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Potential of Bamboo as Green Building Element

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Abstract: *Bamboo is widely utilised not only for food production, handicraft, textile but also as building materials. In the construction sector, they are not as well-known as sustainable building materials, but they may be applied to improve the lives of others with its eco-friendly and sustainable characteristics. The aim of this study is to identify the components of buildings that use bamboo as a green material. The quantitative method was adopted for this study by using a questionnaire survey. The data of 100 respondents from the architects was analysed by using Social Science Statistical Package (SPSS). The findings of the study indicate that among various components in buildings, bamboo materials are highly used as flooring and walls. Besides, bamboo materials are also used for the construction of roofs and structural elements such as beams, columns, and foundations. The results should enable project designers to consider bamboo as a green and sustainable material used in the elements of future building design.*

Keywords: Bamboo, Implementation, Green Material, Sustainable

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1. Introduction

The necessity for adopting sustainability and sustainable growth within the construction sector may be addressed using green building, which is a successful strategy. Many parties all around the globe have embraced green building as a tactic for enhancing the sustainability of the construction sector (Ahmad et al., 2019). Compared to conventional buildings, green buildings demonstrate a substantial reduction in energy consumption (Mi, 2024), potential reductions in water consumption (Talpur et al., 2020) and play a crucial role in resource efficiency (Krause & Hafner, 2022). They also have elements that promote an eco-friendly atmosphere and the effective use of water and energy. The structures integrate effective use of landscape and interior air quality improvements for health and comfort. They also employ renewable energy and recyclable materials (Laaeq et al., 2017).

Green building, sometimes referred to as sustainable building, is a construction technique that uses environmentally friendly and resource-efficient procedures over the entirety of a building's life cycle, from design to demolition. Although green building has recently received increasing attention (Kamil et al., 2018), there are still obstacles in the way of its general acceptance.

Furthermore, the construction industry was identified as a major source of environmental pollution, contributing to air, water, and noise pollution (Kong, 2022). Dust and particulate matter are major air pollutants generated from construction activities such as excavation, drilling, and material transportation. These particulates can cause health issues for workers and nearby residents, and often exceed prescribed air quality limits (Liong et al., 2024). Water pollution can occur from construction sites through the release of harmful chemicals, construction debris, and soil erosion, leading to contamination of waterways and groundwater. Construction sites can contribute to water pollution by discharging wastewater containing petroleum substances and suspended solids. Although some wastewater can be repurposed for dust suppression, improper management can contaminate local water sources (Kong, 2022). Additionally, construction sites produce high levels of noise pollution, which can impact the well-being of workers and nearby residents (Kong, 2022). The construction industry's contribution to environmental pollution underscores the need for sustainable and eco-friendly practices, including the use of materials like bamboo, which can help reduce the industry's environmental impact.

Besides, the construction industry is also a significant contributor to global carbon emissions, accounting for 39% of global carbon emissions (Guo et al., 2023). Therefore, the industry has a crucial role to play in mitigating the effects of climate change by reducing its carbon footprint and adopting sustainable practices. Encouraging the use of sustainable and eco-friendly materials like bamboo in construction can help reduce the industry's carbon footprint and promote sustainable ecosystems. Hence, this study aims to identify the components of buildings that use bamboo as a green building element for reference in future research to enhance its application.

2. Bamboo as green elements in construction

Bamboo is increasingly recognized as an eco-friendly building material due to its rapid growth, sustainability, and versatile applications in construction. Bamboo is a rapidly growing material with significant mechanical strength, making it suitable for various engineering and construction applications. Its mechanical properties, such as tensile strength, are comparable to traditional materials like steel, which allows it to be used as structural reinforcement in concrete beams, offering a sustainable alternative to steel (Nagaraju & Bahrami, 2024). Besides, bamboo fibers can be used to create eco-friendly composites with excellent mechanical properties and thermal resistance. These composites are developed using environmentally friendly binders, such as silylated polystyrene, which enhance the ecological purity of the material (Tatrishvili et al., 2024; Mukbaniani et al., 2023). Furthermore, the use of bamboo in architectural applications not only leverages its mechanical and thermal properties but also its renewable nature and efficient manufacturing process, aligning with sustainable development goals (Wang et al., 2023).

Bamboo is a versatile and sustainable building material suitable for various types of construction in Malaysia, particularly due to its rapid growth, availability, and eco-friendly properties. Its application ranges from structural components in buildings to innovative uses in industries like tourism and aquaculture. The suitability of bamboo in Malaysia is influenced by its mechanical properties, cultural acceptance, and environmental benefits. Bamboo species such as Dendrocalamus Asper, Bambusa Vulgaris, and Gigantochloa Scortechinii have been studied by Awalluddin et al., (2019) for their compressive buckling behavior, making them suitable for structural applications. These species demonstrate adequate strength and stability, which can be effectively utilized in constructing light and strong buildings.

Furthermore, bamboo is suitable for use in tourism accommodation. According to a study by Farina et al., (2021), bamboo is used in the construction of accommodations at Tadom Hill Resort in Selangor, where it serves as a material for walls, foundations, and floors. The types of bamboo used include Semantan, Semeliang, and Betung, which can last up to 20 years with proper maintenance. Bamboo is also proposed as a material for micro housing, offering a sustainable and cost-effective alternative to timber. Its use in compact, multi-story housing designs supports space efficiency and environmental sustainability, aligning with the need for innovative housing solutions in densely populated areas (Nareswarananindya et al., 2021).

Moreover, bamboo can be utilized to construct various building elements, each serving distinct structural or functional roles in a building.

2.1 Structure Elements

Bamboo poles or laminated bamboo beams can be used as load-bearing elements in construction. They provide vertical and horizontal support, distributing the weight of the building. Either used in traditional or modern structures, bamboo beams, and columns are normally integral to the framework of houses, pavilions, and other structures. Recent studies have explored various applications and enhancements of bamboo in construction, focusing on its potential to improve structural performance and sustainability. A systematic literature review by Bahrin et al. (2023) highlights the mechanical properties of bamboo, focusing on species like Dendrocalamus asper and Gigantochloa levis. The review underscores the variability in mechanical properties due to factors such as origin, age, and moisture content. This study provides a foundation for further research and application of bamboo in construction, emphasizing its potential as a structural material. Another study by Ummati et al., (2023) explored using bamboo with perpendicular pivot hooks in concrete beams, demonstrating a 33% improvement in load capacity. This suggests that specific configurations of bamboo reinforcement can significantly enhance the flexural capacity of concrete beams.

According to Fahim et al. (2022), bamboo is a renewable resource with impressive mechanical properties. Its tensile strength ranges from 70 to 210 MPa, and its compressive strength from 20 to 65 MPa. These properties make it a strong candidate for structural applications, including foundations. A study by Deng et al. (2020) indicates that bamboo micropiles have been tested for their effectiveness in supporting shallow foundation pits. These micropiles can reduce horizontal deformation and surface subsidence, providing stable support in soft soil conditions.

2.2 Flooring

Bamboo is a fast-growing, renewable resource, which positions it as a sustainable alternative to traditional building materials. Its use in flooring contributes to ecological and sustainable development goals (Menon & Sharma, 2024). The mechanical properties of bamboo are often superior to conventional timbers, which facilitates its use in both indoor and outdoor flooring applications.

The durability of bamboo flooring varies depending on the treatment and modification processes it undergoes. According to a study by Wei et al. (2023), bamboo aggregates modified with epoxy mortar (EM) show significantly improved durability compared to unmodified bamboo. EM-modified bamboo is less affected by acidic and alkaline conditions, with almost no mass loss, indicating superior resistance to environmental degradation. Another study by Qin et al. (2023) highlights that superheated steam treatment enhances the durability of bamboo scrimbers by improving their resistance to water, ultra violet radiation, and fungal decay. This treatment, however, slightly reduces mechanical properties such as bending strength.

Various types of bamboo flooring are utilized, each offering unique benefits and applications. These types include traditional bamboo flooring, engineered bamboo flooring, and laminated bamboo flooring. Each type leverages bamboo's natural properties while addressing specific construction needs.

Traditional bamboo flooring involves the use of natural bamboo strips that are glued together to form planks. This type of flooring is known for its natural appearance and eco-friendliness, as it utilizes the raw bamboo material with minimal processing (Dey, 2024). It is often used in low-cost housing projects, particularly in tropical and subtropical regions where bamboo is readily available and culturally integrated into construction practices (Bredenoord, 2024).

Engineered bamboo flooring refers to a type of flooring material made from processed bamboo that has been engineered to enhance its physical and mechanical properties, making it a viable alternative to traditional wood flooring. This engineered bamboo is created through processes such as lamination and hybridization, resulting in improved strength and durability comparable to wood materials (Supriadi and Trisatya', 2021). Engineered bamboo products, such as laminated and scrimber bamboo, enhance its utility in flooring by improving its durability and aesthetic appeal (Fahim et al., 2022).

While, laminated bamboo flooring involves layering bamboo strips in a cross-grain pattern, which increases the material's strength and stability. According to Madhushan et al. (2023), this type of flooring is particularly valued for its structural integrity and is used in both residential and commercial buildings. It is also used in innovative construction methods, such as in the creation of structural members and facades, due to its load-bearing capacity and aesthetic appeal.

Overall, bamboo flooring is an adaptable, affordable, and environmentally friendly choice for individuals seeking a substitute for conventional hardwood flooring. However, bamboo flooring has certain disadvantages as it is prone to humidity, which can lead to the growth of fungi and moss, potentially compromising structural integrity (Pradipto et al., 2020).

2.3 Walls

Bamboo walls in building construction are diverse and innovative, leveraging bamboo's natural properties and sustainability. Various types of bamboo walls have been developed, each with unique characteristics and applications. These include laminated bamboo lumber (BLL), bamboo scrimber (BS), bamboo composite panels, and traditional walls.

A study by Li et al. (2023) indicates that BLL and BS are two primary bamboo-based materials used in wall construction. BLL is known for its higher moisture sorption capacity, while BS has a greater heat storage capacity, making it suitable for different climate zones. External insulation systems using these materials are particularly effective in cold climates.

Bamboo composite panels, often combined with steel frameworks and mineral wool insulation, are designed to enhance thermal performance. Adjustments in panel and insulation thickness, as well as framework material, can mitigate thermal bridging and improve energy efficiency. These panels have been shown to outperform conventional materials in thermal performance, suggesting their potential for broader application in residential construction (Li et al., 2024). Traditional bamboo walling involves using whole bamboo culms or split bamboo strips woven into mats, providing a rustic and natural appearance that is ideal for eco-friendly constructions.

Each type of bamboo walling leverages the material's natural properties to create sustainable and versatile building solutions.

2.4 Roof

The roof gives shelter from weather extremes, including rain, sun, and wind, as well as a clear and functional area underneath the canopy. Most importantly, it must be sturdy enough to withstand the powerful pressures produced by the wind and roof coverings. In this regard, bamboo is the perfect roofing material since it is lightweight, sturdy, and durable (Sharma et al., 2014).

Bamboo is used in various forms for roofing in building construction. Its application ranges from traditional methods to modern engineered solutions, each offering unique benefits and challenges. As for traditional roofing, bamboo culms are often used directly as structural members in traditional roofing, providing a natural aesthetic and structural integrity. This method is common in Southeast Asia, where bamboo is abundant (Fahim et al., 2022). Furthermore, engineered bamboo such as laminated and scrimber bamboo, is used for roofing due to its enhanced mechanical properties. These materials offer improved tensile and compressive strength, making them suitable for more demanding structural applications (Fahim et al., 2022).

Bamboo serves as the primary structural element in bamboo architecture and supports the weight of the buildings. Bamboo has excellent flexibility in terms of thickness and strength, and it can be combined in a variety of ways according to architectural design in order to meet the demands of various structural performances. On the other hand, bamboo constructions have very modest technical requirements and may be readily incorporated into existing local architectural designs. For instance, combining bamboo with adhesive, earth, or concrete can help strengthen the structure (Ehimatie, 2020).

3. Research Methodology

This study used a quantitative data approach to obtain the perspectives of experts to generate high-quality research results. The expertise of architects in designing buildings and recommending suitable materials for construction made them the chosen respondents for this study. The questionnaire was developed and used to gather primary research data and instruments on using bamboo as a sustainable material in buildings. In order to provide relevant data, the questionnaire is designed with a consistent format based on a particular topic. The population of architects registered with the Board of Architects, Malaysia (LAM) in Penang was identified as 180. Questionnaires were disseminated to 123 architects as the sample size referred to the table by Krejcie and Morgan. The respondent can utilise the five-point Likert scale when completing the questionnaire. Respondents can select from 1 for "strongly disagree" to 5 for "strongly agree" on the Likert scale.

4. Findings and Discussion

The demographics of the respondents who participated in the study are shown in Table 1. Out of 123 questionnaires distributed, only 100 respondents provided the feedback. 54% (Frequency =54) are male, and 46% (Frequency = 40) are female. The age of the respondents is mostly within 26 to 30 years, 45% (Frequency =45), followed by 20 to 25 years 29% (Frequency =29) and more than 30 years 26% (Frequency =26).

In addition, the majority, 41% (Frequency = 41) of the respondents, has 5 to 10 years working experience and less than 5 years 36% (Frequency = 36). 19% (Frequency = 19) has 11-15 years working experience while only 4% (Frequency = 4) has more than 15 years working experience.

Table 1: Respondents' Demographic Profile

	Category	Frequency	Percentage%
Gender	Male	54	54
	Female	46	46
Age	20-25 years	29	29
	26-30 years	45	45
	> 30 years	26	26
Working experience	< 5 years	36	36
	5-10 years	41	41
	11-15 years	19	19
	> 15 years	4	4

The respondents were asked to give opinions on the use of bamboo materials in the components of buildings. The mean and rank of the components are displayed in Table 2 below.

Table 2: Components of buildings Implemented Bamboo Materials

Variable	Mean Score	Rank
Floor	4.22	1
Wall	4.10	2
Roof	4.08	3
Structure Element	4.04	4

This study reveals that the respondents agreed that bamboo materials are mostly used for floor construction, with a mean of 4.22. Bamboo is known for being hardwearing and comparable in strength to timber flooring, which can make it easier to handle and install without the risk of excessive damage and supported. Besides, bamboo is a highly sustainable resource due to its rapid growth rate, reaching maturity in 3 to 5 years compared to 8 to 10 years for hardwood trees. This makes it an environmentally friendly alternative to traditional wood flooring (Hoang Hiep et al., 2020).

A mean value of 4.10 in the second-rank states bamboo materials are commonly used as building walls. Bamboo walls are ideal for earthquake-prone locations due to their flexibility and low weight. According to Raj and Agarwal (2014), bamboo poles sunk to a depth of 0.5 meters are also ideal for constructing bamboo walls. These walls can be quickly rebuilt if necessary, helping to reduce costs and minimize harm to people and property. Additionally, bamboo's versatility allows it to be used for various types of walls, including both outdoor and internal walls. However, it is important to note that bamboo walls may not be as sturdy as conventional walls and may be more susceptible to insects' bites and scratches.

Besides, the implementation of bamboo materials as roof was identified to be at the third rank with an average of 4.08. As reported by Sharma et al. (2014), bamboo is lightweight, good strength, and durable make it an ideal material for roofing. Bamboo has exceptional strength and thickness flexibility, and it may be mixed in many ways based on architectural design to satisfy different structural performance requirements hence make it suitable for roof materials.

The fourth rank is the implementation of bamboo materials as a structure element, with a 4.04 mean score. Bamboo is less used as a structural material, such as columns, beams, and foundations in buildings, compared to other components, maybe for several reasons. Despite its potential as a sustainable and renewable building material, is underutilized as a structural element in modern construction. This underutilization is primarily due to a combination of technical, cultural, and perception-related challenges. One of the reasons may be the lack of complementary joinery techniques for bamboo, which complicates its use in formwork and other structural applications. This technical gap limits its adoption in modern construction practices (Amede et al., 2022).

5. Conclusion

The main concern of this study is to identify the components of building uses bamboo as a green material. Bamboo was found to be widely used for various components such as for flooring, walls, roofs, and structure elements. The result shows that bamboo materials are mostly used as flooring in a building construction as it is more ecologically friendly and sustainable option compared to other types of flooring. Bamboo also known for being hardwearing and comparable in strength to timber flooring, which can make it easier to handle and install without the risk of excessive damage. Besides, bamboo materials also are mostly implemented for the wall construction. Bamboo walls are flexible and lightweight, making them suitable for areas prone to earthquakes. While, bamboo materials as foundation were found to be less implemented maybe as it is more vulnerable to decay, rot, and insect infestation, especially when in direct contact with soil and moisture, making it less reliable for long-term structural support. However, this study shows the implementation of bamboo materials contribute to sustainability, cost-effectiveness, and versatility and make it an attractive alternative to conventional building materials like timber, steel, and concrete.

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