Development Status and Outlook of Round Bamboo Building Structure

Jinyuan Wang,[a] Daochun Qin,[a] Junfeng Xiong,[a] Changzhuan Shao,[d] Yao Peng,[b] Xuehua Wang,[c] Wanda Nie,[e] Lijun Su,[e] Zixuan Yu,[a,]* and Fengbo Sun [a,]*

Round bamboo is a critical natural construction material in tropical and subtropical regions because of its high strength, light weight, excellent mechanical properties, and simplicity of access to resources. With the advancement of technology and changes in aesthetics, the design of round bamboo architecture has taken on different development directions, such as simplicity, practicality, and innovative design. The structural components and connection methods are approaching standardization, and the products' applications are expanded beyond the confines of the home to include commercial spaces and other application scenarios. The current situation, problems, and development direction of round bamboo structures in terms of material production process, modification technology, and standardized processing are summarized in this study. Also discussed are advantages, structural characteristics, and development rules of round bamboo components as building materials, as well as the evolution and innovative development of connection methods. The purpose of this study is to provide references for the innovation and development of round bamboo.

DOI: 10.15376/biores.21.2.Wang

Keywords: Round bamboo; Building structures; Current state; Future prospects

*Contact information: a: International Center for Bamboo and Rattan, Beijing 100102; b: Beijing Forestry University, Beijing 100083; c: School of Home and Industrial Design, Nanjing Forestry University, Nanjing 210037; d: China Bamboo Industry Association, Beijing 10083; e: Zhonglin Green Carbon (Beijing) Technology Co., Ltd. *Corresponding author: yuzixuan@icbr.ac.cn*

INTRODUCTION

Bamboo, one of the fastest-growing graminaceous plants globally, is renewable and has a high carbon sequestration capacity. It can be harvested within three to five years (Jiang 2016). According to the International Organization for Bamboo and Rattan (2017), bamboo is abundant worldwide, comprising 123 genera and 1,642 species. Over 50 species, including moso, loblolly, solid, and jatropha bamboo, which are suitable for use in construction (Zhao *et al.* 2022). The global bamboo forest area is estimated at 50 million hm^2, with China's bamboo forests covering approximately 7.56 million hm^2, a figure expected to increase by 1.51 million hm^2 by 2021, reflecting a 17.95% growth (Aniñon *et al.* 2024). This vast bamboo resource base supports the development of green bamboo-based structures, offering both material sustainability and environmental benefits.

Bamboo's unique natural structure endows it with superior mechanical properties. In terms of specific strength (strength-to-weight ratio), under the condition of longitudinal tension (Bredenoord *et al.* 2024), the specific strength of four-year-old bamboo with a moisture content of approximately 12% (≈ 200 to 230 $MPa \cdot cm^3/g$) can be comparable to that of high-strength spring steel such as 65Mn, $60Si_2Mn$ (Cacanando *et al.* 2025) which is significantly higher than that of ordinary structural steel (Q235, Q345), but its absolute tensile strength is still significantly lower than that of steel (Liu *et al.* 2015).

The origins of bamboo architecture in China trace back to the Cao Xie Mountain site in Jiangsu Province (Zhou *et al*. 2021). Over time, round bamboo buildings have evolved from simple structures to modern, luxurious designs. Key developments include the creation of advanced connectors and components and improving material treatment and structural design. Today, round bamboo structures are increasingly valued in contemporary architecture and are recognized for their innovative potential in sustainable design. With a growing global emphasis on environmental protection, interest in green building practices continues to rise, reinforcing the role of bamboo as a viable and eco-friendly material in modern construction(Cao *et al*. 2024).

From a global perspective, the development of round bamboo structures remains highly uneven, reflecting differences in regulatory maturity, research focus, and engineering integration across regions. In South America, particularly in Colombia, the structural application of full-culm bamboo has benefited from relatively early regulatory recognition, such as its inclusion in the seismic-resistant code NSR-10. However, despite this institutional support, the majority of applications are still limited to low-rise buildings, and design practices often rely on simplified assumptions due to the variability of bamboo material properties. In Southeast Asia, the development of round bamboo structures has been largely driven by architectural practice rather than engineering standardization. While innovative forms and hybrid bamboo–steel systems have demonstrated the material's architectural potential, many projects remain case-specific, with limited reproducibility and insufficient mechanical validation. The absence of unified design criteria and performance-based evaluation methods constrains the broader structural adoption of these solutions. Recent international research has increasingly emphasized joint behavior, failure mechanisms, and system-level performance of round bamboo assemblies. Nevertheless, most studies remain experimental in nature and focus on isolated components, while comprehensive design frameworks integrating material grading, joint stiffness, and global structural response are still scarce. Numerical modeling and reliability-based design approaches, which are common in timber and steel engineering, are not yet widely established for round bamboo structures (Deng *et al*. 2025).

Progress of Research on Material Properties of Round Bamboo for Structural Use

Bamboo, with its hollow cylindrical structure and fibers primarily oriented along the longitudinal axis, presents a material that excels in axial strength due to the absence of transverse cell growth. This unique structure makes it ideal for load-bearing components such as beams and columns. At the macroscopic level, bamboo culms consist of internodes and nodes. The bamboo wall of the internodes is divided into bamboo green, bamboo flesh, and bamboo yellow from the outside inward, while the nodes contain the culm ring, sheath ring, and node septum. The morphological features of the nodes, including their ring-like protrusions, enhance structural stability by separating internodes during growth and improving the bamboo's circumferential stiffness. The node septum plays a key role in reducing bending moments, significantly improving the static flexural strength of bamboo (Chen *et al*. 2023a; Jia *et al*. 2024).

At the microscopic level, bamboo's composition includes vascular bundles and fundamental tissues, with the density of vascular bundles decreasing from the outer to inner layers. This creates a material with higher mechanical strength and density on the exterior, contributing to bamboo's gradient distribution of fibers. For example, Moso bamboo consists of fibers, thin-walled cells, ducts, and sieve tube cells. The elliptical, thick-walled fibers are arranged into bundles and form fiber sheaths around the ducts, acting as the primary load-bearing components. The thin-walled tissues assist in load transfer, enhancing bamboo's mechanical strength (Xu *et al*. 2024). The gradient distribution of fibers, with a higher volume fraction of reinforcing fibers in the outer layers, gives bamboo exceptional strength and flexibility, enabling it to resist external forces such as wind, rain, and snow without damage (An 2016).

Bamboo's mechanical properties are a direct reflection of its suitability as a construction material. The density gradient allows the outer layers to withstand high tensile and compressive stresses, while the inner layers absorb deformation through less rigid fibers. Tests by Tan *et al*. (2020) on untreated bamboo fibers showed an elastic modulus of 5.95 GPa, an ultimate strain of 0.0136, and a strength of 81.1 MPa . For example, mulberry round bamboo used in paracord demonstrated tensile, compressive, flexural, and shear strengths of 141, 56.7, 133, and 27.4 MPa, respectively. The ring stiffness of moso round bamboo with nodes can reach up to 200 MPa (Ji 2016; Cao *et al*. 2024). Bamboo species such as *Bambusa nutan* and *Bambusa tulda* also show remarkable mechanical properties, with *Bambusa nutan* having a compressive strength of 98.2 MPa and bending strength of 7.67 MPa. *Bambusa tulda* has demonstrated a tensile strength of 226 MPa, while *Bambusa rigidus* achieved a tensile strength as high as 280 MPa, about half that of steel with the same cross-sectional area (Singh *et al.* 2019; Manandhar *et al.* 2019). In this study, the specimens were tested in accordance with Standard IS 6874 under a universal testing machine to determine compression, tension, bending, and shear properties. However, the published report does not specify the moisture content (MC) of the specimens nor the age of the bamboo culms used in the tests, which may influence the interpretation of the measured strengths. Its elastic modulus is approximately 0.84 times that of wood, and its tensile strength is 2.5 times that of steel. Round bamboo also exhibits excellent impact resistance and favorable ductility. In addition, round bamboo can be bent through heating to meet architectural forming requirements, supporting the development of arches and other curved structural members in modern bamboo buildings.

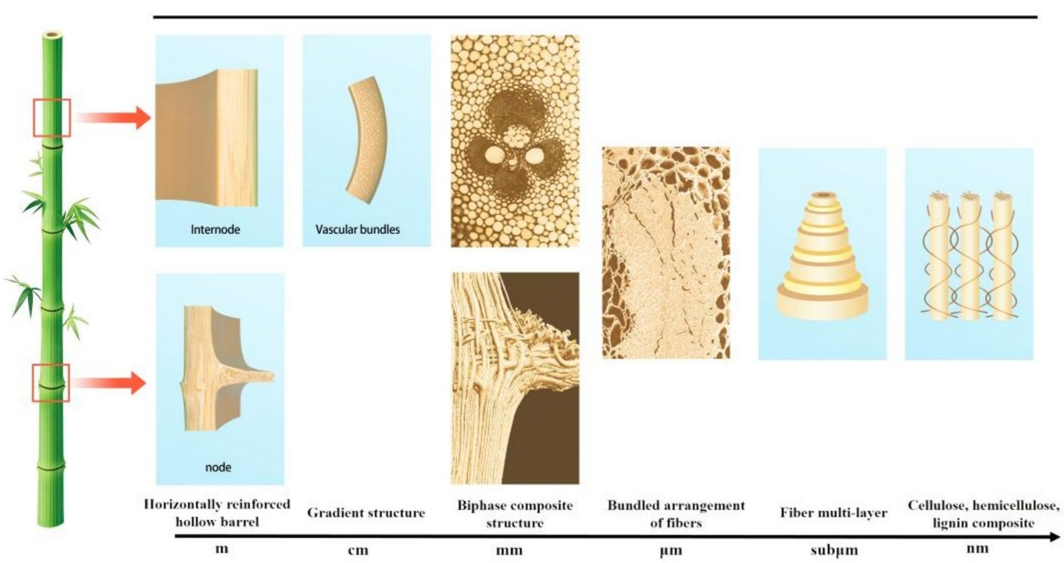

Fig. 1. The multilevel structure of natural bamboo from macro to micro

In broad terms, the hollow cylindrical structure, fiber gradient distribution, microfibril orientation, and specific chemical composition of bamboo collectively confer lightweight strength, impact resistance, and flexibility. These characteristics not only meet the fundamental strength and stability requirements for building structures but also enable bamboo to adapt to complex design needs, expanding architectural possibilities. Thus, bamboo is emerging as an ideal material in modern green construction, offering both ecological value and engineering potential (Chen and Zhang 2014).

In summary, the hierarchical structure of bamboo underpins its structural performance; however, reported properties vary substantially across species and testing protocols, which motivates the need for performance-based grading in structural applications.

Classification and Development of Round Bamboo Components

Round bamboo material is not only simple to shape but also meets the needs of support and load-bearing because of its unique texture, natural mechanical properties and flexibility. Round bamboo buildings have three primary components: structural members, connectors, and foundations. Among them, structural components include beams, columns, walls, and supporting sections of arch and truss structures, and connecting components include knots, sleeves, and steel members (Chainey *et al*. 2022).

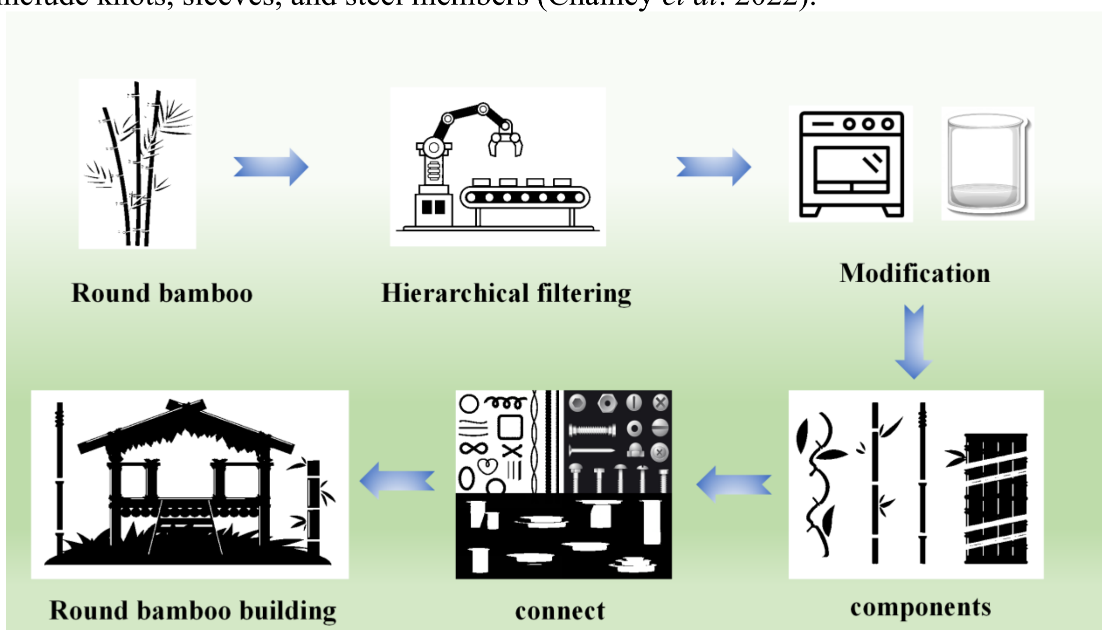

Fig. 2. The construction process of round bamboo buildings

Classification and development of structural components

Round bamboo components can be categorized into structural and decorative elements. Structural components, which serve as the primary load-bearing parts, are further divided into original single bamboo elements, reinforced bamboo elements, and composite elements. To meet varying load-bearing requirements, structural components such as beams, columns, and walls in round bamboo buildings have evolved from simple single bamboo poles into more complex forms. These include reinforced fillings as well as combined and stacked configurations forming truss structures. For example, Li *et al.* (2017) enhanced the mechanical properties of round bamboo by filling it with concrete and cement mortar. Compared to traditional bamboo columns, this treatment significantly improves the axial load-bearing capacity and initial stiffness. Similarly, Kang *et al.* (2022) improved the cyclic stiffness and dimensional stability of single round bamboo elements by filling them with polyurethane rice husk foam. This enhancement also increased the nail-holding capacity, providing a foundation for the development of novel round bamboo connection methods. Additionally, Shao *et al.* (2019). realized the construction of large-span bamboo beams by splicing trusses, effectively exploiting the high-strength characteristics of bamboo fibers along their longitudinal direction.(Ji 2024)

Most existing studies classify round bamboo primarily based on geometric parameters such as diameter and wall thickness. However, a unified classification system incorporating mechanical performance indicators remains lacking, which restricts reliable structural design and standardized application. The table below presents the simplified classification method for round bamboo materials in the Chinese round bamboo industry. In the future, on the basis of the existing "diameter grade – wall thickness – defect" classification, more refined grade divisions can be achieved by introducing quantifiable performance and durability indicators. The procedure entail first establishing a classification test centered on longitudinal tensile/ bending resistance, elastic modulus and dispersion and then use rapid non-destructive testing (ultrasound/stress wave/CT or near-infrared) for on-site judgment. The second step would be to incorporate moisture content and service environment into the grade correction coefficient to form a "structural performance – durability risk" two-dimensional classification. The third step would be to promote the standardization and digital traceability of process parameters for wet heat modification and surface protection, upgrading from empirical classification to a reproducible and verifiable engineering classification system.

Table 1. Bamboo Culm Grading and Application Requirements

Grade	Culm Wall Requirement	Allowable Defects	Typical Applications	Treatment Process
I	Thick and uniform culm wall (≥ 1.2 cm;)	No insect damage; no cracking	Outdoor primary load-bearing members (main beams, load-bearing columns)	Hydrothermal treatment + surface coating with three layers of tung oil
II	Uniform culm wall (thickness deviation ≤ 0.9 cm)	No insect damage; extremely fine cracks permitted	Outdoor secondary load-bearing members (secondary beams, purlins, bracing elements)	Hydrothermal treatment + surface coating with two layers of tung oil
III	Relatively uniform culm wall	Minor defects permitted (small insect holes)	Outdoor non-load-bearing components (railings, handrails, shading frames)	Surface coating with two layers of tung oil (hydrothermal treatment not required)
IV	No specific requirement	Limited defects permitted	Indoor semi-load-bearing or refined decorative components (decorative strips, grilles)	No hydrothermal treatment or tung oil protection required
V	No requirement	Obvious defects permitted	Indoor purely decorative components (decorative hanging rods, display frames)	No treatment required; direct use in natural form

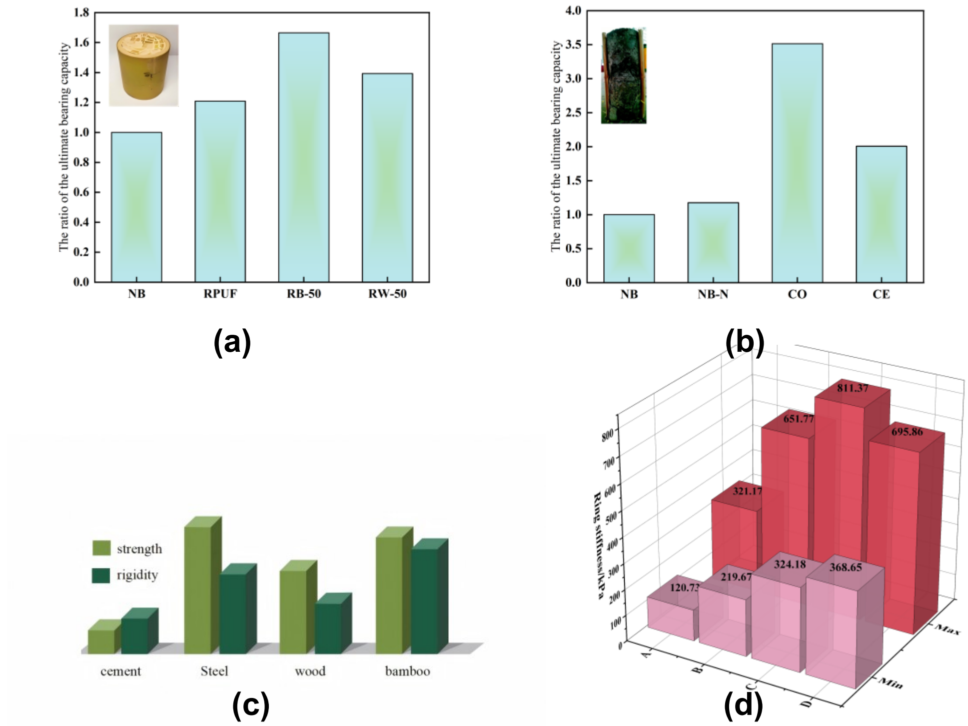

Fig. 3. (a) and (b): The ratio of the ultimate bearing capacity of the filled bamboos with different materials to the natural bamboos, NB: nature bamboo, RPUF: Polyurethane filling, RB-50\RW-50:50 percent of polyurethane and 50% of bamboo \wood strips each; NB-N: nature bamboo with node; CO: Concrete filling; CE: Cement mortar filling; (c) Ratio of strength and stiffness of bamboo to other materials, (d) Ring stiffness of rice husk foam-filled round bamboo, A: nature bamboo; B: Modified round bamboo; C: nature bamboo with node; and D: Modified round bamboo with node (Hildayanti *et al.* 2023; Zhao *et al.* 2023; Su *et al.* 2020).

At present, there are several common treatment methods for round bamboo used in construction: (1) Conventional heat treatment: This method has a relatively high cracking rate. Because of economic considerations, it is less adopted at present; (2) Saturated steam heat treatment: It is more commonly used, with a low cracking rate and less decline in the mechanical strength of bamboo; (3) Oil heat treatment: When the temperature is relatively high, the cracking rate is difficult to control, and the remaining oil stains need to be removed; (4) Traditional soaking and smoking treatment: Prior to construction, soaking the bamboo in slurry for several months followed by smoking. These processes aim to impart long-term anti-degradation properties to the bamboo, making it resistant to decay, insects, and mold.

For larger-span structures, vertical loads are supported by multiple bamboo poles. Such effects often are achieved by usage of stacked beams. The reinforcement method for columns is similar to that for beams, but minimal stacking is required due to round bamboo's high compressive strength and cyclic rigidity (Hildayanti and Wasilah 2023). Ongoing research is exploring the integration of round bamboo with steel pipes and beams, such as using H-type steel beams for the foundation, with round bamboo selected to fit into the grooves of the steel beams Local heating and bending of round bamboo can also create arch structures. Dome-type round bamboo buildings commonly feature this distinct arch form. Combining multiple bamboo arches with various connection methods can significantly enhance the structure's mechanical properties, allowing for a wide range of shapes.

Round bamboo trusses can be spliced to form large-span arched structures. For example, the International Bamboo and Rattan Pavilion at the 2019 Beijing World Park features a 54-meter span round bamboo arch in its roof garden. The structure is formed by two trusses of varying lengths (Su *et al.* 2019). This variable cross-section truss structure effectively distributes vertical loads along the length of the round bamboo, maximizing its compressive strength and enabling it to support heavier loads. This design successfully integrates aesthetic appeal with structural stability.

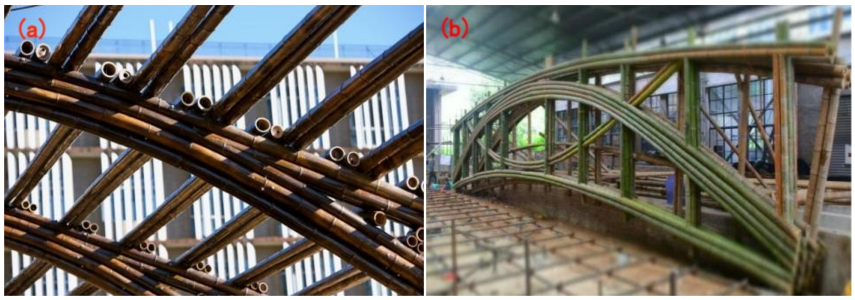

Fig. 4. (a) Round bamboo arch, (b) round bamboo trusses

Classification and development of connectors

The development of round bamboo connections has evolved through two distinct stages: traditional and modern. Early round bamboo buildings predominantly utilized conventional connection methods, such as mortise and tenon joints, weaving, and binding. These techniques, which often incorporated locally available materials such as rope knots and gabions, were simple to construct and disassemble and well-suited to basic round bamboo structures. However, the traditional connection methods suffered from poor weather resistance and durability, with a tendency for mildew and deterioration over time (Zhou *et al.* 2021).

As the number of round bamboo components in a structure increased, the reliability of traditional node connections became a significant concern, and these methods needed to be revised to meet the structural demands. Consequently, round bamboo connections were reinforced with plastic, concrete, and metal elements, leading to various connectors, such as bolts, sleeves, fillers, nails, and prefabricated steel components (Yan and Fei 2020). (Aniñon *et al*. 2024) introduced the concepts of hybrid and auxiliary connections. Hybrid connections combine traditional and modern technical elements, while auxiliary connections—such as sleeves, angle gussets, and infills—cannot function independently as connectors. Instead, they are integral components of a modern connection system designed to address the limitations of traditional methods and enhance the overall structural integrity.

From a mechanical perspective, connection nodes govern load transfer efficiency, rotational stiffness, and failure modes of round bamboo structures. Modern bolt-based joints primarily resist shear and bearing stresses at the bamboo-fastener interface, often accompanied by local crushing and splitting. Sleeve-based systems provide confinement and improve load distribution, thereby increasing joint stiffness and delaying crack initiation. Infilled joints (*e.g.*, mortar, concrete, polymer or foam) further enhance local bearing capacity and reduce slip by increasing radial restraint; however, compatibility between filler stiffness and bamboo anisotropy must be considered to avoid stress concentration.

Table 2. Comparison of Circular Bamboo Connection Methods

Connection Method	Main Load-transfer Mechanism	Typical Advantages	Applicable Scenarios / Notes
Bolted joint	Shear + bearing at bolt holes; friction if clamped	Simple, widely available, easy inspection	Suitable for trusses/frames; requires splitting control (washers, straps, pre-drilling)
Sleeve joint	Confinement + distributed bearing through sleeve; reduced local stress	Higher stiffness; improved durability under cyclic loads	Preferred where rotation control and durability are required; fabrication accuracy matters
Infilled joint	Radial restraint + composite action; reduced slip	Improves bearing capacity; enhances dimensional stability	Useful for columns/beams with local reinforcement; must consider filler-bamboo compatibility

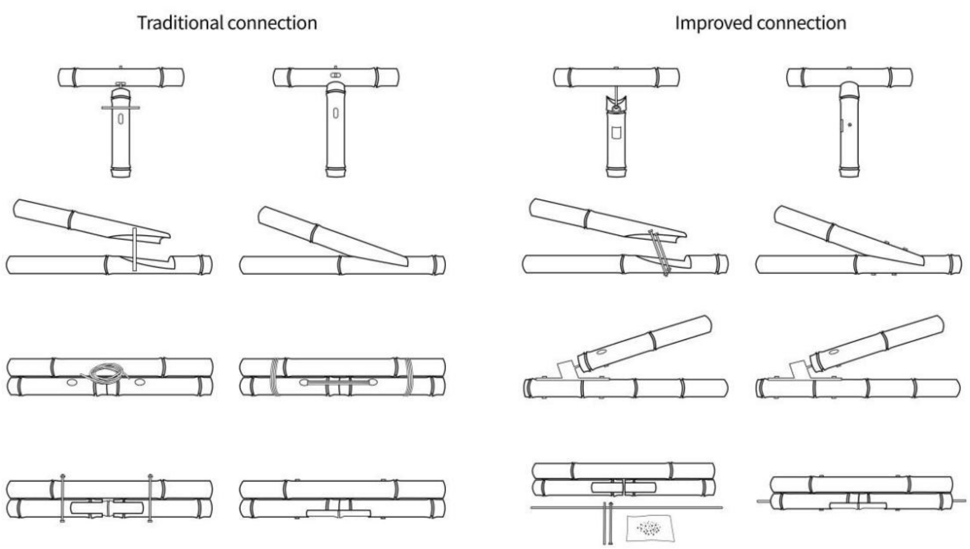

Fig. 5. Modern connection methods

Stages and Directions for Round Bamboo Building Types Development

The structural development of round bamboo architecture has three key directions: simplicity and practicality, emphasis on innovative design, and focus on standardization and modularization. These changes reflect the alterations in the structural functions, connection methods, and the degree of development and utilization of round bamboo.

The first direction, the early period of round bamboo architecture, is characterized by simple and practical building designs. In this phase, component connections were primarily achieved through binding and node weaving methods, resulting in stable triangular structures formed by lap joints, reflecting the low productivity of the period. For example, the shed houses from primitive societies featured circular floor plans supported by a central pillar, while two intermediate pillars supported rectangular structures. These designs are still used today in the cultivation of greenhouse vegetables. Another example is the Ethiopian bamboo hut, which features interwoven round bamboo arches made from bent and burnt bamboo. Ligatures connect these arches to form a dome structure, efficiently reducing the roof load by facilitating rainwater and snow drainage. These early round bamboo buildings were designed to be functional and practical, laying the foundation for later developments in bamboo architecture (Gu *et al*. 2016).

As productivity increased, the number of components in round bamboo buildings grew, and more advanced connection methods, such as mortise and tenon joints, were introduced. This shift is particularly evident in traditional bamboo buildings in China, such as the Dai bamboo houses. The Dai bamboo buildings feature a versatile beam-and-pillar structure that is more complex than basic bamboo scaffolding (Chen *et al*. 2023). Primary load-bearing elements, such as rafters and pillars, are made from round bamboo, with some pillars spanning the full height of the building. These pillars are vital structural components, supporting the overall stability of the building. The triangular structure formed by the beams and roof helps distribute loads, facilitating rainwater drainage and preventing roof degradation. The roofs of these buildings are typically sloped or hermetically sealed. In addition to the mortise and tenon joinery, some components of Dai bamboo buildings are secured using traditional binding methods, allowing for easy disassembly and relocation by the nomadic lifestyle of the Dai people. The internal layout of Dai bamboo buildings typically includes a multi-story structure, with the ground floor used for storage, poultry raising, and other production activities. In contrast, the upper floor serves as the living area, offering a comfortable and functional environment (Guo *et al*. 2023) .

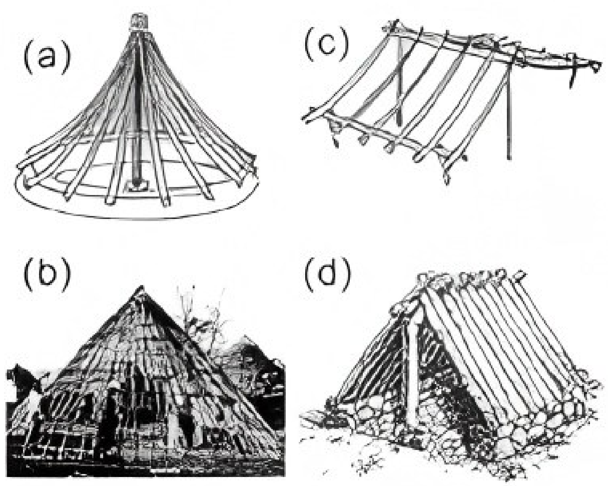

Fig. 6. (a),(b) Primitive bamboo hut I, (c),(d) Primitive bamboo hut II (from www.pinterest.com)

Fig. 7. Dai Bamboo House (Photo from history.ifeng.com and public number HND DESIGN)

The field of round bamboo architecture has entered a second phase characterized by diverse and innovative designs. This phase is driven by new connection methods and materials, such as the introduction of metal components and novel woven connection concepts (Gu *et al*. 2016). These advancements have expanded the potential for designing round bamboo buildings. Various connectors, including sleeves, infill materials, and nailing adhesives, have been developed to enhance the reliability of critical nodes. In addition to the conventional beam-column system, the range of component forms has diversified, incorporating arch and dome structures, complex trusses, and non-traditional shapes (Sun *et al*. 2021). During this phase, round bamboo architecture has increasingly focused on practical functionality and aesthetic value, employing innovative design techniques to highlight its distinctive artistic appeal. Buildings are often adorned with intricate decorative elements, ensuring the stability of the primary structure while enhancing visual interest. The overall design has also become more audacious, incorporating irregular wavy lines, graceful arches, and bionic-inspired bird's nest forms. These features collectively define the unique style of round bamboo architecture in this era (Li *et al*. 2023).

Fig. 8. (a) "Wind and Water Café", (b) "Son La Restaurant", (c), (d) Wind and Water Bar (from vtnarchitects.net)

The innovative design during this period mainly involves integrating new design elements or concepts into bamboo architecture (Ma snap. 2020). The representative figure of this stage is Vo Trong Nghia, who seeks to re-establish the role of bamboo architecture in an industrialized society by exploring its artistic value and pursuing the exquisite and expressive potential of materials and construction. At the same time, he pays close attention to cost and industrialized building methods in order to enable the large-scale application of bamboo architecture. His representative work "The Wind and Water Bar" is located adjacent to the "Wind and Water Café". Unlike the open, linear space of the café, the bar features a closed dome structure designed by architect Vo Trong Nghia. The dome is supported by a bamboo arch structural system, which reaches a height of 10 meters and spans 15 meters. The primary structural framework consists of 48 prefabricated units, each composed of several bamboo components. This design effectively integrates traditional and modern construction techniques to address both aesthetic and functional requirements.

Vo Trong Nghia's approach involves assembling the bamboo into prefabricated structural units, which address the challenge of bamboo's uneven sizing. This method not only improves the precision of the construction but also facilitates easier transportation and assembly, thereby reducing both construction time and costs. As a result, bamboo construction becomes a viable and efficient method characterized by low cost, reduced construction time, and high accuracy, making it suitable for large-scale application in modern architecture.

This integration of traditional bamboo treatment methods with modern prefabrication techniques highlights the versatility of bamboo as a sustainable building material. The Wind and Water Bar serves as a pioneering example of how traditional craftsmanship and modern innovation can be combined to create an aesthetically pleasing, structurally sound, and environmentally responsible architectural solution.

Fig. 9. (a) "The Vietnam Pavilion at the Milan Expo", (b) "Kontum Indochine Café " (from www.archdaily.com)

The design in this direction tends to be a reasonable overall force-bearing design, while also considering the simplicity and elegance of the appearance, informed by extensive research into its mechanical and material characteristics. This direction also reflects broader trends of modularization and prefabrication in construction methods while emphasizing principles of simplicity, modernity, and environmental sustainability .

Representative figure of this direction is Shao Changzhuan. The round bamboo buildings he made are typically employed in large-span buildings, such as auditoriums and halls, where truss structures serve as the primary load-bearing units (Lv 2019). These buildings often incorporate precise connection and assembly techniques, with prefabricated steel components connecting most structural elements. This approach not only enhances the safety and stability of the structure but also streamlines the on-site construction process. For example, the International Bamboo and Rattan Organization Park, part of the 2019 Beijing World Horticultural Expo, features a variable cross-section truss bamboo arch structure. This structural system comprises nine large bamboo arches and their supporting purlins, with a single bamboo arch spanning up to 32 meters. The park was designed with modularity, incorporating arch structures of 28 and 32 meters. Optimal design parameters were determined through finite element analysis, model calculations, and load testing. The resulting bamboo structure integrates architectural artistry with the natural landscape, creating a harmonious coexistence with its environment (Shao *et al*. 2019).

Quality control and fire prevention are critical considerations in the construction process. For instance, the Yibin International Bamboo Products Trading Center, the world's first steel-round bamboo composite structure building, employs round bamboo as the primary load-bearing structure. To mitigate potential fractures in the bamboo, the project team reinforced critical nodes with metal hoops. Additionally, a 1:1 scale fire simulation was conducted to ensure the building's safety. The bamboo arches demonstrated exceptional fire resistance, supporting the roof even under extreme conditions, highlighting the material's durability and structural integrity (Zhao *et al*. 2022).

Fig. 10. International Network for Bamboo and Rattan (INBAR) Garden at the Beijing World Expo

Fig. 11. (a) and (b) Yibin International Bamboo Products Trading Center, (c) fire simulation

Current Problems of Round Bamboo Structures and Components

The structural design, connection technology, and other aspects of round bamboo structures have progressed significantly. However, several key areas, including material treatment technology, industrial mechanization processing, and standardization, still require further development to optimize the utilization of round bamboo as a building material (Wang *et al*. 2018; Li *et al*. 2021).

Limitations of round bamboo treatment techniques

The grading methods for round bamboo are not yet clearly defined, and the material properties are inconsistent, which limits its application in structural design. Its dense surface layer and gradient structure make it prone to cracking, permeability, insect damage, and mold growth. Although various preservation techniques have been proposed, the effectiveness of these methods has not been fully validated by comparative data and experimental results, which also restricts the service life of round bamboo architecture (Khodabakhshi *et al. 2025)*

Limited automation in round bamboo processing

The hollow tubular structure of round bamboo contributes to its bending durability, making it advantageous as a construction component. However, the natural curvature and variable diameters of round bamboo necessitate manual straightening before use. This reliance on manual labor not only lowers productivity but also results in inconsistent quality and a lack of mechanized processing lines. As such, the efficient and high-quality processing of round bamboo is severely constrained. A critical assessment of the current processing methods and potential automation advancements is necessary to enhance production efficiency and product quality (Xu *et al*. 2021).

Lack of comprehensive standards for round bamboo structures

Currently, the design and construction of round bamboo architecture are guided by some existing regulations, such as the CECS 434-2016 ([Technical Code for Round Bamboo Structure Buildings CECS 434:2016 of the China Engineering Construction Association] published by China Planning Press) technical code and the LY/T 2564-2015 ([Determination of physical and mechanical properties of bamboo culm] released by the State Forestry Administration of China). These standards describe testing methods for the physical and mechanical properties of round bamboo. In addition to Chinese standards, international efforts have been made to standardize bamboo construction. Notable examples include ISO 22156 for structural design, ISO 19624 for the grading of bamboo culms, and national codes such as the Colombian earthquake-resistant construction code (NSR-10). These standards have provided crucial guidance for the global application of bamboo, covering aspects from mechanical testing to structural design requirements. However, there is still a lack of comprehensive standards specifically tailored for round bamboo structures. Designers currently rely on experience for their designs, and due to concerns about the inconsistency of the material properties of round bamboo, they often adopt interference fit designs, leading to oversized and unreasonable round bamboo buildings. Additionally, there are no relevant acceptance criteria for fire resistance and flame retardancy in round bamboo construction. The testing of the physical and mechanical properties of round bamboo also lacks assessments for creep and stress relaxation, which affects the evaluation of the service life of round bamboo architecture. Furthermore, the various standards have inconsistent dimensional requirements for round bamboo components, which hampers the development of prefabrication and modular assembly.

Future Development Direction of Round Bamboo Structures

Innovative research should be further pursued to strengthen the use of round bamboo in construction. This research should focus on key areas, including the classification and categorization of round bamboo, standardization of components, diversification of application scenarios, and material treatment. Addressing these aspects will ensure the material's broader adoption and greater contribution to sustainable construction practices.

Development of environmentally friendly modification technologies

Sustainable, efficient, and environmentally friendly surface and cell wall modification technologies should be developed to improve the reliability and performance of round bamboo as a building material. Current modification processes, such as chemical treatments, physical modifications, and biotechnological approaches, need to be optimized to minimize environmental impacts while enhancing the bamboo's mechanical properties, durability, and processability. While several treatments exist, there is a lack of comparative data and long-term performance evaluations to validate their effectiveness. The focus should be on developing modification technologies that address key requirements such as mildew resistance, anti-degradation properties, insect repellence, and cracking prevention. This will ensure that round bamboo can meet the stringent demands of green, low-carbon, and environmentally responsible construction. Additionally, further research should critically assess the environmental impact and long-term reliability of these technologies, ensuring that they align with sustainable building practices. Limitations of current approaches should also be recognized: chemical modifications may introduce environmental pollution and disposal concerns, whereas physical modifications can suffer from limited long-term durability, especially under moisture and biological exposure.

Enhancement of design efficiency and precision

Advancing the design efficiency and precision of round bamboo structures is critical to accelerating its integration into mainstream construction. This can be achieved through promoting the classification and grading of round bamboo and utilizing digital design tools. A comprehensive database of material properties, coupled with mechanical grading, will provide valuable data for informed material selection and enhance the safety and efficiency of round bamboo construction. The extensive variability in round bamboo's strength, density, and other properties necessitates the development of digital design systems that can generate precise models, calculate material quantities, and reduce design cycles. However, a more in-depth, critical evaluation of the existing classification systems and digital tools is needed to identify gaps and improve their practical applicability. Additionally, future research should address the challenges posed by the inherent variability of round bamboo, ensuring that design tools and databases are accurate and reliable.

Standardization of round bamboo building components

Establishing a standardized system for round bamboo building components is essential to enhance production efficiency, ensure consistent quality, and improve safety and reliability in construction. While several standards, such as CECS 434-2016 and LY/T 2564-2015, exist for round bamboo, comprehensive standards specifically tailored to round bamboo building components remain underdeveloped. Research should focus on developing unified standards for material selection, structural design, construction techniques, and quality control processes. The absence of such standards limits the scalability of round bamboo use in large-scale construction projects. A more critical and comparative evaluation of existing standards is necessary to identify gaps in addressing the specific characteristics of round bamboo. Standardization will improve round bamboo structures' overall quality, ensuring the bamboo pieces meet performance requirements. Such work can provide a foundation for broader application in the construction industry, thus maximizing its energy-saving and carbon-reducing potential.

Diversification of round bamboo applications

Expanding the range of round bamboo applications is vital for maximizing its potential as a building material. Its adaptability and ease of processing make it well-suited for small-scale structures, such as bus stops, pavilions, and other temporary or low-rise buildings. Moreover, round bamboo can be integrated into larger-scale commercial and cultural buildings, such as community libraries and exhibition halls, where its aesthetic and functional value can be fully realized. However, there is a need for more critical analysis of the challenges involved in scaling up its use in larger structures. Research should focus on overcoming these barriers by exploring design innovations, hybrid material solutions, and advanced construction techniques. This diversification will not only enhance the aesthetic and functional quality of buildings but also raise public awareness of round bamboo as a sustainable building material, supporting both the green development of the construction industry and strengthening national cultural identity.

CONCLUSIONS AND PERSPECTIVES

This study has reviewed the development status, technical characteristics, and research progress of round bamboo building structures from the perspectives of material properties, component forms, connection systems, architectural typology evolution, current bottlenecks, and future directions.

Current status

Round bamboo offers a favorable balance of strength, weight, and sustainability. Modern projects increasingly adopt prefabricated components and hybrid connection systems to enable larger spans and diversified application scenarios.

Key challenges

(i) Material variability and the absence of performance-based grading lead to uncertain design values;
(ii) Durability enhancement and eco-friendly modification technologies still lack long-term validation;
(iii) Mechanized processing is constrained by intrinsic geometric variability; and
(iv) Existing standards remain incomplete and regionally fragmented, limiting prefabrication and industrialization.

Future outlook

Priority should be given to establishing performance-oriented classification and design databases, developing durable and low-impact modification technologies, advancing digital design and automated processing, and promoting international harmonization of standards to support the sustainable and scalable adoption of round bamboo construction.

Funding

This research was funded by the National Key Research & Development Program of China (2022YFD2200902),Foundation of the International Centre for Bamboo and Rattan（1632022002).

REFERENCES CITED

An, X. (2016). *Research on Microfilament Orientation and Ultrastructure of Moso Bamboo Fiber Cell Wall*, China Academy of Forestry Science.

Aniñon, M. J. C., and Garciano, L. E. O. (2024). "Advances in connection techniques for raw bamboo structures – A review," *Buildings* 14, article 1126. https://doi.org/10.3390/buildings14041126

Bredenoord, J. (2024). "Bamboo as a sustainable building material for innovative, low-cost housing construction," *Sustainability* 16, article 2347. https://doi.org/10.3390/su16062347

Cacanando, C. J. D., López, L. F., Atienza, E., and Pradhan, N. P. N. (2025). "Experimental characterization of mechanical properties of *Bambusa blumeana* bamboo poles and determination of design values," *Construction and Building Materials* 490, article 142498. https://doi.org/10.1016/j.conbuildmat.2025.142498

Cao, Z.-H., Liu, Y., Jang, S.-S., Li, T., Liu G.-G., Bai Y.-J., Liao, Y.-Y., Hu J.-B., and Liu, J.-S. (2024). "Basic mechanical properties of moso bamboo and round bamboo," *Journal of Central South University of Forestry Science and Technology* 44(08), 169-179.

Chainey, S., Shijagurumayum, C., and Thokchom, S. (2022). "Review on the use of bamboo as a construction material," *SAMRIDDHI J. Phys. Sci. Eng. Technol*. 14, 47-51. https://doi.org/10.18090/samriddhi.v14spli01.9

Chen, H., and Zhang, Z. F. (2014). "Finite element analysis of reinforcing bar sleeve grouting connection technology," *Journal of Jiamusi University (Natural Science Edition)* 32(3), 341-344, 349.

Chen, S. M., Zhang, S. C., Gao, H. L., L., Wang, Q., Zhou, L. C., Zhao, H. Y., Li, X. Y., Gong, M., Pan, X. F., and Chen, C. (2023a). "Mechanically robust bamboo node and its hierarchically fibrous structural design," *National Science Review* 10(2), article nwac195. https://doi.org/10.1093/nsr/nwac195

Chen, J.-Y., Shi, M.-X., Guo, Z.-X., and Wang, X.-H. (2023b). "Main forms and applications of traditional bamboo architecture in foreign countries," *World Bamboo and Rattan Newsletter* 21(05), 46-54.

Deng, J., Wang, Z., Cai, B., Gao, Y., Liu, K., Zhang, Y., and Du, H. (2025). "Mechanical properties of round bamboo splicing joints with internal bamboo culm," *Construction and Building Materials* 500, article 144128. https://doi.org/10.1016/j.conbuildmat.2025.144128

Fei, B.-H. (2019a). "Practicing the new concept, speeding up the bamboo industry," *World Bamboo and Rattan Newsletter* 17(02), 1-6.

Fei, B.-H. (2019b). "Bamboo industry leads to better human life," *World Bamboo and Rattan Newsletter* 17(04), 1-4.

Gu, S., Gao, X.-M., Chen, J.-A., Ai, Y.-F., and Ke, X.-X. (2016). "Simple bamboo trellis rainproof cultivation pattern of spring pumpkin and fall quinoa," *China Vegetable* 2016(06), 96-99.

Guo, Z.-X., Lin, Z.-X., Chen, J.-Y., and Wang, X.-H. (2022). "Main forms of traditional Chinese bamboo architecture and their influencing factors," *World Bamboo and Rattan Newsletter*

Han, S.-Y., Xu, H.-Q., Chen, F.-M., and Wang, G. (2023). "Construction relationship between a functionally graded structure of bamboo and its strength and toughness: Underlying mechanisms," *Construction and Building Materials* 379, article 131241. https://doi.org/10.1016/j.conbuildmat.2023.131241

Hao, J.-P., Qin, M.-H., Tian, L.-M., and Kou Y.-F. (2017). "Experimental study on the mechanical properties of moso bamboo in the direction of the grain," *Journal of Xi'an University of Architecture and Technology (Natural Science Edition)* 49(6), 777-783.

Harries, K. A. (2025). "Adoption of full-culm bamboo as a mainstream structural material," *NPJ Materials Sustainability*, article 00050. https://doi.org/10.1038/s44296-025-00050-2

Hildayanti, A., and Wasilah. (2023). "Optimizing bamboo as an alternative building material to respond to global architectural challenges," IOP Conf. Ser. Earth Environ. Sci. 2023, 1157, article 012011. https://doi.org/10.1088/1755-1315/1157/1/012011

Huang, L.H. (2016). *Research on Bamboo Structure Construction System*, PhD Dissertation, Nanjing University. https://doi.org/10.27235/d.cnki.gnjiu.2016.000497

Ji, S.-Y. (2024). *Mechanical Properties and Structural Superiority Verification Analysis of Virgin Moso Bamboo Timber*, Central South Forestry University of Science and Technology.

Ji, S.-Y., Mou, Q.-Y., Li, T., and Li, X.-Z. (2024). "The novel applications of bionic design based on the natural structural characteristics of bamboo," *Forests* 15(7), article 1205. https://doi.org/10.3390/f15071205

Jia, S.-Y., Wang, Y., Wei, P.-L., Ma, X.-X., and Wu, Y.-M. (2024). "Current status of research on the structure and mechanical properties of bamboo joints," *World Bamboo and Rattan Newsletter* 22(03), 90-99.

Jiang, K. (2022). *Research on Modified Round Bamboo with Rice Husk/Polyurethane Foam Filling Based on its Physical and Mechanical Properties*, Sichuan Agricultural University.

Jiang, Z.-H. (2016). *World Bamboo and Rattan*, Liaoning Science and Technology Press, Shenyang, China

Jiang, Z.-H., Wang, G., Fei, B.-H., and Yu, W.-J. (2002). "Research and development of bamboo-wood composites," *Research on Forestry Science* 15(6), 712-718.

Khodabakhshi, N., Chu, S. K. W., Mouka, T., Kum, K. H., and Dimitrakopoulos, E. G. (2025). "Stiffness characterization of bolted multi-culm bamboo members," *Journal of Building Engineering* 103, article 112080. https://doi.org/10.1016/j.jobe.2025.112080

Li, J.-P. (2023). "Research on sustainable utilization and modern structural innovation of bamboo architecture," *Architecture and Culture* 2023(11), 56-58.

Li, J.-W. (2021). *Research on Modern Design of Bamboo Construction*, Beijing Institute of Fashion Technology.

Li, W.-T., Long, Y.-L., Huang, J., Lin, Y. (2017). "Axial load behavior of structural bamboo filled with concrete and cement mortar," *Construction and Building Materials* 148, 273-287. https://doi.org/10.1016/j.conbuildmat.2017.05.061

Liu, H. J., and Yang, L. (2024). "Research progress on drying of raw bamboo," *World Forestry Research* 37(04), 65-71.

Liu, R., Do, J.-Q., and Lin, K.-Q. (2015). "Research on the application of bamboo materials in architectural design," *Sichuan Research on Building Science* 41(02), 250-254.

Liu, Z.-Y., Cui, L.-L., and You, W. (2024). "Research on the application of bamboo materials in the seismic design of buildings," *Chongqing Architecture* 23(07), 70-72+78.

Lv, Z.-Y. (2019). "Analysis of structural construction of modern bamboo architecture," *Residence* 2019(15), article 13.

Ma Snap. (2020). "Research on assembled bamboo houses for rural poor groups in bamboo resource-rich areas of Yunnan," *Kunming Science and Technology*.

Manandhar, R., Kim, J. H., and Kim, J. T. (2019). "Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings," *Journal of Asian Architecture and Building Engineering* 18(2), 49-59. https://doi.org/10.1080/13467581.2019.1595629

Mou, Q.-Y., Ji, S.-Y., Li, X.-Z., Li, X.-J., Chen, Z.-J., He, L., and Li, X.-Z. (2025). "Tension and compression behaviors of Moso bamboo (*Phyllostachys pubescens*) for structural use," *Case Studies in Construction Materials* 22, article e04735. https://doi.org/10.1016/j.cscm.2025.e04735

Obataya, E., Kitin, P., and Yamauchi, H. (2007). "Bending characteristics of bamboo (*Phyllostachys pubescens*) with respect to its fiber-foam composite structure," *Wood Sci. Technol.* 41, 385-400. https://doi.org/10.1007/s00226-007-0127-8

Rincón, C. E, Montoya, J. A, and Archila, H. F. (2023). "Bamboo construction inspired by vernacular techniques for reducing carbon footprint: A life cycle assessment (LCA)," *Sustainability* 15, article 16893. https://doi.org/10.3390/su152416893

Rusch, F., Ceolin, G. B, and Hillig É. (2019). "Morphology, density and dimensions of bamboo fibers: A bibliographical compilation," *Pesqui. Agropecuária Trop*. 49, article e55007. https://doi.org/10.1590/1983-40632019v4955007

Scurlock, J. M. O., Dayton, D. C., and Hames, B. (2000). "Bamboo: An overlooked biomass resource?," *Biomass and Bioenergy* 19(4), 229-244. ISSN 0961-9534, https://doi.org/10.1016/S0961-9534(00)00038-6

Shao, C.-Z., Xiong, J.-F., Luo, Z., Jin, Y.-Z., Ma, J., and Yang, J. (2019). "Design of large-span bamboo structure for the International Bamboo and Rattan Organization Garden at the 2019 Beijing World Parks Congress," *Building Structure* 49(17), 43-50. https://doi.org/10.19701/j.jzjg.2019.17.009

Singh, K., Garg, H., and Pabla, B. S. (2019). "Evaluation of mechanical properties of different bamboo species for structural applications," *Int. J. Innov. Technol. Explor. Eng.* 8, 2927-2935. https://doi.org/10.35940/ijitee.K2218.0981119

Sun, J.-F., Wang, W.-W., and Song, Y.-H. (2021). "Tectonic finish control in original bamboo construction," *New Architecture* 2021(05), 34-37. https://doi.org/10.26689/jwa.v5i6.2735

Su, N., Fei, B.-H., Shao, C.-Z., Zhou, H., Fang, C.-H., Ma, X.-X., and Liu, H.-R. (2020). "Construction technology of large-span round bamboo arch structure - A case study of the Bamboo and Rattan Pavilion at the 2019 Beijing World Horticultural Expo," *World Bamboo and Rattan Newsletter* 18(06), 14-20.

Tan, M.-Q., Jiang, X.-P., Ke, H.-L., Wu, W.-W., and Xia, R. (2020). "Experimental investigations on the mechanical properties of bamboo fiber and fibril," *Fibers Polym*. 21, 1382-1386. https://doi.org/10.1007/s12221-020-9554-z

Van der Lugt, P., Van den Dobbelsteen, A. A. J. F., and Janssen, J. J. A. (2006). "An environmental, economic and practical assessment of bamboo as a building material for supporting structures," *Construction and Building Materials* 20, 648-656. https://doi.org/10.1016/j.conbuildmat.2005.02.023

Xu, H.-C., Li, J., She, Y.-N., Wang, H.-K., and Xu, X.-W. (2024). "The unique flexibility feature of moso bamboo: Arising implications for biomimeticmaterial design," *Construction and Building Materials* 411, article 134568. https://doi.org/10.1016/j.conbuildmat.2023.134568

Xu, H.-P., Chen, S.-N., and Wu, J.-M. (2021). "Constructive strategies of contemporary woven bamboo architecture strengthening the expression of 'lightness'," *Southern Architecture* 2021(03), 60-67.

Yan, Y., and Fei, B.-H. (2020). "Application of round bamboo components in architecture," *Journal of Anhui Agricultural University* 47(02), 205-210.

Zea Escamilla, E., Habert, G., Correal Daza, J. F., Archilla, H. F., Echeverry Fernández, J. S., and Trujillo, D. (2018). "Industrial or traditional bamboo construction? Comparative life cycle assessment (LCA) of bamboo-based buildings," *Sustainability* 10, article 3096. https://doi.org/10.3390/su10093096

Zhao, H., Hou, Y., Wang, J., Sun, L., Gan, J., Meng, Y., Li, Z., Li, S., Fan, Z., Wang, Y., and Fei, B. (2022). "The global atlas of bamboo and rattan (GABR) Phase II: New resources for sustainable development," *GigaScience* 11, article 113. https://doi.org/10.1093/gigascience/giac113

Zhao, Y.-M., Huang, Y.-M., and Gao, X.-R. (2024). "Research on the design method and technical strategy of Wu Chongyi bamboo structure architecture," *Journal of Architecture* 2024(02), 70-77.

Zhou, H., Su, N., Ma, X.-X. Fei, B. H., Fang, C. H., and Liu, H. R. (2021). "Study on flexural properties of round bamboo socketed nailed members," *Forest Industry* 58(06), 21-27+33.

Article submitted: October 8, 2025; Peer review completed: January 17, 2026; Revised version received: January 28, 2026; Accepted: February 2, 2026; Published: March 20, 2026.
DOI: 10.15376/biores.21.2.Wang