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Composite Buckling Performances for Energy Structures and Infrastructures: A Milestone Analysis Based on Finite Element Research (2000–2025)

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Abstract

This study presents a targeted bibliometric analysis of research on composite buckling in energy infrastructure, focusing on works that utilize the finite element method (FEM) between 2000 and 2025. The increasing demand for renewable energy systems has intensified the use of lightweight composite materials in structural elements such as wind turbine towers, solar supports, and offshore platforms. Despite their mechanical advantages, composite structures remain vulnerable to buckling, necessitating the use of accurate computational modeling to ensure reliability. A total of 1855 Scopus-indexed publications were analyzed using Bibliometrix and VOSviewer. The data span 294 journals and over 4200 authors, with China, the United States, and India leading in output. Key publishing platforms include Composite Structures and Thin-Walled Structures. Mapping of keywords, co-authorship, and citation networks indicates that FEM is the dominant analytical tool for assessing buckling behavior, especially in studies involving optimization and failure prediction. This review synthesizes significant developments in the field and reveals the integration of computational mechanics and advanced materials within the energy sector. The results serve as a reference for researchers seeking to enhance the structural resilience of composite-based energy systems.

Keywords: Composite buckling; Energy structure and infrastructure; Finite element analysis; Bibliometric analysis.
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1. Introduction

The global energy crisis has emerged as a critical challenge, with projections indicating that energy demand may triple by the end of this century.[1] A recent report is visualized in Fig. 1 highlights the stark reality of worldwide energy consumption,[2] revealing that countries like the United States, Canada, and Iceland and affluent Middle Eastern nations such as Oman, Saudi Arabia, and Qatar have the highest energy usage. The average citizen in these regions consumes up to 100 times more energy than individuals in some of the world's poorest countries. Despite growing awareness of the environmental impacts associated with traditional energy sources—like coal and oil, which are still dominant in many regions—there's a pressing need to shift toward sustainable alternatives. The combustion of fossil fuels generates harmful emissions, such as carbon dioxide, contributing to issues like acid rain and global warming.[3-5] This awareness has prompted governments, industries, and researchers to explore renewable energy solutions, including wind, solar, and biomass.[6-10] The International Energy Agency (IEA) plays a vital role in this transition by monitoring progress and offering data, analysis, and policy recommendations to help nations provide safe and sustainable energy[11,12] (see Fig. 2). Renewable energy capacity is rising, with hydropower, wind, solar, geothermal, and biomass being the top five sources poised for further development.[13-16] The ambition to transition from conventional to green energy is substantial, with a target cumulative capacity of 7903 gigawatts (GW) by 2030. As of 2024, researchers are estimated to reach around 4909.5 GW, approximately 60% of this ambitious goal.

However, this transition presents significant engineering challenges, particularly concerning the structural stability of the thin-walled systems and components that support renewable energy infrastructures. These infrastructures, which

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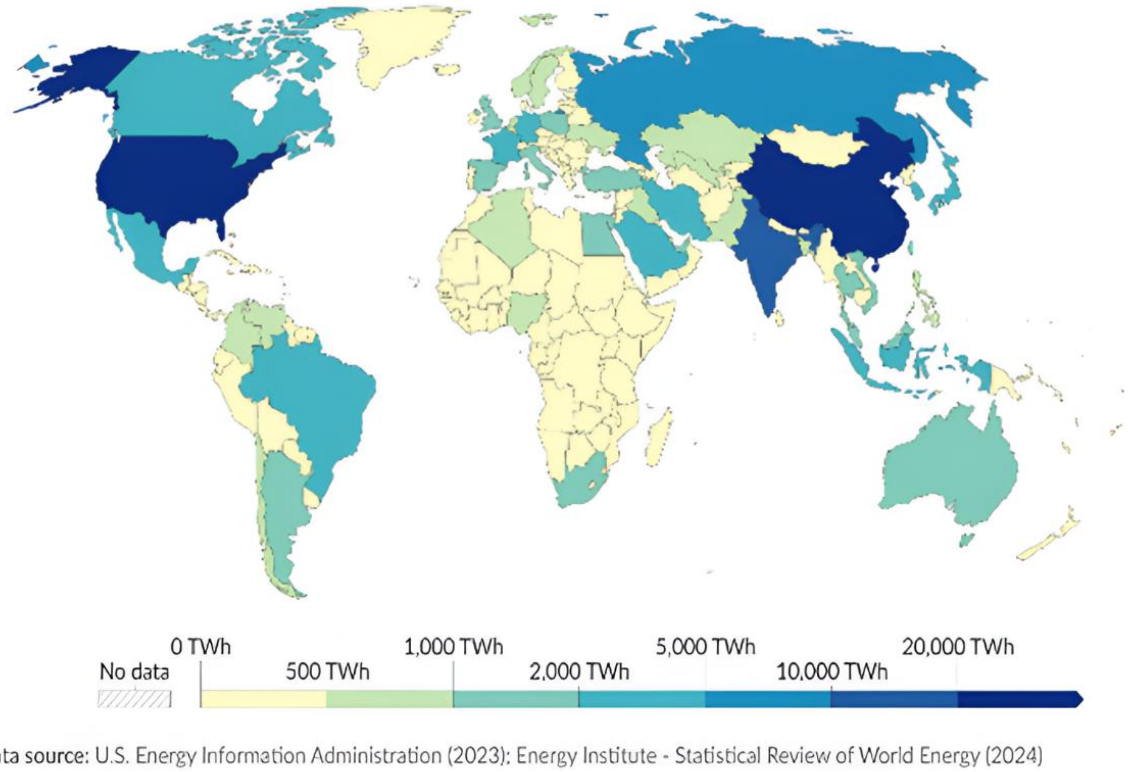

Fig. 1: Energy demand along the world in 2024 Reproduced from.[2]

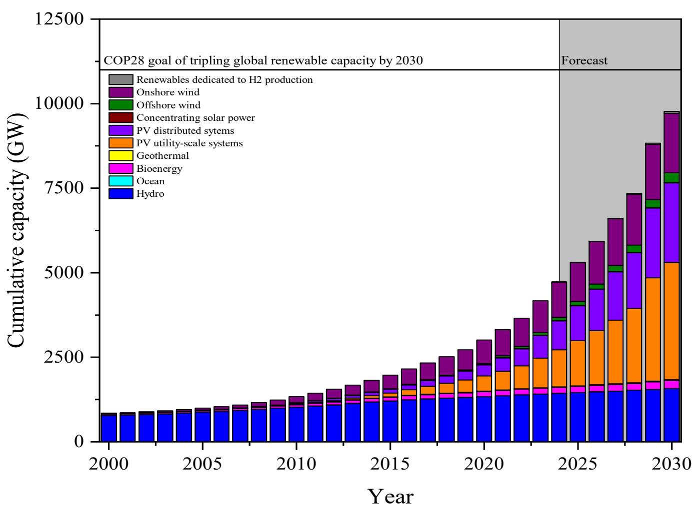

Fig. 2: Renewable energy progress along the world (redrawing based on Reproduced from[12]).

include pipes, poles, and other critical structures (as depicted in Fig. 3), must withstand various loads; otherwise, they risk structural failure.[17-19] One of the most concerning failure modes in these contexts is buckling,[20] especially in composite materials often chosen for their favorable strength-to-weight ratios and versatility. The importance of engineering in the design and optimization of renewable energy facilities cannot be overstated. Numerous studies highlight the link between renewable energy development and advancements in engineering, emphasizing the need for rigorous research and innovation. For example, some of the things that are being developed are optimizing the design of wind turbine poles and airflow on propellers,[21-23] designing pipe support structures to withstand hydrostatic and bending loads,[24-26] compiling schematic diagrams that integrate with other renewable sources,[27-29] and increasing the effectiveness of performance from reducing heat loss[30-32] and using different basic materials.[33-35] This body of work continues to grow, with an increasing number of publications across academic journals increasing number of publications across academic journals and international conferences each.

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Research into composite buckling focuses on structural failures when these materials are subjected to critical pressures, surpassing their elasticity limits. Composite materials play a central role in enhancing the performance and sustainability of modern energy infrastructure due to their advantageous mechanical properties—such as high specific strength, low density, and corrosion resistance.[36] In wind energy systems, composites are widely adopted to fabricate turbine blades, where their stiffness and fatigue resistance contribute to longer service life and improved aerodynamic efficiency under dynamic wind loads.[37] Beyond the blades, innovative approaches now explore the use of composite materials for turbine towers, enabling lighter, taller, and more modular structural systems optimized for offshore deployment.[38] In solar energy, composite materials are increasingly used as encapsulants and support layers in photovoltaic modules. Their thermal stability, flexibility, and barrier properties help protect solar cells from environmental degradation while enhancing durability and power output.[39] Integrating functional composites in energy storage and conversion is also gaining traction. For instance, phase change materials embedded in carbon-based composites have been proposed for thermally efficient concrete in solar-thermal hybrid applications.[40] Moreover, developing biodegradable and bio-based composites—derived from agricultural residues or biofuel co-products—offers a promising route toward more environmentally responsible material systems, particularly in lightweight structural applications for energy technologies.[41] These advances underline composite materials' dual value: they offer technical advantages in load-bearing and thermal regulation and align with broader sustainability goals within the global energy transition.

One of the most effective methods for analyzing composite buckling is the finite element approach (FEA), which enables the digital simulation of conditions that can lead to structural failure.[42,43] This method allows engineers to model the behavior of composite materials with high precision, analyzing stress and force distributions across various structural elements. Using finite element simulations, researchers can predict critical buckling points, test different structural designs, and identify optimal strategies to prevent failure. This approach is essential for developing and optimizing infrastructure designs that incorporate composite materials. The finite element approach also facilitates the integration of various design parameters, including structural geometry, material properties, and load conditions. Over the past few decades, numerous studies have employed this method to model buckling behavior in composites, especially within engineering and infrastructure applications. Jensen *et al*.[44] have conducted tests accompanied by numerical

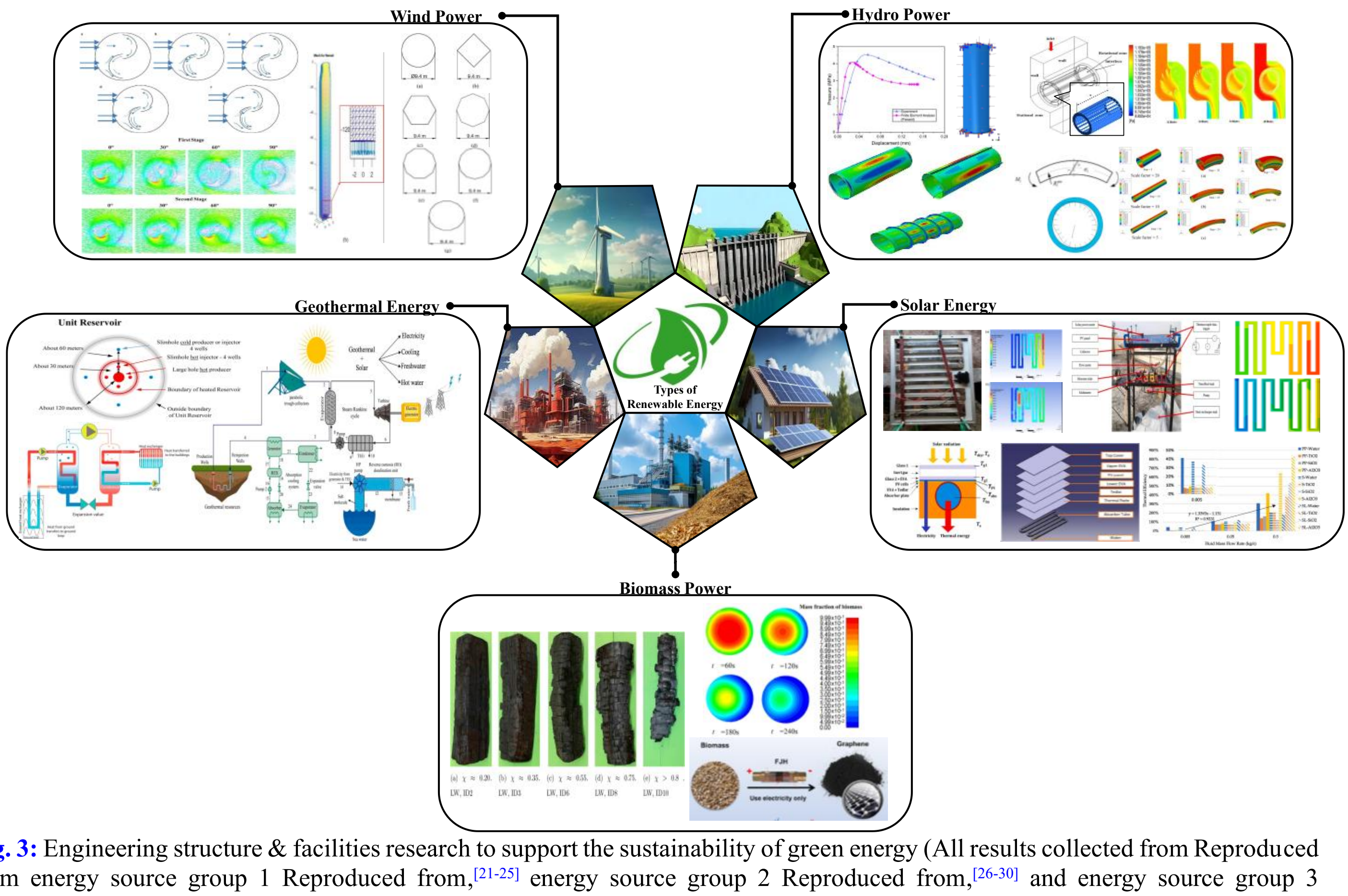

Fig. 3: Engineering structure & facilities research to support the sustainability of green energy (All results collected from Reproduced from energy source group 1 Reproduced from,[21-25] energy source group 2 Reproduced from,[26-30] and energy source group 3 Reproduced from.[31-35])

modeling on wind turbine blades with composite materials. The results indicate that local displacement can trigger catastrophic failure initiated by delamination buckling. Lopes *et al*.[45] used the finite element method to show that the stiffness variable has advantages over straight fiber laminates regarding compressive buckling and first-layer failure. At the same time, Alimerzai *et al*.[46] and Sun *et al*.[47] conducted buckling studies considering magnetic factors and bending loads, respectively. FEA allows for realistic simulations that reduce the need for costly and time-consuming physical experiments, enhancing our understanding of how composites respond to various stress types and extreme environmental conditions.

As the era of transition to renewable energy, the success of infrastructure development hinges on innovations in materials and structural design. Composite materials present a sustainable solution to structural failure challenges, but further research is necessary to tackle existing issues, particularly those related to composite buckling. With modern technologies like the finite element approach, researchers and engineers can continue to develop more efficient and safer solutions, thereby supporting the sustainability of global green energy initiatives. Consequently, research in this field is critical for technological advancements and mitigating structural risks that could impede progress in renewable energy development. Therefore, an appropriate method is needed to facilitate the assessment process of the developing literature. Bibliometric analysis can help understand research trends and identify the main contributions of publication results.[48] Recent bibliometric studies on energy have highlighted various interconnected themes, such as climate change, technological innovation, economic development, and social equity. For instance, Yao *et al*.[49] conducted a bibliometric analysis spanning publications from 1973 to 2022, revealing insights into approximately 600 journals and an average of 41.42 citations per document per year. Other researchers, including Yataganbaba *et al*.[50] Azevedo *et al*.[51] and Mao *et al*.[52] have similarly examined trends in areas like phase change materials, renewable energy supply chains, and sustainability innovations. However, only some bibliometric analyses focus on the intersection of structural engineering and composite materials.

This study aims to fill that gap by conducting a bibliometric analysis of literature related to buckling—the most common failure mode for structures like columns and thin walls under overload—and composite materials, which offer potential solutions to reduce the risk of buckling failure. Through this analysis, we seek to enhance our understanding of research trends, contributions, and field gaps, ultimately offering future study recommendations.

2. Methods

In this study, the data obtained from open literature were processed using the bibliometric analysis method using free software such as bibliometrix and VOSviewer. Data searches will be limited by using additional keywords such as subject area, language, source type, and others, which are done so that the data produced is not excessive and makes it easier to analyze.

A single search was run on Scopus on September 17, 2024, using the following search terms: "TITLE-ABS-KEY (composite AND buckling) AND PUBYEAR > 1999 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (EXACTKEYWORD , "Finite Element Method"))". A single batch of results was exported because the total results did not surpass 2000 publications. Every article was acquired on the same day to prevent discrepancies because daily database changes could happen.

All searches were done only on Scopus because it is the largest peer-reviewed abstract and citation database.[53] Only "articles" and "conference papers" were included in the search results for publishing types, and other limitations were imposed as well, such as language (English), source type (journal), subject of study (engineering), and keywords (Finite Element Method). The following bibliometric information was gathered: the total and yearly number of publications; the open access status; the number of publications per journal; the names and impact factors of the journals; the language of publication; the type of document; the country of publication; the affiliations of the authors; funding sponsors; the most highly cited publications; and the most highly published authors. The authors found and displayed trends related to this selection of publications. The software package (VOSviewer version 1.6.20) created and visualized bibliometric networks.[54,55] Also, bibliometrix include biblioshiny run with R studio software was used in this study.[56] These steps are summarized in Fig. 4.

3. Results

3.1 General publication trends

Between 2000 and 2025, 4333 writers produced 1855 publications in 296 journals. There were few publications on composite buckling at first. After a period of relative stagnation between 2005 and 2012, the number of composite buckling publications surged, reaching its peak in 2016. However, due to the global effects of the COVID-19 virus, the number of publications decreased until 2020, following the initial rise. After that, it began to rise gently once more in 2021 and has continued to do so to this day. The number of papers published annually from 2000 to 2025 is shown in Fig. 5. Composite Structures (n = 370), Thin-Walled Structures (n = 103), and Engineering Structures (n = 101) had the most composite buckling papers among the three journals. Apart from the previously mentioned three journals, SCImago Journal & Country Rank was utilized to manually search the top 15 journals containing the most significant quantity of composite buckling papers to gather pertinent metrics.

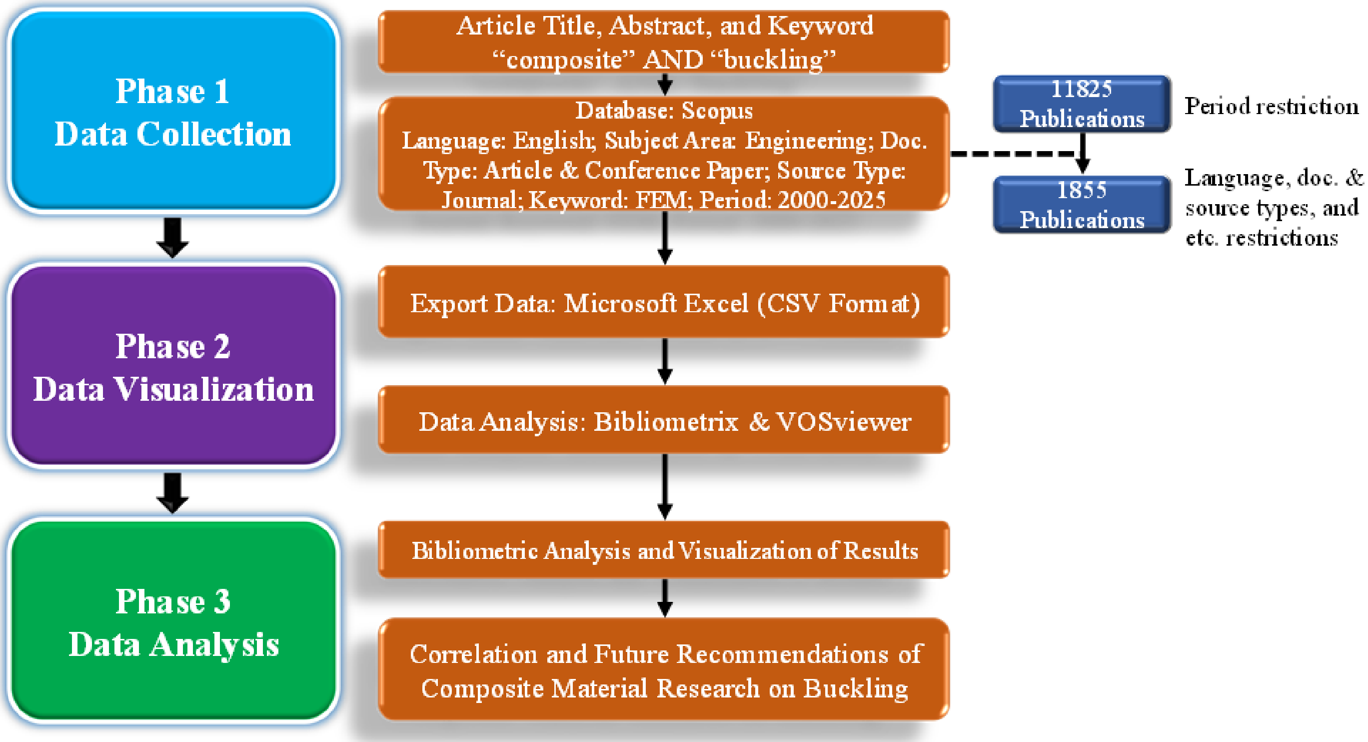

Fig. 4: The methodology of current study.

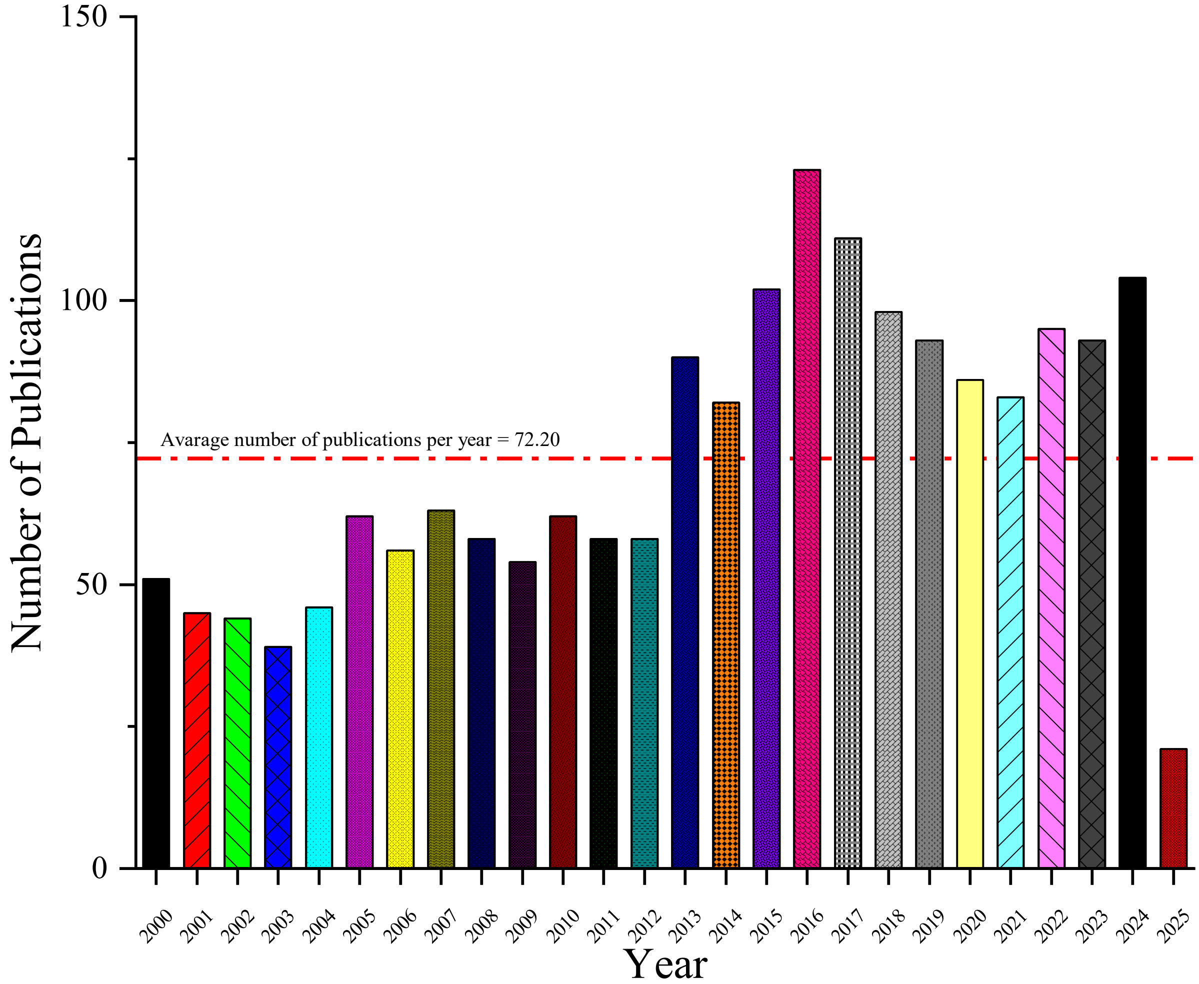

Fig. 5: The annual number of composite buckling publications between 2000 and 2025.

The 2024 impact factors of these journals varied from 2.5 to 24.4. Complete information about the examined journals is provided in Table 1, including their impact factors, the number of publications, and the full journal titles.

The subject areas with the highest volume of publications were engineering (n =1876), material science (n =1060), and mathematics (n = 246). A similar observation was noted in document type, with most publications being articles (n = 1814) with a small number of conference papers (n = 62). The countries with the highest output of publications were China (n = 374), the United States (n = 241), and India (n = 212). As this implies, the Indian Institute of Technology Kharagpur (n = 50), the People's Republic of China's Ministry of Education (n = 47), and the Dalian University of Technology (n = 36) were the most often mentioned affiliations. In terms of funding sponsors, the most common were the National Natural Science Foundation of China (n = 229), the Ministry of Science and Technology of the People's Republic of China (n = 101), and the European Commission (n = 51). The general features of publications that qualify as composite buckling are listed in Table 2. The ten most published authors are listed in Table 3, while the ten most frequently cited papers are included in Table 4.

3.2 Bibliometric Mapping and Thematic Visualization

The field of composite buckling research reflects a highly interconnected and methodologically diverse academic landscape. Using bibliometric visualization tools such as

Table 1: Features of the 15 journals with the most composite buckling publications published.

Journal Name	Number of Publication	Impact Factor (2024)	Name of the Publisher	Subject Area (Scopus)	Cite Score (2024)
Composite Structures	370	6.3	Elsevier	Engineering: Civil and Structural Engineering Material Science: Ceramics and Composites	12.00
Thin-Walled Structures	103	5.7	Elsevier	Engineering: Building and Construction, Civil and Structural Engineering, Mechanical Engineering	9.6
Engineering Structures	101	5.6	Elsevier	Engineering: Civil and Structural Engineering	10.2
Composites Part B: Engineering	63	12.7	Elsevier	Engineering: Industrial and Manufacturing Engineering, Mechanical Engineering, Mechanics of Materials Materials Science: Ceramics and Composites	24.4
Journal of Constructional Steel Research	56	4.0	Elsevier	Engineering: Building and Construction, Civil and Structural Engineering, Mechanics of Materials Materials Science: Metals and Alloy	7.9
Journal of Composite Materials	41	2.3	SAGE Publications	Engineering: Mechanical Engineering, Mechanics of Materials Materials Science: Ceramics and Composites, Materials Chemistry	2.5
Journal of Reinforced Plastics and Composites	40	2.3	SAGE Publications	Engineering: Mechanical Engineering, Mechanics of Materials Materials Science: Ceramics and Composites, Materials Chemistry, Polymers and Plastics	3.2
Composites Science and Technology	35	8.3	Elsevier	Engineering: Engineering (miscellaneous) Materials Science: Ceramics and Composites	16.2
International Journal of Structural Stability and Dynamics	31	3.0	World Scientific	Engineering: Aerospace Engineering, Building and Construction, Civil and Structural Engineering, Mechanical Engineering, Ocean Engineering	5.3
International Journal of Solids and Structures	30	3.4	Elsevier	Engineering: Mechanical Engineering, Mechanics of Materials Material Science: Material Science (Miscellaneous) Mathematics: Applied Mathematics, Modeling and Simulation Physics and Astronomy: Condensed Matter Physics	6.7

Journal Name	Number of Publication	Impact Factor (2024)	Name of the Publisher	Subject Area (Scopus)	Cite Score (2024)
Steel and Composite Structures	30	4.0	Techno-Press	Engineering: Building and Construction, Civil and Structural Engineering Materials Science: Metals Alloy	8.5
AIAA Journal	29	2.5	American Institute of Aeronautics and Astronautics (AIAA)	Engineering: Aerospace Engineering	5.5
Journal of Structural Engineering	29	3.7	American Society of Civil Engineers (ASCE)	Engineering: Building and Construction, Civil and Structural Engineering, Mechanical Engineering, Mechanics of Materials Materials Science: Materials Science (Miscellaneous)	8.0
Computers and Structures	24	4.4	Elsevier	Computer Science: Computer Science Applications Engineering: Civil and Structural Engineering, Mechanical Engineering Materials Science: Materials Science (Miscellaneous) Mathematics: Modeling and Simulation	8.8
Mechanics of Advanced Materials and Structures	24	3.6	Taylor and Francis	Engineering: Civil and Structural Engineering, Mechanical Engineering, Mechanics of Materials Materials Science: Materials Science (Miscellaneous) Mathematics: Mathematics (Miscellaneous)	5.3

Table 2: Overall features of the composite buckling publication.

Publication Volume	
Number of Total Publications ($n = 1855$) Number of Open Access Publications ($n = 305$)	
Document Type (# of publications)	Article ($n = 1776$) Conference paper ($n = 61$)
Source Titles (Journals) Across All Publications ($n = 296$) Total Citations ($n = 57004$) Mean # of Citations per Publication ($n = 30.38$) International Co-Authorship ($n = 21.78$)	
Source Titles of Publication (10 Highest)	
# of publications	Composite Structures ($n = 378$) Thin-Walled Structures ($n = 104$) Engineering Structures ($n = 101$) Composites Part B Engineering ($n = 67$) Journal of Constructional Steel Research ($n = 58$) Journal of Reinforced Plastics and Composites ($n = 41$) Journal of Composite Materials ($n = 41$) Composites Science and Technology ($n = 36$) International Journal of Structural Stability and Dynamics ($n = 32$) AIAA Journal ($n = 31$)
Country of Publications (10 Highest)	
# of publications	China ($n = 387$) United States ($n = 240$)

	India ($n = 215$) United Kingdom ($n = 175$) Iran ($n = 132$) Australia ($n = 129$) Italy ($n = 103$) South Korea ($n = 101$) Turkey ($n = 86$) Poland ($n = 73$)
Institutional Affiliation (10 Highest)	
# of publication	Indian Institute of Technology Kharagpur ($n = 50$) Ministry of Education of the People's Republic of China ($n = 47$) Dalian University of Technology ($n = 36$) Politechnika Lubelska ($n = 34$) Tsinghua University ($n = 34$) Amirkabir University of Technology ($n = 33$) Northwestern Polytechnical University ($n = 27$) Delft University of Technology ($n = 26$) Lodz University of Technology ($n = 25$) Harbin Institute of Technology ($n = 24$)
Funding Sponsor (10 Highest)	
# of publication	National Natural Science Foundation of China ($n = 229$) Ministry of Science and Technology of the People's Republic of China ($n = 101$) European Commission ($n = 51$) Fundamental Research Funds for the Central Universities ($n = 46$) National Key Research and Development Program of China ($n = 36$) China Postdoctoral Science Foundation ($n = 30$) National Research Foundation of Korea ($n = 27$) Engineering and Physical Sciences Research Council ($n = 26$) Conselho Nacional de Desenvolvimento Científico e Tecnológico ($n = 26$) National Science Foundation ($n = 24$)

Table 3: The top 15 writers for composite buckling publications in terms of productivity.

Author Name	Number of Publications	Number of Articles Published	Number of Citations Received	Institution	Country
Singh BN	26	180	5109	Indian Institute of Technology Kharagpur	India
Morozov EV	19	140	2907	University of New South Wales at Australian Defence Force Academy	Australia
Lopatin AV	18	61	876	Federal Research Center for Information and Computational Technologies	Russian Federation
Bisagni C	14	147	2731	Delft University of Technology	Netherlands
Ovesy HR	14	98	1596	Amirkabir University of Technology	Iran
Degenhardt R	13	76	2177	Private Fachhochschule Göttingen	Germany
Qiao P	13	296	9743	Shanghai Jiao Tong University	China
Debski H	12	63	1441	Politechnika Lubelska	Poland
Lee J	11	284	8295	Sejong University	South Korea
Panda SK	11	264	6646	National Institute of Technology Rourkela	India
Patel BP	11	120	2130	Indian Institute of Technology Delhi	India
Lal A	10	121	1594	S. V. National Institute of Technology	India
Falkowicz K	9	37	579	Politechnika Lubelska	Poland
Rajanna T	9	39	285	B.M.S. College of Engineering	India
Ross CTF	9	95	951	University of Portsmouth	United Kingdom

Table 4: 15 Composite buckling publications with the most citations.

Title	Author(s)	Year	Source Title	Number of Citations Received
Mechanical behaviour of laminated composite beam by the new multi-layered laminated composite structures model with transverse shear stress continuity	Karama M., Afaq K.S., Mistou S.	2003	International Journal of Solids and Structures	692
Simulation of wrinkling during textile composite reinforcement forming. Influence of tensile, in-plane shear and bending stiffnesses	Boisse P., Hamila N., Vidal-Sallé E., Dumont F.	2011	Composites Science and Technology	428
Recent developments in finite element analysis for laminated composite plates	Zhang Y.X., Yang C.H.	2009	Composite Structures	407
Analysis and design of concrete-filled stiffened thin-walled steel tubular columns under axial compression	Tao Z., Uy B., Han L.H., Wang Z.B.	2009	Thin-Walled Structures	321
Nonlinear analysis of viscoelastic micro-composite beam with geometrical imperfection using FEM: MSGT electro-magneto-elastic bending, buckling and vibration solutions	Alimirzaei S., Mohammadimehr M., Tounsi A.	2019	Structural Engineering and Mechanics	296
Design of variable-stiffness composite panels for maximum buckling load	Setoodeh S., Abdalla M.M., Ijesselmuiden S.T., Gürdal Z.	2009	Composite Structures	248
Structural testing and numerical simulation of a 34 m composite wind turbine blade	Jensen F.M., Falzon B.G., Ankersen J., Stang H.	2006	Composite Structures	241
Variable-stiffness composite panels: Buckling and first-ply failure improvements over straight-fibre laminates	Lopes C.S., Gürdal Z., Camanho P.P.	2008	Composite Structures	241
Experimental and numerical study on honeycomb sandwich panels under bending and in-panel compression	Sun G., Huo X., Chen D., Li Q.	2017	Materials & Design	238
Free vibration and buckling analysis of laminated composite plates using the NURBS-based isogeometric finite element method	Shojaee S., Valizadeh N., Izadpanah E., Bui T., Vu T.V.	2012	Composite Structures	210
A review on the mechanical behaviour of curvilinear fibre composite laminated panels	Ribeiro P., Akhavan H., Teter A., Warmiński J.	2014	Journal of Composite Materials	206
Hygrothermal effects on the structural behaviour of thick composite laminates using higher-order theory	Patel B.P., Ganapathi M., Makhecha D.P.	2002	Composite Structures	203
Isogeometric analysis of laminated composite and sandwich plates using a layerwise deformation theory	Thai C.H., Ferreira A.J.M, Carrera E., Nguyen-Xuan H.	2013	Composite Structures	200
Low velocity impact on CFRP plates with compressive preload: Test and modelling	Heimbs S., Heller S., Middendorf P., Hähnel F., Weiße J.	2009	International Journal of Impact Engineering	199
Vibration and stability of cross-ply laminated composite plates according to a global higher-order plate theory	Matsunaga H.	2000	Composite Structures	188

VOSviewer and Bibliometrix, several structural patterns and thematic linkages become evident, offering a richer perspective on how knowledge in this area has developed. Fig. 6 illustrates international collaboration among authors, showing that China, the United States, and the United Kingdom serve as central nodes in the global research network. China demonstrates particularly strong academic ties with countries like the US, Australia, Singapore, and the UK, while the United States maintains widespread collaborations across both Europe and Asia. New collaborative clusters are also emerging, including links between Australia and Russia, as well as India's growing partnerships with Iran and Saudi Arabia. Further insights are captured in the author citation map (Fig. 7), which identifies Morozov, Bisagni, and Ovesy as major contributors whose work has significantly shaped the theoretical and methodological underpinnings of the field. These authors are not only prolific but also deeply embedded in international research networks, which may explain their sustained influence. In terms of publication platforms, Fig. 8 shows that Composite Structures is the most cited journal, often cited in conjunction with Engineering Structures and the Journal of Composite Materials—an indication of the field's strong alignment with structural and material science disciplines. Meanwhile, the co-occurrence map of keywords (Fig. 9) highlights "finite element method" as the most prevalent term, emphasizing the reliance on computational tools for simulating and analyzing buckling behavior. Other recurring terms suggest active exploration into laminated

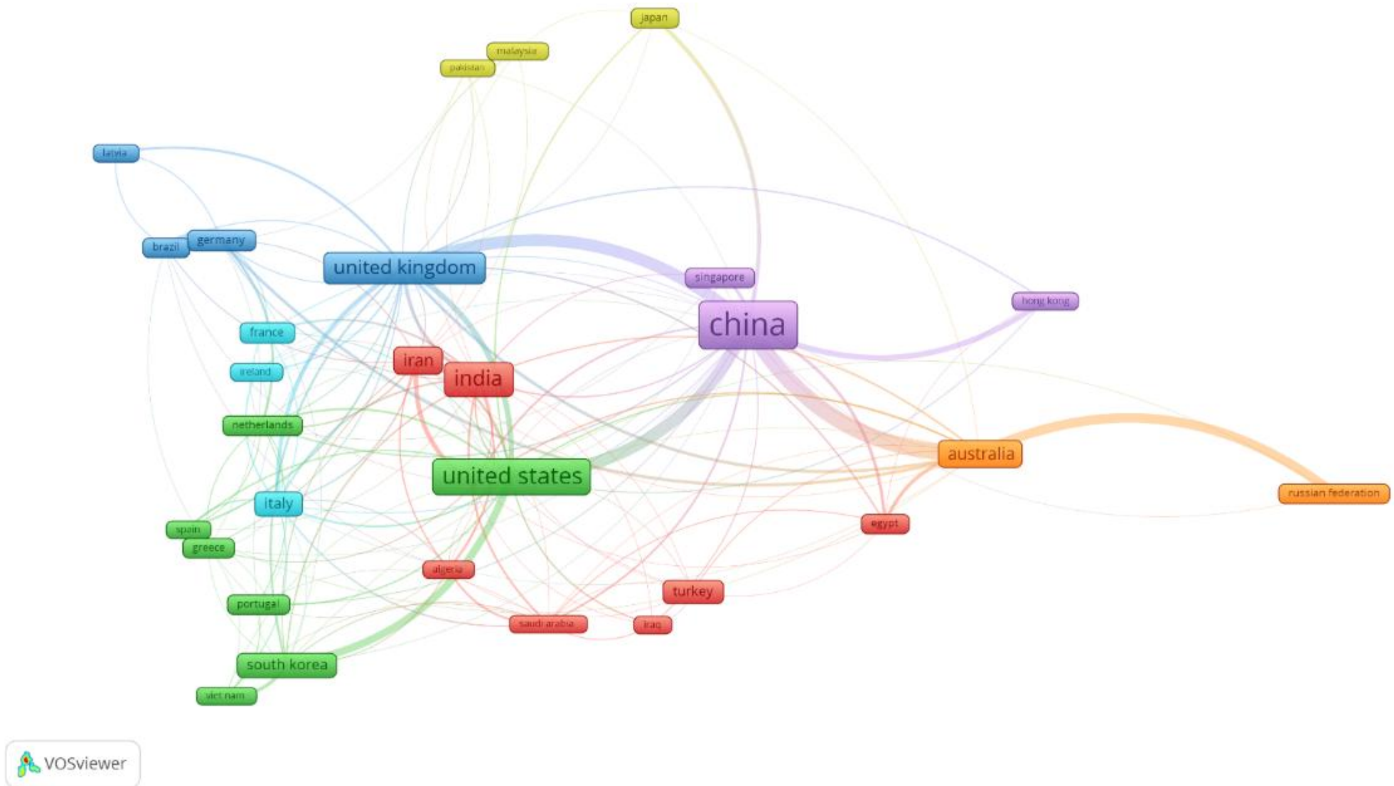

Fig. 6: Co-authorship analysis of the top 30 productive regions/countries.

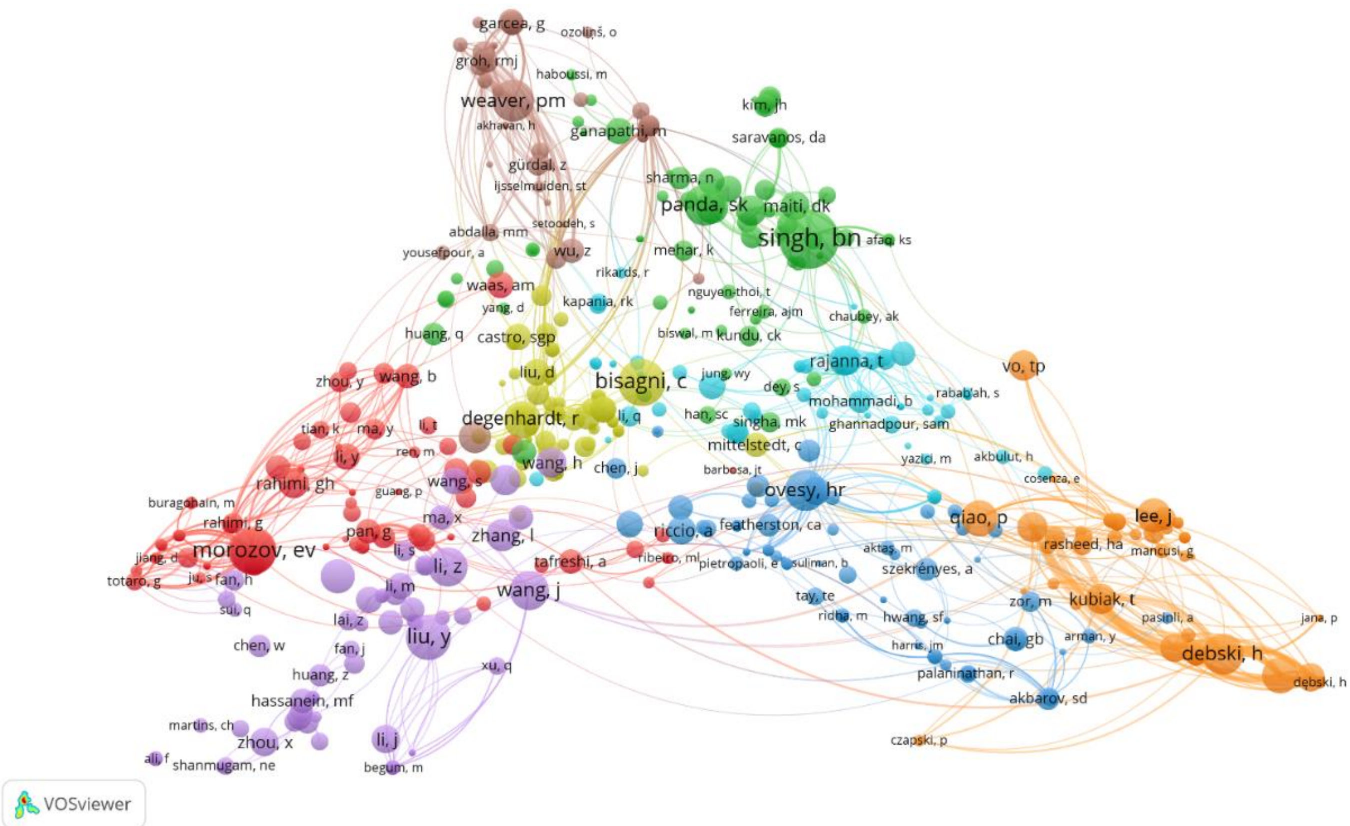

Fig. 7: An analysis of the 500 most cited authors' citations.

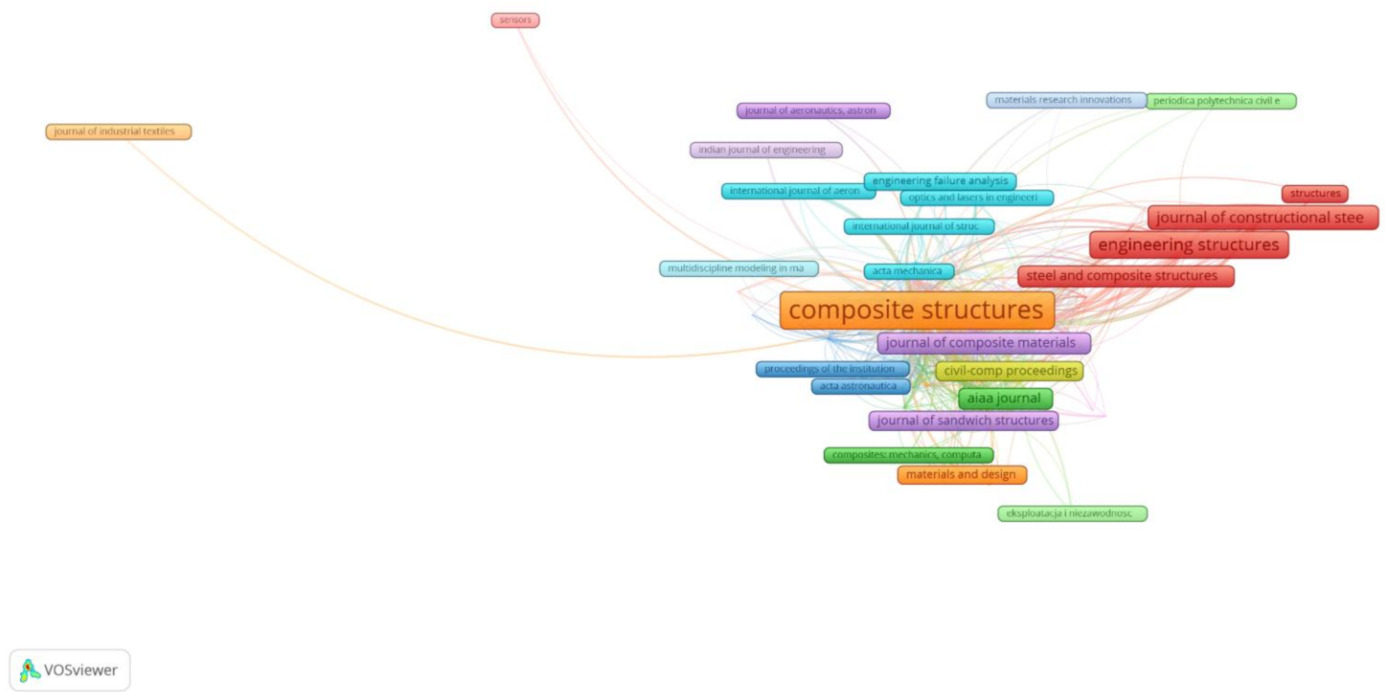

Fig. 8: Citation analysis of the 100 journals with the highest volume of composite buckling publications published.

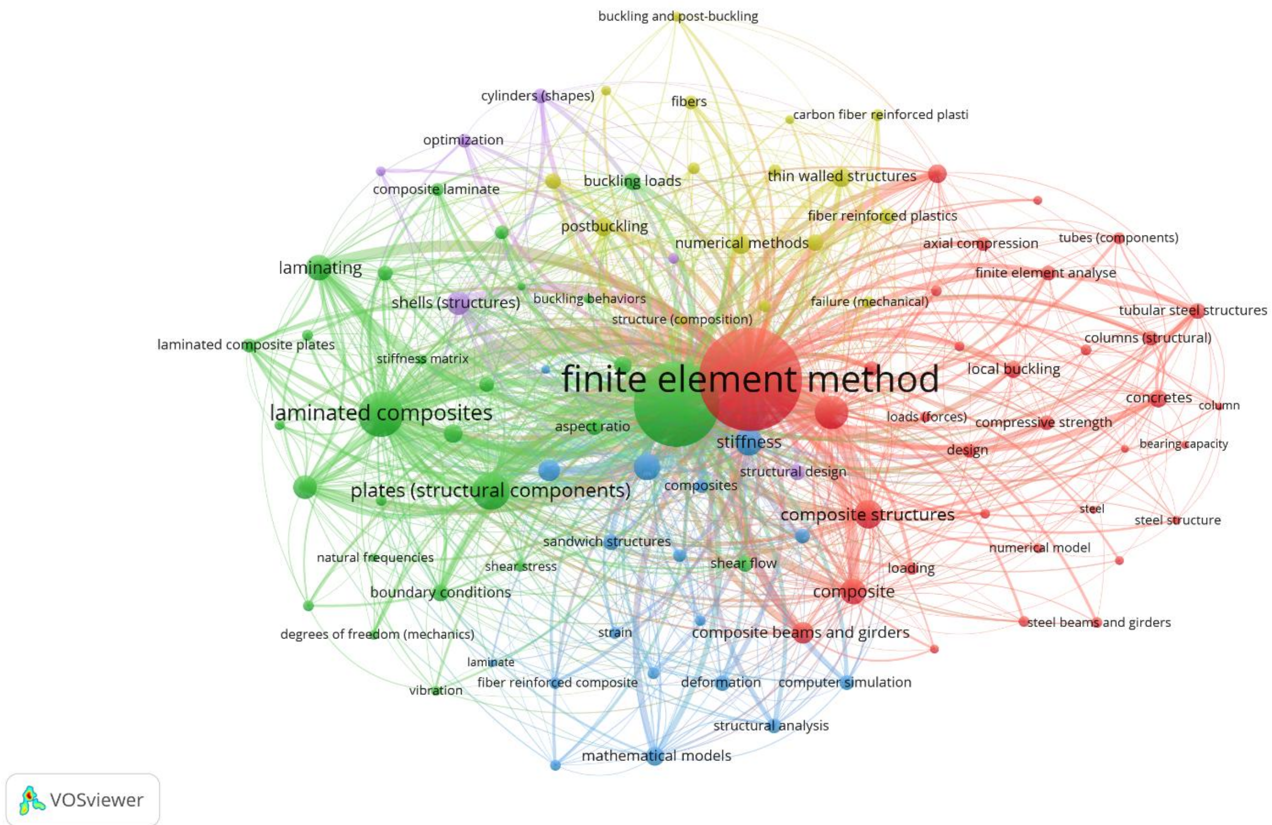

Fig. 9: Analysis of co-occurrences for the top 100 author keywords.

composites, postbuckling responses, and performance optimization. Altogether, these findings confirm that the intellectual direction of composite buckling research is increasingly data-driven and computational in nature, with a strong orientation toward simulation-based reliability analysis and thematic refinement over time.

To complement the co-authorship and keyword-based mapping, this study further explores the structural and intellectual organization of composite buckling research through a series of advanced bibliometric visualizations. The TreeMap (Fig. 10) provides a hierarchical overview of term frequencies, showing that "finite element method" and "buckling" are not only frequently cited but also occupy a foundational role in the literature. Their size and position in the visual hierarchy suggest these terms are conceptually central across a wide range of studies. Meanwhile, terms like "laminated composites," "shear deformation," and "delamination" appear as prominent subfields, indicating a continued interest in material-specific failure mechanisms and geometric influences in thin-walled structures. The Co-occurrence Network (Fig. 11) reinforces this narrative by showing how frequently used terms form tight interconnections. In this visualization, the clustering of "finite element method" with keywords such as "optimization," "composite materials," and "failure analysis" reflects an ongoing trend toward simulation-based performance evaluation and design refinement. This level of thematic density implies that the field is maturing toward interdisciplinary integration—merging structural engineering, materials science, and computational mechanics.

The intellectual structure becomes more evident in the clustering-by-coupling visualizations, which map how documents are grouped based on shared citation profiles. The coupling map (Fig. 12) identifies multiple clusters corresponding to different research emphases—such as numerical simulation of postbuckling behavior, analytical solutions for delamination, and stiffness-driven performance modeling. These clusters suggest a well-organized scholarly ecosystem, where different subdomains evolve around shared methodological tools. The accompanying coupling network (Fig. 13) visually locates pivotal contributions that act as bridges between clusters, particularly works by Lopatin,

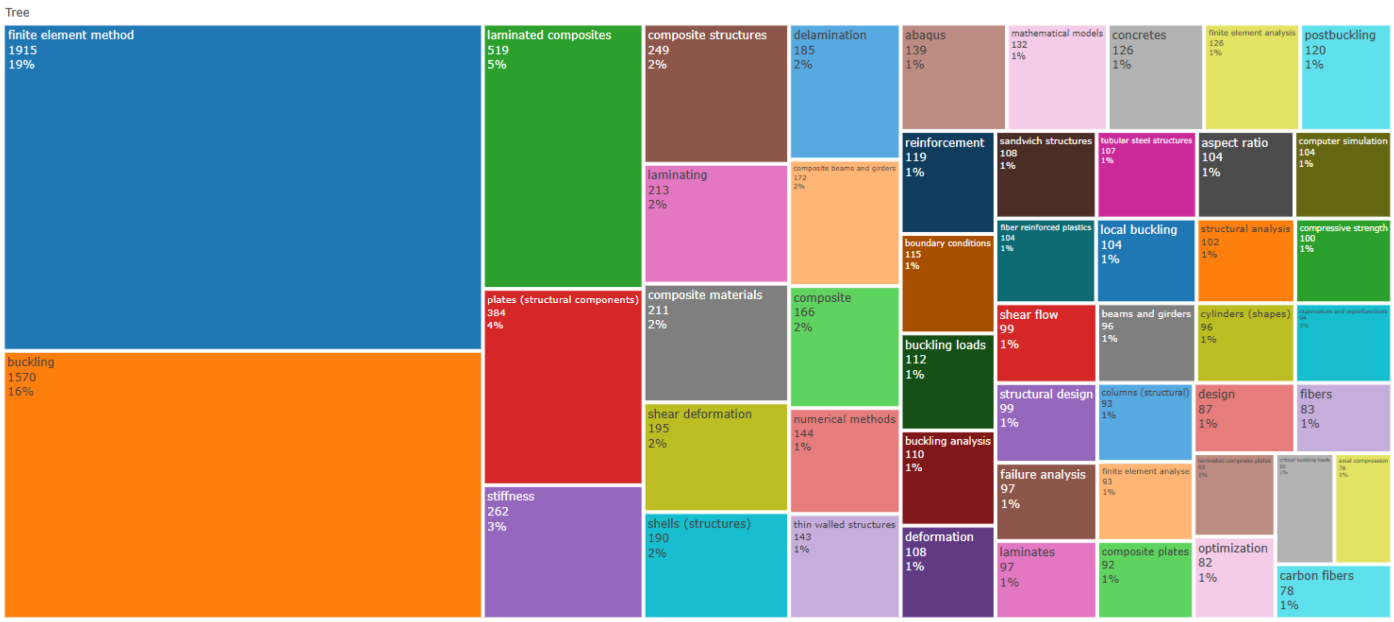

Fig. 10: TreeMap of Keyword Frequency in Composite Buckling Literature.

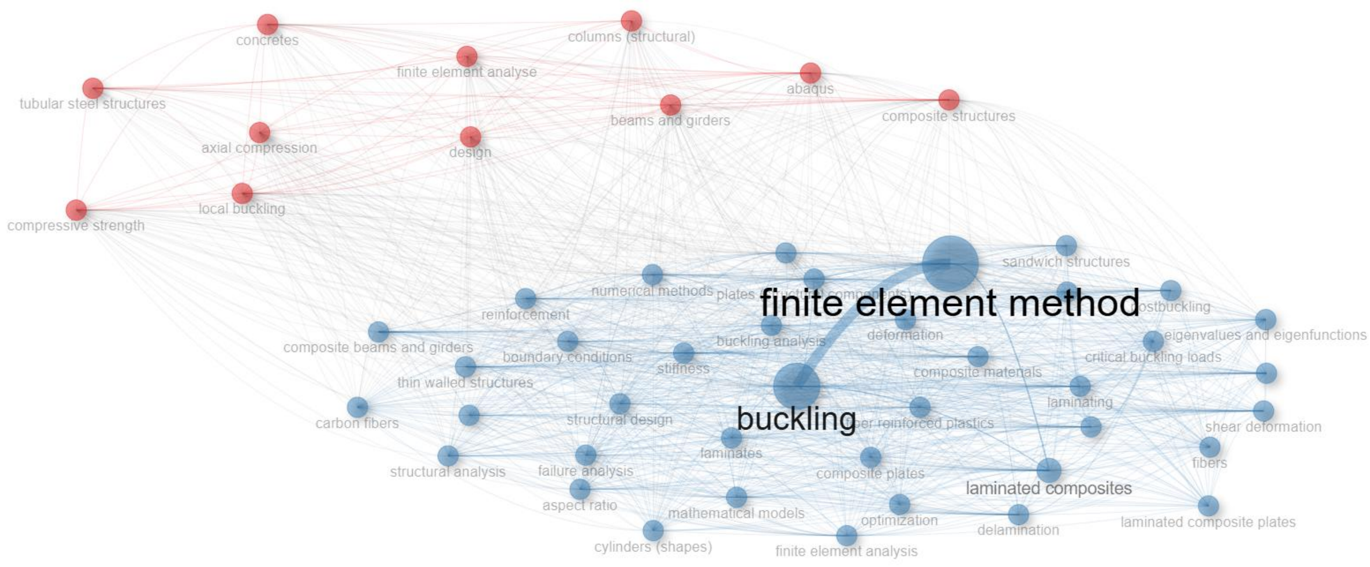

Fig. 11: Co-occurrence Network of Author Keywords.

Morozov, Mittelstedt, and D'Aguiar, which are widely referenced and form the backbone of their respective topics. Their positioning at the intersection of multiple nodes indicates the lasting influence of these studies across both theoretical and applied research trajectories. Thematic development over time is captured in the evolution map (Fig. 14), which demonstrates how early research—often focused on "composite beams and girders" or "laminated plates"—has given way to more advanced inquiries centered on "Abaqus," "tubular steel structures," and platform-specific finite element implementations. This thematic migration reflects the field's shift from abstract modeling toward real-world applications and software-integrated workflows. Factorial Analysis (Fig. 15) further differentiates topics based on their semantic distance, offering a two-dimensional interpretation of how concepts like "critical buckling loads" and "shear flow" align—or diverge—from central methods like "finite element analysis" and "composite structures."

Beyond thematic content, the influence of key scholars and collaborative networks offers another dimension of insight. The Co-citation Network (Fig. 16) maps how foundational thinkers such as Timoshenko (1961) and Jones (1975) continue to shape the intellectual discourse decades after their original contributions. Their central placement and large node size indicate that even with the advancement of numerical tools, classical mechanics remains an indispensable reference point. Clusters around Reddy, Bathe, Whitney, and Allen reflect different schools of thought in finite element theory and structural laminate modeling, suggesting a plurality of influences rather than a singular dominant paradigm. This heterogeneity also appears in the Collaboration Network (Fig. 17), which illustrates how the field is sustained through enduring partnerships. Major authors such as Singh B.N., Morozov E.V., Debski H., and Falkowicz K. appear at the center of tightly connected dyads and research groups, often representing regional centers of expertise (*e.g.*, India, Russia, Poland). These connections emphasize that impactful research in composite buckling is not merely a function of individual output but also the product of sustained academic cooperation. Such collaborative intensity fosters cross-pollination of methods and promotes the emergence of hybridized approaches that blend theoretical formulation with experimental and computational validation. Together, these figures build a cohesive understanding of how the domain has matured—both conceptually and socially—through a complex interplay of ideas, tools, and people.

4. Discussion

This study aims to perform a bibliometric analysis that provides an overview of the current landscape of peer-reviewed publications in composite buckling research. The Scopus database search retrieved 1855 peer-reviewed publications. To the authors' knowledge, this represents the first and only bibliometric analysis of composite buckling literature. It was considered that a slight decline in the volume of literature published occurred during the late 2000s. Then, there was an increase in the number of publications over the next two decades until the peak in 2016. In the next few years, there was a decline in the number of publications, one of the causes of which was a global-scale outbreak caused by the COVID-19 virus. However, after the outbreak subsided, the publications increased slowly until today.

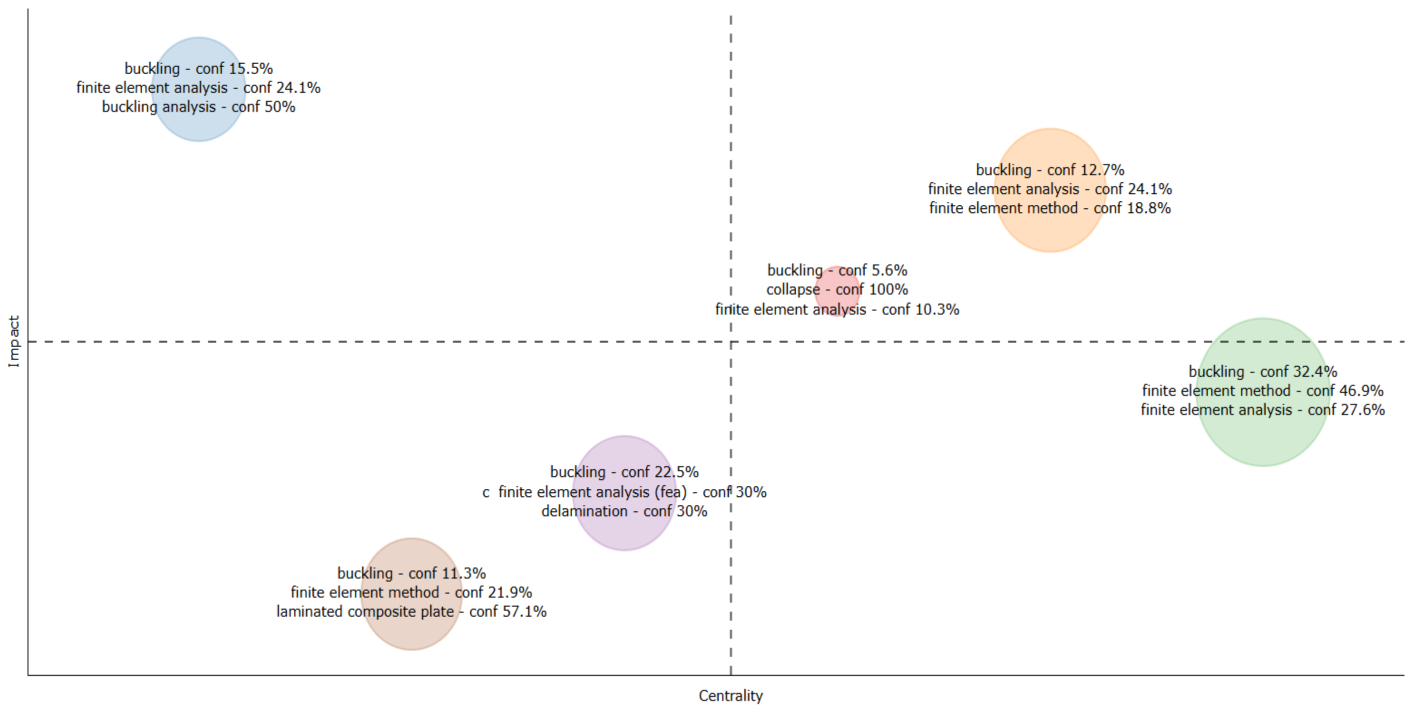

Fig. 12: Clustering by Bibliographic Coupling (Map View).

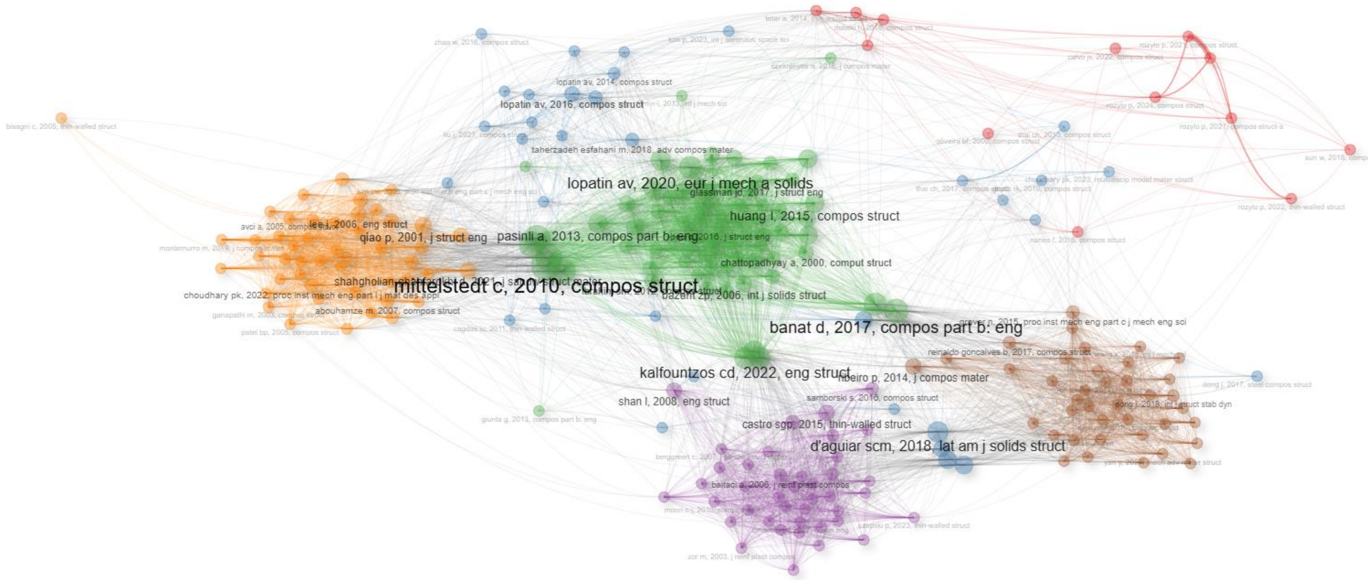

Fig. 13: Clustering by Bibliographic Coupling (Network View).

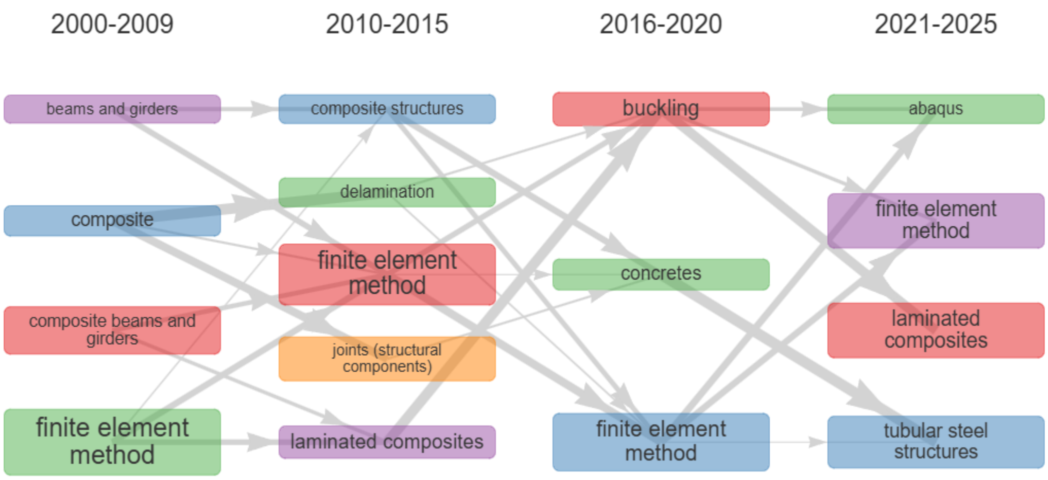

Fig. 14: Thematic Evolution Map from 2000 to 2025.

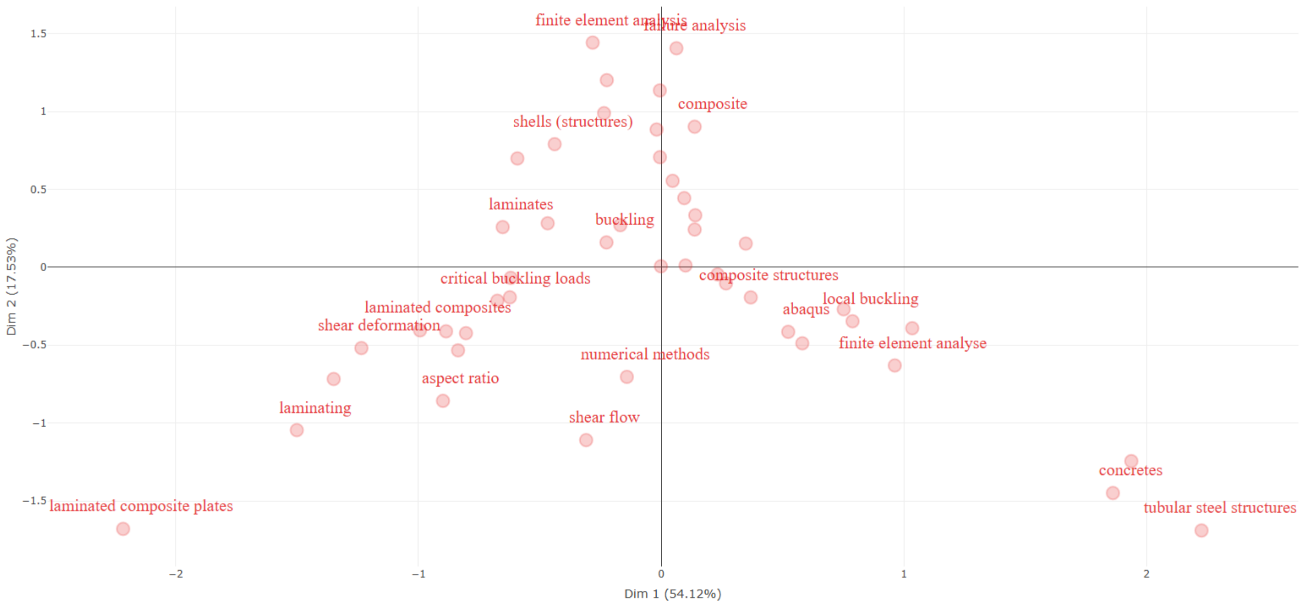

Fig. 15Ta Factorial Analysis of Keyword Dimensions.

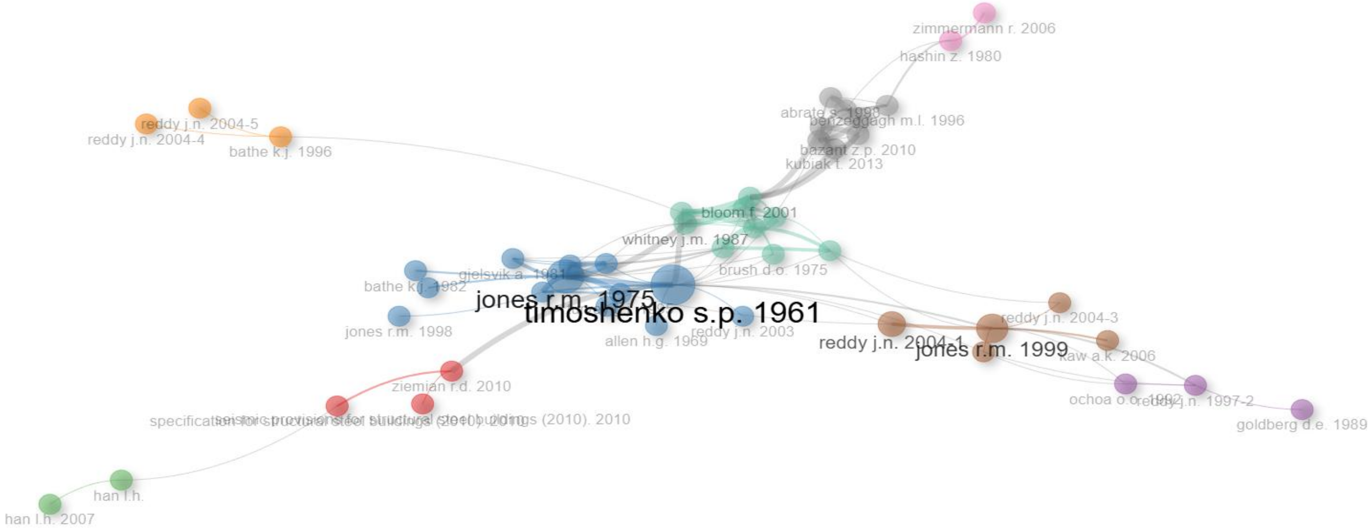

Fig. 16: Co-citation Network of Highly Referenced Authors.

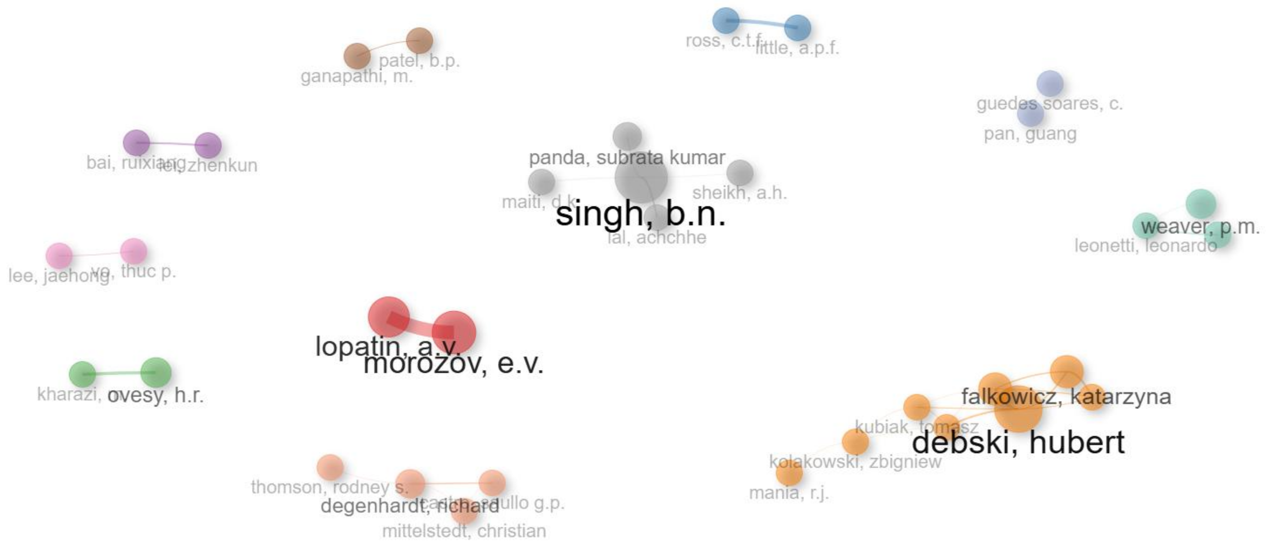

Fig. 17: Collaboration Network Among Leading Authors.

This analysis revealed that 387 publications originated from China, making it the country with the highest publication count in composite buckling. The United States and India followed with 240 and 215 publications, respectively. This global distribution of research is a testament to the international collaboration in the field. Among the top 10 affiliated institutions involved in the publication of composite buckling research, five were from China, two from Poland, and one each from India, Iran, and the Netherlands. Furthermore, five funding sponsors were from China and one from the European Union (EU), further highlighting the global nature of the research.

4.1 Comparative literature

Comparative literature is worth highlighting, as well as a few bibliometric analyses of various engineering-related topics, including materials and structures and their relationship. On the topic of materials, Sekhar *et al.*[57] have conducted a comprehensive analysis of research articles on metal matrix composite (MMC) published in Web of Science (WoS) from 2001 to 2020. The main findings revealed that research articles constitute the majority (80.54%) of MMC publications in WoS. The journal Material Science and Engineering A: Structural Materials, Properties, Microstructure and Processing has published the highest number of MMC articles. This study suggests that future MMC research will focus on the processing and characterizing novel nanocomposites, utilizing reinforcements such as graphene and boron carbide for various applications. In another study, graphene is the topic of discussion, a unique material that can be applied in various fields. For example, it was conveyed by Japri *et al.*[58] in a study using bibliometric analysis. His study found 1,245 papers from the Scopus database that studied graphene-cellulose composites (GCC). This study suggests that GCC can contribute to sustainable development, economic growth, and clean energy production, with a promising future for fundamental studies and practical applications.

On the other hand, several studies using bibliometric analysis have linked materials to implementing a particular structure. Taiwah *et al*.[59] with the scope of discussion on sustainable fire-resistant polysaccharide-based composite aerogels, considered an innovative solution for fire safety across industries. This research uses global trends in this field from 2003 to 2023 using scientometric tools such as VOSviewer and bibliophily. Based on 234 records from Scopus, the top contributors are China, the United States, Australia, Canada, and India. Top publishing journals include ACS Applied Materials and Interfaces and Chemical Engineering Journal. This review offers insight into global research trends and the importance of these materials in advancing fire safety technology. Meanwhile, Alviz-Meza *et al*.[60] presented bibliometric analysis with novelty in the form of a track record of the application of materials science in industry. The findings reveal that the growing interest in materials science research is linked to Industry 4.0 technologies, driven by institutions, journals, researchers, countries, and funding agencies. China and the United States are the leading nations in applying Industry 4.0 to materials science, mainly due to the integration of public policies. This review provides a contemporary perspective on materials science, highlighting the role of new technologies in the discovery, design, management, and use of materials in industry.

Nevertheless, bibliometric analysis has also been conducted in more specific areas, such as marine and offshore engineering. Dragović *et al*.[61] have evaluated the Maritime Bibliometric Study (MBS) to characterize critical areas in the Maritime Industry (MIA). A novel approach was utilized using various bibliometric tools to perform performance analysis, trends, statistics, bibliographic linkage analysis, word cloud analysis, and conceptual thematic maps. The results are designed to improve visibility and readability, offering a new path for bibliometric studies in various research fields. The findings reveal publication trends, key research topics, influential MBS, and evolving MIA dynamics. The study also highlights future research directions and underscores the value of bibliometric methods for evaluating existing and future MIA research. In addition, Gil *et al*.[62] investigated combining bibliometrics with a literature review for accident prevention in marine transportation systems. In this study, the authors revealed that essential aspects such as scientific networks for collaboration, technological readiness level (TRL) of the system, and optimization methods to improve the system are still under development. This study suggests the need for greater international collaboration and technological advancement to improve maritime safety.

4.2 Strengths and limitations

The current bibliometric study has several quite prominent advantages. First, the characteristics of 1855 publications published in 1776 journals were successfully captured. Scopus was chosen as the primary source for searching for relevant journals because it has a broader publication coverage than other databases, *e.g*., Web of Science. However, despite these advantages, the author may have failed to capture all literature related to "composite buckling", which could have been found if other databases had been used. If carried out, this effort would have made the results that have been obtained fat and possible to accumulate, thus complicating the analysis process of the previous search results (from Scopus). Publications on composite buckling tend to include one of the following search strings containing the term "composite buckling", some are supplemented with terms that indicate the results of the relationship between the two, such as laminated composites, composite structures, thin-walled structures, and others. Although the search strategy included many terms commonly used to refer to composite buckling, observations from the initial search showed that the keyword "buckling" was more frequently included in the titles of their articles compared to the word's "composite" or "composite buckling". Despite its scope limitation to the Scopus database, this study provides a sharper, engineering-focused bibliometric mapping, which distinguishes it from broader material science reviews.

5. Recent Works in 2025

5.1 Research landscape on composite buckling

In recent years, the advancement of composite structural elements, particularly in the context of buckling behavior, has become increasingly diversified, spanning material innovation, cross-sectional optimization, and hybrid system integration. A notable trend is the rise of multi-material systems that merge conventional steel or concrete cores with reinforcing layers of fiber-reinforced polymers (FRP), ultra-high-performance concrete (UHPC), and even engineered timber. This integration is designed to exploit confinement effects, delay local instability, and maximize load-carrying capacity under both axial and flexural stresses. Tan *et al*.[63] examined orthotropic steel decks overlaid with UHPC layers. They found that not only did stiffness and strength improve, but the layered interaction also produced a dual load-bearing mechanism, where the concrete and steel alternately governed the failure mode. Their predictive model, based on adjusted provisions from the Chinese bridge code, yielded accuracy within 2% when compared to full-scale test results. On a larger structural scale, Röß *et al*.[64] tested bundle-bar-filled circular hollow steel sections (BBFC) under eccentric loading. Their real-scale column experiments—spanning nearly 8 meters—demonstrated that the bar arrangement and slenderness critically influence the stability regime, with finite element models predicting failure with deviations of less than 10%. These findings underscore the growing focus on column systems designed for high-rise and industrial structures, where stability under combined eccentricities is essential.

Studies on corrugated composite walls—especially those using multi-celled concrete-filled steel tubes (MC-CFST)—have shown that geometric reinforcement through corrugation and multi-cell configuration substantially improves global and local buckling resistance. Zhang *et al*.[65] emphasized that confinement effects are amplified with an increasing number of cells and plate thickness, resulting in residual strength ratios (Nr/Nu) well above 0.5 and improved ductility post-buckling. Traditional design codes (EC3, AISC 360) were found to be unconservative, prompting the authors to propose a modified design equation based on the Perry–Robertson theory. Their work bridges the gap between material enhancement and structural topology. The role of material grading and porosity was highlighted in the study by Zhang *et al*.[66] who investigated functionally graded porous composites reinforced with graphene platelets. Their numerical framework, built upon a high-order GDQFEM scheme, quantified how crack length, defect positioning, and material gradient dominate the critical buckling load—demonstrating that crack-induced instability is far more sensitive than porosity. The results of the current study align with the need for defect-tolerant composite designs, particularly for aerospace-grade panels and microscale structural elements. Hu[67] explored laminated plates under thermal loads, optimizing both fiber orientation and material layout using a penalty-based FEM model and MMA algorithm. The dual optimization approach yielded a 149% increase in thermal buckling capacity while maintaining a 25% mass reduction, showing how coupling lamination parameters and topology can produce lightweight yet stable composite plates. Furthermore, transforming lamination data into a least-squares optimization enabled the practical derivation of fiber angles for real-world manufacturing feasibility.

In the domain of sustainable composites, Yan *et al*.[68] developed concrete-filled steel tube (CFST) columns using geopolymer concrete with recycled brick aggregates. Despite using 100% recycled content, the strength degradation was minimal—less than 8% in circular sections—thanks to the confinement effect of steel and the favorable confinement interaction with geopolymer-based matrices. This study expands the sustainability frontier without sacrificing buckling resistance or modeling predictability. Two studies have also expanded the scope of composite buckling by integrating engineered timber into steel systems. Chen *et al*.[69] evaluated stainless steel–timber composite beams under lateral-torsional and local buckling, identifying that the inclusion of glued laminated timber flanges enhances both strength and ductility. The modified Perry-based equation they developed proved accurate across 81 simulations. Complementarily, Vigneri *et al*.[70] proposed veneer-wrapped steel columns (STIMBER), which retained more than a 25% strength improvement while complying with EN 1993-1-1 predictions. Their layered shell finite element (FE) model captured the orthotropic behavior of timber veneer interacting with thin-walled steel, highlighting a new potential for bio-based hybrid structures. Almeida *et al*.[71] made a significant contribution to buckling analysis in large flexible structures by comparing beam and shell finite element models for a 10-MW wind turbine blade. While the beam model efficiently captured global deflection, only the layered shell model detected trailing edge buckling—a local failure mode that occurred at 85% of the extreme load levels. Their vibration-based nonlinear stability analysis indicated that imperfection amplitudes as small as 8.75 mm could reduce critical loads by up to 26%, reinforcing the critical role of local shell instability in lightweight composite design.

Taken together, this body of literature showcases the evolution of composite buckling research from traditional axial loading models toward highly integrated, defect-sensitive, and sustainability-aware systems. The convergence of advanced numerical schemes, hybridized material systems, and revised design formulations underlines the increasing complexity and rigor with which buckling phenomena are being addressed in structural composites. As the field continues to mature, these contributions provide both foundational knowledge and practical pathways for next-generation composite design under multifaceted loading regimes.

5.2 Recent advances and comparative review

This bibliometric study makes a significant contribution to advancing the understanding of recent developments in the buckling behavior of composite structures, with a particular focus on analyses conducted through the Finite Element Method (FEM). In contrast to recent 2025 bibliometric review that concentrate on a wide range of engineering fields—such as railway safety,[72] advanced transportation technologies[73,74] sustainable building energy retrofits,[75,76] and corrosion detection[77] —our research targets a fundamental yet critical aspect of structural mechanics that underlies the advancement of modern composite materials and engineering structures.

A key strength of this work lies in its systematic integration of bibliometric analysis with numerical validation via the finite element method (FEM), alongside the formulation of regression models for predicting buckling capacity. This integrated approach not only quantitatively maps the research landscape but also offers detailed technical insights that connect evolving research trends to tangible structural performance outcomes. Such depth goes beyond the primarily thematic or conceptual focus characteristic of many other bibliometric reviews.

This distinction is particularly evident when compared to the recent bibliometric analyses.[78,79] Xue Yang *et al*.[78] focus on electrode materials for capacitive deionization, highlighting material innovation and optimization through data-driven computational methods, which parallels our emphasis on material performance but in a different application domain. Similarly, Bello *et al*.[79] explore antioxidant technologies to enhance biodiesel stability, integrating artificial intelligence for optimization in energy materials—a testament to the growing role of computational techniques in materials research, akin to our FEM-regression hybrid approach in structural composites. Additionally, this study offers a longitudinal perspective, encompassing twenty-five years of research (2000–2025), and explicitly incorporates the latest publications from 2025. This ensures that the findings are both comprehensive and current while also uncovering emerging innovation pathways in composite buckling. This niche has been less thoroughly explored by broader multidisciplinary bibliometric analyses, such as Mishra and Singh[80] on power system protection and Chen *et al*.[77] on corrosion monitoring.

Moreover, our approach highlights the importance of integrating bibliometric mapping tools, such as VOSviewer and Bibliometrics, with rigorous technical simulations. This fusion strengthens the robustness of the results, rendering the analysis both descriptively rich and quantitatively substantiated, thereby providing a more holistic and relevant understanding of research dynamics in material mechanics. Conceptually, our findings align with and complement other applied and policy-driven research, such as that by Arshad *et al*.[75] which stresses sustainable development and international collaboration. We emphasize that advancements in composite buckling research have substantial potential to underpin the design of engineering infrastructures that are not only resilient and durable but also aligned with technological and environmental sustainability goals. This study effectively bridges comprehensive bibliometric investigation with FEM-based technical evaluation, significantly broadening scientific insight into the evolution of composite buckling research. This dual methodology integrates theoretical and practical dimensions, reinforcing the relevance of the work within the contemporary engineering research landscape—one increasingly driven by the convergence of advanced technologies and sustainability imperatives.

6. Conclusion

This study successfully identified the characteristics of 1855 publications and was the first published bibliometric analysis on composite buckling research. The data indicates that composite buckling—especially in thin-walled components—has remained a topic of sustained academic interest, driven by the need to ensure structural integrity in advanced engineering systems, particularly those deployed in renewable energy infrastructure. While publication growth experienced a notable surge between 2010 and 2016, a brief stagnation occurred during the COVID-19 pandemic, after which research momentum regained its strength. This pattern reflects not only global research capacity but also broader shifts in technological priorities, particularly toward sustainable and lightweight structural systems. In terms of analytical techniques, the finite element approach has been established as the cornerstone method for modeling, simulating, and predicting the complex buckling behavior of composite materials under various loading conditions. This computational tool enables high-resolution structural assessment that integrates geometry, material anisotropy, and environmental interactions, and remains indispensable for researchers and designers seeking to enhance load-bearing efficiency and failure resistance in composite systems. The contribution of this study lies in its ability to contextualize bibliometric patterns within the broader framework of structural mechanics and material science. Unlike prior bibliometric reviews that adopt a generalized focus on renewable energy or materials research, this work offers a focused narrative that connects publication data to domain-specific modeling practices. It thereby provides engineers, scholars, and decision-makers with actionable insights into how research in composite buckling has evolved, who its leading contributors are, and what critical knowledge gaps remain.

Looking forward, future studies should consider expanding the bibliometric framework to include full-text analyses using natural language processing (NLP) to capture more nuanced conceptual trends. Moreover, integrating machine learning algorithms with FEM workflows can offer predictive modeling capabilities that surpass traditional simulation techniques, particularly for complex, real-world structural configurations subjected to multi-axial, thermal, or impact loading. Another promising avenue is to examine how recent developments in sustainable composites, such as bio-based or recycled fiber reinforcements, perform under buckling scenarios and how these are being reflected in the literature. Lastly, a comparative bibliometric analysis across different engineering failure modes—such as fatigue, delamination, and fracture—would allow researchers to better understand the research emphasis and prioritize interdisciplinary integration for future material innovation.

In summary, this study not only consolidates the current state of knowledge but also serves as a foundational reference for guiding the next phase of research on composite buckling performance. Its findings underline the importance of continuing methodological innovation and cross-disciplinary collaboration to support the design of safer, more resilient, and sustainable structural systems in the decades to come.

Nomenclatures

ACS	: American Chemical Society
AIAA	: American Institute of Aeronautics and Astronautics
ASCE	: American Society of Civil Engineers
BBFC	: Bundle-Bar Filled Circular
CFRP	: Carbon Fiber Reinforced Polymer
CFST	: Concrete-Filled Steel Tube
COP28	: 28th Conference of the Parties to the UN Framework Convention on Climate Change
EC3	: Eurocode 3
EU	: European Union
FEA	: Finite Element Analysis / Finite Element Approach
FEM	: Finite Element Method
FRP	: Fiber Reinforced Polymer
GCC	: Graphene Cellulose Composite

GDQFEM	: Generalized Differential Quadrature Finite Element Method
GW	: Gigawatts
H_2	: Hydrogen
IEA	: International Energy Agency
MBS	: Maritime Bibliometric Study
MC-CFST	: Multi-Celled Concrete-Filled Steel Tube
MIA	: Maritime Industry
MMA	: Method of Moving Asymptotes
MMC	: Metal Matrix Composite
NFLE	: Nonlinear Finite Element
NLP	: Natural Language Processing
PV	: Photo Voltaic
STIMBER	: Steel-Timber Composite
TRL	: Technological Readiness Level
TWh	: Terawatt-hour
UHPC	: Ultra-High-Performance Concrete
US	: United States
WoS	: Web of Science

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Conflict of Interest
There is no conflict of interest.

Supporting Information
Not applicable.

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Suryanto Suryanto: Software, Formal analysis, Investigation, Data curation, Writing - Original draft, Writing - Review & editing, Visualization. **Aditya Rio Prabowo:** Conceptualization, Methodology, Validation, Resources, Writing - Original draft, Writing - Review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Ristiyanto Adiputra:** Conceptualization, Methodology, Writing - Review & editing, Supervision. **Sören Ehlers:** Conceptualization, Formal analysis. **Moritz Braun:** Conceptualization, Investigation. **Indri Yaningsih:** Methodology, Resources. **Iwan Istanto:** Methodology, Data curation. **Rahman Wijaya:** Validation, Writing - Original draft.

References
[1] J. Knox-Hayes, M. A. Brown, B. K. Sovacool, Y. Wang, Understanding attitudes toward energy security: Results of a cross-national survey, *Global Environmental Change*, 2013, **23**, 609-622, doi: 10.1016/j.gloenvcha.2013.02.003.
[2] H. Ritchie, P. Rosado, M. Roser, Energy Production and Consumption, *Our World in Data*, 2020, https://ourworldindata.org/energy-production-consumption.
[3] N. Nakicenovic, A. Grubler, Energy and the protection of the atmosphere, *International Journal of Global Energy Issues*, 2000, **13**, 4-57, doi: 10.1504/ijgei.2000.000865.
[4] F. Brizi, J. L. Silveira, U. Desideri, J. A. dos Reis, C. E. Tuna, W. de Queiroz Lamas, Energetic and economic analysis of a Brazilian compact cogeneration system: Comparison between natural gas and biogas, *Renewable and Sustainable Energy Reviews*, 2014, **38**, 193-211, doi: 10.1016/j.rser.2014.05.088.
[5] F. R. Pazheri, M. F. Othman, N. H. Malik, A review on global renewable electricity scenario, *Renewable and Sustainable Energy Reviews*, 2014, **31**, 835-845, doi: 10.1016/j.rser.2013.12.020.
[6] K. V. Narayanan, E. Natarajan, Experimental studies on cofiring of coal and biomass blends in India, *Renewable Energy*, 2007, **32**, 2548-2558, doi: 10.1016/j.renene.2006.12.018.
[7] P. Söderholm, T. Sundqvist, Empirical challenges in the use of learning curves for assessing the economic prospects of renewable energy technologies, *Renewable Energy*, 2007, **32**, 2559-2578, doi: 10.1016/j.renene.2006.12.007.
[8] G. Resch, A. Held, T. Faber, C. Panzer, F. Toro, R. Haas, Potentials and prospects for renewable energies at global scale, *Energy Policy*, 2008, **36**, 4048-4056, doi: 10.1016/j.enpol.2008.06.029.
[9] F. Kern, A. Smith, Restructuring energy systems for sustainability? Energy transition policy in the Netherlands, *Energy Policy*, 2008, **36**, 4093-4103, doi: 10.1016/j.enpol.2008.06.018.
[10] Z.-Y. Zhao, J. Zuo, L.-L. Fan, G. Zillante, Impacts of renewable energy regulations on the structure of power generation in China–A critical analysis, *Renewable Energy*, 2011, **36**, 24-30, doi: 10.1016/j.renene.2010.05.015.
[11] Z. Y. Zhao, J. Hu, J. Zuo, Performance of wind power industry development in China: A DiamondModel study, *Renewable Energy*, 2009, **34**, 2883-2891, doi: 10.1016/j.renene.2009.06.008.
[12] IEA, Renewable Energy Progress Tracker, 2024, https://www.iea.org/data-and-statistics/data-tools/renewable-energy-progress-tracker.
[13] S. Dey, A. Sreenivasulu, G. T. N. Veerendra, K. V. Rao, P. S. S. A. Babu, Renewable energy present status and future potentials in India: an overview, *Innovation and Green Development*, 2022, **1**, 100006, doi: 10.1016/j.igd.2022.100006.
[14] Y. Majeed, M. U. Khan, M. Waseem, U. Zahid, F. Mahmood, F. Majeed, M. Sultan, A. Raza, Renewable energy as an alternative source for energy management in agriculture, *Energy Reports*, 2023, **10**, 344-359, doi: 10.1016/j.egyr.2023.06.032.
[15] T.-Z. Ang, M. Salem, M. Kamarol, H. S. Das, M. A. Nazari, N. Prabaharan, A comprehensive study of renewable energy sources: Classifications, challenges and suggestions, *Energy Strategy Reviews*, 2022, **43**, 100939, doi: 10.1016/j.esr.2022.100939.
[16] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, R. Gorini, The role of renewable energy in the global energy transformation, *Energy Strategy Reviews*, 2019, **24**, 38-50, doi:

10.1016/j.esr.2019.01.006.
[17] A. R. Prabowo, R. Ridwan, T. Tuswan, J. M. Sohn, E. Surojo, F. Imaduddin, Effect of the selected parameters in idealizing material failures under tensile loads: Benchmarks for damage analysis on thin-walled structures, *Curved and Layered Structures*, 2022, **9**, 258-285, doi: 10.1515/cls-2022-0021.
[18] A. Fajri, N. Muhayat, A. R. Prabowo, F. Imaduddin, T. D. Danardono Dwi Prija, A. Prasetyo, Y. Kuswardi, J. M. Sohn, D. F. Smaradhana, Failure analysis: Hardness and stress study of failed IC engine rocker arms, *International Conference on Materials Engineering and Manufacturing Systems: ICMEMS2022*, AIP Publishing, Chennai, India, 2023, 030030, doi: 10.1063/5.0117567.
[19] D. Budisetyawan, R. Adiputra, A. R. Prabowo, E. Erwandi, The tendency of failure probability on offshore wind turbine components: a review, *Proceedings of the 9th International Conference and Exhibition on Sustainable Energy and Advanced Materials*, Springer Nature Singapore, 2024, 609-613, doi: 10.1007/978-981-97-0106-3_96.
[20] A. R. Kusuma Sarwoko, A. R. Prabowo, T. Ghanbari-Ghazijahani, Q. Thang Do, R. Ridwan, M. I. Hanif, Buckling of thin-walled stiffened panels in transportation structures: benchmarking and parametric study, *Engineered Science*, 2024, **30**, 1137, doi: 10.30919/es1137.
[21] R. Adiputra, F. N. Fauzi, N. Firdaus, E. M. Suyanto, A. Kasharjanto, N. Puryantini, E. Erwandi, R. Rasgianti, A. R. Prabowo, Roundness and slenderness effects on the dynamic characteristics of spar-type floating offshore wind turbine, *Curved and Layered Structures*, 2023, **10**, 20220213, doi: 10.1515/cls-2022-0213.
[22] D. M. Prabowoputra, A. R. Prabowo, Effect of the Phase-Shift Angle on the vertical axis Savonius wind turbine performance as a renewable-energy harvesting instrument, *Energy Reports*, 2022, **8**, 57-66, doi: 10.1016/j.egyr.2022.06.092.
[23] D. D. D. P. Tjahjana, Z. Arifin, S. Suyitno, W. E. Juwana, A. R. Prabowo, C. Harsito, Experimental study of the effect of slotted blades on the Savonius wind turbine performance, *Theoretical and Applied Mechanics Letters*, 2021, **11**, 100249, doi: 10.1016/j.taml.2021.100249.
[24] P. W. Adie, R. Adiputra, A. R. Prabowo, E. Erwandi, T. Muttaqie, N. Muhayat, N. Huda, Assessment of the OTEC cold water pipe design under bending loading: a benchmarking and parametric study using finite element approach, *Journal of the Mechanical Behavior of Materials*, 2023, **32**, 20220298, doi: 10.1515/jmbm-2022-0298.
[25] I. Widiyanto, A. Prabowo, T. Muttaqie, N. Muhayat, I. Yaningsih, D. Tjahjana, W. Juwana, T. Miyazaki, Effects of geometry and material factors on the behavior of stiffened offshore pipe structures under hydrostatic pressure, *Journal of Applied Engineering Science*, 2022, **20**, 1103-1121, doi: 10.5937/jaes0-38728.
[26] D. M. Prabowoputra, A. R. Prabowo, I. Yaningsih, D. D. D. P. Tjahjana, F. B. Laksono, R. Adiputra, H. Suryanto, Effect of blade angle and number on the performance of Bánki hydro-turbines: assessment using CFD and FDA approaches, *Evergreen*, 2023, **10**, 519-530, doi: 10.5109/6782156.
[27] S. Green, J. McLennan, P. Panja, K. Kitz, R. Allis, J. Moore, Geothermal battery energy storage, *Renewable Energy*, 2021, **164**, 777-790, doi: 10.1016/j.renene.2020.09.083.
[28] E. Assareh, S. M. Alirahmi, P. Ahmadi, A Sustainable model for the integration of solar and geothermal energy boosted with thermoelectric generators (TEGs) for electricity, cooling and desalination purpose, *Geothermics*, 2021, **92**, 102042, doi: 10.1016/j.geothermics.2021.102042.
[29] L. Kumar, M. S. Hossain, M. El Haj Assad, M. U. Manoo, Technological advancements and challenges of geothermal energy systems: a comprehensive review, *Energies*, 2022, **15**, 9058, doi: 10.3390/en15239058.
[30] S. D. Prasetyo, A. R. Prabowo, Z. Arifin, The use of a hybrid photovoltaic/thermal (PV/T) collector system as a sustainable energy-harvest instrument in urban technology, *Heliyon*, 2023, **9**, e13390, doi: 10.1016/j.heliyon.2023.e13390.
[31] S. D. Prasetyo, Z. Arifin, A. R. Prabowo, E. P. Budiana, Investigation of the addition of fins in the collector of water/Al_2O_3-based PV/T system: Validation of 3D CFD with experimental study, *Case Studies in Thermal Engineering*, 2024, **60**, 104682, doi: 10.1016/j.csite.2024.104682.
[32] Z. Arifin, S. D. Prasetyo, D. D. D. P. Tjahjana, R. A. Rachmanto, A. R. Prabowo, N. F. Alfaiz, The application of TiO_2 nanofluids in photovoltaic thermal collector systems, *Energy Reports*, 2022, **8**, 1371-1380, doi: 10.1016/j.egyr.2022.08.070.
[33] K. Wang, H. Zhang, S. Chu, Z. Zha, Pyrolysis of single large biomass particle: Simulation and experiments, *Chinese Journal of Chemical Engineering*, 2021, **29**, 375-382, doi: 10.1016/j.cjche.2020.09.032.
[34] G. Caposciutti, H. Almuina-Villar, A. Dieguez-Alonso, T. Gruber, J. Kelz, U. Desideri, C. Hochenauer, R. Scharler, A. Anca-Couce, Experimental investigation on biomass shrinking and swelling behaviour: Particles pyrolysis and wood logs combustion, *Biomass and Bioenergy*, 2019, **123**, 1-13, doi: 10.1016/j.biombioe.2019.01.044.
[35] C. Jia, M. Pang, Y. Lu, Y. Liu, M. Zhuang, B. Liu, J. Lu, T. Wei, L. Wang, T. Bian, M. Wang, F. Yu, L. Sun, L. Lin, T. Teng, X. Wu, Z. He, J. Gao, J. Luo, S. Zhang, L. Feng, X. Yin, F. You, G. Li, L. Zhang, Y.-G. Zhu, X. Zhu, Y. Yang, Graphene environmental footprint greatly reduced when derived from biomass waste *via* flash Joule heating, *One Earth*, 2022, **5**, 1394-1403, doi: 10.1016/j.oneear.2022.11.006.
[36] A. Fajri, S. Suryanto, R. Adiputra, A. R. Prabowo, D. D. D. P. Tjahjana, I. Yaningsih, F. B. Laksono, A. Nurrohmad, A. Nugroho, F. A. Wandono, P. A. Budiantoro, S. Ramayanti, M. Soedjarwo, Tensile assessment of woven CFRP using finite element method: a benchmarking and preliminary study for thin-walled structure application, *Curved and Layered Structures*, 2024, **11**, 20240002, doi: 10.1515/cls-2024-0002.
[37] H. G. Willett, Characterisation of composites for wind turbine blades, *Reinforced Plastics*, 2012, **56**, 34-36, doi: 10.1016/s0034-3617(12)70111-x.
[38] K. O'Leary, V. Pakrashi, D. Kelliher, Optimization of composite material tower for offshore wind turbine structures,

Renewable Energy, 2019, **140**, 928-942, doi: 10.1016/j.renene.2019.03.101.

[39] S. K. Gaddam, R. Pothu, R. Boddula, Advanced polymer encapsulates for photovoltaic devices − A review, *Journal of Materiomics*, 2021, **7**, 920-928, doi: 10.1016/j.jmat.2021.04.004.

[40] C. Zheng, Z. Huang, D. Wang, Z. Ju, Z. Zhang, H. Zhang, Y. Zhu, Z. Jiang, Synthesis and properties of biomass derived carbon/PEG composite as photothermal conversion effective phase change material for functional concrete, *Cement and Concrete Composites*, 2024, **149**, 105495, doi: 10.1016/j.cemconcomp.2024.105495.

[41] J. Lim, E. Pesaranhajiabbas, M. R. Snowdon, A. K. Mohanty, M. Misra, Sustainable biocomposites from biofuel co-product and biodegradable plastic: effect of pyrolysis and compatibilizer on performance, *Composites Part C: Open Access*, 2022, **9**, 100301, doi: 10.1016/j.jcomc.2022.100301.

[42] A. R. Prabowo, R. Ridwan, M. Braun, S. Song, S. Ehlers, N. Firdaus, R. Adiputra, Comparative study of shell element formulations as NLFE parameters to forecast structural crashworthiness, *Curved and Layered Structures*, 2023, **10**, 20220217, doi: 10.1515/cls-2022-0217.

[43] H. G. Lee, S. J. Kim, J. M. Sohn, A. R. Prabowo, Machine learning based prediction of buckling in composite cylindrical shells under external pressure using design code and FEM analysis, *ASME 43rd International Conference on Ocean, Offshore and Arctic Engineering*, Singapore, 2024, June 9-14, doi: 10.1115/omae2024-127261.

[44] F. M. Jensen, B. G. Falzon, J. Ankersen, H. Stang, Structural testing and numerical simulation of a 34m composite wind turbine blade, *Composite Structures*, 2006, **76**, 52-61, doi: 10.1016/j.compstruct.2006.06.008.

[45] C. S. Lopes, Z. Gürdal, P. P. Camanho, Variable-stiffness composite panels: Buckling and first-ply failure improvements over straight-fibre laminates, *Computers & Structures*, 2008, **86**, 897-907, doi: 10.1016/j.compstruc.2007.04.016.

[46] S. Alimirzaei, M. Mohammadimehr, A. Tounsi, Nonlinear analysis of viscoelastic micro-composite beam with geometrical imperfection using FEM: MSGT electro-magneto-elastic bending, buckling and vibration solutions, *Structural Engineering and Mechanics*, 2019, **71**, 485-502, doi: 10.12989/sem.2019.71.5.485.

[47] G. Sun, X. Huo, D. Chen, Q. Li, Experimental and numerical study on honeycomb sandwich panels under bending and in-panel compression, *Materials & Design*, 2017, **133**, 154-168, doi: 10.1016/j.matdes.2017.07.057.

[48] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W. M. Lim, How to conduct a bibliometric analysis: an overview and guidelines, *Journal of Business Research*, 2021, **133**, 285-296, doi: 10.1016/j.jbusres.2021.04.070.

[49] Y. Yao, H. Du, H. Zou, P. Zhou, C. H. Antunes, A. Neumann, S. Yeh, Fifty years of Energy Policy: a bibliometric overview, *Energy Policy*, 2023, **183**, 113769, doi: 10.1016/j.enpol.2023.113769.

[50] A. Yataganbaba, B. Ozkahraman, I. Kurtbas, Worldwide trends on encapsulation of phase change materials: a bibliometric analysis (1990–2015), *Applied Energy*, 2017, **185**, 720-731, doi: 10.1016/j.apenergy.2016.10.107.

[51] S. G. Azevedo, M. Santos, J. R. Antón, Supply chain of renewable energy: a bibliometric review approach, *Biomass and Bioenergy*, 2019, **126**, 70-83, doi: 10.1016/j.biombioe.2019.04.022.

[52] G. Mao, X. Liu, H. Du, J. Zuo, L. Wang, Way forward for alternative energy research: a bibliometric analysis during 1994–2013, *Renewable and Sustainable Energy Reviews*, 2015, **48**, 276-286, doi: 10.1016/j.rser.2015.03.094.

[53] M. Gusenbauer, N. R. Haddaway, Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources, *Research Synthesis Methods*, 2020, **11**, 181-217, doi: 10.1002/jrsm.1378.

[54] N.J. Van Eck, L. Waltman VOSviewer manual, *Manual for VOSviewer version*, 2011, **1**, https://www.vosviewer.com/documentation/Manual_VOSviewer_1.5.2.pdf.

[55] N. J. van Eck, L. Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, *Scientometrics*, 2010, **84**, 523-538, doi: 10.1007/s11192-009-0146-3.

[56] M. Aria, C. Cuccurullo, Bibliometrix: an R-tool for comprehensive science mapping analysis, *Journal of Informetrics*, 2017, **11**, 959-975, doi: 10.1016/j.joi.2017.08.007.

[57] R. Sekhar, D. Sharma, P. Shah, R. Sekhar, D. Sharma, P. Shah, State of the art in metal matrix composites research: a bibliometric analysis, *Applied System Innovation*, 2021, **4**, 86, doi: 10.3390/asi4040086.

[58] N. F. Japri, Z. A. Majid, S. K. Ghoshal, W. H. Danial, H. H. See, M. Z. Othman, On the versatility of graphene-cellulose composites: an overview and bibliometric assessment, *Carbohydrate Polymers*, 2024, **337**, 121969, doi: 10.1016/j.carbpol.2024.121969.

[59] B. Tawiah, E. A. Ofori, F. Bin, B. Tawiah, E. A. Ofori, F. Bin, Scientometric review of sustainable fire-resistant polysaccharide-based composite aerogels, *Sustainability*, 2023, **15**, 12185, doi: 10.3390/su151612185.

[60] A. Alviz-Meza, M. H. Vásquez-Coronado, J. G. Delgado-Caramutti, D. J. Blanco-Victorio, Bibliometric analysis of fourth industrial revolution applied to heritage studies based on web of science and scopus databases from 2016 to 2021, *Heritage Science*, 2022, **10**, 189, doi: 10.1186/s40494-022-00821-3.

[61] A. Dragović, N. Zrnić, B. Dragović, M. A. Dulebenets, A comprehensive review of maritime bibliometric studies (2014–2024), *Ocean Engineering*, 2024, **311**, 118917, doi: 10.1016/j.oceaneng.2024.118917.

[62] M. Gil, K. Wróbel, J. Montewka, F. Goerlandt, A bibliometric analysis and systematic review of shipboard Decision Support Systems for accident prevention, *Safety Science*, 2020, **128**, 104717, doi: 10.1016/j.ssci.2020.104717.

[63] X. Tan, Z. Fang, Y. Zhang, R. Yuan, X. Liu, Q. Liu, Compressive behavior of orthotropic steel–UHPC composite decks: an experimental and analytical study, *Engineering Structures*, 2025, **334**, 120269, doi: 10.1016/j.engstruct.2025.120269.

[64] R. Röß, T. Ghanbari-Ghazijahani, M. Mensinger, Real-scale tests on bundle-bar-filled circular hollow sections (BBFC) under eccentric compression, *Engineering Structures*, 2025, **322**, 118901, doi: 10.1016/j.engstruct.2024.118901.
[65] J.-M. Zhang, G.-S. Tong, J.-Z. Tong, Global buckling prevention of multi-celled corrugated-plate CFST walls under pure in-plane bending loads, *Engineering Structures*, 2025, **332**, 120061, doi: 10.1016/j.engstruct.2025.120061.
[66] J. Zhang, Y. Lv, J. Wu, L. Li, Buckling of functionally graded graphene platelets reinforced porous composite plate with defects, *Engineering Structures*, 2025, **326**, 119530, doi: 10.1016/j.engstruct.2024.119530.
[67] C. Hu, Fiber Orientation optimization and topology optimization for thermal buckling of laminated plates, *Archive of Applied Mechanics*, 2025, **95**, 103, doi: 10.1007/s00419-025-02810-x.
[68] G.-Y. Yan, S.-D. Chen, L. Xu, D. Wang, R.-Y. Liu, X. Gao, Behavior of eccentrically loaded geopolymer recycled brick aggregate concrete-filled steel tube columns, *Journal of Constructional Steel Research*, 2025, **227**, 109409, doi: 10.1016/j.jcsr.2025.109409.
[69] L. Chen, L. Yang, K. Xu, Experimental and numerical research on overall stability of stainless steel-timber composite beams, *Engineering Structures*, 2025, **331**, 119982, doi: 10.1016/j.engstruct.2025.119982.
[70] V. Vigneri, M. Giulieri, A. Taras, Veneer-wrapped steel columns: Proof-of-concept experimental and numerical investigations, *Engineering Structures*, 2025, **323**, 119254, doi: 10.1016/j.engstruct.2024.119254.
[71] I. T. de Almeida, G. V. P. Lapa, A. Gay Neto, S. F. M. de Almeida, Design and extreme structural analysis of wind turbine blades: Beam and shell model comparison and discussion for a 10-MW reference turbine, *Engineering Structures*, 2025, **334**, 120155, doi: 10.1016/j.engstruct.2025.120155.
[72] A. M. Umar, M. K. A. M. Lazi, S. A. Hassan, H. I. C. Hashim, Y. Zhang, A bibliometric analysis of railway safety research: Thematic evolution, current status, and future research directions, *Journal of Traffic and Transportation Engineering (English Edition)*, 2025, **12**, 1-11, doi: 10.1016/j.jtte.2024.07.001.
[73] E. Puspitasari, C. W. Yuen, M. R. Ibrahim, The research landscape of first- and last-mile in public transport systems: a bibliometric analysis, *KSCE Journal of Civil Engineering*, 2025, **29**, 100159, doi: 10.1016/j.kscej.2025.100159.
[74] M. Hassan, S. S. Shraban, M. A. Islam, K. S. Basaruddin, M. F. Ijaz, N. S. Bin Kamarrudin, H. Takemura, Integration of extended reality technologies in transportation systems: a bibliometric analysis and review of emerging trends, challenges, and future research, *Results in Engineering*, 2025, **26**, 105334, doi: 10.1016/j.rineng.2025.105334.
[75] M. O. Arshad, A. Haleem, M. Nadeem, Understanding the energy retrofit strategies towards Net Zero Energy Building in sync with the SDGs: a review and bibliometric analysis, *Journal of Building Engineering*, 2025, **106**, 112574, doi: 10.1016/j.jobe.2025.112574.
[76] F. Odoi-Yorke, J. E. Davis, R. Nyarkoh, A. A. Abbey, E. B. Agyekum, F. P. Lamptey, G. S. Otoo, S. A. Kaburi, R. O. Darko, L. Atepor, A review of research trends, innovations, and future directions in phase change materials for energy storage in solar drying systems: a bibliometric approach, *Journal of Energy Storage*, 2025, **118**, 116233, doi: 10.1016/j.est.2025.116233.
[77] W. Chen, J. Hou, S. Hao, Y. Zhu, M. Yu, Mapping knowledge structure and themes trends of corrosion detection of steel: a bibliometric analysis, *Computational Materials Science*, 2025, **253**, 113889, doi: 10.1016/j.commatsci.2025.113889.
[78] X. Yang, J. Li, W. Qu, W. Wang, P. Wang, J. Ma, Bibliometrics and systematic reviews: Recent development and prospects of electrode materials for capacitive deionization, *Desalination*, 2025, **599**, 118450, doi: 10.1016/j.desal.2024.118450.
[79] U. Bello, H. Adamu, S. Samsuri, H. Ibrahim, M. Qamar, Improving biodiesel oxidative stability using antioxidants: an insight into the research trends and future prospects from a bibliometric approach, *Results in Engineering*, 2025, **26**, 105185, doi: 10.1016/j.rineng.2025.105185.
[80] M. Mishra, J. G. Singh, A comprehensive review on deep learning techniques in power system protection: Trends, challenges, applications and future directions, *Results in Engineering*, 2025, **25**, 103884, doi: 10.1016/j.rineng.2024.103884.