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Use of bamboo species for industrial supply: a bibliometric analysis

Utilização de espécies de bambu para abastecimento industrial: uma análise bibliométrica

Uso de especies de bambú para el abastecimiento industrial: un análisis bibliométrico

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ABSTRACT: Bamboo has emerged as a prominent structural material worldwide due to its high mechanical strength, low density, flexibility, and sustainability, demonstrating strong potential for applications in civil construction, furniture, textiles, and industrial

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products. This study conducted a bibliometric analysis of publications addressing the use of bamboo species for industrial purposes, with particular emphasis on the physical and mechanical properties of engineered products, using the Scopus database and analytical tools such as Bibliometrix and VOSviewer. A total of 133 articles published between 2008 and 2024 were analyzed, considering countries, institutions, journals, authors, citations, and keywords. China stood out as the leading research hub, followed by the United States, Indonesia, India, and Brazil, reflecting historical traditions, species diversity, and national policies promoting research on sustainable materials. The international collaboration network revealed that countries with well-established scientific infrastructure function as central nodes of cooperation, fostering knowledge exchange and joint research initiatives. Construction and Building Materials and Journal of the Royal Society Interface were identified as the most influential journals, while the most highly cited articles focused on the mechanical and physical properties of species such as *Phyllostachys pubescens, Guadua angustifolia*, and *Dendrocalamus giganteus*. Keyword analysis highlighted a strong emphasis on mechanical performance and tensile strength, reinforcing prevailing research trends in the field. Overall, the results provide a comprehensive overview of the state of the art, identifying knowledge gaps, recent advances, and future directions for the sustainable development of bamboo as an industrial material.

Keywords: mechanical properties, glued laminated bamboo, structural applications, sustainable materials, global trends.

RESUMO: O bambu tem se destacado como material estrutural pela sua elevada resistência mecânica, leveza, flexibilidade e sustentabilidade, apresentando potencial para aplicações na construção civil, mobiliário, têxteis e produtos industriais. Este estudo realizou uma análise bibliométrica das publicações sobre o uso de espécies de bambu para fins industriais, com foco nas propriedades físicas e mecânicas de produtos de engenharia, com uso da base de dados Scopus e ferramentas como Bibliometrix e VOSviewer. Foram analisados 133 artigos publicados entre 2008 e 2024, ao considerar países, instituições, periódicos, autores, citações e palavras-chave. A China se destacou como principal centro de pesquisa, seguida pelos Estados Unidos, Indonésia, Índia e Brasil, refletindo tradição histórica, diversidade de espécies e políticas de incentivo à pesquisa em materiais sustentáveis. A rede de colaboração internacional evidenciou que países com maior infraestrutura científica atuam como núcleos de cooperação, promovendo intercâmbio de conhecimento e projetos conjuntos. Os periódicos Construction and Building Materials e Journal of the Royal Society Interface foram os mais relevantes, e os artigos mais citados investigaram propriedades mecânicas e físicas de espécies como *Phyllostachys pubescens, Guadua angustifolia* e *Dendrocalamus giganteus*. A análise de palavras-chave revelou foco em propriedades mecânicas e resistência à tração, reforçando as tendências da pesquisa. Os resultados fornecem um panorama detalhado do estado da arte, ao identificar lacunas, avanços e direções futuras para o desenvolvimento sustentável do bambu como material industrial

ISSN: 2448-0916

Palavras-chave: propriedades mecânicas, bambu laminado colado, aplicações estruturais, materiais sustentáveis, tendências globais.

RESUMEN: El bambú se ha destacado como material estructural por su elevada resistencia mecánica, ligereza, flexibilidad y sostenibilidad, presentando potencial para aplicaciones en la construcción civil, mobiliario, textiles y productos industriales. Este estudio realizó un análisis bibliométrico de las publicaciones sobre el uso de especies de bambú con fines industriales, con enfoque en las propiedades físicas y mecánicas de productos de ingeniería, utilizando la base de datos Scopus y herramientas como Bibliometrix y VOSviewer. Se analizaron 133 artículos publicados entre 2008 y 2024, considerando países, instituciones, revistas, autores, citas y palabras clave. China se destacó como el principal centro de investigación, seguida por Estados Unidos, Indonesia, India y Brasil, reflejando tradición histórica, diversidad de especies y políticas de incentivo a la investigación en materiales sostenibles. La red de colaboración internacional evidenció que los países con mayor infraestructura científica actúan como núcleos de cooperación, promoviendo el intercambio de conocimiento y proyectos conjuntos. Las revistas Construction and Building Materials y Journal of the Royal Society Interface fueron las más relevantes, y los artículos más citados investigaron propiedades mecánicas y físicas de especies como *Phyllostachys pubescens*, *Guadua angustifolia* y *Dendrocalamus giganteus*. El análisis de palabras clave reveló un enfoque en propiedades mecánicas y resistencia a la tracción, reforzando las tendencias de investigación. Los resultados proporcionan un panorama detallado del estado del arte, al identificar vacíos, avances y direcciones futuras para el desarrollo sostenible del bambú como material industrial.

Palabras clave: propiedades mecánicas, bambú laminado encolado, aplicaciones estructurales, materiales sostenibles, tendencias globales.

1. INTRODUCTION

In regions with a strong forestry tradition, the local economy is closely linked to timber exploitation. However, there has been growing impatience among forest growers regarding long rotation periods, rendering cutting cycles of 5 to 7 years unsuitable as short-rotation systems. Within this context, there is increasing demand for renewable, fast-growing species with competitive physico-mechanical properties and low production costs. Bamboos stand out in this scenario, as they reach full culm growth within a few

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months and attain maximum mechanical strength within a few years, making them a highly promising alternative for a wide range of industrial sectors.

Historically, bamboo has been extensively used in tropical and subtropical countries, particularly in Asia and Latin America, for the construction of houses, temples, furniture, and handicrafts (Leite *et al.,* 2023). It is a highly adaptable plant, occurring on all continents except Antarctica, and capable of thriving under a wide range of soil and climatic conditions (Alves, 2019). With approximately 1,200 species described across more than 90 genera, bamboo diversity is especially pronounced in tropical and subtropical regions (Lugt; Vogtlander, 2015).

Nevertheless, species selection is a critical determinant of final use, as different bamboo species exhibit substantial variation in culm height and mechanical properties. For structural or artisanal applications, it is essential to select species that combine rapid growth with adequate mechanical strength. Among the most suitable species are *Dendrocalamus giganteus* Munro (giant bamboo), *Dendrocalamus asper* Backer ex K.Heyne (giant bamboo), *Guadua angustifolia* Kunth (taboca bamboo), and *Phyllostachys pubescens* Mazel ex J.Houz (moso bamboo) (Rios *et al.*, 2022). Bamboo is therefore valued for its mechanical strength, sustainability, rapid growth, and high carbon sequestration potential.

Studies on bamboo's physico-mechanical properties, such as its high compressive strength and excellent strength-to-weight ratio, have expanded its application in structural systems, including columns, beams, and roofing elements (Ludwig *et al*., 2019). In industrial contexts, bamboo is processed into engineered materials and synthetic composites, with increasing use as a substitute for timber and plastics. However, research on processing methods remains essential to ensure their efficient and safe application (Akinbade *et al*., 2021; Guo *et al*., 2016; Zhao *et al*., 2019). Despite its recognized potential, there is still a scarcity of studies that consolidate information on the industrial use of bamboo and guide researchers regarding existing challenges, advances, and knowledge gaps in the literature.

ISSN: 2448-0916

In this regard, bibliometric analysis emerges as a strategic tool for identifying trends, geographic patterns, influential authors, journals, and institutions through keyword clustering and the generation of consolidated databases (Silva *et al*., 2020; Ucella-Filho *et al*., 2022). Within this framework, the present study aimed to conduct a bibliometric analysis of bamboo use for industrial supply, compiling publication data and identifying research trends to support future studies and strategic decision-making related to the topic.

2. METHODOLOGY

To compile data for a bibliometric analysis of the physical and mechanical properties of engineered bamboo products, a systematic survey of the existing scientific literature was conducted. The Scopus database was used following the methodological frameworks proposed by Sweileh (2021) and Ucella-Filho *et al*. (2022). Scopus is one of the largest international and multidisciplinary databases of peer-reviewed scientific publications, indexing more than 53 million records across approximately 21,000 journals. Owing to its broad coverage and comprehensive indexing, it is widely recommended for bibliometric studies (Sweileh, 2018). Furthermore, Scopus indexes nearly twice as many journals as Web of Science and includes all journals covered by PubMed (Falagas *et a*l., 2008).

The search was conducted within article titles, abstracts, and keywords using a query that combined terms related to bamboo, structural products, and their physical and mechanical properties. The search string included the most relevant genera, such as *Bambusa*, *Dendrocalamus*, *Guadua*, and *Phyllostachys*, while excluding publications from 2025 and restricting results to original research articles. Data collection was performed on 26 May 2025 and considered only publications up to the year 2024. Only studies that investigated bamboo as a structural material, analyzed glued laminated bamboo as a structural component, and assessed the physical and mechanical properties of bamboo

ISSN: 2448-0916

across different regions of the world were included. Review articles were excluded from the analysis.

The retrieved records were exported in Comma-Separated Values (CSV) format and analyzed using the Bibliometrix and VOSviewer software packages (version 1.6.20). Bibliometrix, an R package, enables comprehensive bibliometric and scientometric analyses and is highly flexible and compatible with other statistical tools (Aria; Cuccurullo, 2017). Its web-based interface, Biblioshiny, was used for result visualization. VOSviewer was employed to analyze keyword frequency and co-occurrence patterns, allowing the identification of the most recurrent terms in the selected publications.

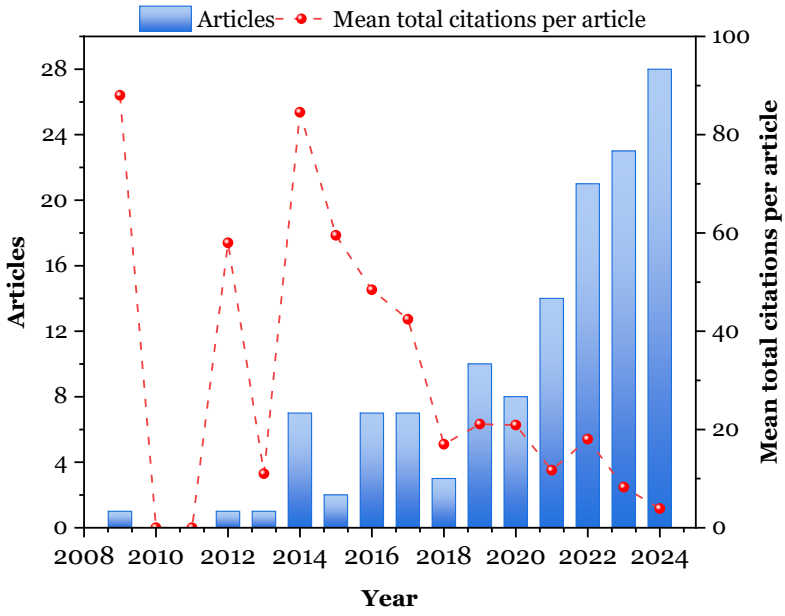
Several bibliometric indicators were evaluated, including the annual number of publications, the most productive countries, the most influential journals and articles, and the most prominent authors, considering their institutional affiliations. The resulting figures and tables were exported to Excel and used to generate the final graphics in OriginPro 2025b (Learning Edition). Additionally, a map illustrating the ten most productive countries was produced using the open-source software QGIS Geographic Information System, version 3.28.6 (QGIS Development Team, 2023).

3. RESULTS AND DISCUSSIONS

In total, 239 articles were retrieved from the Scopus database, of which 133 (approximately 55.7%) met the inclusion criteria and were incorporated into the final dataset for analysis. The final database comprised publications spanning the period from 2008 to 2024 (Figure 1).

ISSN: 2448-0916

Figure 1. Number of publications over time and average citations per article.



Source: Prepared by the authors themselves.

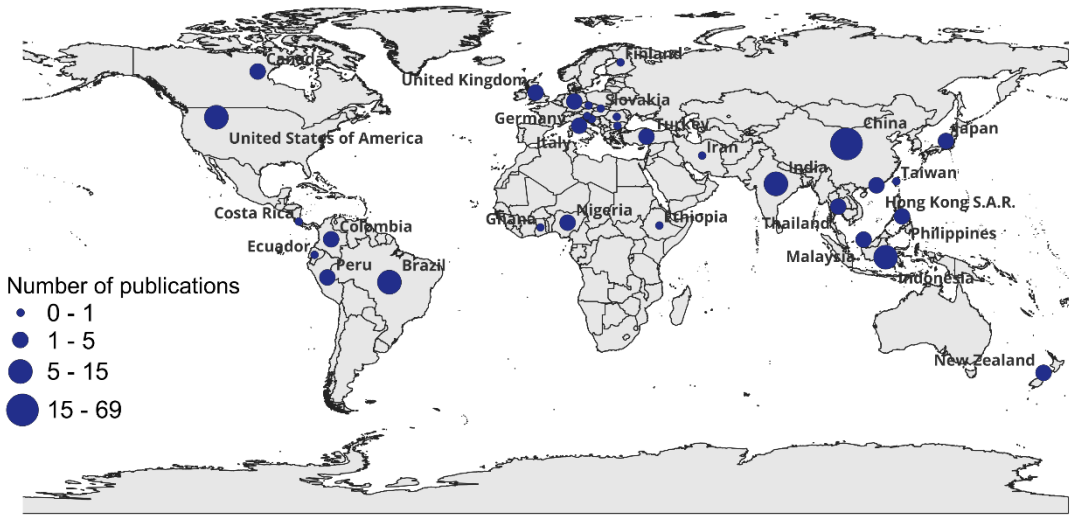
During the initial years (2008–2013), the number of studies addressing the topic was limited, reflecting the emergent nature of research on engineered bamboo materials. From 2014 onward, a clear upward trend can be observed, culminating in a peak in 2024. Minor declines in publication output occurred in 2015 and 2018, possibly associated with the completion of research projects initiated in previous years or with temporary stabilization in research activity.

Figure 2 illustrates the geographic distribution of publications by country. China clearly stands out, with 69 articles (40.35%), reinforcing its position as a global reference in bamboo-related research. This leadership can be attributed to several factors, including the long-standing historical and cultural use of bamboo in construction, the wide availability of bamboo resources, and sustained governmental support for research and development of innovative and sustainable construction materials. China is followed by the United States with 15 articles (8.8%), Indonesia with 11 (6.43%), India with nine (5.3%), and Brazil with eight (4.7%). The Philippines, Thailand, and the United Kingdom

ISSN: 2448-0916

each contributed five articles (2.9%), while Hong Kong and Italy each accounted for four publications (2.3%).

Figure 2. Number of articles by country related to the studied topic.



Source: Prepared by the authors themselves.

The ten most productive countries collectively account for 78.9% of all publications (Figure 3). Although research activity is predominantly concentrated in China and other Asian countries, contributions from regions such as North America and South America particularly the United States, Indonesia, India, and Brazil also play a relevant role in advancing the field, albeit at a smaller scale. The participation of countries such as the Philippines, Thailand, the United Kingdom, Hong Kong, and Italy, although still limited, suggests potential for expansion in regions with favorable conditions for bamboo cultivation but where scientific production remains incipient. Overall, this pattern highlights the concentration of research efforts in Asia and underscores the need to strengthen international research initiatives to broaden the global development of bamboo-based technologies.

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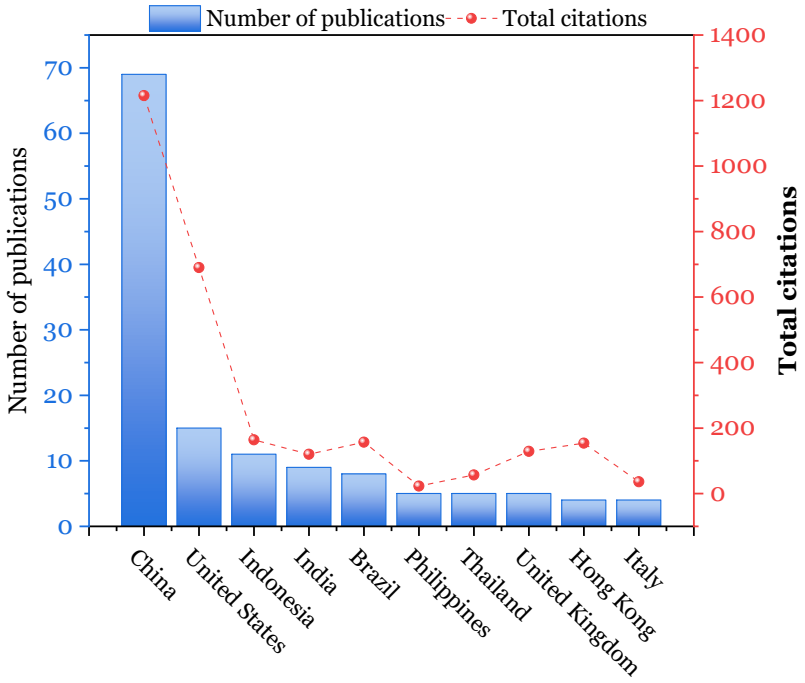
Figure 3. Number of articles by country and total citations per publication.



Source: Prepared by the authors themselves.

Figure 4 presents the international collaboration network among countries. The thickness of the connections between regions reflects the number of jointly authored publications. China, the United States, Indonesia, and Brazil exhibit the highest number of connections, with China and Indonesia showing particularly strong collaborative linkages.

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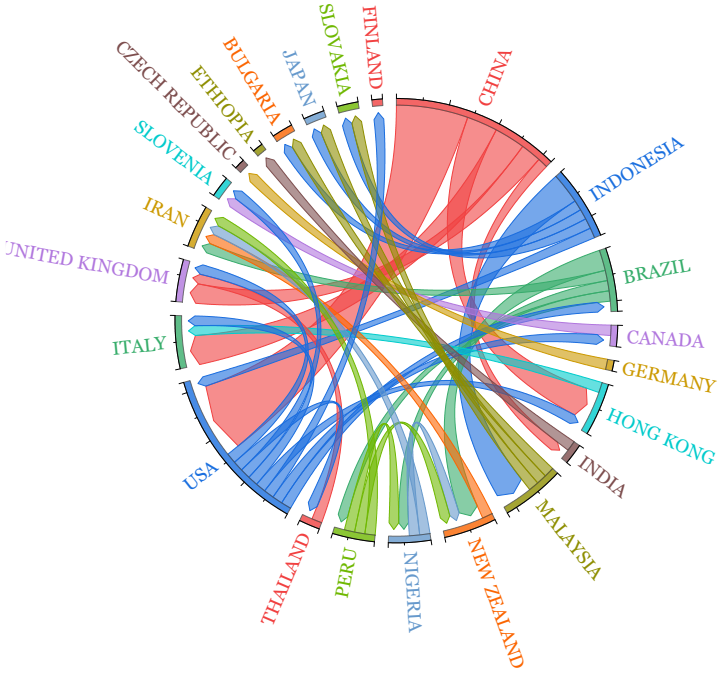
Figure 4. Network diagram of international collaborations among publishing countries.



Source: Prepared by the authors themselves.

Bamboo belongs to the grass family Poaceae (or Gramineae), which comprises approximately 45 genera and 1,300 species worldwide, characterized by their fibrous structure (Pedrangelo *et al.*, 2020). Bamboo occurs naturally on all continents and is especially abundant in Asia, which accounts for approximately 65% of global production, followed by Central and South America (28%) and Africa (7%) (Correal, 2020).

Historically, bamboo has been widely used as a structural material in tropical and subtropical regions, particularly in Asia and Latin America, for the construction of houses, temples, furniture, and handicrafts (Skuratov *et al.*, 2021; Leite *et al.*, 2023). In Asia, China hosts the greatest species diversity, with approximately 500 native species, and bamboo use dates back to the Tang Dynasty (618–907 AD) (Correal *et al.*, 2022; Leite *et al.*, 2023). Japan harbors 139 species traditionally used in residential and temple construction, while India, Indonesia, and Myanmar contain 119, 118, and 97 species, respectively (Correal *et al.*, 2022). In India, bamboo has gained prominence in contemporary projects, including disaster-resistant buildings, in addition to its historical use in monuments such as the Taj Mahal (Leite *et al.*, 2023). In Indonesia, several bamboo species are employed in advanced

ISSN: 2448-0916

architectural applications, including hotels, restaurants, and tourism-oriented buildings (Bredenoord, 2024).

In Latin America, countries such as Colombia, Ecuador, and Costa Rica widely employ *Guadua angustifolia* in structural projects, including social housing initiatives in Colombia (Arenas; Arenas, 2022). Brazil, due to its favorable climate, holds substantial potential for the use of bamboo as an engineered material. Species such as *Dendrocalamus asper*, *Phyllostachys aurea*, *Phyllostachys edulis*, *Bambusa vulgaris*, *Bambusa tuldoides*, and *Guadua angustifolia* are abundant and suitable for construction applications (Gauss, 2020). Research on *Guadua*, giant bamboo, and Moso bamboo has been conducted for more than three decades by Professor Khosrow Ghavami at the Pontifical Catholic University of Rio de Janeiro (PUC-Rio), contributing significantly to the promotion of bamboo as a structural material in Brazil (Martins, 2024).

In Africa, extensive natural bamboo forests occur from sea level to mountainous regions, representing approximately 4% of the continent's forest cover. Bamboo can be used both in the manufacture of consumer goods and in the construction of affordable housing. However, the adoption of improved processing and construction techniques is essential to ensure sustainable use by local communities (Bredenoord, 2024). Taken together, these findings suggest that countries with greater species diversity or more developed scientific infrastructure not only produce more research outputs but also act as hubs of international collaboration, facilitating knowledge exchange and joint research initiatives.

The analyzed articles were published across 20 different journals. Figure 5 shows the distribution of publications by journal, considering only those with five or more published articles. This analysis helps identify the most influential outlets for disseminating research on bamboo, complementing the assessment of scientific production by country and international collaboration networks.

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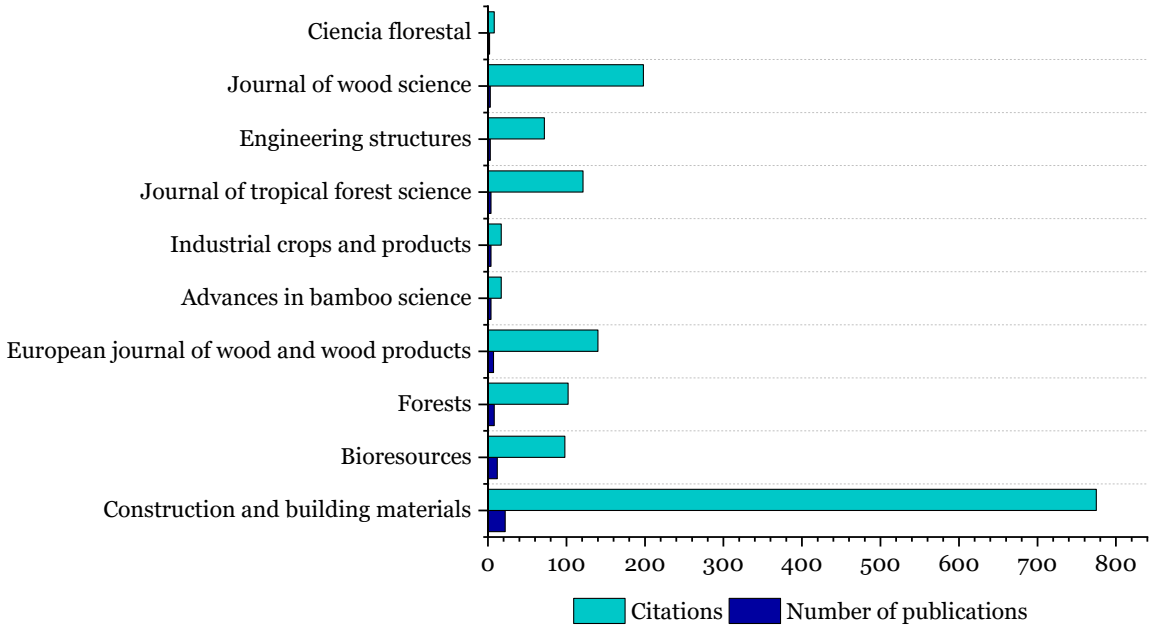
Figure 5. Main journals based on the total number of publications indexed in Scopus.



Source: Prepared by the authors themselves.

Construction and Building Materials ranks first in terms of publication output, underscoring its relevance as a primary source of scientific information on the topic. Despite this concentration, the literature is distributed across a wide range of journals with solid impact factors. The ten most productive journals (Figure 5) account for approximately 77.5% of all publications. This concentration is likely associated with journal impact, prestige, and international visibility (Baldiotti et al., 2021; Paladugu et al., 2002).

When citation counts are considered as an indicator of relevance (Table 1), four articles received more than 100 citations, while the remaining articles accumulated fewer than 100 citations. Among the most cited works, the earliest was published in 2012 in the *Journal of Wood Science* with 58 citations, whereas the most recent appeared in 2023 in *BioResources* with 88 citations.

ISSN: 2448-0916

Table 1. Most cited articles indexed in Scopus, including authors, title, year of publication, and journal (up to 2024).

Article	Authors	Journal	TC	IF
The structure and mechanics of Moso bamboo material	(Dixon; Gibson, 2014)	*Journal of the Royal Society Interface*	323	3,5
Engineered bamboo scrimber: Influence of density on the mechanical and water absorption properties	(Kumar *et al.*, 2016)	*Construction and Building Materials*	168	8,0
Experimental evaluation of physical and mechanical properties of Glued Laminated *Guadua angustifolia* Kunth	(Correal *et al.*, 2014)	*Construction and Building Materials*	111	8,0
Effects of heat treatment on the properties of bamboo scrimber	(Shangguan *et al.*, 2016)	*Journal of Wood Science*	106	2,4
Comparative study of mechanical properties of bamboo laminae and their laminates with woods and wood-based composites	(Verma *et al.*, 2014)	*Composites: Part B*	90	14,2
Physical and mechanical properties of glued laminated bamboo	(Lima *et al.*, 2023)	*BioResources*	88	1,747
Comparison of the structure and flexural properties of Moso, Guadua, and Tre Gai bamboo	(Dixon *et al.*, 2015)	*Construction and Building Materials*	87	8,0
Fatigue characterization of structural bamboo materials under flexural bending	(Song *et al.*, 2017)	*International Journal of Fatigue*	64	6,8
Bending strength and nondestructive evaluation of structural bamboo	(Sá Ribeiro *et al.*, 2017)	*Construction and Building Materials*	60	8,0
Finger joint performance of structural laminated bamboo member	(Yeh; Lin, 2012)	*Journal of Wood Science*	58	2,4

TC: Total citations, IF: Impact factor.
Source: Prepared by the authors themselves

The most cited article in the dataset was that of Dixon and Gibson (2014), with 323 citations, which provided a detailed analysis of the microstructure and physical and mechanical properties of *Phyllostachys pubescens* (Moso bamboo) for structural applications using scanning electron microscopy and mechanical testing. The second most cited study, by Kumar *et al.* (2016), examined the influence of density on the mechanical performance of engineered bamboo scrimber, comparing results with existing literature and employing phenol–formaldehyde resin. Correal *et al.* (2014) evaluated the physical and mechanical properties of glued laminated *Guadua angustifolia* for structural characterization. Shangguan et al. (2016) investigated the effects of heat treatment on phenolic-resin-bonded bamboo scrimber from *Neosino calamus affinis*,

ISSN: 2448-0916

while Verma et al. (2014) assessed cold-pressed glued laminated bamboo (*Dendrocalamus strictus*) bonded with epoxy resin and explored its potential as a substitute for wood.

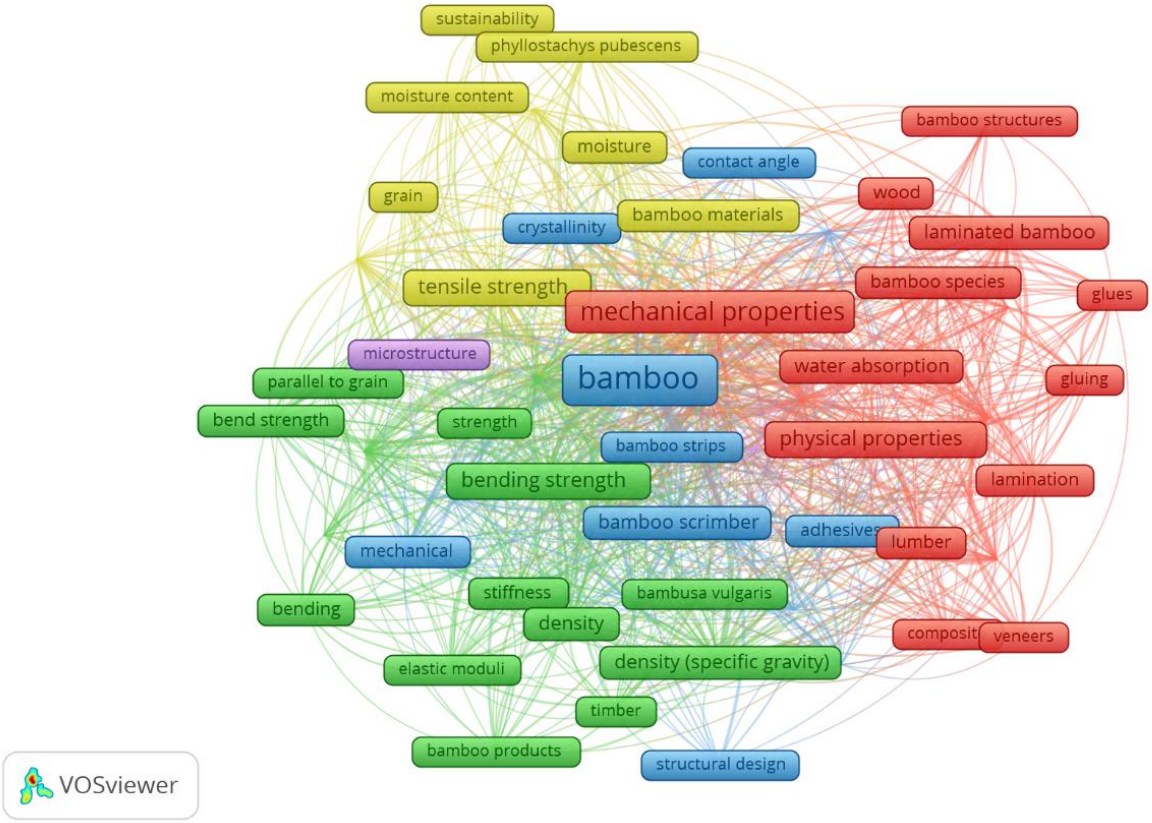
More recently, Lima et al. (2023) analyzed glued laminated bamboo (*Dendrocalamus giganteus*) bonded with resorcinol–formaldehyde and polyvinyl acetate adhesives, reporting physico-mechanical properties comparable to those of hardwood species. Dixon *et al.* (2015) compared the ultrastructure, microstructure, and flexural properties of three bamboo species (Moso, Guadua, and Tre Gai), emphasizing the importance of mechanical performance for sustainable construction alternatives.

Other studies addressed more specific aspects, such as Song *et al.* (2017), who investigated the fatigue behavior of bamboo strips subjected to cyclic bending loads. Sá Ribeiro *et al.* (2017) evaluated density, stiffness, and bending strength of entire culms of *Bambusa vulgaris* 'vittata' using nondestructive testing methods. Yeh and Lin (2012) analyzed the structural performance of laminated bamboo members with finger joints in *Phyllostachys pubescens* and *Dendrocalamus latiflorus*.

In addition, the analysis of authors' keywords enabled the identification of research trends and thematic priorities within the field (Li *et al*., 2009; Song; Zhao, 2013). In the visualization, word size reflects frequency, highlighting the most recurrent and influential topics in the literature on bamboo and engineered products (Figure 6).

ISSN: 2448-0916

Figure 6. Frequency and interaction of the main keywords associated with the study.



Source: Prepared by the authors themselves.

Keyword analysis revealed a total of 890 distinct terms. Among the most frequent were “bamboo”, the overarching keyword of the study, followed by “mechanical properties”, “physical and mechanical properties”, and “tensile strength” (Figure 6). The prominence of these terms indicates that most research is focused on bamboo as a structural material, with particular emphasis on its physical and mechanical performance—key attributes for engineering and construction applications. Beyond identifying the central research theme, the frequency of these keywords reflects prevailing trends in the field, notably the scientific community’s strong interest in tensile strength, compressive behavior, and the performance of bamboo-based composites.

ISSN: 2448-0916

4. CONCLUSION

In summary, bamboo stands out for its high mechanical strength combined with low density, flexibility, and sustainability, making it a promising material for applications in civil construction, furniture, textiles, and electronic products. This study enabled the identification and mapping of the main research centers working on bamboo, considering scientific output over time, as well as contributing countries, institutions, and funding sources. China clearly leads in terms of publications, authors, institutions, and funded projects, reflecting public policies that promote the development of natural and sustainable construction materials.

Overall, the results demonstrate that bamboo-related research has expanded both in volume and in diversity of applications, while also highlighting the importance of strengthening international collaboration and disseminating advanced techniques to regions with substantial yet underexplored potential. These findings provide a comprehensive overview of the state of the art and may guide future research efforts and investments aimed at advancing bamboo as a sustainable structural material.

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