A review of the current state and future trends in Modern Methods of Construction research

Literature Review

Abstract

- **Purpose:** This study aims to identify the primary research areas of Modern Methods of Construction (MMC) along with its current trend and developments.
- **Design/methodology/approach:** A combination of bibliometric and qualitative analysis is adopted to examine 1957 MMC articles in the Scopus database. With the support of CiteSpace 6.1.R6, the clusters, leading authors, journals, institutions, and countries in the field of MMC are examined.
- **Findings:** Prefabricated buildings, inter-modular connections, augmenting output, prefabricated concrete beams, and earthquake-resilient prefabricated beam-column steel joints are the top five research areas in MMC. Among them, prefabricated buildings and inter-modular connections are significantly focused, with many research articles. The potential for collaboration among prominent authors such as Wang, J., Liu, Y., and Wang, Y. explains the recent rapid growth of the MMC field of research. With a total of 225 articles, 'Engineering Structures' is the journal that has published the most articles on MMC. China is the leading country in this field, and the Ministry of Education China is the top institution in MMC.
- **Originality:** The findings of this study bear significant implications for stakeholders in academia and industry alike. In academia, these insights allow researchers to identify research gaps and foster collaboration, steering efforts towards innovative and impactful outcomes. For industries utilizing MMC practices, the clarity provided on MMC techniques facilitates the efficient adoption of best practices, thereby promoting collaboration, innovation, and global problem-solving within the construction field.

Keywords: Modern Methods of Construction (MMC); Offsite Construction (OSC); Modular Construction; Bibliometric; CiteSpace

1. Introduction

The construction sector is crucial in advancing economic growth (Assaad and El-Adaway, 2020) and impacts various aspects of the economy (Žarković et al., 2022). Despite its significance, the industry has been facing persistent challenges that remain unaddressed by both practitioners and academic experts (Assaad et al., 2020). The industry is characterized by strict schedules, demanding cost limitations, and challenging working conditions (Cheng and Hoang, 2015).

The construction industry is expected to see an increasing adoption of Modern Methods of Construction (MMC) due to its potential advantages (Ofori-Kuragu and Osei-Kyei, 2021). The most common forms of MMC, also known as OffSite Construction (OSC) (Maqbool et al., 2023), encompass modular construction, prefabrication, pre-assembly, and offsite fabrication and production. The recent surge in the popularity of modular construction can be attributed to its various benefits as an innovation in the construction sector (Assaad et al., 2020). Modular structures offer numerous advantages, primarily due to the capability to prefabricate and mass-produce components. This enhances the benefits of OSC, especially when the same module can be utilized for multiple structures (Tumbeva et al., 2021). The rise in modular construction can be attributed to advancements in manufacturing and is regarded as a means to address the global speed and quality concerns prevalent in the construction industry (Ofori-Kuragu et al., 2022), improve safety and reduce waste on construction sites (Southern, 2016). Prefabrication, in contrast to conventional construction, involves assembling or fabricating construction components and modules in a controlled environment, followed by transportation and installation on-site, resulting in quicker construction and decreased costs and duration (Lim et al., 2021).

Despite the extensive literature on the potential advantages of OSC and related processes, the emphasis on specific OSC techniques is not always well-defined (Ofori-Kuragu et al., 2022). This lack hinders the effective utilization of OSC's benefits and may lead to inefficient practices in this field. Therefore, there is a pressing need to conduct a comprehensive study to unravel the issues of OSC, identify key research

areas, and outline future directions in this field. This study aims to clarify the main research areas and future direction, as well as to identify the leading authors, journals, institutions, and countries in the field of MMC. Additionally, the study analyzes citation trends, providing insights into the evolution of MMC-related research over time, thereby enabling researchers and practitioners to stay abreast of the latest developments and future directions in the field.

2. Methodology

Various types of review papers, including rapid, scoping, systematic, and critical reviews provide different insights into scholarly research (Zhai et al., 2022). Bibliometric analysis, a systematic quantitative review of existing research, uses statistical methods to analyze trends and impact in scientific fields (Barnes et al., 2019). It presents findings systematically, transparently, and quantitatively, helping identify leading authors, institutions, and research structures (Aria and Cuccurullo, 2017, Kurnaz, 2022). It offers valuable insights by revealing patterns, recognizing changes, and determining leaders in specific fields (Aria and Cuccurullo, 2017, Sun and Grimes, 2016). In this study, bibliometric analysis is combined with qualitative review, aimed at achieving a comprehensive understanding of MMC, examining trends, structures, and performing a detailed analysis of the identified articles (Tariq et al., 2022).

The literature search, MMC network generation, and data analysis steps are summarized in Figure 1.

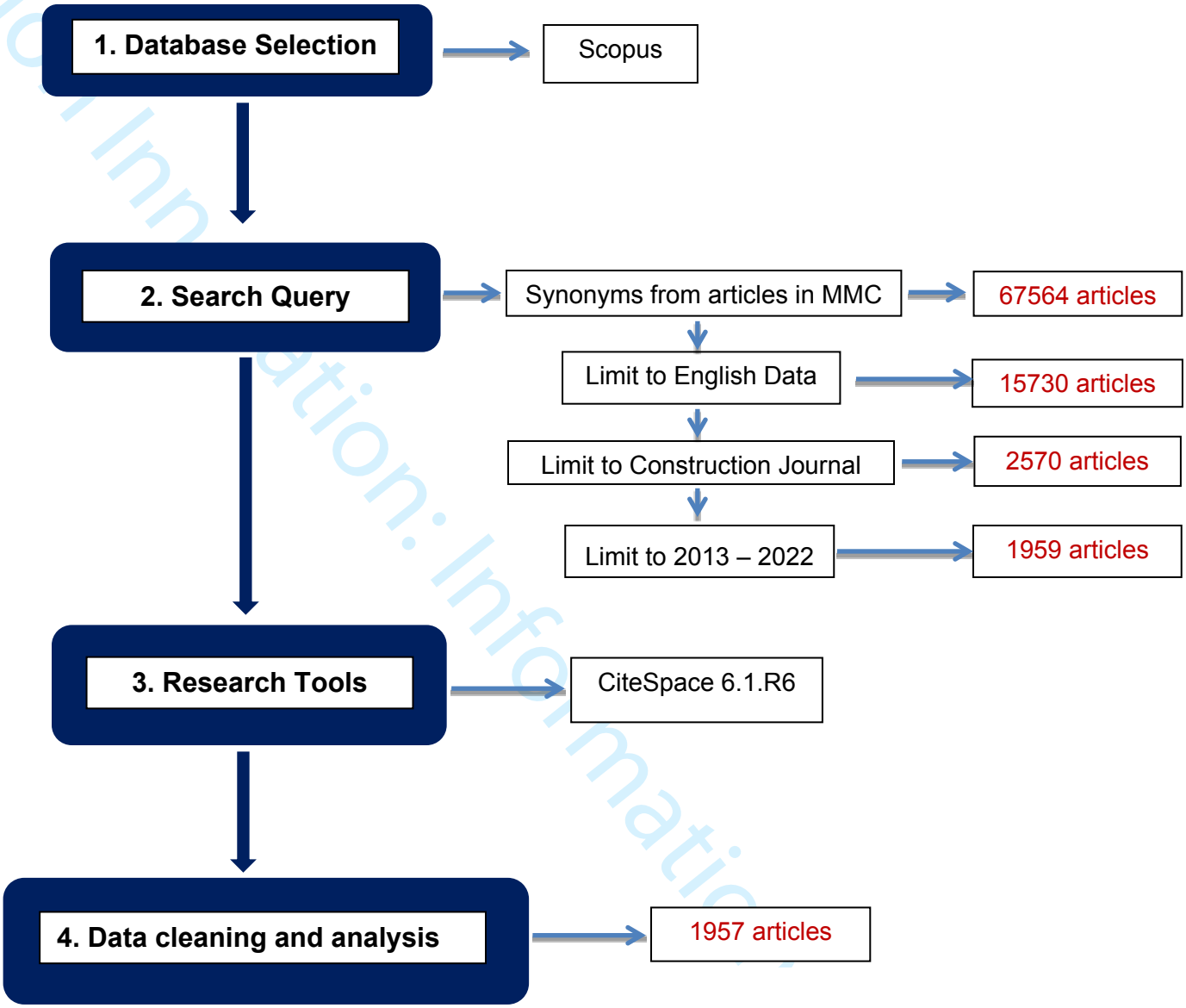

Figure 1. Methodological framework of the bibliometric analysis

2.1. Database Selection

The Scopus database was selected for this study, as it furnishes access to many academic articles across diverse disciplines and offers tools to gauge journal impact and reputation based on contributions and citation counts (Aghaei Chadegani et al., 2013). Additionally, Scopus is renowned for its balance between the volume of material covered and the quality of the articles (Adilović, 2022, Singh et al., 2020).

2.2. Search Query

Based on the definition of OSC, which involves the pre-fabrication of building structural elements outside of traditional construction sites (Goulding and Rahimian, 2019), a system of synonyms was utilized in the literature search. This included using keywords related to OSC in articles and referencing the reference lists to ensure the comprehensive inclusion of relevant articles in the search results. The following keywords are used in this research: ""Off-site construction"; "Offsite construction"; "Off-site fabrication"; "Off-site manufacturing"; "Offsite production"; "Modern methods of construction"; "Prefabricated"; "Prefabrication"; "Precast construction"; "Pre-assembly"; "Prefab"; "Construction mass production"; "Modularization"; "Modular construction"; "Modular building"; "Modular homes"; "Modular integrated construction"; "Modular homebuilding"; "Systematic construction"; "Industrialized construction"; and "Manufactured construction." The search was conducted using the "title, abstract, keywords" section of the Scopus database, and the preliminary publications were retrieved by applying the search query within quotation marks and combining all results using the "OR" operator, retrieving 67,564 publications.

After an initial retrieval, the data was narrowed to English-language articles, yielding 15,730 publications. Subsequently, the Source Title was assessed via the Scimago Journal and Country Rank, focusing on the Engineering and Construction categories, leaving a pool of 2,570 publications. Considering the voluminous number of articles and the evolution in MMC from 2013 to 2022, this time frame was chosen for the bibliographic analysis. The refined and methodical search culminated in a final total of 1,959 pertinent publications.

2.3. Research Tools

In recent years, various visualization programs such as VOSviewer, Co-PalRed, Bibexcel, and CiteSpace have emerged, providing access to the reference co-citation networks in specific fields (Lei and Cui, 2022). Among these tools, CiteSpace is a prominent visual referencing analysis tool that focuses on the core principles of data science investigation (Yu, 2022). CiteSpace streamlines the science mapping process

and offers advantages through its Cluster Explorer to analyze cluster nodes (Markscheffel and Schröter, 2021). CiteSpace allows for the identification of the evolution of various disciplines and provides insight into research subjects through the analysis of keyword co-occurrence and original data centrality (Zhou and Xie, 2022). In this study, CiteSpace 6.1.R6 was utilized to visualize the networks and analyze the structure and dominant research clusters in MMC.

2.4. Data Cleaning and Analysis

The data was imported into CiteSpace 6.1.R6, and the analysis was conducted from 2013 to 2022. After the deduplication processing, 1,957 valid data were obtained. CiteSpace's robust features allow for in-depth analysis and visualization, generating results on the co-citation of documents, journals, co-authorship patterns, institutions, countries, and co-occurring author keywords. Additionally, CiteSpace analyzed the significant clusters and citation burst views to uncover the dominant publications in MMC.

3. Findings and Discussion

3.1. Descriptive Analysis

3.1.1. Trend of publications

Figure 2 shows the rising trend in OSC research literature from 2013 to 2022. The number of publications increased steadily from 49 in 2013 to 106 in 2017 before experiencing a sharp increase from 164 in 2018 to 510 by the end of 2022. This finding highlights the ongoing and growing interest among researchers in MMC. Researchers worldwide view industrialized construction techniques as a productive method of building, with well-established benefits in terms of time, cost, and quality (Attouri et al., 2022).

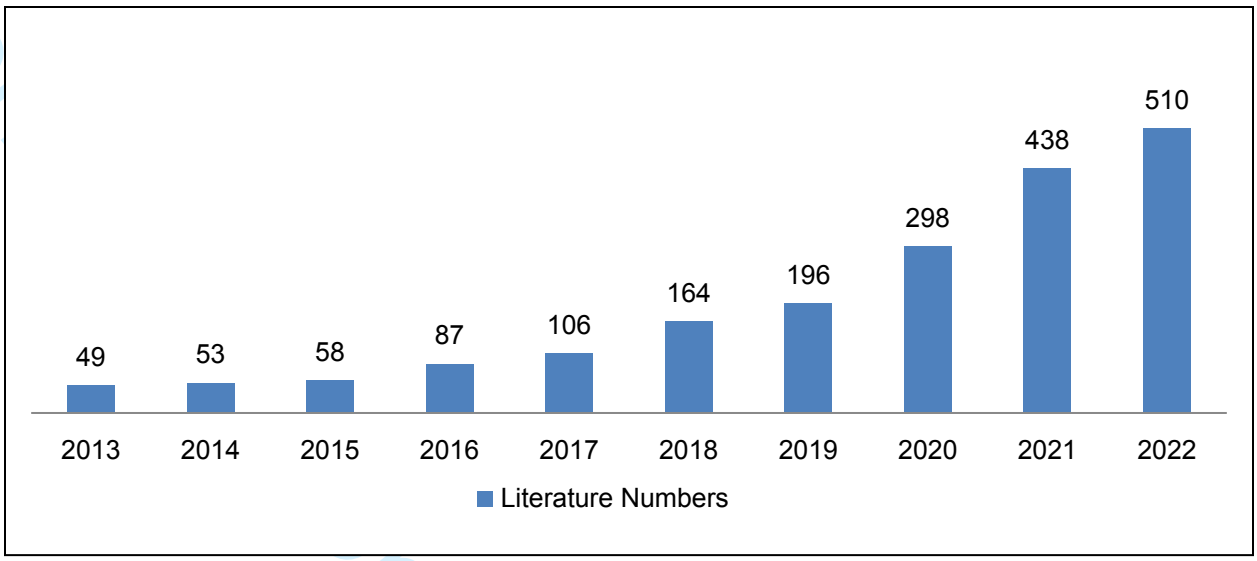

Figure 2. Number of MMC papers from 2013 to 2022

3.1.2. Journal analysis

A significant number of construction journals have shown an engagement with the MMC topic. Table I lists the top 10 journals with the most articles published in this field, accounting for 62.3% of all publications. Engineering Structures leads the pack with 225 papers, representing 11.5% of all publications. Construction and Building Materials and Journal of Building Engineering are close behind, with 141 and 140 articles, respectively.

Table I. Top 10 publication titles

3.1.3. Author analysis

Authors play a pivotal role in research, and the CiteSpace software allows researchers to analyze the number of articles published by authors, identify the leading researchers driving the field's development, and understand how authors collaborate with each other (She et al., 2022). The authors with the highest citation network were Wang, J.; Liu, Y.; and Wang, Y., with 43, 39, and 37 citations, respectively, as shown in Figure 3. These highly cited authors play a crucial role in the MMC network.

Figure 3. Collaboration network of authors in MMC

3.1.4. Country analysis

According to Figure 4, China had the largest number of cited publications (897 papers) in MMC, with the Ministry of Education China and Beijing University of Technology being the top institutions with the most publications (144 and 80 articles, respectively), Table II. Prefabricated construction is an affordable and high-quality solution that can meet the increasing demand for housing in China and reduce environmental impact (Arif and Egbu, 2010, Shen et al., 2010). China's urgent need for high-speed urbanization has resulted in a growing number of studies investigating the benefits and barriers of precast construction in different regions of the country (Hong et al., 2018, Arif and Egbu, 2010).

Figure 4. Collaboration network of countries in MMC

Table II. Top 12 institutions

Australia had 251 papers in MMC, second only to China. Both countries have a rising interest in modular construction, with Australia's expected to reach 10% by 2030 (Ferdous et al., 2019). Other countries such as the United States, the United Kingdom, Canada, and Hong Kong have also made substantial contributions to MMC, with notable numbers of cited articles.

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3.2. Thematic Analysis

3.2.1. High co-citation literature of MMC

Co-citation analysis is a crucial tool to identify the leading articles in a particular field. Table III presents the top 10 most frequently co-cited articles in MMC research, which can be categorized into several primary content areas, including environmental impacts, cost frameworks of MMC, modular building structures, advances, challenges, and potential of prefabricated buildings, and the integration of Building Information Modelling (BIM) and OSC.

Table III. The top 10 most frequently co-cited articles in MMC

The most co-cited article, with 34 citations, is Kamali and Hewage (2016)'s work that highlights the environmental impacts of modular buildings throughout their lifespan and thoroughly examines the advantages and drawbacks of offsite production compared to traditional methods. The study concluded that modular construction improved life cycle performance, particularly regarding energy efficiency.

The second-most co-cited article, with 33 citations, emerged from Hong et al. (2018), offering a comprehensive analysis of prefabricated construction's underlying cost framework. It presented an insightful evaluation of how prefabrication adoption influences construction projects' overall costs. The study's findings revealed that the costs associated with prefabricated concrete and steel segments constituted the majority share, ranging between 26% and 60% of the cumulative cost.

The next five articles with high co-cited frequency pertain to modular steel building structures. Lacey et al. (2019), 31 citations, summarized existing bolted inter-modular connections to decipher force-displacement and moment-rotation tendencies, comparing them with empirical outcomes to expose the prevailing theoretical framework's shortcomings. Chen et al. (2017a) and Chen et al. (2017b), with 31 and 27 citations, suggested an innovative design using bolted connections between beams, facilitating straightforward installation and accessibility in modular steel buildings. Fathieh and Mercan (2016) and Liu et al. (2018), with 27 and 21 citations, evaluated the seismic performance of offsite manufactured steel connections. Fathieh and Mercan (2016) explored a four-story steel modular building's ability to comprehend multi-story modular steel structures' dynamic behavior. Whereas, Liu et al. (2018) assessed two suggested bolted connections concerning seismic performance, discovering a more ductile slipping connection with enhanced power dissipation.

Lacey et al. (2018), 21 citations, conducted an extensive literature review on modular construction structures, underscoring the reliance on module interconnections and the associated risks that necessitate proper design and methodology.

Ferdous et al. (2019), 21 citations, thoroughly probed prefabricated edifices' advancements, constraints, and potential. They posited that logistical shortages have impeded modular construction's adoption in the industry but emphasized the economic, social, and environmental virtues of prefabricated modules, proclaiming modular construction as the industry's future.

Finally, Yin et al. (2019), 20 citations, applied a bibliometric review technique to study the integration of BIM and OSC research. Through a comprehensive qualitative analysis, research directions on BIM for OSC were determined, such as BIM-based prefabrication design and OSC data exchange using BIM.

3.2.2. Main research areas of MMC

A visualization of the current prominent content distribution was generated to gain a more comprehensive understanding of research hotspots in MMC. Employing the log-likelihood ratio (LLR) technique, CiteSpace generated automatic labels for each cluster by pinpointing unique terms in publication titles (Chen, 2014), as illustrated in Figure 5.

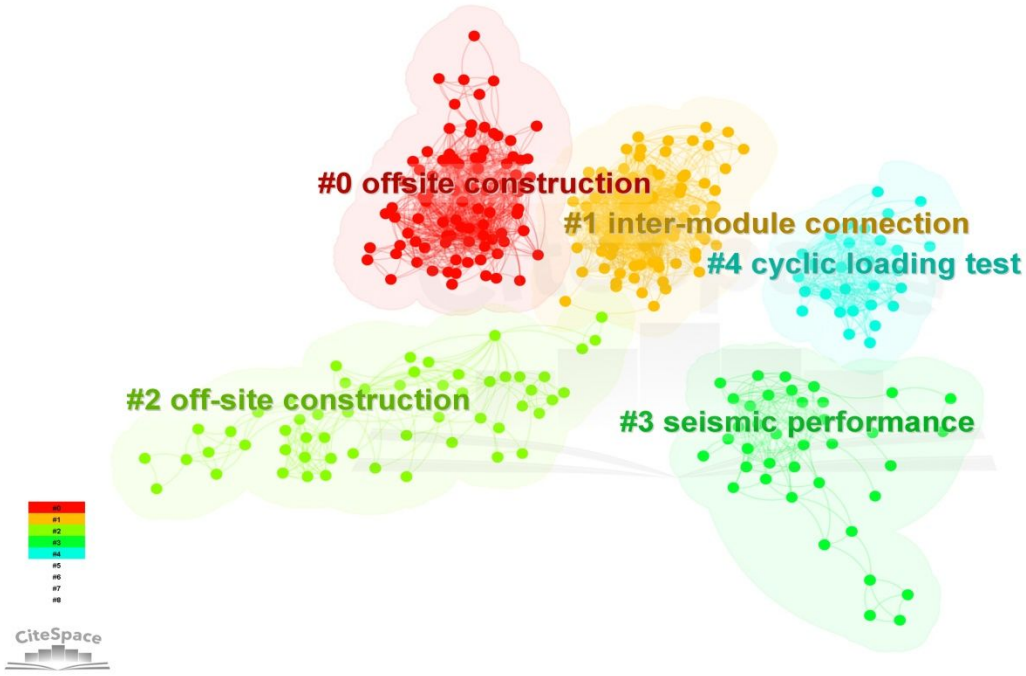

Figure 5. The largest 5 clusters view in MMC

Five major clusters, marked for in-depth scrutiny in this study, were labeled as #0 Offsite Construction, #1 Inter-Module Connection, #2 Off-Site Construction, #3 Seismic Performance, and #4 Cyclic Loading Test, Table IV. Some labels, however, may be revised to better represent the articles' content following a meticulous examination of the top terms within each cluster.

Table IV. Summary of the five largest clusters:

Table IV shows a correlation between the cluster number and the number of papers it contains; clusters with smaller numbers contain more papers. The discussion of clusters will cover both citing and cited publications. The contributing papers in each cluster will be analyzed based on their coverage and global citing score. The cited papers will be characterized by their frequency of citation.

Cluster #0, containing 91 articles, is primarily labeled as "offsite construction." This cluster provides an in-depth exploration of various construction techniques and

methodologies. There are two articles on reinforced concrete (Jang et al., 2022, Liu et al., 2020), two on steel structures (Yu et al., 2022, Liu et al., 2021), one on timber and mechanical/electrical/plumbing (Lopez et al., 2022), and two on panel construction (Ahn et al., 2022, Kwok et al., 2022). Beyond these specific examples, most articles discuss modular technologies applied to diverse structures and materials. These studies highlight the many benefits of OSC, including the advantages of automation, increased efficiency, and quality control. However, significant challenges are also addressed, such as issues related to future adjustments, incompatibility with typical project management, performance uncertainty, and inadequate precision in module manufacturing. Several major citing articles delve into innovative solutions and best practices in OSC. Cai et al. (2022) presented a high-level offsite manufacturing technology procedure that combined subjective and objective adoptions, utilizing the Technology Acceptance Model and the task-technology fit theory. Gao et al. (2018) and Hwang et al. (2018) pointed out the lack of flexibility for future adjustments, incompatibility with typical project management, performance uncertainty, and inadequate precise module manufacture of this mechanism. However, these elements significantly interacted (Gan et al., 2018, Luo et al., 2019, Wuni and Shen, 2020), leading to further investigation into adopting this mechanism. The proposed name "offsite construction" is appropriate for labeling this cluster as it generally analyzed characteristics of prefabricated buildings.

Cluster #1, labeled "inter-module connection," is the second largest cluster with 90 articles. Most of the articles in this cluster focused on analyzing the inter connections in steel structures. There is one article by Zhao et al. (2022) that mentioned the precast composite shear wall model in concrete modular buildings, and four other articles that discussed inter-module connections in concrete modular high-rises (Pan et al., 2022, Pan et al., 2021, Wang et al., 2021, Peng et al., 2020). Dan-Adrian and Tsavdaridis (2022) proposed a scientific terminology for rigorously classifying joining methods of inter-module connections and developed a multi-attribute rating system based on the benefits and constraints of existing connections. This significant citing paper referred to the most frequently cited paper, Lacey et al. (2019), who evaluated four of twelve bolted inter-module connections for stiffness based on theory and experiment. Lacey et al.

(2018) also summarized the works of eighteen inter-modular connections in which their capability of providing vertical and/or horizontal connectivity was evaluated. As articles in this cluster analyzed aspects of inter-modular connections in precast buildings, the proposed name “inter-modular connections” is considered appropriate for labeling.

Cluster #2, labeled "off-site construction," is the third largest cluster with 55 articles. The majority of articles within this cluster focused on requirements concerning time, cost, labor-related, and production process aspects to facilitate the proficient implementation of OSC. However, it is noteworthy that only two articles addressed the enhancement of environmental efficacy within this context (Teng et al., 2018, Tao et al., 2018). Arashpour et al. (2015a) focused on the feasibility of automatic production monitoring to improve productivity, and the latter focused on maximizing the utilization of multi-skilled resources and integrating processes in precast construction. Direct capacity balancing and indirect skill chaining are solutions for resource imbalance and variable timeframes. As the articles in this cluster emphasized methods to enhance performance in OSC, a more specific label for this cluster would be "augmenting output."

Cluster #3, labeled "seismic performance", comprised 38 articles. Lu et al. (2021) investigated the flexural capacity of precast beams connected by double steel couplers and concluded that the load-bearing capacity of precast beams could be estimated using the method for cast-in-place beams. The most cited member in the cluster is Bahrami et al. (2017), with 14 times cited in the cluster. This article suggested and examined two prefabricated beam connections to column connections. Although there were several articles in this cluster related to seismic performance (Huang et al., 2021, Yuan et al., 2022, Zhang et al., 2021c), most of them investigated precast concrete beams behaviors (Lu et al., 2021, Li et al., 2020) or related to the seismic behavior of precast concrete beams (Huang et al., 2021, Yuan et al., 2022, Zhang et al., 2021c, Ghayeb et al., 2020). Therefore, labelling this cluster as “prefabricated concrete beams” would be more encompassing.

Cluster #4, labeled "cyclic loading test", contained 29 articles. Jiang et al. (2020c) proposed an earthquake-resistant prefabricated cross joint design with a single flange cover plate. The testing results showed that the joint had a high load-carrying capacity and seismic performance with appropriate parameter values. Repair work after earthquakes was efficiently performed by replacing the connection components, and the standards for earthquake resilience were met. To limit damage, “a new earthquake-resilient prefabricated column-flange beam-column joint” (Zhang et al., 2020d) and “end-plate type prefabricated steel frame beam-column joint” (Zhang et al., 2020b) were also proposed and demonstrated feasible results. The most cited member in the cluster is Liu et al. (2018), cited 21 times in the cluster. A beam-column bolt joint for precast steel structures in multi-story buildings was proposed, and its performance was tested using finite element analysis, static, and hysteresis. It is noticeable that all the citing papers in the cluster studied types of joints to mitigate the impact of earthquakes, such as earthquake-resilient prefabricated cross joint (ERPCJ) with single flange cover plate (FCP) (Jiang et al., 2020c); prefabricated column-flange beam-column joint (PCFBCJ) (Zhang et al., 2020c, Jiang et al., 2019); end-plate type prefabricated steel frame beam-column joint (EPPSFJ) (Zhang et al., 2020a); prefabricated beam-column steel joint (PBCSJ) with double flange cover plates (FCPs) (Jiang et al., 2020e); PBCSJ with L-shaped plate (Jiang et al., 2020a), T-shape connector (Zhang et al., 2021a); prefabricated sinusoidal corrugated web steel beam-column joint (PSCWJ) (Jiang et al., 2020d); prefabricated steel cross joints with different FCP connections (Zhang et al., 2021b); prefabricated opening-web steel channel beam-to column joint (POWSCBCJ) with flange cover plates (FCPs) (Jiang et al., 2020b). Therefore, this cluster's name should be changed to "earthquake-resilient prefabricated beam-column steel joint".

Clustering visually represents the main research domains, and the foundational literature within the clusters forms the basis of study. The first two clusters, which examined modular building characteristics and inter-modular connections of prefabricated buildings, had a notably higher number of articles than the other clusters. The studies in these clusters had the most recent average year (2018), indicating a recent trend in research.

3.2.3. Research process of MMC

The Burstness metric was used with a minimum duration of 3 years to identify references with the strongest citation bursts. The top 11 references with the most significant citation bursts were then presented in chronological order (Table V), providing insight into the evolution of research hotspots in MMC.

Table V. Top 11 references with the strongest citation burst

The citation burst for Jaillon and Poon (2014) started in 2015 and lasted until 2019. This burst highlights the focus on industrialized, adjustable, and demountable construction techniques, as well as design for deconstruction in prefabricated concrete construction. The 2016 citation burst, which occurred between 2016 and 2018, is associated with Arashpour et al. (2015b), which centered on the optimal number of additional skills needed in modular construction. Using simulation tests with Australian data, the study identified strategies for process integration in offsite building networks.

The 2017 strongest citation explosion stage, which occurred between 2017 and 2022, is related to Fathieh and Mercan (2016) on the seismic analysis of steel modular structures. Significant results are summarized as follows: (i) the floor-to-floor inter-story drift was found to be an adequate method for assessing the displacement between floors and produced satisfactory outcomes; (ii) the distribution of displacement between floors was found to vary in the elastic range of response, causing most of the inelasticity to occur primarily on the ground floor; (iii) modeling individual diaphragms for each module was found to improve the accuracy of the representation of a braced frame's lateral stiffness, displacement, and natural frequency; (iv) the 3D model was found to have a weaker structural capacity for incipient collapse compared to the 2D model when evaluated using IDA and nonlinear pushover analysis; and (v) modular Steel Building structures were found to possess a relatively higher capability to withstand maximum base shear due to the significantly larger number of columns that support lateral shear.

The 2018 strongest citation explosion stage, which occurred between 2018 and 2022, is related to Kamali and Hewage (2016). The results of their literature review led to the following conclusions: (i) modular construction has both advantages and difficulties; (ii) further research is needed to quantify the benefits and drawbacks of modular techniques by clearly identifying and evaluating them using appropriate performance criteria; (iii) modular structures are generally expected to have better life cycle performance, but there is a lack of research on the environmental, social, and economic life cycle assessments of modular structures; (iv) integrating the findings of LCA, LCC, and SLCA within a life cycle sustainability assessment framework can provide a sustainability rating for modular construction in comparison to conventional options for a specific scenario and assist construction industry decision-makers in choosing the optimal construction method for specific circumstances.

4. Conclusion

The lack of well-defined emphasis on specific MMC methods hinders the effective utilization of its benefits, leading to potential inefficiencies in the field. To comprehensively investigate the MMC research landscape, an examination of visual representation using CiteSpace software was conducted on a total of 1957 documents from the primary compilation of the Scopus database, yielding the following results:

(1) The literature in MMC research has shown a steady upward trend, increasing steadily from 2013 to 2017 and then experiencing a significant spike in the next five years.

(2) The journals with the highest level of citations in MMC are Engineer Structures, Journal of Structural Engineering, and Journal of Constructional Steel Research.

(3) Notable researchers in MMC research include Wang, J., Liu, Y., and Wang, Y.. The general state of the collaboration network among authors highlights the potential for collaboration and explains the recent rapid growth of the field of MMC research.

(4) The top institutions with the largest MMC publications are the Ministry of Education China and the Beijing University of Technology. The most dominant nation is China, followed by Australia, the United States, the United Kingdom, Canada, and Hong Kong.

(5) MMC research's most frequently used term is “modular construction”. The research hotspots include research on concrete and reinforced concrete.
(6) The primary research frontiers in MMC include studies on the characteristics of prefabricated buildings, inter-modular connections, augmenting output, prefabricated concrete beams, and earthquake-resilient prefabricated beam-column steel joints.
(7) The methodology of inquiry in MMC is established through citation explosion analysis, which reveals the temporal progression of MMC research.

Based on the synopsis of the current state of the MMC research field, there are a few notable points for future research directions and potential applications. Among the five largest clusters, there is a significant gap in the number of publications between cluster #0 (91 publications), cluster #1 (90 publications), and the remaining clusters (55, 38, and 29 publications for clusters #2, #3, and #4, respectively). However, with the increasing popularity of MMC, topics related to "augmenting output," "prefabricated concrete beams," and "earthquake-resilient prefabricated beam-column steel joints" require more research attention and may be considered future trends. Firstly, modular construction aims to industrialize the building construction process; thus, solutions to increase production efficiency or integrate processes should be given more attention. Secondly, studies on the behavior of prefabricated concrete beams contribute to the efficient use of modular buildings. Earthquakes have inflicted significant economic and social damage, necessitating that the construction industry gives paramount consideration to developing earthquake-resistant structures. The beams and columns in prefabricated structures often exhibit varying levels of plastic damage following an earthquake, complicating achieving earthquake resilience. Therefore, earthquake-resilient prefabricated beam-column steel structures should receive more attention.

The findings of this study will have significant implications for various stakeholders in both academia and industry. Academically, researchers can leverage this knowledge to identify gaps in existing research and direct their efforts towards areas that require further exploration. Additionally, the insights into the leading authors, journals, institutions, and countries will foster collaboration and knowledge exchange, leading to

more impactful and innovative research outcomes. The study's implications apply to industries and organizations that utilize OSC practices. The clarity on OSC techniques will enable these entities to implement and adopt best practices efficiently, promoting collaboration, innovation, and global problem-solving.

This study has limitations in that it only analyzed English journal papers from the Scopus database, which does not provide comprehensive coverage. Additionally, including the analysis of monographs, conference reports, and papers in other languages can offer a broader perspective for studying the MMC field. Further research can be enhanced by incorporating a wider range of literature sources and utilizing alternative visualization software. By acknowledging the limitations of this study, future researchers can build upon its foundation and expand the knowledge base of the MMC field more effectively.

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Table I. Top 10 publication titles

Publication Titles	Literature Numbers
Engineering Structures	225
Construction and Building Materials	141
Journal of Building Engineering	140
Automation in Construction	139
Journal of Constructional Steel Research	115
Structures	109
Buildings	108
Advances in Civil Engineering	98
Journal of Construction Engineering and Management	83
Energy and Buildings	61

Table II. Top 12 institutions

Institution	Literature Numbers	Countries
Ministry of Education China	144	China
Beijing University of Technology	80	China
Southeast University	73	China
Hong Kong Polytechnic University	66	Hong Kong
Tongji University	62	China
The University of Hong Kong	56	Hong Kong
University of Alberta	50	Canada
Central South University	39	China
Western Sydney University	37	Australia
Tsinghua University	37	China
University of Melbourne	37	Australia
Xi'an University of Architecture and Technology	37	China

Table III. The top 10 most frequently co-cited articles in MMC

Author	Title	Year	Citation Counts	Source
Kamali, M.; Hewage, K.	Life cycle performance of modular buildings: A critical review	2016	34	Renewable and Sustainable Energy Reviews
Hong, J.; Shen, G.Q.; Zhang, B.; Li, Z.; Zhang, W.	Barriers to promoting prefabricated construction in China: A cost–benefit analysis	2018	33	Journal of Cleaner Production
Lacey, A.W.; Chen, W.; Hao, H.; Bi, K.	Review of bolted inter-module connections in modular steel buildings	2019	31	Journal of Building Engineering
Chen, Z.; Liu, J.; Yu, Y.	Experimental study on interior connections in modular steel buildings	2017	31	Engineering Structures
Chen, Z., Liu, J., Yu, Y., Zhou, C., Yan, R.	Experimental study of an innovative modular steel building connection	2017	27	Journal of Constructional Steel Research
Fathieh, A.; Mercan, O.	Seismic evaluation of modular steel buildings	2016	27	Engineering Structures
Liu, X.C.; Zhan, X.X.; Pu, S.H.; Zhang, A.L.; Xu, L.	Seismic performance study on slipping bolted truss-to-column connections in modularized prefabricated steel structures	2018	21	Engineering Structures
Lacey, A.W.; Chen, W.; Hao, H.; Bi, K.	Structural response of modular buildings - An overview	2018	21	Journal of Building Engineering
Ferdous, W.; Bai, Y.; Ngo, T.D.; Manalo, A.; Mendis, P.	New advancements, challenges and opportunities of multi-storey modular buildings - A state-of-the-art review	2019	21	Engineering Structures

Yin, X.; Liu, H.; Chen, Y.; Al-Hussein, M.	Building information modelling for off-site construction: Review and future directions	2019	20	Automation in Construction

Table IV. Summary of the five largest clusters:

Cluster ID	Size	Silhouette	Top terms (LSI)	Average Year
0	91	0.892	offsite construction; prefabricated building; modular integrated construction project; prefabricated construction; systematic review	2018
1	90	0.907	inter-module connection; modular steel building; modular building; modular building system; seismic performance	2018
2	55	0.867	off-site construction; process integration; augmenting output; autonomous production tracking; multi-skilled resource utilization	2014
3	38	0.947	seismic performance; seismic behavior; prefabricated concrete beam; double-grouted sleeve; flexural behaviour	2017
4	29	0.962	cyclic loading test; earthquake-resilient prefabricated beam-column steel joint; steel frame; cross joint; single flange cover plate	2017

Table V. Top 11 references with the strongest citation burst

References	Strength	Begin	End	2013 - 2022
Jaillon and Poon (2014)	6.35	**2015**	2019	
Arashpour et al. (2015)	3.89	**2016**	2018	
Lawson et al. (2014)	6.16	**2017**	2019	
Liu et al. (2015b)	4.9	**2017**	2020	
Chen et al. (2015)	3.58	**2017**	2019	
Fathieh and Mercan (2016)	3.42	**2017**	2022	
Liu et al. (2015a)	3.14	**2017**	2020	
Kamali and Hewage (2016)	5.65	**2018**	2022	
Bock (2015)	3.87	**2018**	2020	
Goulding et al. (2015)	3.49	**2018**	2020	
Liu et al. (2017)	2.64	**2018**	2020	