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Trends in Modular Construction Research: A Bibliometric Examination of Developed and Developing Regions

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Abstract

Modular construction is a process in which various building types, standardized structural components and pre-designed floor plans are constructed offsite under controlled plant conditions before being transported and assembled on-site. This method of construction has gained significant recognition in recent years due to its numerous benefits, including increased efficiency, improved safety, greater flexibility in design, reduced construction time, enhanced quality control, reduced waste and improved sustainability. Despite its well-documented benefits, its adoption varies significantly across developed and developing regions. To better understand the trends and patterns in modular construction research, this study conducted a bibliometric analysis of studies published and indexed in Scopus. The analysis focused on the period between 2004 and 2024 and covered both developed and developing regions. Keywords used in the search were “modular construction” OR “prefabricated construction” OR “offsite construction” OR “sustainable construction” AND “construction industry” AND “urban development”. Major findings from this study revealed that regions such as China, the United States and Australia demonstrated consistent research output, while African countries, particularly South Africa, showed limited contributions. This highlighted a significant knowledge gap in modular construction research within developing regions. Additionally, the study identified critical areas of focus in modular construction research and highlighted a lack of integration between developing and developed regions within collaborative research networks. The findings underscore the need for enhanced research capacity and cross-regional collaboration to address localized challenges and foster the equitable adoption of modular construction practices globally. The novelty of this study lies in its comparative analysis of developed and developing countries, which provides valuable insights into disparities in research output and collaboration patterns. However, the study’s scope is limited to publications indexed in Scopus, which may not capture industry-driven innovations or more recent research beyond 2024.

Keywords: Construction industry, Modular construction, Offsite construction, Prefabricated construction, Research collaboration, Sustainable construction, Urban development.

1. Introduction

The global construction industry faces numerous challenges that hinder its efficiency, sustainability and resilience. One of the most pressing issues is the persistent inefficiency and

low productivity that plague the sector (Li *et al.,* 2024). Unlike other industries, construction productivity has remained stagnant over the years, with the RICS Construction Productivity Report 2024 stating that from 2000 to 2022, global construction productivity improved only 10%, which is significantly lower than the productivity growth of the overall economy (Sawhney *et al.,* 2024). Fragmentation within the industry is another critical concern, with disjointed processes and a lack of standardization often leading to delays, cost overruns and quality compromises (Oke *et al.,* 2024). In addition to inefficiencies, the construction sector is a significant contributor to environmental degradation, accounting for approximately 39% of global carbon emissions (IEA, 2019). This environmental impact is exacerbated by traditional construction methods that generate excessive waste and consume vast amounts of resources. Labor shortages further compound these issues, particularly in developed regions where aging workforces and declining interest among younger generations create workforce gaps (Si *et al.,* 2020). Conversely, developing regions face challenges related to unskilled labor and limited access to modern construction technologies (Akinradewo *et al.,* 2023). Also, rapid urbanization and population growth are placing unprecedented pressure on construction industries worldwide, necessitating innovative solutions to meet the escalating demand for housing, infrastructure and energy-efficient buildings (Wuni *et al.,* 2020). These challenges underscore the urgent need for transformative approaches that can address inefficiencies, mitigate environmental impacts and enhance the industry's adaptability to evolving demands.

Modular construction has emerged as a viable solution to address many of the challenges faced by the construction industry. Often referred to by various terminologies such as 'off-site construction', 'prefabrication', or 'industrialized construction', modular construction involves the manufacturing of building components in a controlled environment, which are then transported and assembled on-site (Li *et al.,* 2022; Akinradewo *et al.,* 2023; Sajid *et al.,* 2024). This approach is recognized for its potential to improve construction speed, reduce waste and enhance overall quality. According to Abdelmageed and Zayed (2020), the adoption rates of modular construction vary significantly between developed and developing regions. Developed regions, such as the United States, the United Kingdom, and parts of Europe, have embraced modular construction as a means to tackle labor shortages, meet sustainability targets and optimize project timelines (Akinradewo *et al.,* 2023). According to Dodge Data & Analytics (2020), the modular construction market in North America grew by 6% annually between 2015

and 2020, with high adoption in healthcare, education and residential projects (Dodge Data and Analytics, 2020). On the other hand, adoption in developing regions remains relatively low due to barriers such as high initial costs, limited access to technology and a lack of skilled labor and low labor rates that reduce the incentive to invest in innovative construction methods (Oke *et al.,* 2024). For example, in Africa, modular construction is often constrained by insufficient investment in research and infrastructure, despite its potential to address housing deficits and support disaster resilience (Akinradewo *et al.,* 2023). However, countries such as China and India are beginning to integrate modular techniques into large-scale urban development projects, signaling a gradual shift (Xu *et al.,* 2020). The inconsistent adoption rates across regions highlight the need for tailored strategies that address specific regional challenges while leveraging the universal benefits of modular construction.

The benefits of modular construction extend beyond addressing industry inefficiencies and environmental concerns. Key advantages include reduced construction time, cost savings, enhanced quality control and lower environmental impacts (Li *et al.,* 2022; Akinradewo *et al.,* 2023; Sajid *et al.,* 2024). By allowing construction to occur in parallel on-site and off-site, modular methods can reduce project timelines by up to 50% (Bertram *et al.,* 2019). Additionally, the controlled factory environment minimizes material waste and improves precision, resulting in higher-quality outcomes (Rane, 2023). Modular construction also aligns with global sustainability goals by reducing carbon footprints and enabling the integration of renewable energy systems into buildings (Xu *et al.,* 2020). These benefits are particularly relevant in the context of developing regions, where rapid urbanization and resource constraints necessitate cost-effective, scalable and environmentally friendly construction solutions (Akinradewo *et al.,* 2023). Despite its potential, existing research on modular construction has predominantly focused on developed regions, leaving a significant knowledge gap concerning its application and impact in developing countries. This study aims to address this gap by examining global trends in modular construction research through a bibliometric analysis of developed and developing regions. By identifying key research themes, influential studies and regional disparities, this study seeks to provide insights that can guide future research, foster international collaboration and promote the equitable advancement of modular construction practices across diverse contexts.

In the context of global research, developed regions are typically characterized by well-established academic institutions, advanced technological infrastructure, greater access to research funding and a history of strong industrialization. These regions, such as North America, Europe and parts of Asia, generally exhibit robust research ecosystems that support innovation across various sectors, including construction (Sabir *et al.,* 2019). Countries in these regions are typically classified as "developed" based on indicators such as high Gross Domestic Product (GDP), advanced technological capabilities and widespread access to education and healthcare. On the other hand, developing regions, often found in parts of Africa, Latin America and Asia, are typically characterized by emerging research capacities, lower access to research resources and greater socio-economic challenges, including rapid urbanization, poverty and limited infrastructure development (Ganda, 2019). Countries in these regions are classified as "developing" based on criteria such as lower GDP per capita, less developed technological infrastructure and ongoing challenges in areas such as healthcare, education and poverty alleviation.

2. Understanding the Modular Construction Concept

Modular construction has deep historical roots and a rich evolution that reflects humanity's pursuit of efficiency in building practices. The origins of modular construction trace back to the 17th century, when prefabrication techniques began to emerge. One notable example is the "kit houses" exported from England to colonial America in the 1620s, where timber-framed components were shipped and assembled on-site to provide quick housing solutions (Gutiérrez *et al.,* 2024). By the 19th century, the Industrial Revolution accelerated the adoption of prefabrication, as the demand for rapid urbanization and industrial infrastructure grew. The Crystal Palace, constructed in 1851 for the Great Exhibition in London, is an iconic example of this era's advancements, showcasing prefabricated iron and glass components (Ersoy, 2008). The late 19th and early 20th centuries saw further innovation, with prefabricated housing systems gaining traction in response to urban overcrowding and the rise of industrialized labor. The introduction of standardized parts, made possible by advances in manufacturing technology, set the stage for modern modular construction practices (Akinradewo *et al.,* 2023).

The 20th century marked a transformative period for modular construction, characterized by widespread adoption and diversification of its applications. During World War II (1939–1945),

the urgent need for military barracks, hospitals and housing spurred the use of prefabrication at an unprecedented scale (Gutiérrez *et al.,* 2024). The United States and Europe embraced modular methods to meet wartime demands, producing structures like the Quonset Hut, a lightweight and portable building used extensively by the military (Vanderbilt, 2005). In the post-war era (1945–1960), modular construction became the basis of reconstruction efforts in war-torn regions, particularly in Europe. The United Kingdom led this movement, introducing prefabricated housing units to address acute housing shortages. These "prefabs" were cost-effective and quick to assemble, offering a practical solution for displaced populations (Gutiérrez *et al.,* 2024). By the 1970s and 1980s, modular construction began to diversify beyond residential projects, gaining prominence in commercial, healthcare and educational sectors (Akinradewo *et al.,* 2023). The late 20th century saw significant technological advancements, including the integration of computer-aided design (CAD) and improved manufacturing processes, which enhanced the precision and scalability of modular systems (Bănică *et al.,* 2024).

The 21st century heralded a new era for modular construction, marked by digital innovation and a global shift toward sustainability. Since the 2000s, Building Information Modeling (BIM), robotics and advanced materials have revolutionized modular construction, enabling greater customization, environmental efficiency and reduced project timelines (Si *et al.,* 2020; Shahjalal *et al.,* 2024). Studies indicate that modern modular techniques can reduce construction timelines by 20–50%, making them an attractive option for industries facing time-sensitive demands. A McKinsey & Company report in 2019 highlighted modular construction's potential to revolutionize global productivity, estimating it could deliver $130 billion annually in cost savings by 2030 if adopted widely (Bertram *et al.,* 2019). The COVID-19 pandemic (2020–2022) further emphasized the value of modular construction, with many countries leveraging it to build temporary healthcare facilities, quarantine centers and housing units at remarkable speeds (Hwang and Kim, 2022).

The impact of modular construction on productivity has been transformative, particularly in addressing challenges such as labor shortages, project delays and cost overruns (Shahjalal *et al.,* 2024). By shifting a significant portion of construction activities to controlled factory environments, modular construction minimizes disruptions caused by weather, enhances quality control and optimizes resource utilization (Sabir *et al.,* 2019). The method's efficiency lies in its

ability to parallelize construction processes (manufacturing modules off-site while site preparation occurs simultaneously), thus, accelerating project delivery. In addition to productivity gains, modular construction aligns with global sustainability goals by reducing material waste and energy consumption. This dual impact has cemented its reputation as a game-changer in the construction industry, offering both economic and environmental benefits ((Si *et al.,* 2020; Shahjalal *et al.,* 2024).

In developing regions, modular construction has emerged as a catalyst for economic growth and a solution to critical infrastructure challenges. South Africa, for example, has embraced modular construction to address pressing issues such as housing shortages, rapid urbanization and access to essential services. Modular classrooms and clinics have been deployed in underserved areas, providing cost-effective and timely solutions for educational and healthcare needs. *Kwikspace* and *Prefab Sprout* are just a few of the companies leading this effort. Additionally, firms like *HouseZero* and *Ecomo* are also making significant contributions by offering sustainable and innovative modular solutions. The adoption of modular methods has also stimulated domestic industries by fostering demand for skilled labor, manufacturing facilities and supporting technologies (Akinradewo *et al.,* 2023). Similarly, in Nigeria, modular construction is being utilized to address urban housing deficits and support government-led affordable housing initiatives, with companies like *African Land* and *Karmod* offering innovative and efficient building solutions. By integrating modular methods into their construction ecosystems, developing regions are not only addressing immediate infrastructure needs but also positioning themselves as competitive players in the global construction market. These advancements underscore the potential of modular construction to drive domestic growth while contributing to global sustainability efforts.

3. Research Methodology

The concept of bibliometrics was first introduced by Paul Otlet in 1934 under the term “bibliométrie” (Buckland, 2017) as the measurement of all aspects related to the publication and reading of books and documents. The anglicized term “bibliometrics” was later popularized by Alan Pritchard in 1969 (Pritchard, 1969). Over time, the field has evolved and bibliometrics is now widely used to assess research trends, publications and the relationships between authors, institutions and disciplines. It is particularly valuable for identifying research patterns,

understanding collaboration dynamics and discovering emerging areas of focus within specific fields (Pessin *et al.,* 2022). Thus, this study adopts the bibliometric technique to map and identify research trends, patterns and emerging themes in the field of modular construction. Scopus was used for this study due to its comprehensive database, which includes a vast range of peer-reviewed journals, conference papers and other scholarly articles across various disciplines. According to Aliu *et al.,* (2023), Scopus provides robust citation data and tools for analyzing publication trends, citation counts and author collaborations, making it an ideal platform for conducting bibliometric analysis.

The final search string employed for this study was: (TITLE-ABS-KEY) ("modular construction" OR "prefabricated construction" OR "offsite construction" OR "sustainable construction") AND ("construction industry" AND "urban development") AND (PUBYEAR > 2004 AND PUBYEAR < 2024) AND (LIMIT-TO [SUBJAREA, "ENGI", "ENV", "BUSI", "SOC", "MATE", "EART"]) AND (LIMIT-TO [DOCTYPE, "j"] OR LIMIT-TO [DOCTYPE, "cp"]) AND (LIMIT-TO [LANGUAGE, "English"]). This search string was tailored to include relevant topics such as modular construction, sustainable building practices and urban development while focusing on high-impact research across engineering, environmental science and other related fields. The search was conducted in late December 2024, and the initial result yielded 987 documents. The screening was done to refine the results, focusing on relevant publications while excluding those that did not meet the study's criteria, such as non-peer-reviewed sources, irrelevant topics and duplicates. The period considered for the search was the 2004 to 2024 time frame, capturing both historical and recent trends in modular construction research. Other languages, such as non-English publications, were also excluded to ensure the analysis was based on English-language studies. After applying the inclusion and exclusion criteria, the final number of documents retained for analysis was 664. Figure 1 presents a PRISMA flow diagram illustrating the document selection process and the number of documents retained for the final analysis.

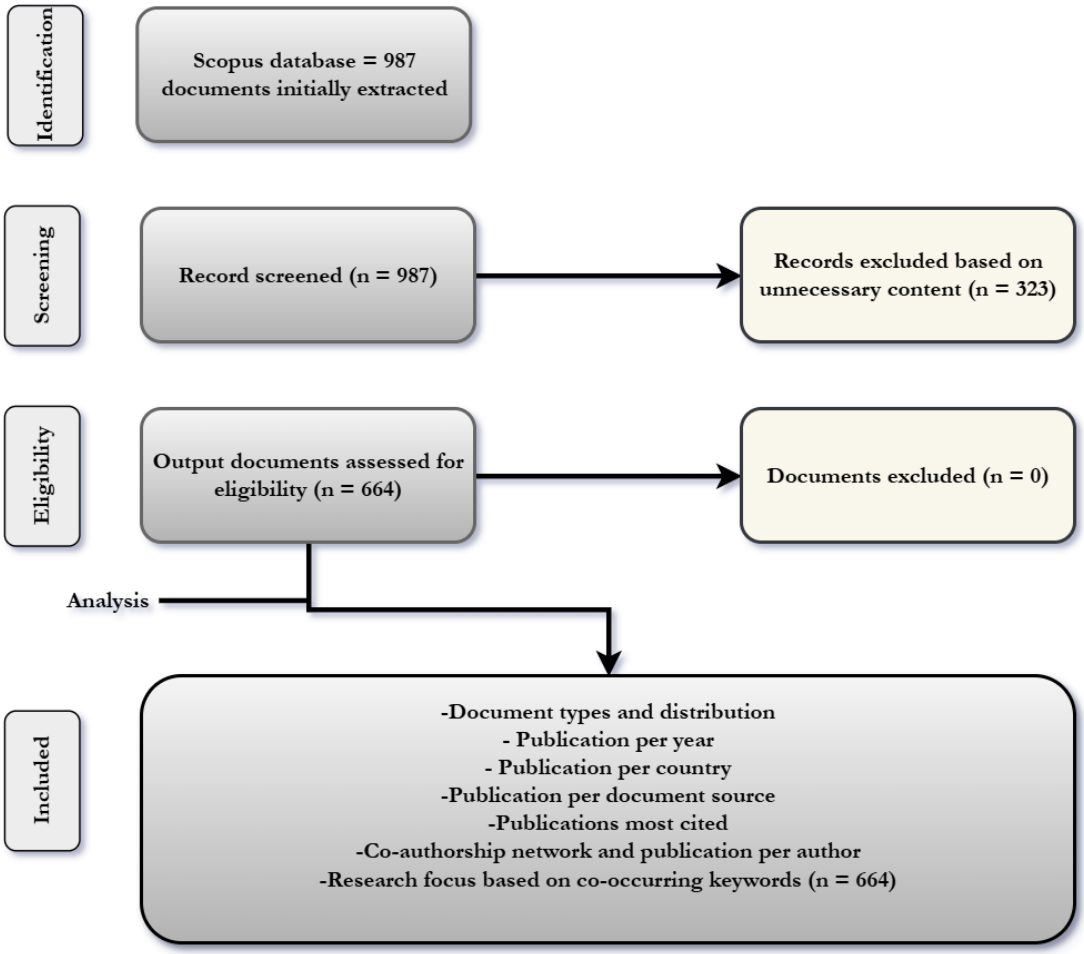

Figure 1: Research methodological framework for the study

4. Results and Discussion

4.1. Document Types and Distribution

The analysis revealed a total of 664 documents retained for the study, categorized into two main types: journal articles and conference papers. Among these, 361 documents (54.4%) were journal articles, while 303 documents (45.6%) were conference papers. Journal articles, as the dominant document type, reflect the depth of research and rigorous peer-reviewed contributions to the field of modular construction. These articles often provide in-depth studies, theoretical advancements, and empirical analyses that shape the foundation of the discipline. On the other hand, conference papers highlight the dynamic and evolving nature of the research domain. They capture emerging ideas, preliminary findings and innovative methodologies presented at scholarly gatherings and

conferences, which often precede more extensive journal publications. This distribution underscores the balance between established research outputs and the exploration of new frontiers in modular construction. It also indicates active engagement within the research community, where knowledge is disseminated through diverse scholarly avenues. Figure 2 visually represents the distribution of document types.

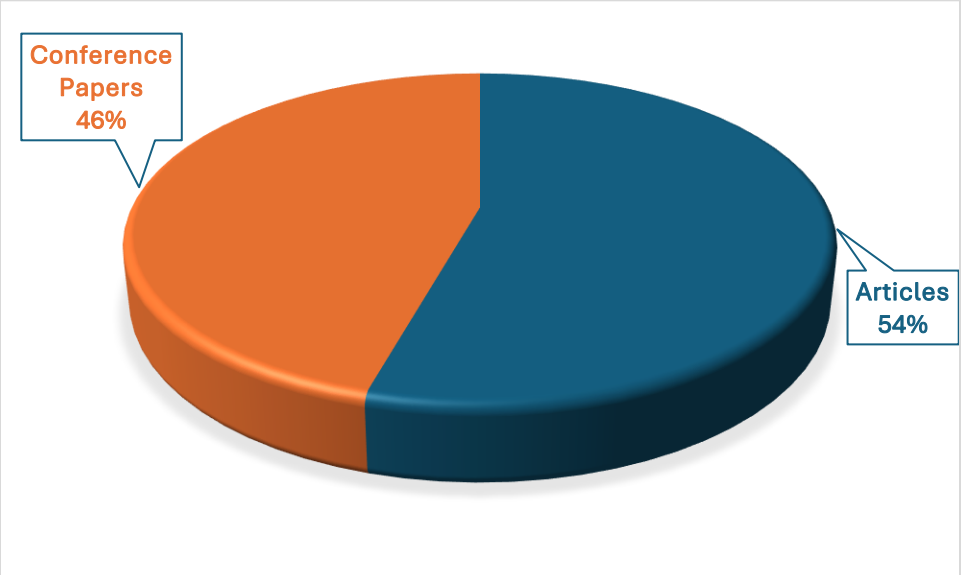

Figure 2: Documents by type

4.2. Publications per Year

The trend in publications per year from 2004 to 2024 shows a significant increase in research activity over the years, reflecting the growing interest and advancements in modular construction. Figure 3 illustrates the annual distribution of documents. The initial years (2004–2010) saw relatively low publication outputs, with fewer than 20 documents annually. This gradual growth indicates the nascent stage of modular construction research during this period. However, from 2015 onward, there is a notable upward trend, with research output increasing steadily, particularly after 2018. The peak was observed in 2023, with 85 publications, followed closely by 2022 and 2021, with 82 and 81 publications, respectively. The high publication numbers in recent years suggest accelerated advancements and interest in modular construction, potentially driven by increased funding opportunities, technological innovations and a growing global focus on sustainable building practices. This trend aligns with the findings of Akinradewo

et al., (2023), who highlighted the rising significance of modular construction in addressing challenges such as sustainable building, cost efficiency and rapid urbanization. The steady increase in research reflects its importance in reshaping the construction industry and addressing global sustainability goals.

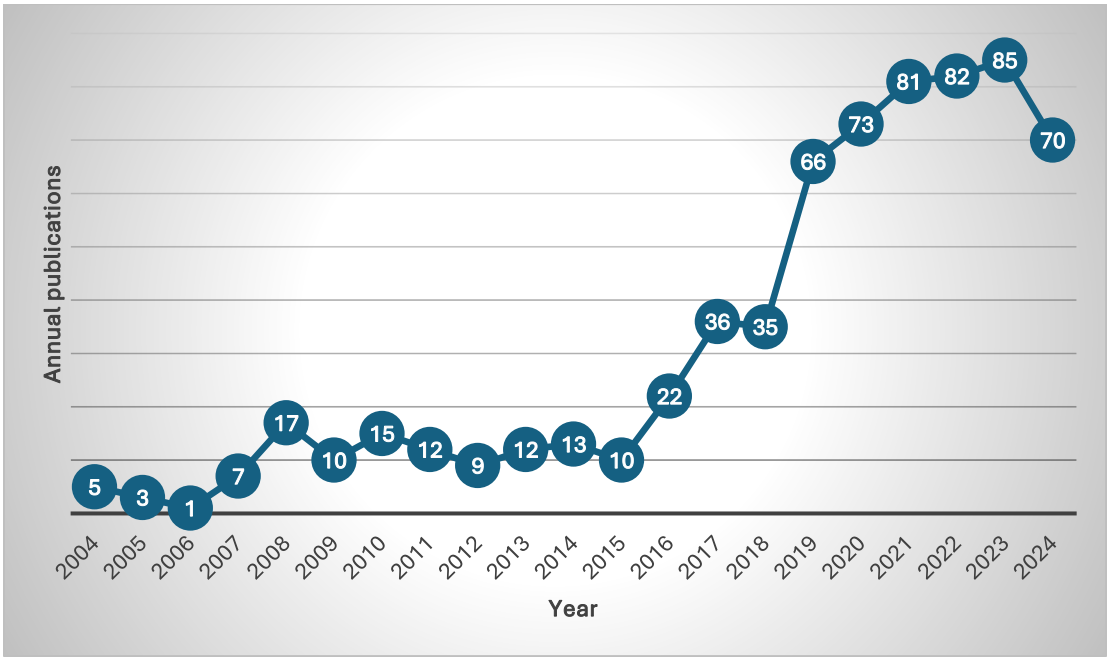

Figure 3: Publication trend over the years

4.3. Publications per Country

Based on country of origin, citations and document count, data were gathered from 14 countries that each had at least seven publications in the area of modular construction. Among these countries, China led with 201 publications, followed by the United States (112) and Australia (86) as shown in Table 1. These countries not only had high publication counts but also amassed significant citations, with China standing out with 4,135 citations, reflecting its prominent role in advancing research in modular construction. The United States and Australia followed closely with 2,970 and 2,771 citations, respectively, further underscoring their contributions to the field. The United Kingdom (80 publications, 2,445 citations) and Hong Kong (49 publications, 3,047 citations) were also key contributors, demonstrating strong research activity and international engagement in modular construction. Other notable countries with a relatively high volume of research include Canada (67 publications), South Korea (20) and India (16), all of which have

made meaningful contributions to the modular construction discourse. In contrast, the only African nation represented in this research area was South Africa, with 9 publications and 62 citations as shown in Table 1. The relatively low representation and citation count from South Africa highlights a gap in research within the African context, indicating that these zones should be the subject of further study. Given the unique challenges faced by many African nations in terms of infrastructure development and housing, further exploration of modular construction in these regions could provide valuable insights and innovations.

Table 1: Distribution of publications by country/region

Country	Documents	Citations	Total link strength
China	201	4135	57
Australia	86	2771	52
United Kingdom	80	2445	43
United States	112	2970	39
Hong Kong	49	3047	36
Canada	67	1579	31
Sri Lanka	11	90	14
Netherlands	9	241	13
India	16	176	10
South Korea	20	486	10
Ireland	8	157	9
New Zealand	15	150	8
Italy	10	269	6
Brazil	8	314	5
Germany	16	285	4
Iran	7	210	4
Saudi Arabia	7	110	4
Sweden	12	265	4
Malaysia	9	134	1
South Africa	9	62	0

4.4. Publications per Document Source

In this next set of analyses, sources with at least 10 published studies are displayed in Table 2. Among these, the *Journal of Cleaner Production* stands out with 26 documents and 2,314 citations, reflecting its pivotal role in promoting sustainability, a core principle in modular construction. Similarly, *Automation in Construction* with 20 documents and 1,304 citations, plays a leading role due to its focus on automation and digital technologies, which are increasingly integrated into modular construction methods to improve efficiency and precision. Other key sources like the *Journal of Building Engineering* and *the Journal of Construction Engineering and Management*, with 17 and 23 documents respectively, also made substantial contributions, indicating their importance in the broader construction and engineering fields.

These journals are central to discussions on modular construction, which intersects with multiple domains, including design, management, sustainability, and technology. Most of these journals also adopt an interdisciplinary approach, which helps attract a wider range of contributors and readership. This is particularly relevant for modular construction, which blends engineering, architecture, construction management and sustainability practices. Journals with such a broad focus, such as *Sustainability* (Switzerland) and *Engineering, Construction and Architecture Management*, provide a platform for diverse perspectives, making them more likely to attract citations from various fields. As modular construction touches on a multitude of sectors, publications that engage a wider academic audience are more likely to see their research cited by scholars from other disciplines.

Table 2: Publications based on document source

Documents	Citations	Total Link Strength
Automation in Construction	20	1304
Buildings	25	230
E3S Web of Conferences	10	6
Engineering, Construction and Architecture Management	17	448
IOP Conference Series: Earth and Environmental Science	38	141
Journal of Building Engineering	17	855
Journal of Cleaner Production	26	2314
Journal of Construction Engineering and Management	23	750
Journal Of Management in Engineering	10	626
Sustainability (Switzerland)	23	444

4.5. Publications Most Cited

This study employed a scientific mapping approach to identify influential articles within the chosen timeframe. This is shown in Table 3. One of the most cited papers is Tam *et al.,* (2007), titled "*Towards adoption of prefabrication in construction*," published in *Building and Environment*, with a total citation count (TC) of 512 and a high normalized citation count of 6.13. This study remains influential in the field, contributing significantly to the early discourse on the adoption of prefabricated construction methods, a core aspect of modular construction. Its impact is evident in its consistent citation rate of 28.44 citations per year, highlighting its enduring relevance in the field. Another highly cited publication is Hong *et al.,* (2018), "*Barriers to Promoting Prefabricated Construction in China: A Cost-benefit Analysis*," published in the *Journal of Cleaner Production*. With 373 citations and an impressive 53.29 citations per year, this paper provides valuable insights into the challenges faced in the widespread adoption of

prefabricated construction in China. Its focus on the economic aspects, such as cost-benefit analysis, has made it a key reference for studies examining the feasibility and barriers to modular construction in developing economies. The normalized citation count of 10.26 further emphasizes its significant influence. Kamali *et al.,* (2017), in their article "*Development of performance criteria for sustainability evaluation of modular versus conventional construction methods*," published in the *Journal of Cleaner Production*, have contributed to the conversation on sustainability in modular construction. With 227 citations and a normalized citation count of 8.63, this study is pivotal for comparing the sustainability of modular construction methods against conventional approaches. It emphasizes the need for specific performance criteria in evaluating the environmental and economic benefits of modular construction. The work of Pan *et al.,* (2008), "*Leading UK housebuilders' Utilization of Offsite Construction Methods*," published in *Building Research & Information*, has also been widely cited, with 197 citations and a high normalized citation count of 12.69. This paper sheds light on the adoption of offsite construction methods in the UK, making it an important reference for those studying the history and progression of modular construction in the housing sector.

Table 3: Top cited publications

Document	Title	Source	Country of Study	TC	TC per Year	Normalized TC
Tam *et al.,* (2007)	Towards adoption of prefabrication in construction	Building and Environment	Hong Kong	512	28.44	6.13
Hong *et al.,* (2018)	Barriers to promoting prefabricated construction in China: A cost-benefit analysis	Journal of Cleaner Production	China	373	53.29	10.26
Hong *et al.,* (2016)	Life-cycle energy analysis of prefabricated building components: an input–output-based hybrid model	Journal of Cleaner Production	Hong Kong	241	26.78	5.22
Kamali *et al.,* (2017)	Development of performance criteria for sustainability evaluation of modular versus conventional construction methods	Journal of Cleaner Production	Canada	227	28.38	8.63
Rahman (2014)	Barriers of implementing modern methods of construction	Journal of Management in Engineering	United Kingdom and China	208	18.91	6.47
Kim *et al.,* (2016)	Automated dimensional quality assurance of full-scale precast concrete elements using laser scanning and BIM	Automation in Construction	Hong Kong	204	22.67	4.42
Pan *et al.,* (2008)	Leading UK housebuilders' utilization of offsite construction methods	Building Research & Information	United Kingdom	197	11.59	12.69

Goulding *et al.,* (2015)	New offsite production and business models in construction: priorities for the future research agenda	Architectural Engineering and Design Management	United Kingdom	174	17.40	6.17
Nahmens and Ikuma (2012)	Effects of lean construction on the sustainability of modular homebuilding	Journal of Architectural Engineering	United States	173	13.31	2.81
Quale *et al.,* (2012)	Construction matters: Comparing environmental impacts of building modular and conventional homes in the United States	Journal of Industrial Ecology	United States	168	12.92	2.72

4.6. Co-Authorship Network and Publications per Author

Next, a co-authorship link was created to identify the collection of authors who have collaborated on modular construction research over the years. This is shown in Figure 4. Notable clusters include those featuring Abdul Nabi M. and El-Adaway I.H., which reflect strong, sustained collaborations and shared research agendas in the field. These clusters highlight the interconnectivity among researchers and the role of partnerships in advancing modular construction research. Researchers such as Al-Hussein M. and Picard I., represented by blue nodes, were more active in the earlier part of the analysis period (2010–2015). Conversely, more recent contributions (2018–2020) are evident from researchers such as Rangasamy Y. and Memari A.M., marked by yellow nodes. Also, certain nodes are notably larger and more connected, indicating influential contributors within their clusters. For instance, El-Adaway I.H. and Salama T. stand out as central figures, acting as hubs for collaboration and facilitating extensive knowledge sharing. These researchers' connections span across both older and newer nodes, reflecting their enduring influence in the field. However, alongside these central figures, isolated nodes and weaker connections are visible, representing independent researchers or niche studies that may not yet be fully integrated into broader collaborations. A key observation from the visualization is the absence of African researchers among the identified co-authorship clusters. This gap highlights a significant underrepresentation of African contributions to modular construction research in the indexed literature. Despite the growing relevance of modular construction for urban development and disaster relief (issues that are highly pertinent to many African contexts), researchers from the continent appear largely absent from the global collaborative network. This lack of representation suggests potential barriers, such as limited access to funding, restricted research visibility, or challenges in forming international

collaborations. It also points to missed opportunities for integrating unique perspectives and addressing context-specific challenges that could enrich the field.

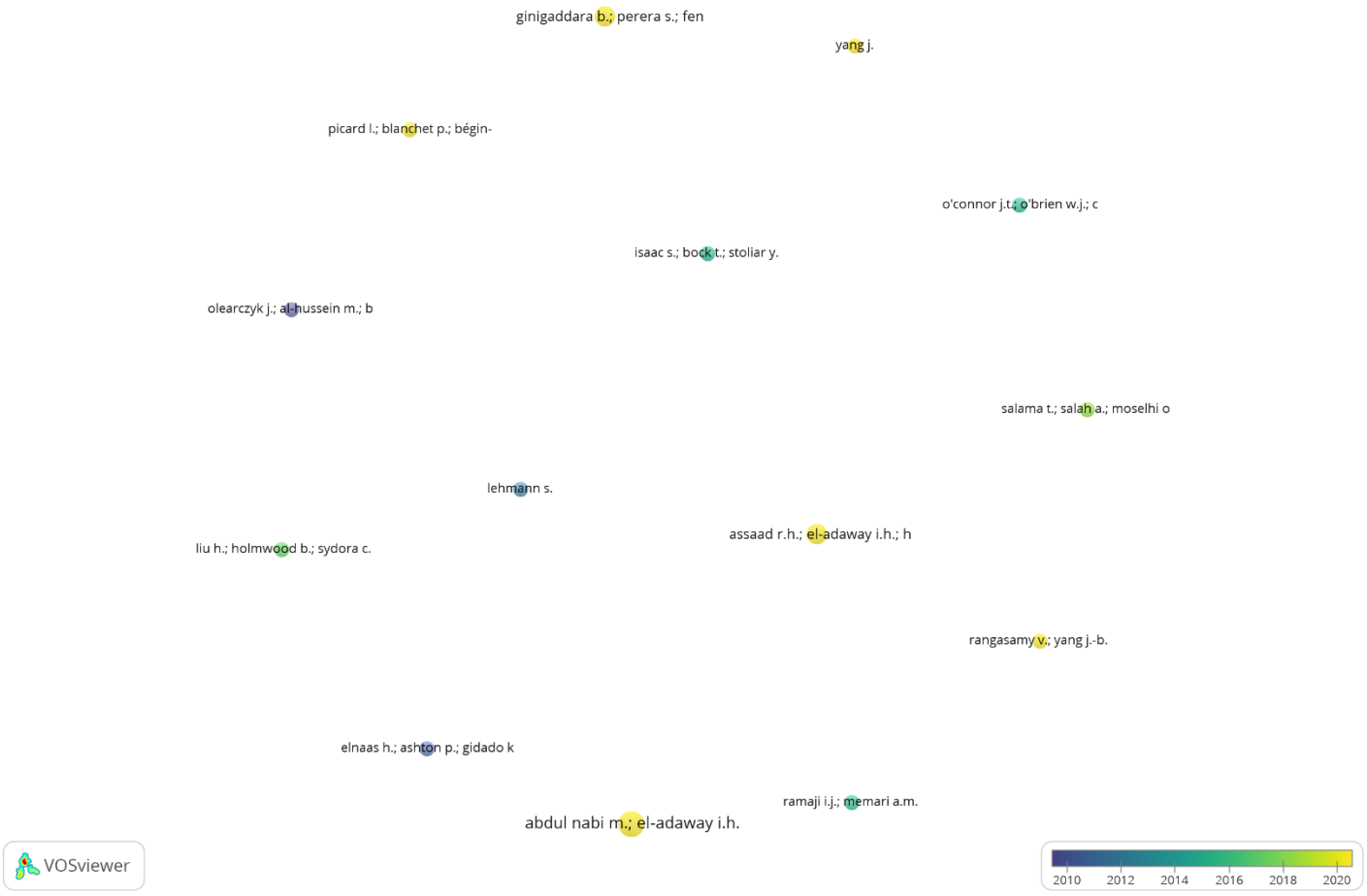

Figure 4: Overlay visualization of authorship network

4.7. Research Focus Areas Based on Co-Occurring Keywords

A total of 4,980 keywords were identified in the analysis, reflecting the different and evolving themes in modular construction research. These keywords were categorized and analyzed using co-occurrence network analysis to determine the main areas of focus. The analysis revealed five distinct clusters, each representing a thematic area in the field of modular construction. A predetermined minimum of five keywords per cluster was used to establish these groupings. The co-occurrence network map in Figure 5 provides a visual representation of these clusters, with

each cluster distinguished by a unique color. The clusters and their respective themes are detailed below.

Cluster 1: Sustainability and Environmental Impact

The red cluster focuses on the environmental implications of modular construction, emphasizing sustainability and resource efficiency. Keywords such as “sustainability”, “environmental impact”, “Life Cycle Assessment (LCA)”, “green building”, “renewable energy”, “circular economy” and “sustainable materials” dominate this area, reflecting a growing interest in mitigating climate change through construction practices. Research in this cluster underscores the role of modular construction in reducing the environmental burden of the built environment. Studies, such as those by Abdelmageed and Zayed (2020) have demonstrated that modular construction significantly decreases waste generation, with reductions of up to 84% compared to traditional construction methods. This reduction is attributed to the precision manufacturing of components in off-site facilities, where waste can be minimized and recycled. The integration of Life Cycle Assessment (LCA) tools has been pivotal in quantifying the environmental impacts of modular construction across its lifecycle, from material extraction to decommissioning. Sajid *et al.,* (2024) highlighted that modular buildings often have lower embodied carbon due to optimized material usage and transportation logistics. Recent research also explores the Circular Economy (CE) framework in modular construction. This approach prioritizes designing buildings for disassembly and reuse, enabling materials and components to re-enter the construction cycle. Scholars like Garusinghe *et al.,* (2023) have emphasized the potential of circular strategies to drastically reduce resource consumption and landfill waste.

Cluster 2: Technology and Innovation

The green cluster focuses on the integration of cutting-edge technologies into modular construction. Dominant keywords include “digitalization”, “Building Information Modeling (BIM)”, “artificial intelligence (AI)”, “automation”, “3D Printing” and “Construction 4.0”. This cluster highlights how technological advancements are transforming every stage of the construction process, from design to assembly. Research in this area often centers on BIM, a digital tool that facilitates collaboration among architects, engineers and contractors. Studies Li *et al.,* (2022) revealed that BIM reduces errors and rework by enabling detailed 3D modeling of modular units. When integrated with AI, BIM can perform predictive analytics, optimizing

material use and project timelines (Rane, 2023). Emerging technologies like 3D Printing are also revolutionizing the manufacturing of modular components. This method allows for rapid prototyping and customization, reducing material waste and enabling intricate designs (Bănică *et al.,* 2024). Additionally, robotics and automation are increasingly employed in prefabrication facilities, enhancing precision and efficiency. Oke *et al.,* (2024) reported significant productivity gains in projects that adopted robotic assembly lines for modular units. Virtual Reality (VR) and Augmented Reality (AR) have also gained prominence, offering immersive design visualization and real-time feedback during construction (Bănică *et al.,* 2024). These tools allow stakeholders to assess spatial configurations and detect potential issues before physical assembly.

Cluster 3: Construction Management and Logistics

The blue cluster emphasizes the practical aspects of managing modular construction projects. Keywords such as "project management", "logistics", "supply chain management", "lean construction", "Just-in-Time (JIT)", "off-site construction", "risk management" and "quality control" reflect the operational challenges and solutions in this field. A significant focus of this cluster is optimizing supply chains for modular construction. Hussein *et al.,* (2021) highlighted how effective supply chain management ensures the timely delivery of prefabricated components while minimizing costs. The JIT approach, widely adopted in modular construction, reduces storage requirements and ensures modules are delivered precisely when needed, as demonstrated in case studies by Si *et al.,* (2020). Lean Construction (LC) principles, as described by Nahmens and Ikuma (2012), are another area of interest. These principles emphasize waste reduction and process efficiency, aligning well with the prefabrication model. Additionally, integrated project delivery (IPD) methods foster collaboration among stakeholders, thus, enhancing project outcomes. Risk management is a critical area of research, addressing uncertainties in transportation, on-site assembly, and regulatory compliance. Studies by Garusinghe *et al.,* (2023) have proposed frameworks for identifying and mitigating risks specific to modular construction.

Cluster 4: Design and Engineering

The yellow cluster focuses on the technical and architectural aspects of modular construction. Keywords such as "structural engineering," "architectural design," "seismic design," "fire safety," "acoustics," "building codes," "performance-based design," "design for manufacturing and assembly (DFMA)" and "modular design principles", dominate this area. Research in this

cluster often examines the structural integrity of modular buildings. Akinradewo *et al.,* (2023) highlighted the role of DFMA in creating modular units that are both structurally sound and easy to transport. Advanced engineering techniques, such as seismic design, ensure that modular buildings can withstand earthquakes and other natural disasters (Shahjalal *et al.,* 2024). Architectural design in modular construction prioritizes flexibility and aesthetics. According to Si *et al.,* (2020), modular units are increasingly designed to be reconfigurable, allowing them to adapt to changing user needs. Performance-based design frameworks, as explored by Rane (2023), evaluate modular units under various environmental conditions, ensuring optimal functionality and safety. Future research could explore the integration of biophilic design principles and smart technologies into modular architecture, enhancing user experience and building performance.

Cluster 5: Social and Economic Impacts

The purple cluster examines the societal and economic dimensions of modular construction. Keywords such as “affordability,” “housing,” “economic development,” “social equity,” “community impact,” “job creation,” “skills development,” “market analysis” and “policy analysis,” underscore the broad implications of this construction approach. Modular construction is often regarded as a solution to housing shortages and affordability crises. Hussein *et al.,* (2021) demonstrated how modular methods reduce construction costs and timelines, making housing accessible to low-income populations. Additionally, modular construction can stimulate economic development by creating jobs in manufacturing, transportation and on-site assembly (Si *et al.,* 2020). Social equity is another critical area of focus. Li *et al.,* (2022) highlighted the potential of modular construction to provide high-quality housing for underserved communities, reducing disparities in living conditions. Policy analyses suggest that government incentives and supportive regulations can accelerate the adoption of modular construction, maximizing its social and economic benefits (Si *et al.,* 2020). Future studies could explore the long-term community impacts of modular construction, including its role in fostering sustainable urban development and enhancing resilience to climate-related challenges.

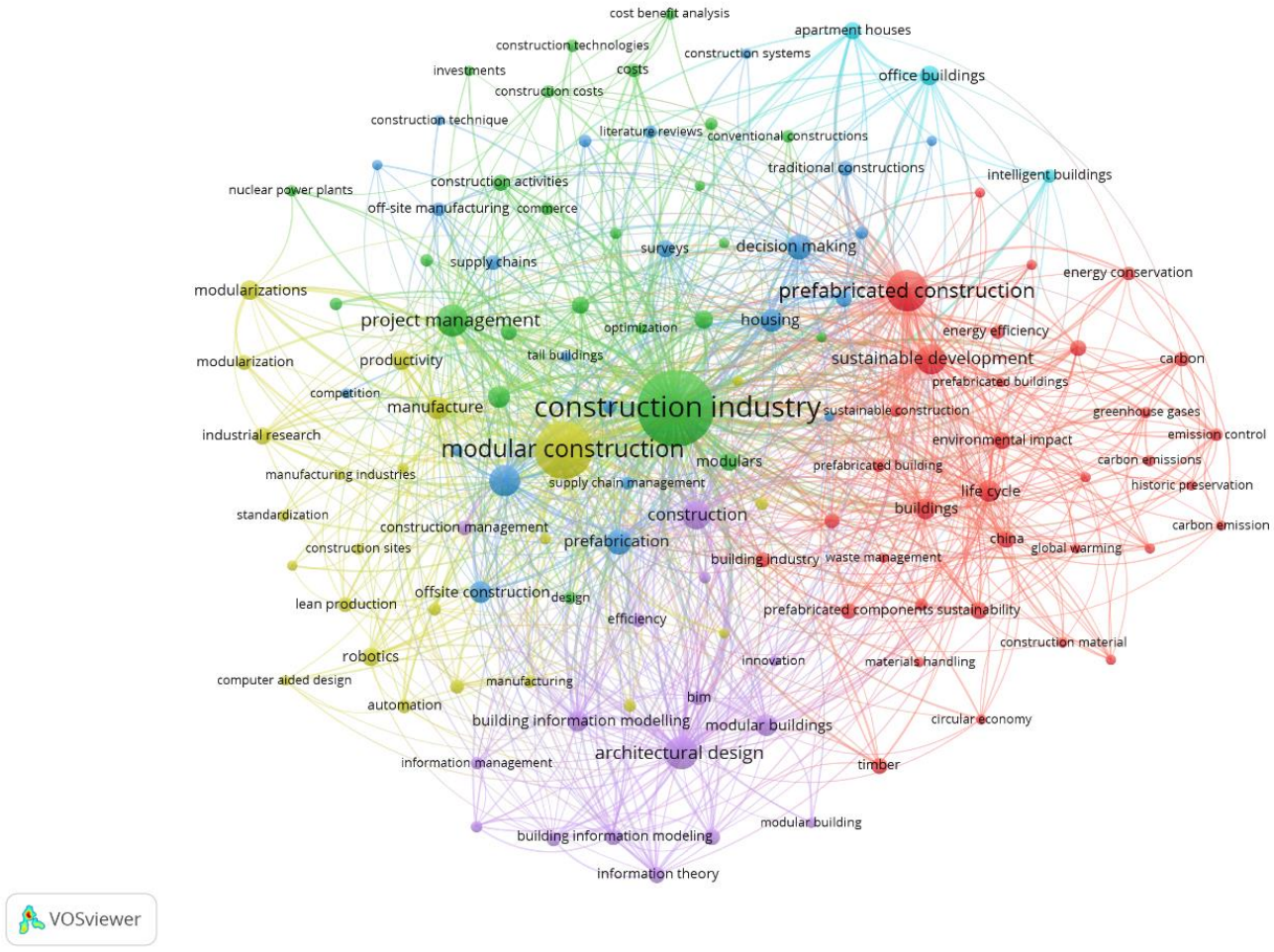

Figure 5: Network map of co-occurring keywords.

5. Comparative Trends in Developed vs. Developing Regions

The analysis reveals a clear contrast in the volume of publications and citations between developed and developing regions. Developed regions, particularly China, the United States and Australia, dominate the modular construction research landscape. China leads with 201 publications, followed by the United States (112) and Australia (86). These countries also have substantial citation counts, with China contributing 4,135 citations. This high output is indicative of the well-supported research infrastructure and industrial demand for modular construction solutions in these nations. In contrast, developing regions exhibit much lower publication and

citation numbers. South Africa, the only African country included in this analysis, had just 9 publications and 62 citations. This points to a significant research gap, as modular construction could be a solution to many challenges faced by developing regions, such as inadequate housing and infrastructure. The lack of research activity in these areas highlights the need for greater investment in research and development, particularly in modular construction solutions that could address local needs.

The co-authorship network analysis provides further insight into the collaborative dynamics between developed and developing regions. In developed regions, a network of well-connected researchers exists, with strong collaborations among leading scholars such as Abdul Nabi M., El-Adaway I.H., Al-Hussein M., and Picard I. These scholars have established sustained partnerships, creating a vibrant research community that drives innovation in modular construction. This collaborative structure reflects the mature academic and research environment in developed nations. However, developing regions appear to be underrepresented in these networks. The absence of African researchers in the identified co-authorship clusters is notable, highlighting a lack of integration into global research partnerships. This gap may be due to several factors, including limited access to research funding, insufficient institutional support and barriers to international collaboration (Wuni *et al.,* 2020). The absence of strong regional research networks in developing countries suggests missed opportunities for knowledge exchange and the development of modular construction solutions suited to the unique challenges these regions face, such as affordable housing, disaster relief and sustainable urbanization.

Key publications in modular construction research show the varying impact between developed and developing regions. In developed regions, influential papers such as Tam *et al.,* (2007) on the adoption of prefabrication and Hong *et al.,* (2018) on cost-benefit analyses of prefabricated construction in China have shaped the discourse on sustainability, economic feasibility, and adoption barriers in modular construction. These studies are widely cited and remain crucial references for researchers, reflecting the advanced stage of modular construction research in these regions. In contrast, research in developing regions is less cited, with South Africa's limited number of publications further emphasizing the gap in scholarly engagement. The lack of influential publications from developing regions suggests that the potential for modular construction to address infrastructure challenges in these areas remains underexplored. While

modular construction holds promise for tackling issues such as rapid urbanization and disaster resilience, the limited research output from developing regions may hinder the development of localized solutions that are contextually appropriate.

6. Opportunities for Bridging the Gap

The comparative analysis between developed and developing regions reveals significant opportunities for growth and collaboration in modular construction research. Developed regions continue to lead in terms of publication volumes, citations and established research networks, but developing regions, especially in Africa, hold immense untapped potential. Modular construction could provide transformative solutions for infrastructure challenges in these regions, such as rapid urbanization, housing shortages and vulnerability to climate-related disasters. By investing in research capacity, promoting international collaborations and focusing on region-specific challenges, developing regions could significantly enhance their contribution to the global modular construction discourse. Furthermore, the integration of African researchers into global co-authorship networks, facilitated by targeted research funding and collaborative initiatives, could foster the development of tailored modular construction solutions that address local needs. As the field continues to evolve, it will be crucial to ensure that research in modular construction is inclusive, addressing both the technological advancements seen in developed regions and the unique challenges faced by developing nations. This can be achieved via the following recommendations:

1. *Strengthening research networks in developing regions, particularly in Africa, by creating platforms for knowledge exchange among local researchers, international collaborators and industry experts.*
   The analysis revealed that developing regions, such as South Africa, are underrepresented in global co-authorship networks, with a notable absence of African researchers in key clusters. Strengthening research networks will help bridge this gap by facilitating collaboration and fostering a more inclusive research environment.
2. *Increasing funding and grant opportunities directed towards modular construction research in developing regions, enabling the establishment of research hubs and fostering local innovation.* The limited research output from developing regions, coupled with the lack of influential publications, suggests a need for more financial support. By increasing

funding, developing regions can build research infrastructure and generate localized innovations to address unique challenges, such as affordable housing and disaster resilience.

3. *Focusing on adapting modular construction technologies to meet regional needs such as affordable housing, climate-resilient infrastructure and low-cost materials.* The research highlights the pressing need for modular construction in developing regions to address challenges like inadequate housing and vulnerability to climate-related disasters. Tailoring these technologies to local needs will ensure their effectiveness and sustainability.
4. *Establishing knowledge transfer and training programs to equip researchers, industry professionals and government officials in developing regions with skills in modular construction design, methods and project management.* The absence of strong regional research networks and knowledge exchange in developing regions points to a gap in capacity building. Training programs will equip local stakeholders with the necessary expertise to advance modular construction solutions.
5. *Encouraging public-private partnerships to promote the adoption of modular construction in critical infrastructure sectors like housing, healthcare and disaster recovery.* The need for greater investment in research and development, especially in addressing infrastructure needs, can be met by promoting partnerships between public and private sectors. These collaborations can drive adoption and scalability of modular construction solutions in vital sectors.
6. *Organizing regional research workshops and conferences to facilitate collaboration among researchers from both developed and developing regions, discussing challenges and exploring region-specific solutions.* The analysis showed that there is a gap in global collaboration between developed and developing regions. Organizing regional workshops will create platforms for shared learning, address challenges specific to developing regions, and enhance cross-regional research efforts.
7. *Enhancing inclusion of developing regions in global research initiatives, fostering co-authorship opportunities and creating joint projects to integrate local perspectives and challenges.* The lack of integration of developing regions into global research networks was evident. Increasing participation in global initiatives will ensure that research

outcomes are more inclusive, promoting solutions that are contextually appropriate for developing regions.

8. *Advocating for policies that promote modular construction as a solution to key infrastructure issues in developing regions, particularly in housing, urbanization and disaster resilience.* Modular construction was identified as a potential solution to many challenges in developing regions, including urbanization and disaster resilience. Advocating for supportive policies can help institutionalize modular construction as a mainstream approach to addressing these challenges.

7. Conclusions and Recommendations

This study used a bibliometric approach to investigate the trends and research focus in modular construction, particularly examining the differences between developed and developing regions. The analysis, based on a selection of publications indexed in the Scopus database over the last 20 years, identified key patterns in modular construction research, including variations in publication volume, citation impact and research themes across regions. Notably, regions such as China, the United States and Australia demonstrated consistent research output, while African countries, particularly South Africa, showed limited contributions. This points to a significant knowledge gap in modular construction research, especially in the context of developing regions, where the potential for innovation in infrastructure solutions remains largely untapped. In the developed regions, research has predominantly focused on technological advancements, sustainability and the integration of modular construction into mainstream building practices. Conversely, developing regions, especially in Africa, face unique challenges, including rapid urbanization, housing shortages and vulnerability to climate-related disasters. These regions are currently underrepresented in the global modular construction discourse, which limits their ability to leverage modular solutions for infrastructure development. The relatively low representation of African researchers in co-authorship networks further highlights this gap.

Given the disparities identified in this study, there is a clear opportunity for bridging the research divide between developed and developing regions. By fostering international collaborations, providing targeted research funding and addressing region-specific challenges, modular construction could become a key solution to infrastructure problems in developing regions. This research also lays the groundwork for future studies that could explore the intersection of

modular construction with local needs, helping to create tailored, sustainable solutions. From a practical standpoint, the findings of this study underscore the need for greater investment in research capacity in developing regions, particularly in Africa. By identifying the gaps in modular construction research, the study offers a pathway for policymakers, researchers and industry stakeholders to focus their efforts on promoting sustainable construction practices in these regions. Theoretically, this study contributes to the growing body of knowledge on modular construction by offering an analysis of research trends across developed and developing regions.

While this study provides key insights into the trends of modular construction research, its scope is limited to the data available in the Scopus database, and only journal articles and conference papers were considered. Future research could expand on this by incorporating additional databases and industry-specific trade literature, which often captures cutting-edge advancements led by construction firms. Publications such as *ASPIRE* (Concrete Bridges), *Ascent Magazine* (Precast Concrete Buildings), *Modern Steel Construction* (Steel Buildings) and *Think Wood* (Mass Timber) offer valuable insights into industry-driven innovations that may not yet be widely documented in academic literature. Additionally, including other forms of academic contributions, such as book chapters, could further enrich the analysis. A broader timeframe could also help capture emerging trends in modular construction, particularly as the field continues to evolve. It is important to note that publications from 2025 were not included in this analysis and extending the research period while incorporating industry literature could provide additional insights into recent advancements and emerging patterns within the field. Finally, while the study captures the trends in modular construction research, it does not examine the specific socio-economic, cultural, or environmental factors that may influence the implementation of modular construction solutions in different regions. For example, social acceptance of modular buildings, local attitudes toward innovation and environmental concerns related to material sourcing and sustainability are key factors that could affect the adoption and success of modular construction techniques. Addressing these factors in future research would provide a more comprehensive understanding of the barriers and opportunities associated with modular construction adoption globally.

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