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SYSTEMATIC LITERATURE REVIEW AND BIBLIOMETRIC ANALYSIS: PERFORMANCE AND EFFECTIVENESS OF TIMBER STRUCTURES IN MODERN CONSTRUCTION BASED ON ENGINEERED MATERIALS

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ABSTRACT

Timber structures have experienced a significant resurgence driven by innovations in engineered wood materials such as Cross-Laminated Timber (CLT) and Glued Laminated Timber (glulam). This study presents a Systematic Literature Review (SLR) and bibliometric analysis of research on the performance and effectiveness of timber structures in modern construction. A total of 1,895 Scopus-indexed publications (2020–2025) were analyzed using VOSviewer and RStudio for bibliometric mapping. Five main research clusters were identified: sustainability and environmental performance, mechanical properties of engineered materials, structural and seismic analysis, structural failure and safety, and construction technology and innovation. Key research gaps were found in tropical climate studies, structural performance of local Indonesian timber species, long-term field validation, and integration of seismic, sustainability, and material innovation aspects. This study provides a scientific foundation for advancing sustainable timber construction standards in Indonesia.

Keywords: timber structures, engineered wood, CLT, glulam, systematic literature review, bibliometric analysis.

1. INTRODUCTION

In the planning of modern multi-story building structures, selecting the appropriate construction material is a decisive factor for project success in terms of strength, cost efficiency, and environmental sustainability. Timber, as one of the oldest materials used by humankind, is now experiencing a significant resurgence thanks to technological innovations in engineered wood, resulting in products such as Cross-Laminated Timber (CLT) and Glued Laminated Timber (glulam) [1]. This development has made timber structures increasingly relevant as a competitive alternative to conventional modern construction materials.

The construction sector is responsible for approximately 39% of global carbon emissions, driving the scientific and industrial community to seek more sustainable material solutions [2]. Engineered timber offers advantages such as renewability, long-term carbon storage capacity, a high strength-to-weight ratio, and a substantially lower production carbon footprint compared to concrete and steel [3], [4], [5]. These innovations demonstrate that timber can compete with conventional construction materials in terms of strength, efficiency, and sustainability.

Nevertheless, the implementation of timber structures in modern construction faces complex technical challenges. The anisotropic nature of timber results in mechanical characteristics that depend on grain direction, requiring more careful structural analysis compared to isotropic materials [6]. The natural variability of timber caused by defects, density differences, and environmental conditions results in non-homogeneous mechanical properties [7]. Environmental factors such as high humidity, temperature fluctuations, and biological attack also pose serious threats to the durability of timber structures, particularly in tropical climate regions such as Indonesia [8], [9], [10], [11].

Connection design is one of the most critical issues in timber structural engineering. Research shows that most failures in timber structures occur at the connections rather than in the main structural elements such as beams or columns [12]. The complexity of connection design, including the selection of fastener type, stress distribution, and dynamic behavior under seismic loading, remains an active and relevant research topic.

Based on bibliometric analysis using VOSviewer, current research trends are largely focused on numerical simulation approaches and the development of engineered materials. Meanwhile, topics related to dimensional efficiency, durability in tropical climates, and the utilization of local Indonesian timber species remain relatively underexplored [13]. Therefore, a systematic literature review (SLR) is needed to identify research developments, uncover research gaps, and explore further development opportunities in timber structure design.

This study has three main objectives: (1) to analyze the development of research related to the design and performance of timber structures in modern buildings based on a systematic approach and bibliometric analysis; (2) to synthesize existing literature on the influence of engineered timber materials (CLT, glulam) on the structural behavior of building elements based on the finite element method (FEM) and experimental studies reported in previous research; and (3) to analyze research gaps related to timber structures in modern construction, particularly regarding durability in tropical climates and the utilization of local timber, using VOSviewer and RStudio tools.

Recent developments in research on the design and performance of timber structures show a significant shift from conventional approaches toward numerical simulation, full-scale experimentation, and innovative materials [14]. Five main research themes were identified based on the Scopus database search:

(a) Numerical Simulation and 3D Modeling: 3D numerical modeling reveals that the thickness and geometry of engineered timber elements have a critical influence on their structural behavior [15]. CLT material behaves differently under various loading and environmental conditions, with stress distribution strongly influenced by layer configuration and grain direction. Christovasilis and Brunetto [16] found that changes in moisture content significantly affect internal stress distribution, consistent with updated mechanical models for CLT under combined loading [17].

(b) Strut-and-Tie Model (STM) and Topology Optimization: The STM method has proven effective for analyzing engineered timber structures because it can represent internal force paths more accurately than conventional methods, a foundational finding that remains relevant to current STM applications despite its earlier publication date [18]. Topology-optimized designs achieve significant material cost reductions while maintaining maximum load capacity [19].

(c) Probabilistic Approaches and Reliability-Based Design: Reliability-based approaches have been developed to address the limitations of deterministic methods in timber structural design [20]. These approaches probabilistically account for uncertainty in timber material parameters, load variation, and construction factors.

(d) Seismic Behavior and Dynamic Loading: Experimental testing and numerical simulation demonstrate that innovative connections in CLT structures can significantly reduce peak bending moments compared to conventional connections [3], [21]. CLT systems with slip-friction connections show superior seismic performance [4], [22].

(e) Innovative Materials and Sustainability: The use of CLT and glulam as primary materials in multi-story building construction has been shown to produce a substantially lower carbon footprint compared to concrete and steel [14], [23].

Based on the literature synthesis and bibliometric analysis using VOSviewer, several critical research gaps were identified: (1) a lack of research in tropical climates with high humidity and extreme temperatures; (2) minimal research on local Indonesian timber species (Merbau, Ulin, Bangkirai) indexed in Scopus; (3) limited long-term field validation (more than 10 years) for engineered timber

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structures; (4) a gap in Indonesian national design standards that have yet to cover modern engineered timber materials; and (5) a lack of research that holistically integrates seismic, material innovation, and sustainability aspects. These thematic patterns are consistent with the keyword co-occurrence and clustering results obtained from the VOSviewer analysis presented in Section 3, reinforcing the identified research gaps with bibliometric evidence.

The novelty of this study lies in the development of a Systematic Literature Review (SLR) approach that systematically integrates the analysis of mechanical performance, environmental durability, material efficiency, and sustainability of engineered timber structures within a single integrated framework using the Scopus database. Bibliometric analysis using VOSviewer produces a comprehensive visual map, systematically identifying thematic clusters and research gaps, particularly those related to the tropical climate context and the use of local Indonesian timber, which had not previously been synthesized in the form of an SLR.

2. RESEARCH METHOD

2.1. Research Approach

This study employs a Systematic Literature Review (SLR) approach combined with narrative synthesis. SLR was chosen because it enables the systematic and transparent identification, evaluation, and synthesis of all relevant research [24]. This approach aligns with the research objective of mapping developments, identifying research gaps, and producing evidence-based recommendations in the field of engineered timber structure design and performance [14].

The research procedure follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility. In addition to the SLR, this study also employs bibliometric analysis using VOSviewer and RStudio software to map research clusters, keyword co-occurrence, and citation networks.

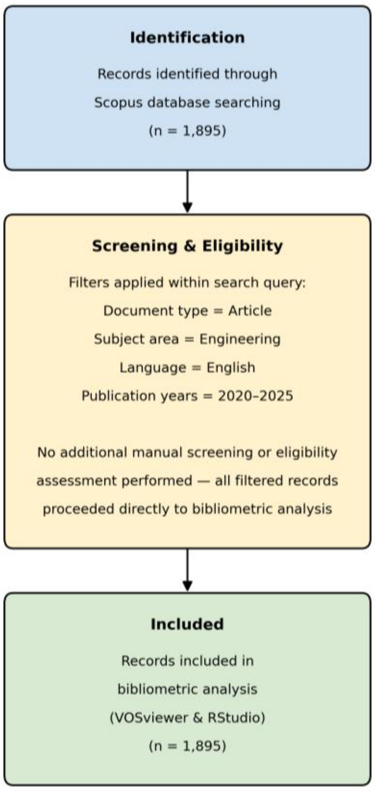

Figure 1. PRISMA-Style Flow Diagram of the Search Strategy. Source: Author's compilation based on Scopus query filters, 2025.

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2.2. Data Sources and Literature Search Strategy

The database search was conducted using Scopus as the primary database with a pre-configured keyword format. Filters were applied to limit the results to publications from the 2020–2025 period. Table 1 presents the details of the search query and its results.

Table 1. Scopus Search Query and Results

No.	Query	Number of Articles
1	TITLE-ABS-KEY (("engineered wood" OR "mass timber" OR "structure timber" OR "CLT" OR "glulam" OR "glued laminated timber" OR "timber structure" OR "wood structure" OR "structural wood" OR "wood composite" OR "laminated wood" OR "timber frame" OR "wood frame" OR "hybrid timber" OR "nail laminated timber" OR "dowel laminated timber" OR "DLT") AND ("civil engineering" OR "structural engineering" OR "construction" OR "building" OR "architecture" OR "infrastructure" OR "structural performance" OR "mechanical properties")) AND PUBYEAR > 2019 AND PUBYEAR < 2027 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE, "English"))	1,895

Source: Scopus database, 2025.

Based on Table 1, the search yielded 1,895 articles that met the inclusion criteria after applying restrictions on document type (article), subject area (Engineering), language (English), and the publication year range of 2020–2025.

All 1,895 articles retrieved from the Scopus query were used for bibliometric mapping (co-occurrence and co-authorship analysis) without additional manual screening beyond the database filters applied in Table 1. No separate full-text eligibility screening was conducted, as the study is primarily bibliometric in nature; a subset of publications most representative of the five thematic clusters identified in Section 3 was examined in greater depth to support the narrative synthesis presented in this review.

2.3. Bibliometric Analysis Procedure

The bibliometric analysis procedure was carried out using two main software tools, namely VOSviewer and RStudio.

VOSviewer was used to analyze bibliometric data from Scopus in BibTeX, CSV, and RIS formats. The analysis types used include co-occurrence (to map relationships between keywords) and co-authorship (to map author collaboration networks). RStudio with the bibliometrix package was used for additional bibliometric statistical analysis and data visualization.

For the keyword co-occurrence analysis, a minimum keyword occurrence threshold of 5 was applied using the full counting method, resulting in 239 author keywords meeting the threshold out of 5,903 unique keywords extracted from the dataset. The resulting network consisted of 13 keyword-level clusters, 1,507 links, and a total link strength of 2,051. These 13 clusters were subsequently consolidated into five overarching thematic groups based on the semantic similarity of their constituent keywords, as presented in Section 3.1, to facilitate interpretation and synthesis.

The research flow began with a literature study phase to understand the concepts, theories, and developments related to the topic under study, followed by retrieval of the scientific article dataset from Scopus as the primary research source, and concluded with analysis using VOSviewer and RStudio.

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3. RESULTS AND DISCUSSION

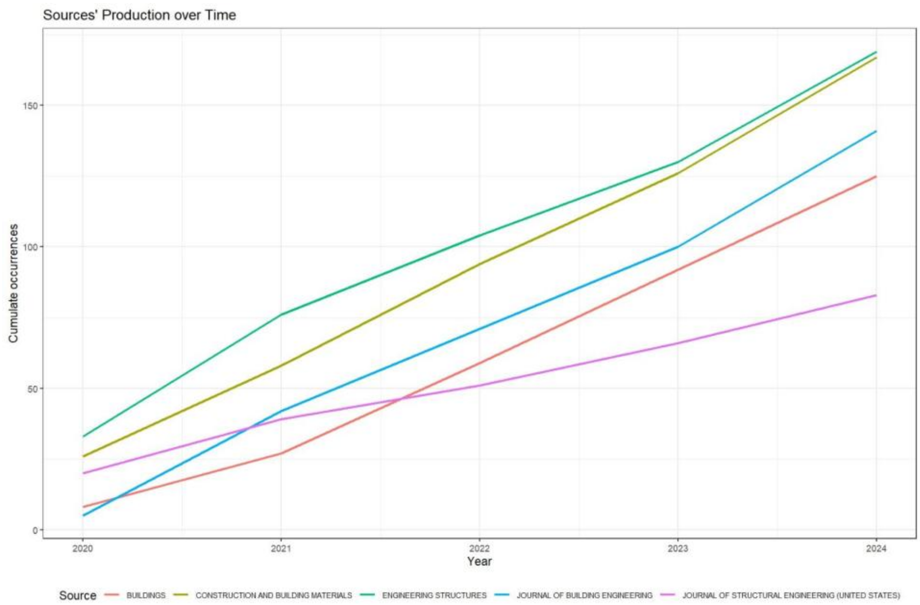

Figure 2. Sources' Production over Time (Cumulative Publication Chart per Source Journal, 2020–2024). Source: VOSviewer and RStudio Bibliometric Analysis, 2025.

3.1. VOSviewer Co-occurrence Analysis

Co-occurrence analysis is a bibliometric method used to identify how frequently two elements, such as keywords, authors, journals, or references, appear together or are connected within a corpus of scientific literature. Figure 3 shows the keyword co-occurrence network map derived from the entire body of literature on timber structures and engineered wood, analyzed using VOSviewer.

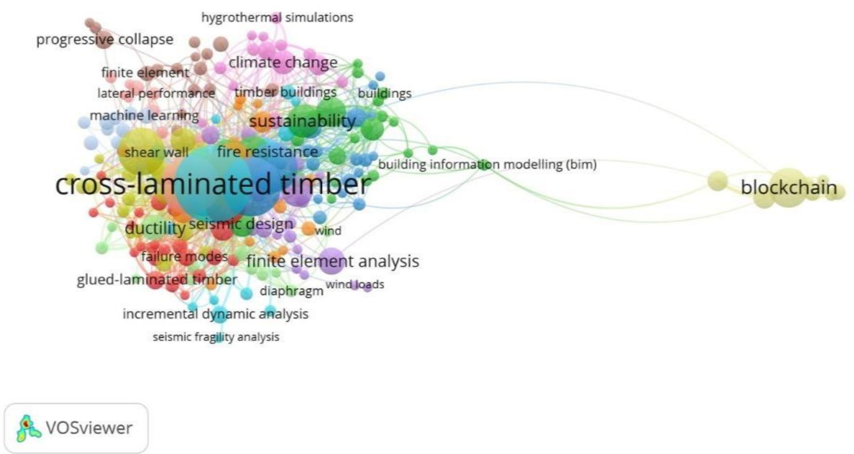

Figure 3. Keyword Co-occurrence Network (VOSviewer). Source: VOSviewer Analysis, 2025.

Based on Figure 3, the size of the circles and text reflects the frequency of keyword occurrence. The term "timber structure" appears the largest, indicating that it is the central and most frequently examined topic. The connecting lines indicate co-occurrence relationships: two keywords that frequently appear

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together in the same article are connected by a thicker line. At least five main clusters were identified from the map: (1) Green: sustainability and environment, including sustainability, climate change, carbon footprint, and timber buildings; (2) Red: material and mechanical properties, including cross-laminated timber, mechanical properties, glued laminated timber, and composites; (3) Blue: structural and seismic analysis, including seismic design, finite element analysis, ductility, and failure modes; (4) Purple: structural collapse and safety, including progressive collapse, finite element, and seismic behavior; and (5) Yellow: construction technology and innovation, including building information modeling, parametric design, and machine learning.

The limited visibility of tropical climate and Indonesian local timber species within the co-occurrence network suggests that these topics remain peripheral in the global research landscape. This gap represents a strategic opportunity for Indonesian researchers to contribute novel, regionally grounded data to the global body of knowledge on engineered timber performance.

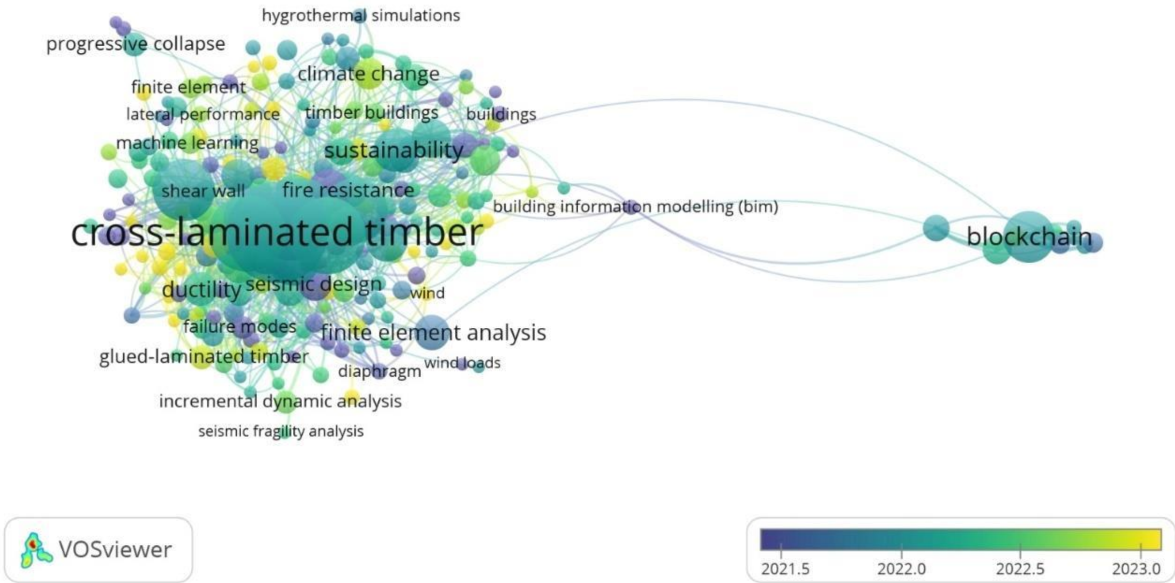

Figure 4. Overlay Visualization Based on Publication Time Range (2021–2023). Source: VOSviewer Analysis, 2025.

Figure 4 shows the overlay visualization, which uses a color gradient from dark purple/blue through green to yellow to represent the time range from 2021 to 2023. Dark purple/blue indicates keywords that have, on average, been studied for a longer time, such as mechanical properties, glued laminated timber, and seismic design, which are already well-established topics. Bright green-yellow indicates keywords that have recently become popular research topics, such as sustainability, climate change, fire resistance, and machine learning.

3.2. Co-authorship Network Analysis

Co-authorship analysis is a bibliometric analysis method based on research authorship, in which every article written by two or more authors creates a co-authorship relationship between them. Figure 5 shows the author collaboration network visualization (co-authorship network) depicting collaborative relationships among authors based on publications addressing the related research topic.

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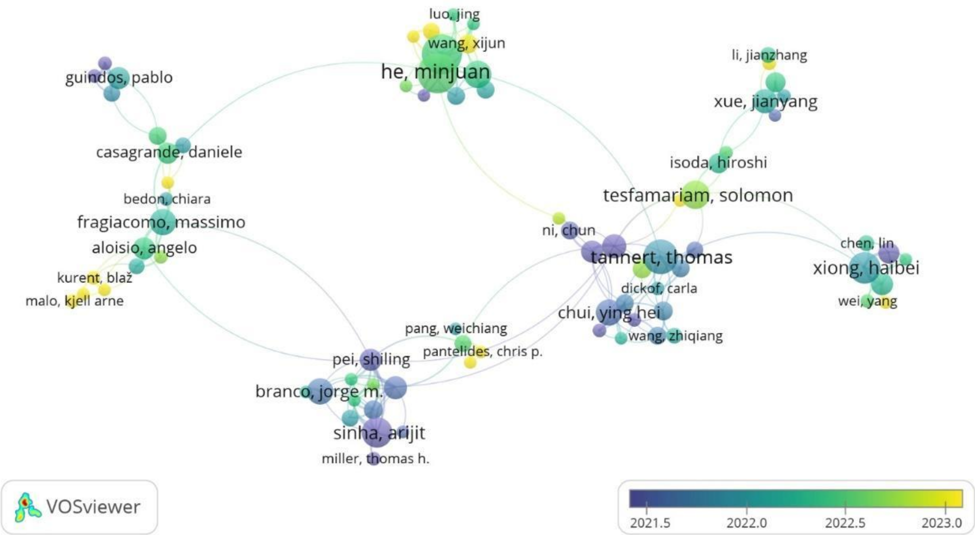

Figure 5. Co-authorship Network (VOSviewer). Source: VOSviewer Analysis, 2025.

Several colored clusters represent groups of author collaboration. The dominant clusters include the green group led by Sinha, Arijit and Branco, Jorge M., which focuses on the mechanical performance of engineered timber materials; the blue group centered on He, Minjuan, which is active in cross-laminated timber structure research in Asia; and the red group led by Tannert, Thomas and Tesfamariam, Solomon, which focuses on the seismic design of timber structures.

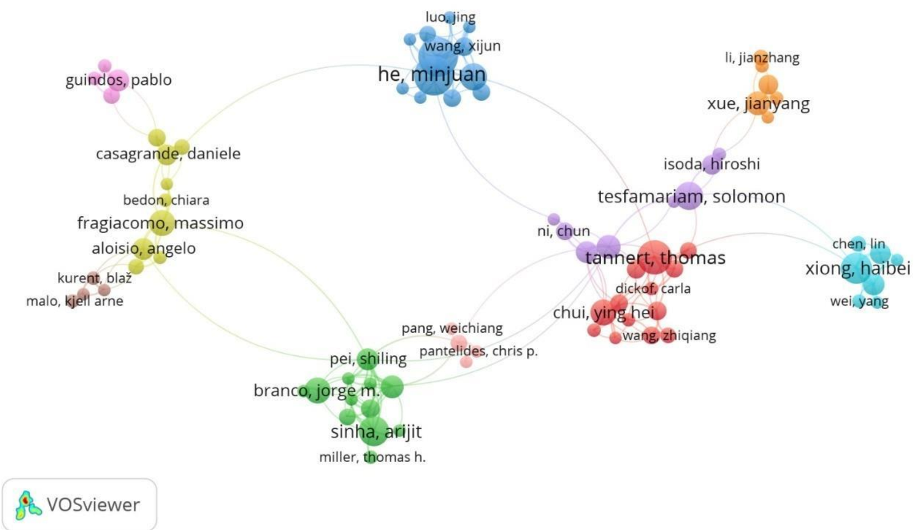

Figure 6. Co-authorship Overlay Visualization Based on Average Publication Year. Source: VOSviewer Analysis, 2025.

Figure 6 shows the co-authorship overlay visualization based on the average publication year. Authors active in the earlier period (2021–2022) tended to focus on the basic characterization of CLT and glulam materials. Authors active in the more recent period (2022–2023) more frequently examined topics such as sustainability, fire resistance, and the integration of building information modeling technology in timber construction.

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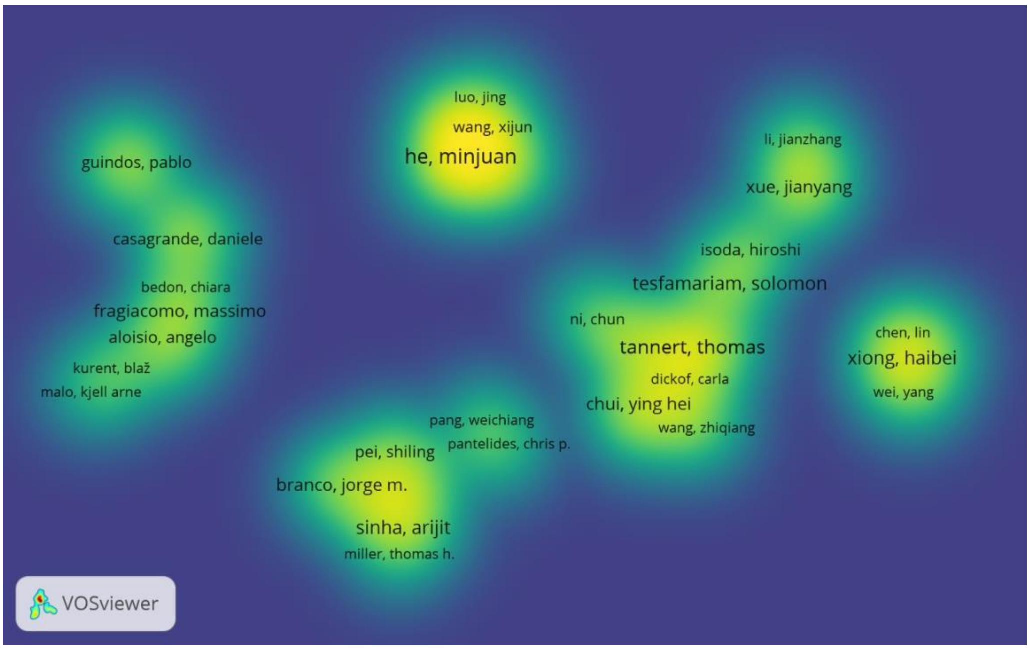

Figure 7. Co-authorship Network Density Visualization. Source: VOSviewer Analysis, 2025.

The density visualization in Figure 7 shows three main groups with substantial influence: He, Minjuan; Tannert, Thomas and Tesfamariam, Solomon; and Sinha, Arijit and Branco, Jorge M. Researchers from Southeast Asia and Indonesia are still not visible within this network.

3.3. RStudio Bibliometric Analysis

RStudio with the bibliometrix package was used to validate and complement the VOSviewer analysis. Figure 8 shows the keyword co-occurrence density visualization from RStudio. The red-toned region is dominated by finite element analysis, seismic performance, and progressive collapse. The green-toned region features glued laminated timber, cross-laminated timber, and engineered wood products. The blue-toned region represents sustainability, durability, and hygrothermal performance. A separate region shows blockchain as an emerging theme in the context of digital construction management.

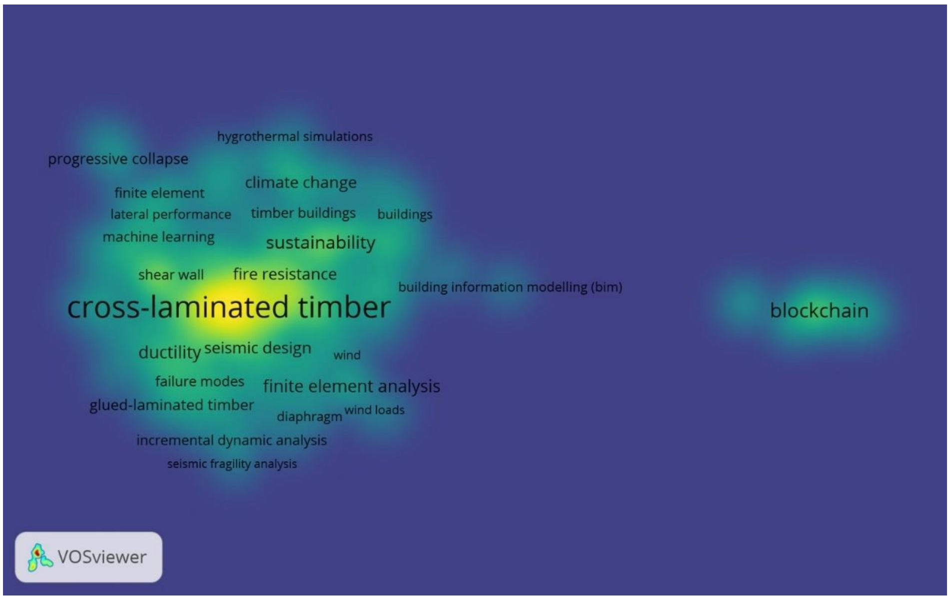

Figure 8. Keyword Co-occurrence Network (RStudio: bibliometrix). Source: RStudio Bibliometrix Analysis, 2025.

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3.4. Publication Trend and Leading Sources

Figure 9 shows the 'Most Relevant Sources' chart, illustrating the number of documents published by the leading source journals. Engineering Structures shows the highest publication output, with 169 documents. Construction and Building Materials also shows a significant contribution, with 157 documents. Journal of Building Engineering and Buildings show stable output, with 141 and 125 documents, respectively.

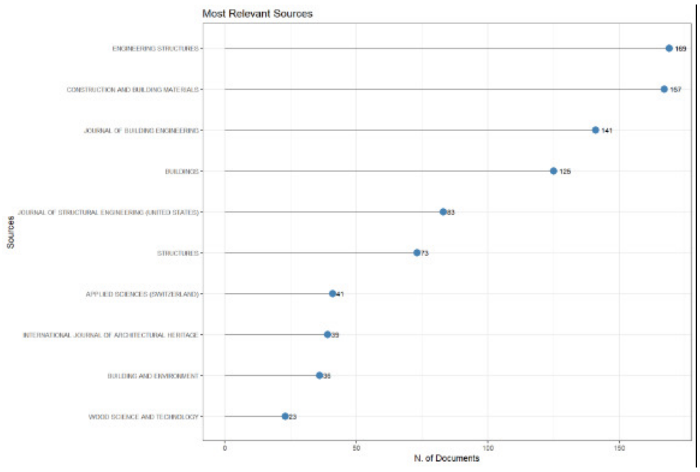

Figure 9. Most Relevant Sources (Number of Documents per Journal). Source: RStudio Bibliometrix Analysis, 2025.

3.5. Thematic Mapping

Figure 10 shows the Thematic Map, which divides research themes into four main quadrants. Motor Themes (upper right) represent themes with high relevance and development that are the primary focus of current research. Niche Themes (upper left) include themes that are developing specifically but are not yet widely connected. Basic Themes (lower right) represent the foundational basis of research that is commonly used but still requires further development. Emerging or Declining Themes (lower left) include themes that are either newly emerging or beginning to experience a decline in research interest.

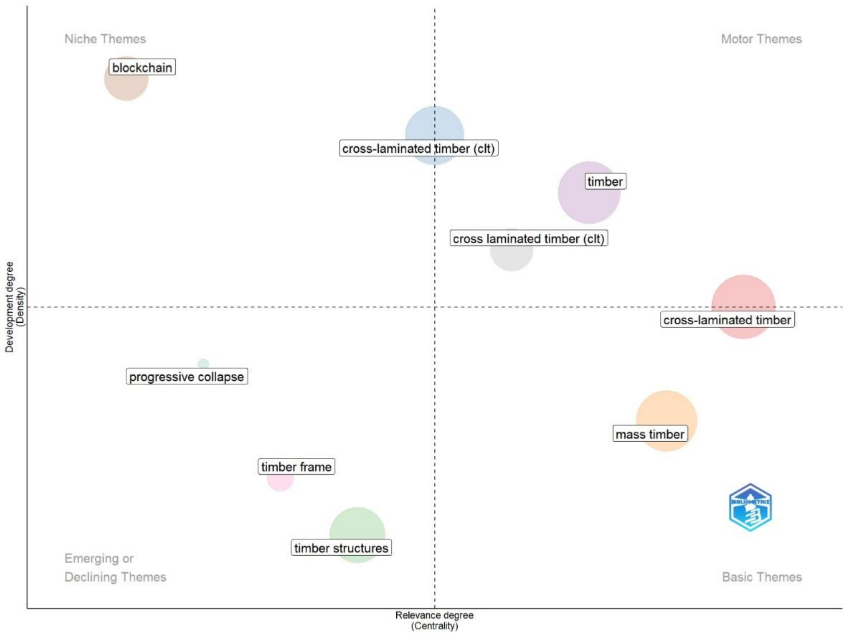

Figure 10. Thematic Map (bibliometrix). Source: RStudio Bibliometrix Analysis, 2025.

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4. CONCLUSION

This study presents a Systematic Literature Review (SLR) and bibliometric analysis of 1,895 Scopus publications (2020–2025) on the performance and effectiveness of timber structures in modern construction based on engineered materials. Bibliometric analysis using VOSviewer and RStudio successfully identified five main thematic clusters: sustainability and environment, material and mechanical properties, structural and seismic analysis, structural collapse and safety, and construction technology and innovation.

The dominance of research from temperate-climate regions (Europe, North America, and Japan) is an important finding indicating a significant geographical gap. Aspects such as durability in tropical climates, the utilization of local Indonesian timber, long-term field validation, and the integration of national design standards (SNI) for CLT and glulam materials still require greater research attention.

This study provides a tangible contribution by identifying the gap between current timber structural design practice in Indonesia and recent global developments, providing a scientific foundation for the development of sustainable construction, and establishing a structured research agenda for the development of SNI standards related to engineered timber materials. Further research is recommended to focus on the characterization of local Indonesian timber species, durability testing under tropical climate conditions, and the integration of seismic and sustainability aspects within a single comprehensive design framework.

REFERENCES

[1] D. W. Green, "Wood material for sustainable construction," *J. Sustain. Mater.*, vol. 12, no. 3, pp. 145–160, 2020.
[2] IEA, "Tracking Buildings 2023," International Energy Agency, Paris, 2023.
[3] S. Pei, J. van de Lindt, A. R. Barbosa, and J. W. Berman, "Seismic design and performance of a mass timber building in Seattle," *J. Struct. Eng.*, vol. 146, no. 9, p. 04020180, 2020.
[4] M. Shahnewaz, M. S. Alam, and T. Tannert, "Seismic performance of CLT buildings with slip-friction connections," *Eng. Struct.*, vol. 225, p. 111286, 2020.
[5] L. Gustavsson, R. Sathre, and A. Dodoo, "Carbon balance of wood-based construction," *Build. Environ.*, vol. 248, p. 111057, 2024.
[6] H. Zhou, X. Li, and Y. Wang, "Mechanical properties of timber under different moisture conditions," *Constr. Build. Mater.*, vol. 301, p. 124321, 2021.
[7] Z. Li, J. Chen, and L. Huang, "Influence of density and defects on the mechanical performance of wood structures," *Mater. Today Commun.*, vol. 33, p. 104567, 2022.
[8] F. Silva, J. M. Branco, and P. B. Lourenco, "Influence of environmental conditions on timber durability," *Constr. Build. Mater.*, vol. 241, p. 118043, 2020.
[9] X. Wang, R. J. Ross, and P. Carter, "Decay and insect damage in wood structures," *For. Prod. J.*, vol. 70, no. 2, pp. 123–130, 2020.
[10] M. H. Ramage, T. Reynolds, D. U. Shah, and Z. Li, "Mass timber in tropical climates: durability and performance," *Renew. Sustain. Energy Rev.*, vol. 190, p. 114102, 2025.
[11] A. L. Christoforo, J. Fiorelli, and F. A. R. Lahr, "Characterization of structural timber in tropical regions," *Wood Mater. Sci. Eng.*, vol. 18, no. 4, pp. 1205–1215, 2023.
[12] A. Hassan, K. Mahmoud, and M. Ali, "Behavior of bolted timber connections under load," *Structures*, vol. 34, pp. 256–267, 2021.
[13] A. T. Balasbaneh and W. Sher, "A systematic literature review of life cycle sustainability assessment of mass timber in the construction industry toward circular economy," *Environ. Dev. Sustain.*, 2024, doi: 10.1007/s10668-024-05377-9.
[14] M. H. Ramage, T. Reynolds, and D. U. Shah, "Advances in structural use of timber in construction," *Renew. Sustain. Energy Rev.*, vol. 158, p. 112093, 2022.
[15] P. Dobeš, A. Lokaj, and K. Vavrušová, "Stiffness and deformation analysis of cross-laminated timber (CLT) panels made of Nordic spruce based on experimental testing, analytical calculation and numerical modeling," *Buildings*, vol. 13, no. 1, p. 200, 2023, doi: 10.3390/buildings13010200.

P-ISSN : 2598-1277
E-ISSN : 2621-3966

[16] I. P. Christovasilis and M. Brunetto, "Hygromechanical response of CLT under natural climate variations," *Constr. Build. Mater.*, vol. 319, p. 125943, 2022.
[17] R. Brandner and A. Thiel, "Updated mechanical models for CLT under combined loading," *Eur. J. Wood Wood Prod.*, vol. 82, no. 1, pp. 45–63, 2024.
[18] H. Pearson, M. Evernden, and R. Harris, "Analysis of engineered timber panels using a strut and tie model for use in folded plate structures and deep beams," in *Proc. 12th World Conf. Timber Eng. (WCTE 2012)*, Auckland, New Zealand, 2012, pp. 344–353.
[19] R. R. Amaral, H. M. Gomes, J. Luis, and P. Tamayo, "Topology optimization of engineered timber structures," *Comput. Struct.*, vol. 315, 2025.
[20] G. Fink, J. Kohler, and R. Brandner, "Reliability-based design of CLT structures," *Struct. Saf.*, vol. 101, p. 102296, 2023.
[21] S. Pei, J. D. Dolan, and J. van de Lindt, "Seismic resilience of mass timber buildings," *Earthq. Eng. Struct. Dyn.*, vol. 53, no. 3, pp. 1025–1045, 2024.
[22] M. Shahnewaz and T. Tannert, "Seismic fragility assessment of CLT platform-frame buildings," *J. Build. Eng.*, vol. 82, p. 108245, 2024.
[23] M. H. Ramage, D. U. Shah, and T. Reynolds, "Structural timber for net-zero buildings," *Nat. Sustain.*, vol. 7, no. 2, pp. 145–157, 2024.
[24] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *PLoS Med.*, vol. 6, no. 7, p. e1000097, 2009.