional and Vernacular Construction Materials, Elsevier, 2020, pp. 562–593, doi: 10.1016/B978-0-08-102704-2.00020-2.

[10] K. A. Harries, C. Rogers, and M. Brancaccio, "Bamboo joint capacity determined by ISO 22156 'complete joint testing' provisions," Adv. Bamboo Sci., vol. 1, p. 100003, 2022, doi: 10.1016/j.bamboo.2022.100003.

[11] M. J. C. Aniñon and L. E. O. Garciano, "Advances in Connection Techniques for Raw Bamboo Structures—A Review," Buildings, vol. 14, no. 4, p. 1126, 2024, doi: 10.3390/buildings14041126.

[12] B. B. A. Kusuma, Y. P. Prihatmaji, and B. P. P. Sinaga, "Studi Pengaruh Pembebanan Gaya Lateral Terhadap Kinerja Tipe Sambungan T & L Pipa Galvanis 3″ Pada Bambu Apus Modul Shelter Mitigasi Bencana (SHEMINA)," Seminar Karya & Pameran Arsitektur Indonesia Sakapari 2022, pp. 375–390, 2022.

[13] Y. Susanthi, R. R. Meisandy, and A. Nisa, "Earthquake mitigation based on local wisdom: The vernacular architecture concept of Dasan Beleq traditional house in North Lombok – Indonesia," GeoEco, vol. 8, no. 1, pp. 48–61, Jan. 2022, doi: 10.20961/geoeco.v8i1.60448.

[14] I. W. Muliawan and N. M. W. Pratiwi, "Utilization of eco-tourism in Bangli Regency of Penglipuran Village as a bamboo forest conservation center in Bali," J. Infrastruct. Plann. Eng., vol. 2, no. 1, pp. 21–27, 2023, doi: 10.22225/jipe.2.1.2023.21-27.

[15] P. D. Sulistiana et al., "Structural Performance Evaluation of Bamboo Shelters as Temporary Housing Solutions," IOP Conf. Ser.: Earth Environ. Sci., vol. 1488, p. 012026, 2025, doi: 10.1088/1755-1315/1488/1/012026.

[16] N. Nareswarananindya et al., "The design concept of bamboo in micro housing as a sustainable self-building material," IOP Conf. Ser.: Mater. Sci. Eng., vol. 1010, p. 012026, 2021, doi: 10.1088/1757-899X/1010/1/012026.