Offsite Construction in Housing: A Scientometric Review of Information Management Trends and Technological Integration

Journal:	*Engineering, Construction and Architectural Management*
Manuscript ID	ECAM-10-2024-1314.R3
Manuscript Type:	Original Article
Keywords:	Construction Planning, International Construction, Knowledge Management, Strategic Management
Abstract:	

Offsite Construction in Housing: A Scientometric Review of Information Management Trends and Technological Integration

Abstract:

Design/methodology/approach: This study conducted a bibliometric and scientometric analysis of 68 selected publications from 1995 to 2024, exploring trends in information management within offsite construction (OSC, particularly in housing. The analysis of the selected papers on OSC in housing revealed a growing research interest since 2009.

Purpose: The global housing shortage has underscored the need for innovative solutions, such as OSC. Despite its potential to improve efficiency, reduce costs, and enhance sustainability, the adoption of OSC has been slow due to economic, social, and technical barriers.

Findings: Publications have increased steadily, peaking in 2022, with *Automation in Construction*, *Journal of Cleaner Production*, and *Buildings* emerging as the leading journals. Keyword analysis highlighted "building information modelling" and "prefabrication" as dominant themes, reflecting their crucial role in the field. The co-authorship and co-citation analyses identified Geoffrey Qiping Shen as a leading researcher, with Hong Kong and China leading in publication and citation counts, highlighting their significant impact on the field. The findings also revealed a growing interest in integrating advanced technologies, such as BIM, artificial intelligence, and the Internet of Things, alongside a focus on sustainability, modular construction, and lifecycle management.

Originality/value: This analysis in this study highlights key themes like building information modelling (BIM), prefabrication, and sustainability, and identifies leading researchers and regions, emphasizing the integration of advanced technologies such as AI and IoT in the field. Limitations include reliance on existing publications and the exclusion of industry practices not yet widely documented. Future research should broaden its scope to include recent industry developments and regional case studies, emphasizing the need for more comprehensive information management systems to support the evolving OSC discipline.

Keywords

Modern methods of construction, Prefabrication, Modular construction, Offsite construction, Information management, Advanced technologies, Housing shortage

1. INTRODUCTION

To keep up with existing demand, around 200,000 homes in the United Kingdom (UK) should be constructed annually, and the target of around 300,000 new homes per year is crucial to alleviating the supply deficit that contributes to rising prices. Unfortunately, the UK government targets have been missed consistently for decades (B. S. Association, 2017). Like the UK, other countries, such as the United States, China, and South Korea, are no exception, and the housing shortage is not new to the world. According to the UN report (2023), a staggering 1.6 billion people worldwide lack adequate housing and basic services, with projections suggesting this number could increase to three billion by 2030. Additionally, an estimated 100 million people globally are homeless (Nations, 2023). There is no one straightforward solution to this lack of affordable homes and the consequent wave of homelessness.

Nevertheless, offsite construction (OSC) is acknowledged as one of the recognizable approaches within the array of modern methods of construction (MMC) to challenge speed expectations and quality issues prevalent in the global construction housing industry (Ofori-Kuragu, 2022; Smith, 2015; Moon et al. 2020), and a trend within the housing and residential industry favoring prefabrication elements has been gaining momentum in recent years, as it offers advantages such as increased efficiency, cost savings, and improved quality control (Alwisy, 2019; Mullens, 1995; Zaalouk et al. 2023). By shifting more of the construction process to controlled factory environments, contractors can streamline operations, reduce waste, and accelerate project timelines (Chiang, 2008; Hou et al. 2022; Na et al. 2022). With the introduction of OSC using the latest technology—known as MMC—and increasing demand for sustainable and affordable housing, the widespread adoption of prefabrication methods in the housing industry is expected to continue.

Despite those benefits, it is surprising to observe how many countries have been slow to embrace change and innovation in housebuilding. Previous research has identified a range of factors that contribute to the slow adaptation of OSC, such as economic factors, including affordability, external regulations, and funding; social factors, including shifts in tenure mix, the challenge of housing a growing and changing population, and views on OSC; and environmental and technical factors, including the condition of existing housing stock, design factors, supply chain, maintenance skills for OSC, and data and records management (B. S. Association, 2017; Kempton, 2009).

(Persson, 2009) argue that challenges in information management for OSC in housing are likely to hinder productivity growth and the exploitation of economies of scale in the OSC sector. This is primarily because information management practices in these companies have not evolved sufficiently and still largely mirror those of traditional onsite construction projects. Despite the shift from project-oriented building to production-oriented manufacturing due to prefabrication strategies, the documentation processes have not adapted adequately to reflect this change. Additionally, there is currently no information management model or framework being used for the existing housing stock to record data and maintain information, as (Kempton, 2009) highlight that the storage of electronic data on housing stock presents specific challenges for MMC housing due to the diverse range of element types and materials that are not easily compatible with existing data systems. These concerns raise questions about the sufficiency of information systems to support future maintenance plans for MMC housing. More recently, (Agapiou, 2022) conducted a quantitative study to identify the barriers to OSC adoption in the UK housing sector. This study identified key challenges, including cost issues, supply chain capacity constraints, and a preference for traditional construction methods, as major factors

hindering OSC adoption. These barriers highlight that the lack of a robust information management framework and the absence of standardization remain critical challenges that must be addressed. This research used bibliometric and scientometric analysis to answer the following research questions:

RQ1. What are the most relevant keywords in information management and OSC in housing studies?
RQ2. Who are the most productive authors and important journals on information management and OSC in housing studies?
RQ3. What are the future trends of publication on information management and OSC in housing studies?

This research aimed to conduct a systematic review of existing academic literature to better understand information management practices within the OSC sector—specifically focusing on housing from 1995 to 2024 (as of the end of February)—and seek an answer to the questions above with the following objectives: (1) to identify the relevant keywords and key contributors to OSC and housing research via a data visualization technique; (2) to analyze the existing academic studies on OSC and housing, with a specific focus on information management; and (3) to propose the evolution of research themes and future directions in information management for OSC in housing.

2. BACKGROUND

2.1 Definition of MMC/OSC

OSC represents an innovative approach within the construction industry, adopting a "factory production – onsite assembly" method (Mtech Group, 2007). This involves the production of key construction components in a factory setting, which are then transported to the site for assembly (Taylor, 2010). Compared to traditional onsite construction methods, this approach significantly enhances the efficiency of the construction process, reduces construction time, and contributes to the improvement of the final building's quality. Additionally, it offers important benefits, such as enhancing safety on construction sites and promoting environmental sustainability (Hosseini et al., 2018).

This growing adoption of OSC in housing has prompted extensive research into its multifaceted benefits and applications. Recent studies have explored OSC's ability to address critical issues such as environmental sustainability, cost-efficiency, and technological integration. For example, (Rathnasinghe, Thurairajah, Jones, & Goulding, 2024)) highlight OSC's potential to simultaneously achieve environmental sustainability and economic efficiency, while (Daniel et al., 2024)) demonstrate that integrating Lean Construction (LC) principles into OSC enhances productivity and reduces waste. (Clyde Zhengdao Li et al., 2022) and (Z. Zhang et al., 2024) emphasize the role of advanced technologies, including BIM, AI, and digital twins, in improving OSC project efficiency and fostering collaboration. Furthermore, (Han, Yan, & Piroozfar, 2023) propose that IoT and blockchain technologies can optimize logistics and reduce costs in OSC supply chains. These studies collectively illustrate how OSC is evolving into a forward-looking construction methodology that combines sustainability, cost-efficiency, and technological innovation, making it a key area of research and practice in addressing global housing challenges.

Nonetheless, the nomenclature for OSC varies by country (Ayinla, Cheung, & Tawil, 2020). This variation reflects the unique technical and cultural contexts within each country's construction industry. The diversity of terms used internationally for OSC projects or research can complicate the efficient exchange of information and cooperation (Lou, Lu, Xu, Li, & Wang, 2022). Due to this, it is necessary to examine and consolidate the various national terminologies closely into a single, unified term. The different terminologies used by national associations were investigated, and different categories of OSC from current practices were identified (Eren, 2016; Page, 2023). The list below and Table 1 present terms used to describe this kind of construction method, which is centered around a manufacturing approach:

(1) Modern methods of construction (MMC)
(2) Prefabrication
(3) Offsite manufacturing
(4) Modular integrated construction (MIC)
(5) Prefabricated prefinished volumetric construction (PPVC)

The definitions of these terms focus either on the process, the outcome, or both, encompassing the entire methodology. In the United Kingdom (UK), the term MMC is used to describe various construction techniques that differ from traditional building methods, serving a broad meaning (Foundation, 2016). In Australia, "prefabrication" encompasses a wide array of systems and processes under the umbrella of prefabricated construction, which can be referred to as the method of 2D-preassembly in other countries (Page, 2023;

prefabAUS). New Zealand uses "offsite manufacturing" to denote buildings constructed away from the construction site, a term interchangeable with prefabrication (OffsiteNZ). Hong Kong's use of MIC encapsulates the concept of "factory assembly followed by onsite installation," covering both the process and the product (MiC). Singapore employs the term PPVC, indicating the assembly of stand-alone three-dimensional modules externally, offering a more specific definition compared to the other terms (Authority).

Table 1. Definitions of terms in different countries

Terminology	Definitions	Country	Reference
Modern Methods of Construction (MMC)	Encompasses various approaches related to manufacturing or assembling away from the construction site	UK	(T. a. C. P. Association, 2020; Foundation, 2016; Sanchez-Garrido, 2023)
Prefabrication	All parts of a building manufactured in a different location than its final site	Australia	(prefabAUS)
Offsite manufacturing	All parts of a building created away from the final building site.	New Zealand	(OffsiteNZ)
Modular Integrated Construction (MiC)	Adopts the concept of factory assembly followed by onsite installation	Hong Kong	(MiC; Zhou, 2023)
Prefabricated Prefinished Volumetric Construction (PPVC)	A construction method where stand-alone three-dimensional modules are completed with interior finishes, fixtures, and fittings at an external fabrication facility before being delivered and installed on site	Singapore	(Authority)

The diversity of these terms reflects the varying perceptions and approaches to OSC within the construction industries of different countries. OSC can be categorized into different levels of factory work, covering subassembly, 2D/3D preassembly, and volumetric systems (Page, 2023). This categorization implies that the different terms need to be compared to the practical level(s) of factory work in each country. Additionally, this diversity can lead to confusion in the sharing of information, highlighting the need for the adoption of a unified term. Recognizing this diversity, this paper advocates for the use of "offsite construction (OSC)" as a term to facilitate international standardization. This term is broadly applicable and suitable for encapsulating the entire process from manufacturing at the factory to assembly onsite.

2.2 OSC in housing

OSC has emerged as a highly innovative approach to meet the urgent demands for housing (Xiao, 2023) since it allows houses to be constructed much more quickly than traditional construction methods and is increasingly used in housing to build high-quality, energy-efficient homes. In countries such as the UK, Singapore, Hong Kong, and Sweden, the adoption of OSC has been promoted as a component of policies aimed at addressing the increasing need for housing, particularly among low-income households (Brissi, 2023). In addition to permanent residential houses, offsite and modular construction methods are increasingly used to create temporary accommodation and other buildings, such as the two emergency hospitals that were constructed in Wuhan, China, in just 12 days during the COVID-19 pandemic (T. Li, Yuan, L. ming, Hou, G. qiu, & Wu, Y. feng., 2022). The rising demand for high-quality housing and environmentally friendly construction has led the rigorous standards and qualifications of housing construction to meet the demands of modern society (Sanchez-Garrido, 2023) and a wide range of OSC methods, including integrated module construction, prefabrication, preassembly, panelized systems, industrialized construction, offsite production or manufacturing, and various onsite and hybrid construction methods (Rahman, 2014).

When any specific OSC method is adopted for housing in different countries, it relies on various factors, such as construction materials, components, processes, and government initiatives. As traditional housing methods in the UK involve constructing with various components, such as brick/block walls and a timber-supported, pitched, tiled, or slated roof [6], panelized components and precast panels have been popular in housing and residential construction due to the benefits of reducing the scheduled duration of the convectional project (Patil, 2023); in addition, more than 80% of newly constructed homes in Scotland utilize OSC, primarily employing timber framing, such as cross-laminated timber panel construction delivered to the site, as innovation and improved productivity are essential in light of the current shortage of newly built rural areas (Scotland, 2020), and timber is less detrimental to the environment, compared with steel and concrete production (and transportation) (T. a. C. P. Association, 2020).

While timber has been used primarily for housing construction in European countries, concrete has been preferred as an offsite housing construction material for high-rise residential buildings in some East Asian countries due to limited land availability in densely populated urban areas. For example, the Hong Kong government, through its Housing Authority, has made prefabrication mandatory since the mid-1980s due to the shortage of skilled labor and quality improvement (Chiang, 2008), and concrete has been mainly used for precast concrete components, including staircases, façade, partitions, and structural walls, as the case in Singapore, which has seen remarkable success in precast concrete housing construction in the past 20 years (Beushausen, 2002).

In terms of design and construction processes, design for manufacturing and assembly (DfMA) has been adopted in order to build offsite houses effectively and efficiently as per the guidelines, and DfMA is comprised of design for manufacturing and design for assembly (Vakaj, Cheung, Cao, Tawil, & Patlakas, 2023). The increasing adoption of OSC methods is facilitated by the integration of DfMA principles, enabling housing developers to achieve mass customization in modular prefabrication (Hwang, 2023). Through the integration of these principles, OSC can provide extensive customization opportunities while enhancing the advantages of standardized, replicable modules. However, there is no systematic and holistic approach to integrating DfMA knowledge and practices in housing construction, and a primary challenge in implementing DfMA for housing modular construction is the absence of tools capable of assessing modular design, construction, and information

management, often necessitating input from multiple professionals with expertise in offsite production, costing, and scheduling (Vakaj et al., 2023).

3. RESEARCH METHODOLOGY AND METHODS

A research framework incorporating systematic review and meta-analysis methodologies (PRISMA) (Hirabayashi, Nakayama, Yahaba, Yamanashi, & Kawasaki, 2023; Zhang, Antwi-Afari, Zhang, & Xing, 2024) was employed to directly review relevant and essential scholarly references related to OSC in housing and its information management. The PRISMA method outlines protocols for searching, selecting, and analyzing existing scientific literature and includes a checklist to ensure the validation of the process; this procedure enables the literature review to be conducted in a systematic, transparent, and comprehensive manner, minimizing bias and ensuring reliable results (X. Zhang et al., 2024). This process proceeded through five key stages (Karimi, Baghalzadeh Shishehgarkhaneh, Moehler, & Fang, 2024): 1) study scope definition, 2) research question formulation, 3) paper selection, 4) bibliometric/scientometric analysis, and 5) findings presentation. While this study focuses on peer-reviewed academic literature, it is acknowledged that this may exclude practical insights from industry. However, this approach was chosen to align with the scientometric goal of analyzing verified, citation-based research trends.

A systematic literature review (SLR) is the standard approach to thoroughly understanding the research domain in construction (Herath Mudiyanselage Samadhi Nayanathara Samarasekara * & Rotimi, 2024), and keyword searches were employed to identify relevant studies and literature on this research topic. This process typically involves selecting keywords closely related to the topic, including synonyms, related terms, and variations among the main concepts. Table 2 shows the search keywords and the results of both Web of Science (WoS) and Scopus databases applied.

Table 2. Search strings and results of database search

Database	Search Keyword	Inclusions	Exclusions	Range (1994-2024)
Web of Science	"Information" OR "Management" OR "Information Management"; AND "Modern Methods of Construction" OR "offsite construction" OR "off-site construction" OR "prefabrication" OR "prefabricated construction" OR "Modular Integrated Construction" OR "Prefabricated Prefinished Volumetric Construction" OR "Modular construction" OR "industrialized construction" OR "digital fabrication"; AND "Housing" OR "House" OR "Houses" OR "Home" OR "Residential" OR "Domestic building"	Subject Area—Engineering Language—English	Conference paper/review Note Data paper	91
Scopus		Subject Area—Engineering Language—English	Conference paper/review Note Data paper	90
Total				181

The systematic review process covers studies from December 1994 to February 2024 because the selected keywords appeared in the literature in 1994, and have shown a gradual increase in academic output

since 2009, as shown in Figures 1 and 2. An extensive dataset of 181 papers, comprising journal articles and book chapters, was initially collected from prominent databases, such as Scopus and WoS, which served as the primary data sources for the study. Exclusion criteria were implemented to refine this extensive collection: papers unrelated to housing construction or information management in OSC and those not written in English were removed from the dataset. This rigorous screening process narrowed the selection to 68 papers, which were then subjected to a detailed bibliometric and scientometric analysis, which is defined as "a quantitative study of the research on the development of science" (Ghaleb, Alhajlah, Bin Abdullah, Kassem, & Al-Sharafi, 2022; Yalcinkaya & Singh, 2015). Both analyses were used to analyze information management and OSC in housing within the construction domain and were adopted as an approach to visualizing and mapping the knowledge area. To overcome the limitations of manual quantitative analysis, such as subjective interpretation (X. Zhang et al., 2024), VOSviewer, as a bibliometric analysis tool, was utilized to analyze the trend and impact of information management on OSC in housing research and to visualize the research pattern and trend as follows: (1) keyword co-occurrence analysis, (2) co-occurring keywords timeline, (3) co-authorship, (4) document co-citation, (5) the co-occurrence of countries, and (6) research institutions. This approach has been widely suggested and accepted for an SLR and a scientometric analysis (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011; Ghaleb et al., 2022; Song, Zhang, & Dong, 2016; X. Zhang et al., 2024).

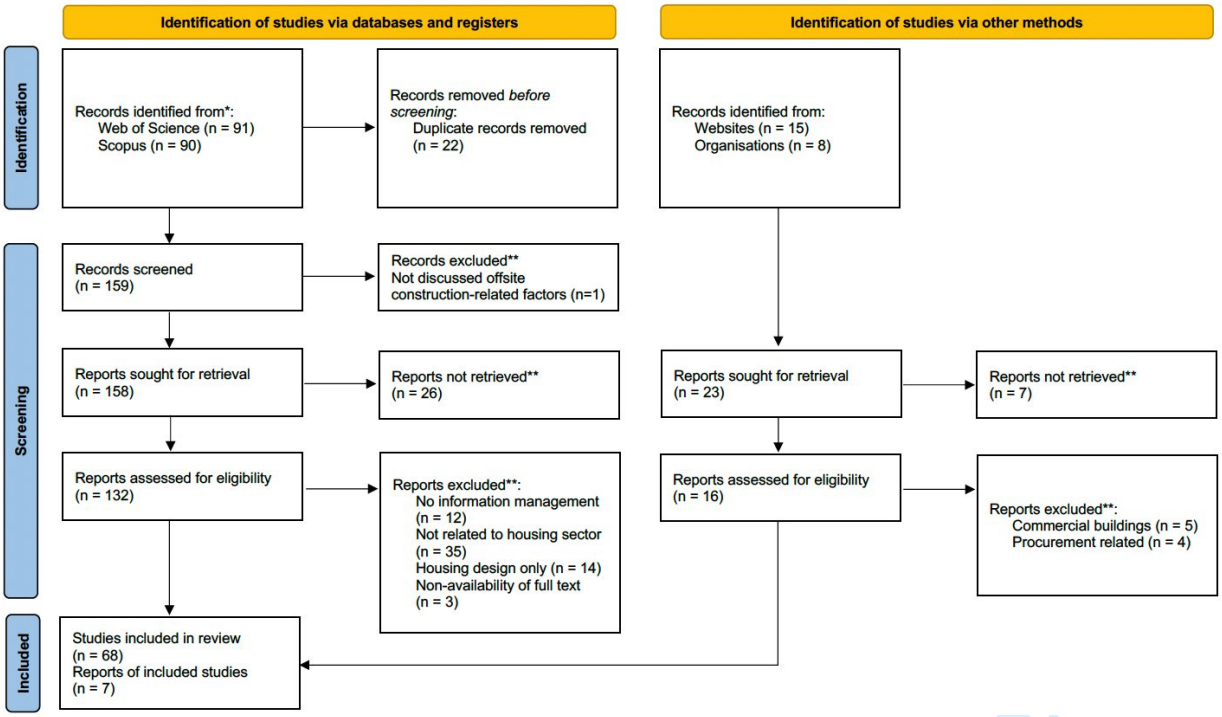

Figure 1. PRISMA Flow Chart. (* Records excluded via automation; ** records excluded via human reviewer.)

4. FINDINGS

4.1 Overall trend of selected journals and annual publications

Using the bibliometric and scientometric approach, the 68 selected papers were analyzed to demonstrate clarification and relevance to the literature, research keywords, authorship, citation, research institutions, and collaborating countries involved in information management and OSC in housing. This approach shows a tendency to be thematic and can be categorized into distinct clusters according to similarities in content and the issues it addresses (Tanko, Zakka, & Heng, 2024).

The 68 papers on information management and OSC in housing between 1994 and 2024 (as of the end of February) were selected, and the basic information of those papers was analyzed. Figure 2 presents a gradual increase in academic output since 2009, and the trend illustrates that research on information management and OSC in housing has remained largely unexplored until 2009. The number of publications was consistent with one to three publications per year from 2009 to 2015, and there was a gradual increase with minor fluctuations, peaking at ten publications in 2022. The years 2018 and 2019 stood out with a notable rise to seven and nine publications, respectively. It is noted that the number of publications only reflects research output available online up until the end of February 2024, when this paper was drafted.

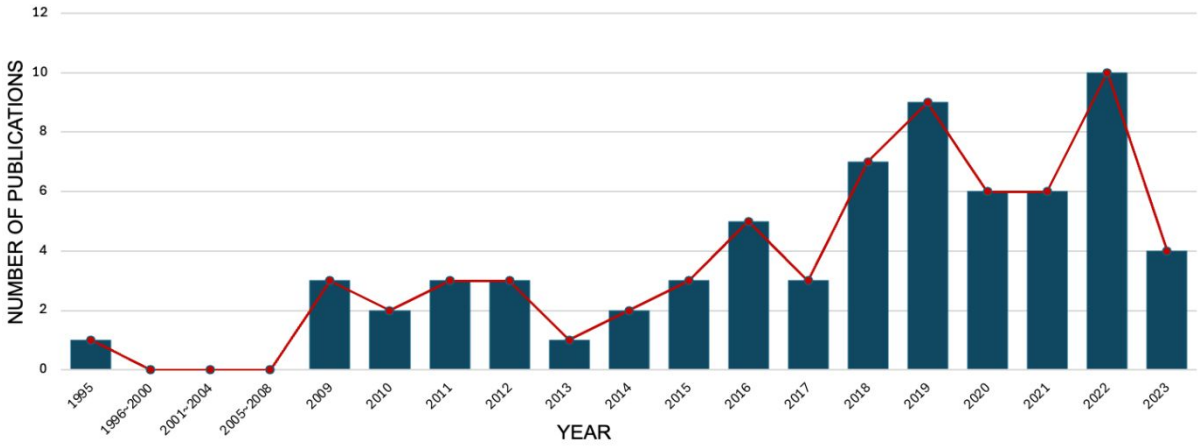

Figure 2. Number of annual publications of Information management for offsite construction in housing

As shown in Table 3, the 68 selected papers were examined by peer-reviewed journals, revealing that the top three journals are *Automation in Construction*, *Journal of Cleaner Production*, and *Buildings*, with a total of 16 published papers. *Construction Management and Economics*, *Journal of the Architectural Institute of Korea*, *Sustainability (Switzerland)*, and *Sustainable Cities and Society* contributed three relevant particles each to this topic. Overall, the 68 selected articles spanned a range of multiple research areas, including MMC, prefabrication, offsite manufacturing, OSC, modular design and construction, housing, and building information modeling (BIM).

Table 3. Relevant peer-reviewed journals

Journal Name	Number of Publications	% Total Publications
Automation in Construction	6	8.82%

Journal of Cleaner Production	6	8.82%
Buildings	4	5.88%
Construction Management and Economics	3	4.41%
Journal of the Architectural Institute of Korea	3	4.41%
Sustainability (Switzerland)	3	4.41%
Sustainable Cities and Society	3	4.41%
Advanced Engineering Informatics	2	2.94%
Construction Innovation	2	2.94%
Electronic Journal of Information Technology in Construction	2	2.94%
Energy and Buildings	2	2.94%
Journal of Building Engineering	2	2.94%
Journal of Construction Engineering and Management	2	2.94%
Korean Journal of Construction Engineering and Management	2	2.94%
Proceedings of Institution of Civil Engineers: Management, Procurement and Law	2	2.94%
Structural Survey	2	2.94%
American Journal of Environmental Sciences	1	1.47%
Engineering, Construction and Architectural Management	1	1.47%
Habitat International	1	1.47%
IFAC-PapersOnLine	1	1.47%
International Journal for Housing Science and Its Applications	1	1.47%
International Journal of Architectural Computing	1	1.47%
International Journal of Construction Management	1	1.47%
International Journal of Housing Markets and Analysis	1	1.47%
Journal of Architectural Engineering	1	1.47%
Journal of Communications Technology and Electronics	1	1.47%
Journal of Engineering, Design and Technology	1	1.47%
Journal of Industrial Ecology	1	1.47%
Journal of Information Technology in Construction	1	1.47%
Journal of Management in Engineering	1	1.47%
KSCE Journal of Civil Engineering	1	1.47%
LHI Journal of Land, Housing, and Urban Affairs	1	1.47%
Periodica Polytechnica Civil Engineering	1	1.47%
Procedia Engineering	1	1.47%
Science of the Total Environment	1	1.47%
Smart and Sustainable Built Environment	1	1.47%
Sustainable Computing: Informatics and Systems	1	1.47%
Wood Material Science and Engineering	1	1.47%
Total	68	100%

4.2 Research keyword co-occurrence network analysis

Keywords are one of the primary marketing components of any scientific paper and play a critical role in enhancing the research visibility and impact of scientific research (Pottier et al., 2024). The keyword co-occurrence analysis using “author keywords” was conducted to create a distance-based network on the 68

selected papers and visualize the knowledge domain of information management for OSC in housing. The closeness between nodes typically indicates a stronger relationship between the keywords, while the size of each node is directly proportional to the number of documents that contain that keyword (Ghaleb et al., 2022).

The minimum number of keyword occurrences was set at two, and out of 255 keywords, 42 keywords remained. Figure 3 illustrates a keyword co-occurrence network with 41 nodes, eight clusters, 105 links, and a total link strength of 155. It is noted that some keywords with the same meanings were further reviewed and considered as the same keyword due to different spellings, such as (a) "building information modeling (BIM)," "building information modeling," "building information modelling," and "building information modelling (BIM)"; (b) "Internet of Things (IoT)" and "Internet of Things"; and (c) "schedule risk" and "schedule risks."

The visualized map provided in the network analysis graph in Figure 3 highlights the significance of keywords and the larger font size of author keywords such as "building information modelling (BIM)" and "prefabrication," which indicates the most extensively researched keyword in the field of information management for OSC in housing, followed by "modular construction," "offsite construction," "prefabrication housing production," and "housing." The number of links refers to the connections among nodes, excluding any duplicate links, while the total link strength represents the combined frequency of co-occurrences among nodes, including repeated instances. The dense interconnections between the most extensively researched keywords and others depict direct and strong relationships, illustrating how information management, such as BIM, can be incorporated into OSC, including prefabrication and modular construction, in housing.

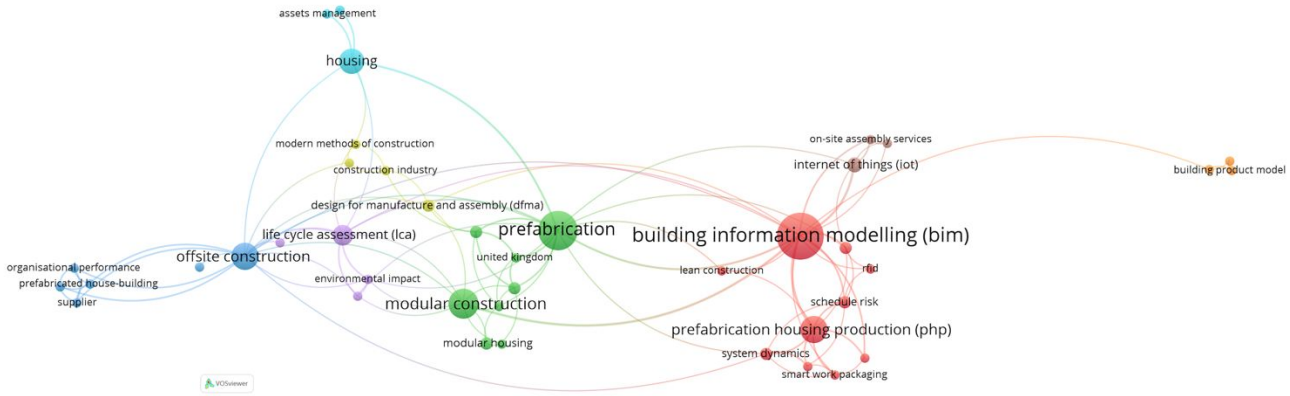

Figure 3. Keyword co-occurrence network (1994-2024)

Table 4 illustrates the number of keyword occurrences and the strength of links and indicates that "building information modelling (BIM)" and "prefabrication" were the most frequently occurring keywords between 2016 and 2019 based on the number of keyword occurrences and Mean Year published. The strong linkages to those frequently occurring keywords suggest that BIM can be considered an information management platform for OSC in housing, implying its prevalent adoption for construction projects. The total link strength in Table 4 for "building information modelling (BIM)," "prefabrication," "modular construction," "offsite construction," "prefabrication housing production," and "housing" reflects not only the strong research keywords but also the intensity of the connections among these research concepts, underlining their importance in managing information for OSC in housing.

Table 4. List of selected keywords and network parameters

Keyword	Occurrences	Mean Year Published	Links	Total Link Strength
Building information modelling (BIM)	19	2019	16	32
Prefabrication	15	2016	14	22
Modular construction	10	2019	10	13
Offsite construction	9	2020	16	21
Prefabrication housing production (PHP)	9	2018	8	17
Housing	8	2013	6	10
Life cycle assessment (LCA)	6	2016	9	13
Internet of Things (IoT)	4	2018	5	9
Construction management	3	2015	6	9
Offsite production	3	2011	6	9
Schedule risk	3	2017	6	8
System dynamics	3	2019	6	8
Hong Kong	3	2017	6	7
Design for Manufacture and Assembly (DfMA)	3	2022	5	5
Modular housing	3	2017	3	3
RFID	3	2017	3	3
Organisational performance	2	2022	4	8
Prefabricated house-building	2	2022	4	8
Supplier	2	2022	4	8
Supply chain management	2	2022	4	8
Environmental impact	2	2017	5	7
Residential building	2	2017	5	7
United Kingdom	2	2012	4	7
Discrete event simulation	2	2019	4	6
Residential housing	2	2017	6	6
Smart work packaging	2	2020	5	6
Constraints management	2	2020	3	5
On-site assembly services	2	2020	3	5
Assets management	2	2010	2	4
Construction industry	2	2022	4	4
Maintenance	2	2010	2	4
Modern methods of construction	2	2017	4	4
Building product model	2	2010	2	3
Industrialized construction	2	2010	2	3
Lean construction	2	2017	3	3
Prefabricated construction	2	2017	3	3
Product customization	2	2013	3	3
Quality management	2	2014	3	3
Systematic literature review	2	2023	3	3
Modular building	2	2013	2	2

Project Management	2	2020	1	1

According to the timeline of the co-occurring keywords network in Figure 4, previous research on information management for OSC in housing between 2009 and 2012 initially focused on product modeling in housing and a range of ICT tools, such as computer-aided design and enterprise recourse planning systems, as parts of asset management. The processes, products, and ICT environments involved in industrialized house construction were investigated from an information management perspective, and product modeling was considered an appropriate technology to create the product structure of modular houses (Malmgren, 2011; Persson, 2009).

When there was a steady increase of relevant publications with slight fluctuations between 2013 and 2019, more research on integrating BIM into prefabrication, modular housing, and prefabrication housing production was conducted to enhance cost efficiency, improve schedules, boost environmental performance, and increase quality and productivity in housing design and construction. The BIM authoring tools were incorporated into the overall design process by modeling rule-based BIM objects using automated design verification for modular construction (Singh, 2015) and various advanced technologies, including radio frequency identification (RFID) and a multi-dimensional Internet of Things (IoT)–enabled BIM platform, were examined to achieve real-time visibility and traceability in prefabricated construction for speeding up housing delivery, mitigating risks, and improving schedule performance for prefabricated house construction (C. Z. Li, FanLi, XiaoHong, JingkeShen, Geoffrey Qiping, 2018; C. Z. Li, Ray Y.Xue, FanXu, GangyanChen, KeHuang, George GuoquanShen, Geoffrey Qiping, 2017; X. Li, Geoffrey QipingWu, PengFan, HongqinWu, HengqinTeng, Yue, 2018; Zhong et al., 2017).

From 2020 to 2023, the terms “modular construction” and “offsite construction,” rather than “prefabrication,” have become more popular in publications, as those terms comprise a broad range of advanced construction techniques and systems, both offsite and onsite, providing an alternative to traditional construction, particularly in the housing sector (Sanchez-Garrido, 2023). During this period, various information on offsite housing construction at the project stage has been examined, and various management approaches in modular housing related to sustainability and supply chains were explored through a project lifecycle. For example, a BIM-based lifecycle assessment (LCA) approach for carbon emission energy management was developed based on the LCA method, and a hierarchical-based framework was proposed to evaluate the environmental performance of modular buildings versus conventional buildings (Hao, 2020; M. Kamali, KasunRana, AnberAlam, M. ShahriaSadiq, Rehan, 2023; Luo, 2020). There was also a particular focus on adopting a circular economy approach and the technical and process platforms to generate standardized, digital, and reusable information and manage information flows in the use phase (Kedir et al., 2023).

Some researchers investigated the prefabrication and OSC strategy by-products and supply chain roles and the OSC housing supply strategy, which is compared with a traditional building approach to reducing informational asymmetries during development planning stages to deliver better affordable rental housing (MacAskill, 2021; R. L. Masood, J. B. P.González, V. A., 2021). The offsite housing construction was conceptualized on supply chain management, and the performance of the supply chains for offsite housebuilding was modeled to implement prefabricated housebuilding technologies (R. Masood, James B. P.Gonzalez, Vicente A.Roy, KrishanuKhan, Khurram Iqbal Ahmad, 2022; R. R. Masood, K.Gonzalez, V. A.Lim, J. B. P.Nasir, A. R., 2023).

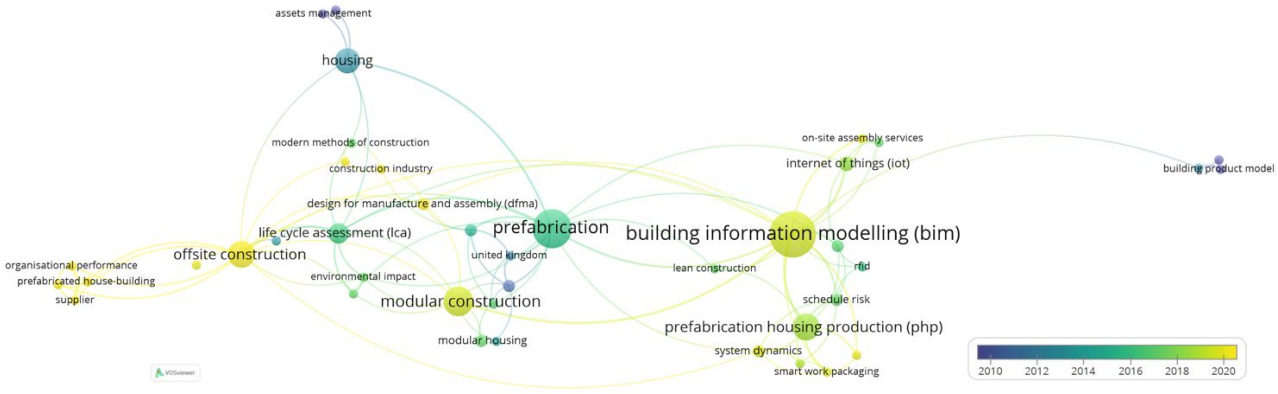

Figure 4. Timeline of co-occurring keywords network

4.3 Influential co-authors and co-citation analysis

The co-author co-occurrence network presents the relationship between authors whose publications are cited in the same documents and the links between authors in a particular field (Ghaleb et al., 2022). When investigating a specific research field, identifying the leading researchers in that domain is highly beneficial. To achieve this, the data were submitted to VOSviewer, with the type of analysis set as "co-authorship," the unit of analysis as "authors," and the counting method set to "fractional counting." The minimum number of documents per author and the minimum number of citations were again set to 2 and 1, respectively, resulting in 29 out of 195, with 16 interconnected authors identified in total with three main clusters, as shown in Figure 5. The node size represents each author's co-citation frequency, and connections among nodes reflect citation relationships created by the number of citations. Figure 5 indicates that Geoffrey Qiping Shen remains the leading researcher, while the prominence of Clyde Zhengdao Li and Fan Xue has increased, which suggests that these researchers continue to exert significant influence in the field of information management for OSC in housing. These results contribute to a clearer understanding of the relationships between major keywords and researchers in this field, providing valuable insights for setting future research directions.

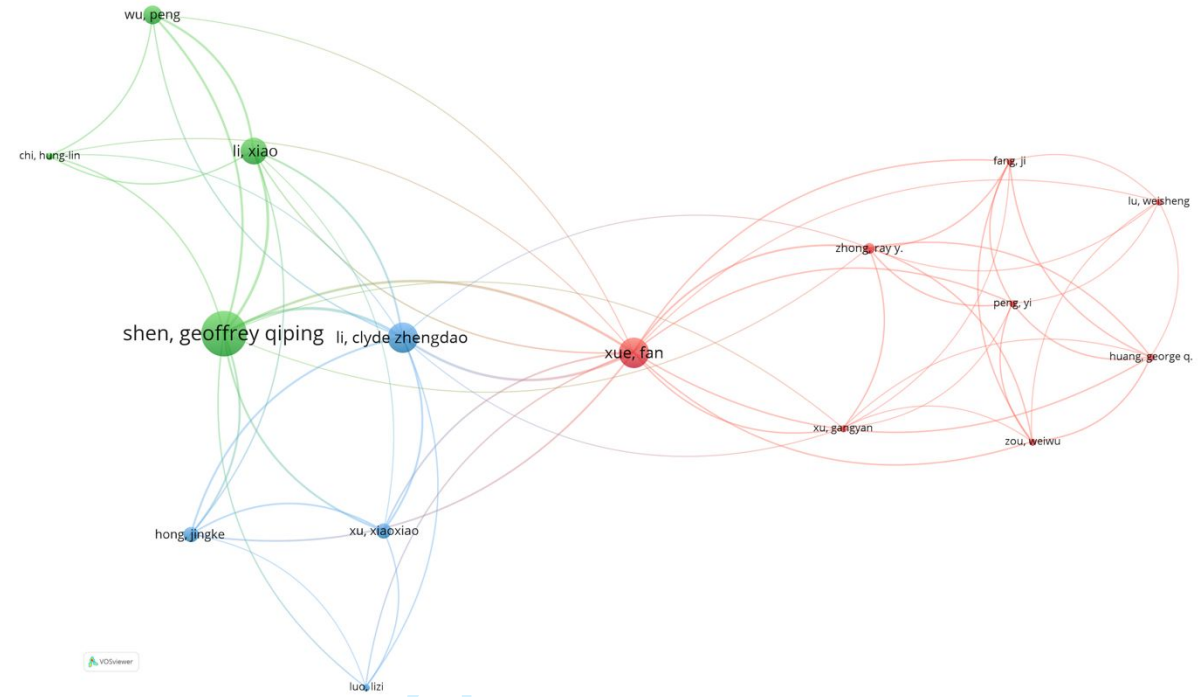

Figure 5. Co-author co-occurrence network

The document co-citation network in Figure 6 and analysis of citation in Table 5 maps the research area and groups documents based on the citation relationships among publications. This approach helps identify authoritative publications within a specific research domain. After conducting multiple tests, the minimum citation threshold was set at 20 to achieve the desired results. As shown in Figure 6, a document co-citation network was created with 20 nodes and 33 links, and five clusters. Each node represented one of 68 selected papers, and node size indicated the co-citation frequency. This allows for an assessment of the impact and influence of individual publications within the research community. Table 5 provides a detailed quantitative assessment of author citations, encompassing the title, citation links, total citation counts, and normalized citation metrics. According to Table 5, the article titled "An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction" exhibits the strongest citation links. Furthermore, it demonstrates strong relationships with four other publications, highlighting the critical importance of integrating IoT-enabled BIM platforms with offsite production technologies in housing construction.(C. Z. Li, FanLi, XiaoHong, JingkeShen, Geoffrey Qiping, 2018; C. Z. Li et al., 2016; C. Z. Li, Ray Y.Xue, FanXu, GangyanChen, KeHuang, George GuoquanShen, Geoffrey Qiping, 2017; C. Z. Li, Xue, Li, Hong, & Shen, 2018; W. G. Pan, A. G. F.Dainty, A. R. J., 2012).

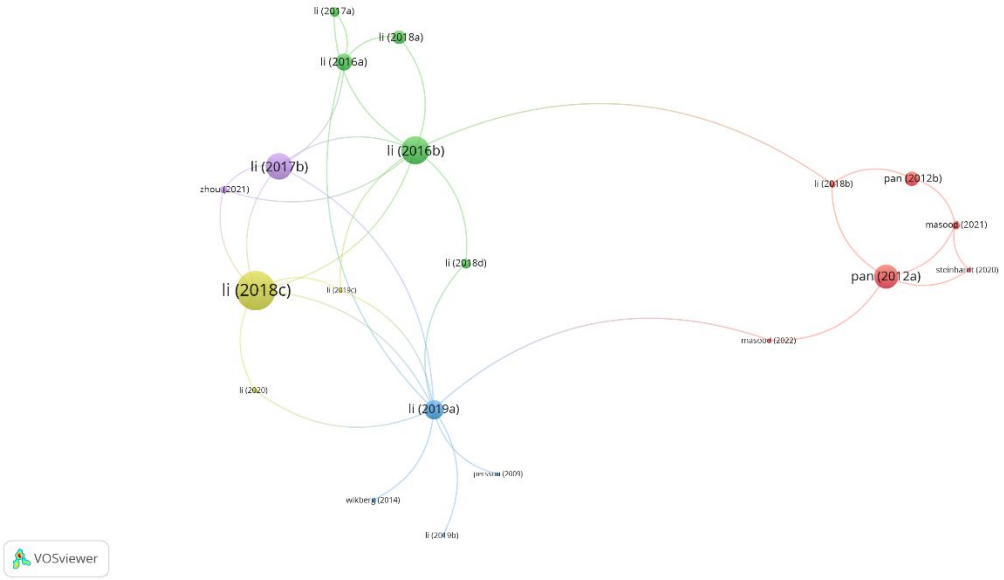

Figure 6. Document co-citation network

Table 5. Analysis of citation

Main Authors	Title	Links	Citations	Norm. citations
Li, X.	Integrating Building Information Modeling and Prefabrication Housing Production	10	33	2.94
Li, C.Z.	Schedule risks in prefabrication housing production in Hong Kong: a social network analysis	8	49	2.02
Li, C.Z.	An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction	6	149	3.55
Li, C.Z.	Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction	5	122	1.03
Li, C.Z.	SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong	4	106	1.23
Pan, W.	Strategies for integrating the use of off-site production technologies in house building	4	309	1.21
Zhou, J.X.	Customization of on-site assembly services by integrating the internet of things and BIM technologies in modular integrated construction	3	32	1.61
Masood, R.	Performance of the supply chains for New Zealand prefabricated house-building	3	55	1.93
Li, X.	SWP-enabled constraints modeling for on-site assembly process of prefabrication housing production	3	45	0.45
Li, L.	Critical success factors for project planning and control in prefabrication housing production: A China study	3	42	0.58
Masood, R.	A Systematic Review on Supply Chain Management in Prefabricated House-Building Research	2	36	3.13
Steinhardt, D.A.	The structure of emergent prefabricated housing industries: a comparative case study of Australia and Sweden	2	40	0.69
Li, X.	Smart work packaging-enabled constraint-free path re-planning for tower crane in prefabricated products assembly process	2	66	0.94
Pan, W.	Establishing and weighting decision criteria for building system selection in housing construction	2	74	0.72

Li, X.	RBL-PHP: Simulation of Lean Construction and Information Technologies for Prefabrication Housing Production	2	22	1.25
Li, C.Z.	A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong	2	30	0.88
Li, C.Z.	Schedule risk modeling in prefabrication housing production	2	23	0.38
Li, X.	Developing a conceptual framework of smart work packaging for constraints management in prefabrication housing production	1	34	0.59
Wikberg, F.	Design configuration with architectural objects: Linking customer requirements with system capabilities in industrialized house-building platforms	1	75	1.90
Persson, S.	Information management in industrial housing design and manufacture	1	138	0.51

Table 6. Top 20 cited publications

Main author	Year	Title	Source title	Total Citations	TCbY	Ref
Monahan, J.	2011	An embodied carbon and energy analysis of modern methods of Constr. in housing: A case study using a lifecycle assessment framework	Energy and Buildings	435	33.5	(Monahan, 2011)
Zhong, R.Y.	2017	Prefabricated Construction enabled by the Internet-of-Things	Autom. in Constr.	309	44.1	(Zhong et al., 2017)
Li, C.Z.	2018	An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated Constr.	Autom. in Constr.	302	50.3	(C. Z. Li, FanLi, XiaoHong, JingkeShen, Geoffrey Qiping, 2018)
Cao, X.	2015	A comparative study of environmental performance between prefabricated and traditional residential buildings in China	J. of Cleaner Production	276	30.7	(Cao, 2015)
Li, C.Z.	2016	Schedule risks in prefabrication housing production in Hong Kong: a social network analysis	J. of Cleaner Production	213	26.6	(C. Z. Li et al., 2016)
Li, C.Z.	2017	Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house Constr.	J. of Cleaner Production	201	28.7	(C. Z. Li, Ray Y.Xue, FanXu, GangyanChen, KeHuang, George GuoquanShen, Geoffrey Qiping, 2017)
Pan, W.	2012	Strategies for integrating the use of off-site production technologies in house building	J. of Constr. Eng. and Manage.	186	15.5	(W. G. Pan, A. G. F.Dainty, A. R. J., 2012)
Quale, J.	2012	Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States	J. of Industrial Ecology	165	13.8	(Quale, 2012)
Hao, J.L.	2020	Carbon emission reduction in prefabrication Constr. during materialization stage: A BIM-based life-cycle assessment approach	Science of the Total Environment	157	39.25	(Hao, 2020)
Li, X.	2019	Integrating Building Information Modeling and Prefabrication Housing Production	Autom. in Constr.	149	29.8	(X. Li, Shen, Wu, & Yue, 2019)
Steinhardt, D.A.	2016	Adoption of prefabricated housing-the role of country context	Sustainable Cities and Society	138	17.3	(Steinhardt, 2016)
Li, C.Z.	2016	SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong	Habitat International	129	16.1	(C. Z. Li, JingkeXue, FanShen,

Kamali, M.	2019	Conventional versus modular Constr. methods: A comparative cradle-to-gate LCA for residential buildings	Energy and Buildings	122	24.4	Geoffrey QipingXu, XiaoxiaoLuo, Lizi, 2016) (M. H. Kamali, K.Sadiq, R., 2019)
Pan, W.	2012	Establishing and weighting decision criteria for building system selection in housing Constr.	J. of Constr. Eng. and Manage.	110	22.0	(W. D. Pan, A. R. J.Gibb, A. G. F., 2012)
Li, X.	2018	RBL-PHP: Simulation of Lean Constr. and Inf. Technologies for Prefabrication Housing Production	J. of Manage. in Eng.	106	17.7	(C. Z. Li, Xue, et al., 2018)
Johnsson, H.	2009	Defects in offsite Construction: Timber module prefabrication	Constr. Manage. and Economics	96	19.2	(Johnsson, 2009)
Li, C.Z.	2018	A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong	J. of Cleaner Production	75	12.5	(C. Z. Li, Xu, et al., 2018)
Li ,C.Z.	2017	Schedule risk modeling in prefabrication housing production	J. of Cleaner Production	74	10.6	(C. Z. Li et al., 2017)
Begum, R.A.	2010	Waste generation and recycling: Comparison of conventional and industrialized building systems	American J. of Environmental Sciences	70	5.0	(Begum, 2010)
Masood, R.	2021	Performance of the supply chains for New Zealand prefabricated house-building	Sustainable Cities and Society	66	22.0	(R. L. Masood, J. B. P.González, V. A., 2021)

Table 6 presents the list of top 20 cited papers and main authors related to this research field from 2009 to 2020, with more than 66 citations out of the 68 selected papers with at least one citation. It is noted that duplicate contributions from research groups were removed, with only one entry attributed to the main author being considered. Li, C. Z., as the main author, was the most active researcher based on six papers published, and the author had the highest number of citations, totaling 926, although Monahan, J., and Zhong, R. Y., had the most cited articles, with 435 and 309 citations per publication, respectively. Pan, W., and Li, X., followed with two papers, receiving 296 and 255 citations, respectfully. As shown in Table 5, the most cited paper compared the embodied carbon of an MMC house with an equivalent home constructed using traditional masonry construction and was published in *Energy and Buildings* in 2011. In this paper, information on embodied carbon of an offsite panelized modular timber frame system was managed by an LCA framework (Monahan, 2011). The other two of the top three papers addressed an IoT-enabled BIM platform in prefabricated construction (C. Z. Li, FanLi, XiaoHong, JingkeShen, Geoffrey Qiping, 2018; Zhong et al., 2017).

Interestingly, five papers of the top 20 cited papers were published in *The Journal of Cleaner Production*, which does not cover a wide range of OSC research, but its coverage includes discussing theoretical and practical cleaner production, encompassing environmental and sustainability issues in corporations, governments, education institutions, regions, and societies (B.V.). The most cited papers seemed to originate from *Energy and Buildings* and *Automation in Construction*, primarily focusing on energy use in buildings (B.V.) and the application of information technologies in design, engineering, construction technologies, maintenance, and the management of constructed facilities (B.V.).

Comparing citations between articles over a specific timespan, as done in this study, does not necessarily reflect a greater or lesser impact based solely on the total number of citations (TC). Therefore, total citations by year (TCbY) were normalized to determine the most influential articles. As indicated in Table 5, the article with the highest total citations (TC = 435) did not align with the one having the greatest impact on the

scientific community (TCbY = 50.3), which ranked third on the list of the top 20 cited papers in terms of total citations.

4.4 Co-occurrence analysis of countries and research institutions

Figure 7 highlights the top seven countries in terms of the number of publications. Hong Kong (19 papers) led OSC in housing research, followed by China (16 papers), the UK (13 papers), Australia (13 papers), South Korea (eight papers), the USA (seven papers), and Sweden (seven papers), which were the most active countries in information management and OSC in housing. Notably, most of these countries are all developed countries. This is due to the higher labor costs and the rising interest in modular construction in these countries, particularly in the residential sector. Besides, the USA, the UK, and Sweden have a relatively mature OSC market, and they possess more market shares in the residential construction sector (R. Masood, James B. P.Gonzalez, Vicente A.Roy, KrishanuKhan, Khurram Iqbal Ahmad, 2022). This spatial distribution highlights global recognition of, and response to, the demand for information management and OSC in housing caused by housing shortage, high labor costs, insufficient manpower, safety, and environmental concerns. This ensures the representativeness of the reviewed publications.

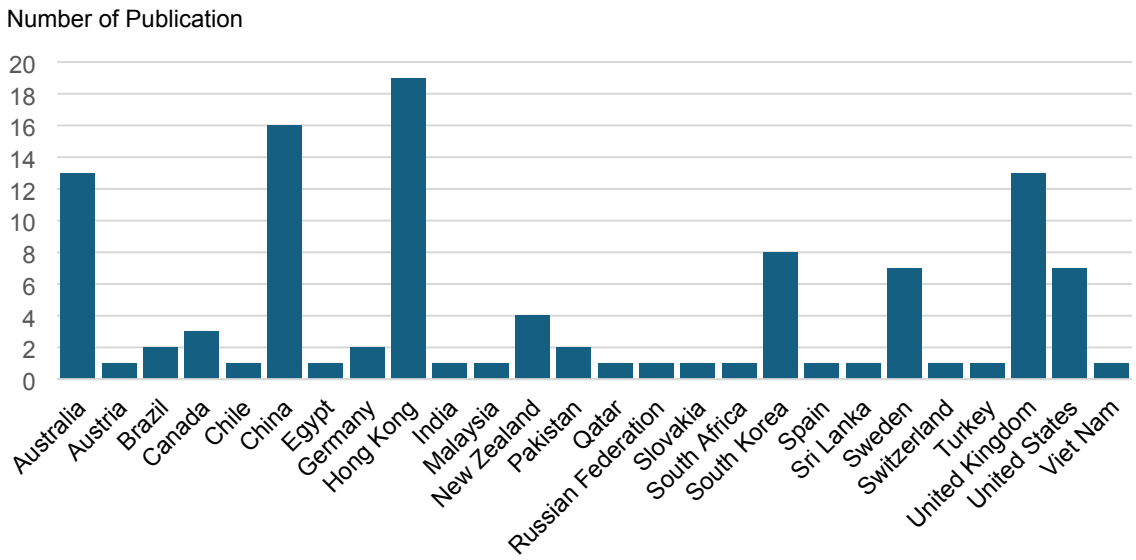

Figure 7. Number of publications by countries

As with the number of publications by countries, Hong Kong had the highest number of citations (2,205), which is consistent with the fact that this is where OSC is applied in housing construction due to inefficient housing supply (C. Z. Li, Xu, et al., 2018). This is followed by China (2,065 citations), which ranks similarly in terms of the number of publications. The origins of industrialized construction, such as prefabrication and OSC, were closely linked to developments in other countries, such as the United States, the UK, and Australia (Sanchez-Garrido, 2023), and they had a high number of citations, reporting 514, 970, and 716 citations, respectively. This means that a higher number of publications can lead to a greater impact. South Korea, Sweden, and New Zealand, with eight, seven, and four papers, respectively, rounded out the top eight countries with the most

impactful scientific publications in housing OSC. In terms of the region, Asia stood out with a total of 4,377 citations, compared to 2,838 citations from other regions.

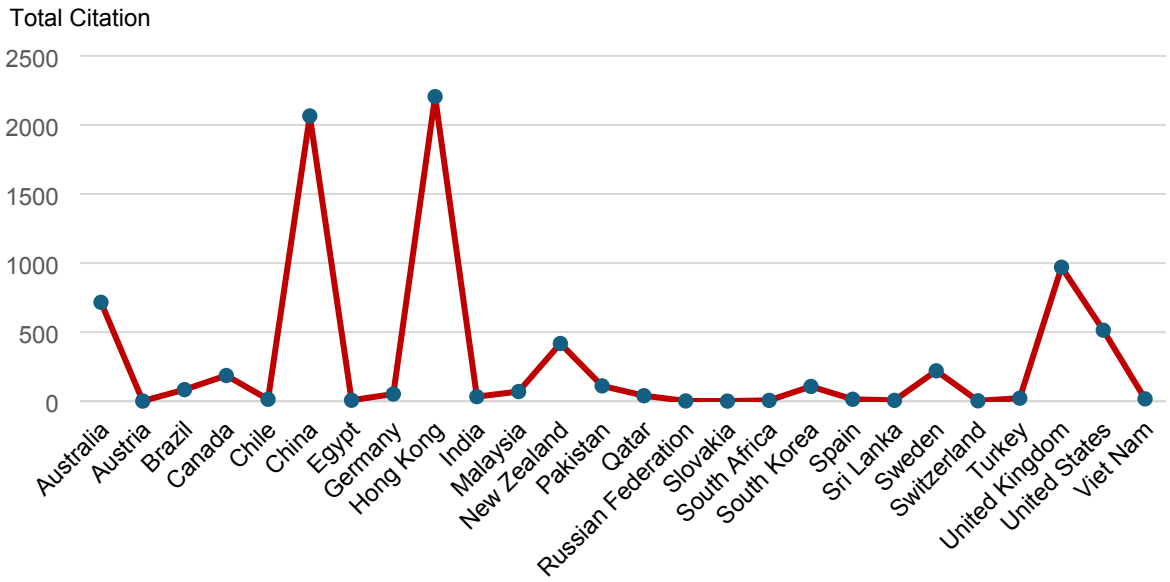

Figure 8. Number of citations by countries

The minimum number of documents for a country and the minimum number of documents for an organization were set to 0 and 2, respectively. A total of 26 countries met this threshold to create a collaborative network of countries (as shown in Figure 9), and a total of 22 out of 97 organizations met this threshold to visualize the relationships between research institutions (as seen in Figure 10).

Figure 9 shows a collaborative network map of countries based on their research output on information management and OSC in housing, and the size of each node reflects the number of publications from a country, whereas the links among nodes indicate co-authorship relationships across countries. This network map facilitates the recognition of the location of critical contributions and publication interactions and visualizes that Hong Kong, Brazil, Australia, and the UK are well connected and play a leading role in international collaboration on this topic. However, global collaborative studies on information management and OSC in housing remain limited to only a few countries.

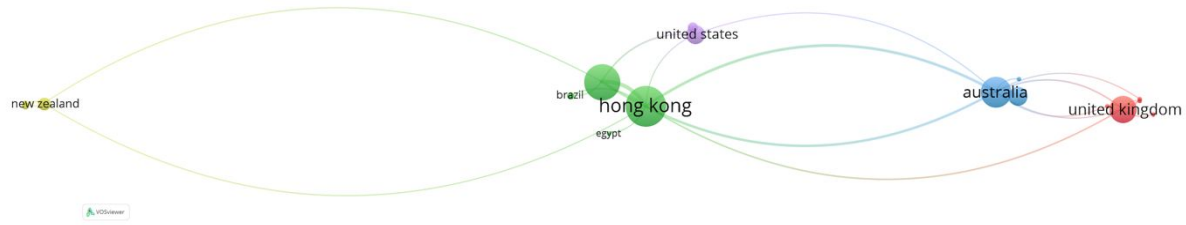

Figure 9. A collaborative network of countries

Other active countries in this research area include New Zealand, Canada, Pakistan, and Germany. These countries are less connected in the network map, suggesting that their research on this topic is more independent.

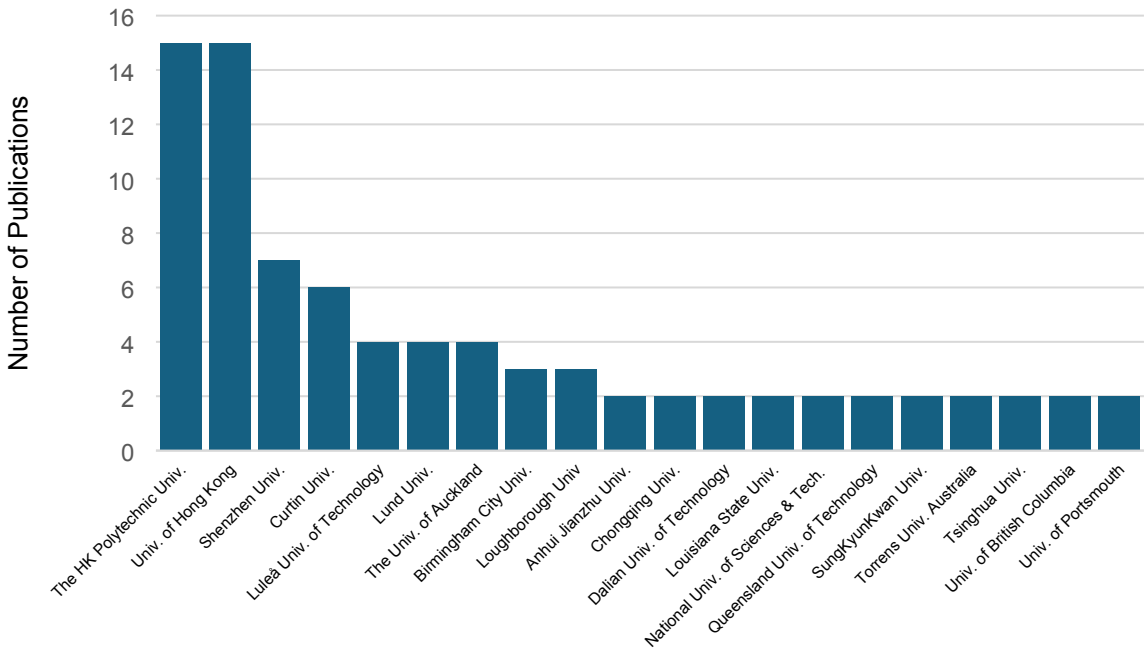

Figure 10. Number of publications by countries

Figure 10 highlights the top 20 out of 87 research institutions engaged in studying OSC in housing in terms of the number of publications, while the rest of the research institutions published only one paper on this research topic. As shown in Figure 10, the Hong Kong Polytechnic University and the University of Hong Kong were the most active research institutions in this field of research with 15 publications, followed by Shenzhen University (China, seven publications), Curtin University (Australia, six publications), Luleå University of Technology and Lund University (Sweden, four publications), and The University of Auckland (New Zealand, four publications). Of the 87 research institutions, most were higher education establishments, primarily universities, and only 13 of the research institutions were either commercial companies or government research organizations.

Figure 11 illustrates a strong collaborative network of research institutions, including the Hong Kong Polytechnic University, Curtin University (Australia), Chongqing University (China), and the University of Auckland (New Zealand). Similar to the collaborative network among countries, research collaborations on this topic were limited to just a few institutions. This limited interconnectivity indicates a notable lack of collaboration among research institutions in the study of OSC in housing.

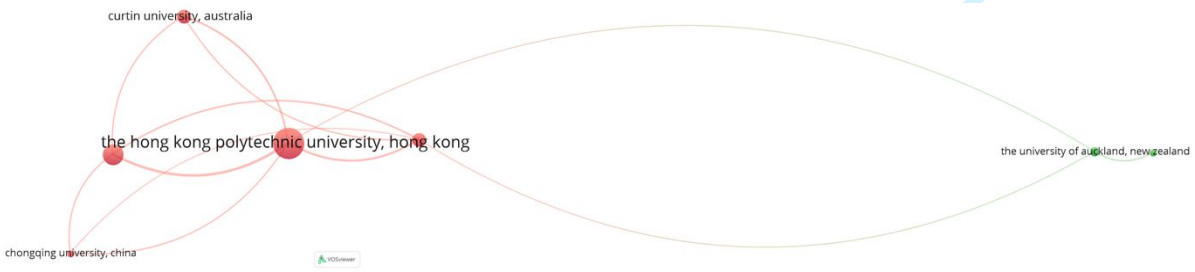

Figure 11. A collaborative network of research institutions

Figure 12 represents the global geographic distribution of OSC in housing research on a world map to demonstrate the location of critical contributions and the number of publications by countries.

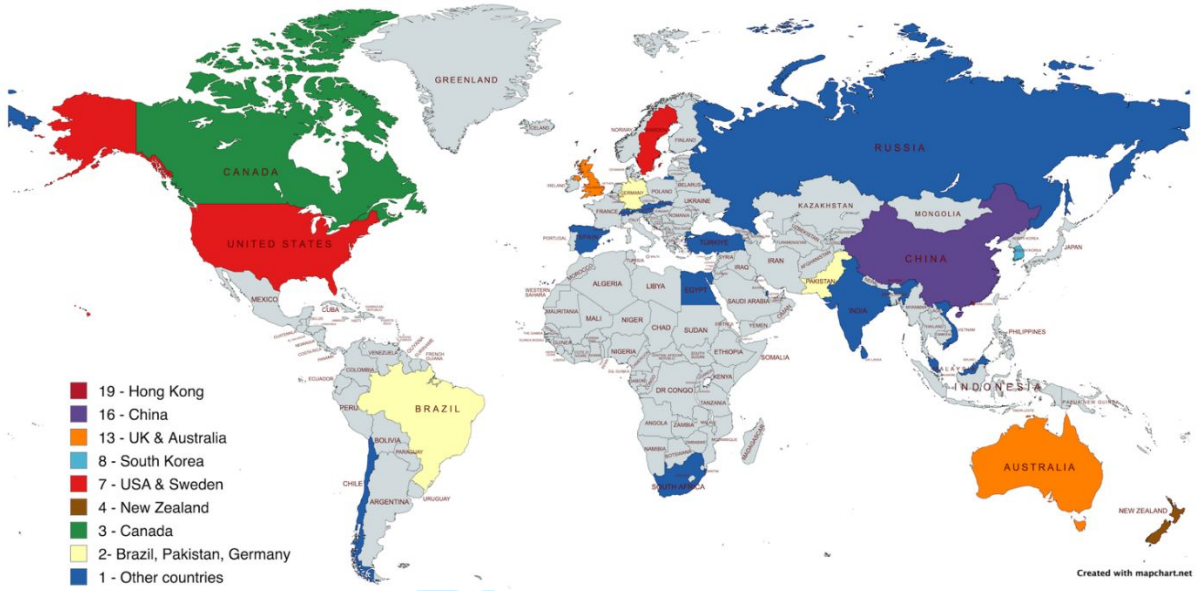

Figure 12. World map of the number of publications by countries

4.5 Frequency analysis on classification, project phases, and information types

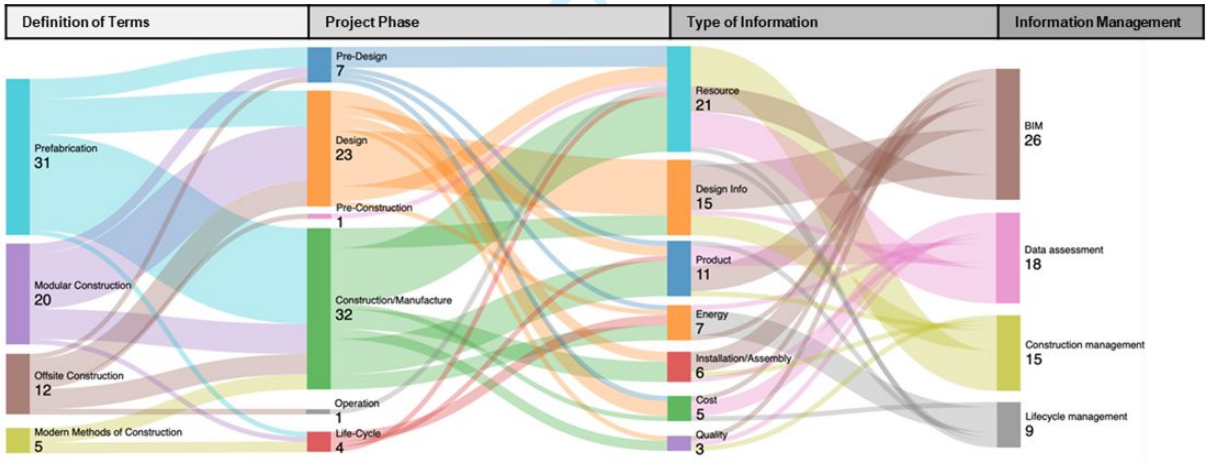

Figure 13. Sankey diagram of information management for offsite construction in housing

Figure 13 presents a Sankey diagram illustrating an overview of the 68 selected publications, which displays four distinct categories represented as columns from left to right. As shown in the first column, the studies are classified into four categories according to the different terms by countries and publications: “Prefabrication (31 papers),” “Modular Construction (20 papers),” “Offsite Construction (12 papers),” and “Modem Methods of Construction (five papers).” The second column represents the phases/stages of a construction project lifecycle, while the subsequent two columns depict the interaction with the types of information and the types of information management for OSC in housing, such as BIM (26 publications), data assessment (18 publications), construction management (15 publications), and lifecycle management (nine publications), with the different

types of information on the third column. The thickness of curved flow lines between elements displays the frequency of co-occurrence between them.

5. SUMMARISED FINDINGS AND FUTURE TRENDS

5.1 Summary and key findings

OSC is an innovative approach that enhances efficiency, safety, and sustainability significantly by manufacturing key components in a factory and assembling them onsite. However, the varying terminology used across different countries, such as MMC in the UK and PPVC in Singapore, can complicate international collaboration and information sharing. To address this, the adoption of a unified term such as "Offsite Construction (OSC)" was proposed to standardize global practices and facilitate clearer communication across the industry.

OSC has become a crucial strategy for addressing global housing demands by enabling faster, high-quality, and sustainable building processes. The adoption of various OSC methods tailored to regional needs and materials highlights their versatility and effectiveness in both rural and urban settings. However, fully integrating OSC principles, such as DfMA, remains challenging, requiring better tools and multidisciplinary collaboration to optimize their benefits.

The bibliometric and scientometric analysis of the 68 selected papers in this study revealed a growing interest in information management and OSC in housing, with a notable increase in publications since 2009. The research is thematically clustered, covering diverse topics, such as MMC, BIM, and modular design, with key contributions from top journals, such as *Automation in Construction* and *Journal of Cleaner Production*, Elsevier. This analysis highlights the evolving focus on OSC in housing, reflecting its increasing relevance and the need for continued research in this area.

The keyword co-occurrence analysis of the 68 selected papers on information management and OSC in housing revealed that "building information modelling (BIM)", "prefabrication" and "internet of things (IoT)" are central themes, reflecting their significant impact on the field. Recent studies have demonstrated how these technologies are transforming OSC practices. For instance, (Kordestani, Babaeian Jelodar, Paes, Sutrisna, & Rahmani, 2024) showed that BIM integrates and visualizes data across design, manufacturing, and installation in OSC, enabling collision detection, enhanced collaboration, waste reduction, and sustainability improvements. These capabilities contribute to increasing project efficiency and accuracy while reducing costs and time. Furthermore, the integration of BIM and IoT digitizes and automates all aspects of data management, assembly processes, collaboration, and maintenance, significantly improving the overall efficiency and precision of OSC projects . These technologies play a pivotal role in transitioning OSC from traditional construction methods to a future-oriented construction approach.

The co-author co-occurrence network analysis identified key researchers in the field of information management for OSC in housing, with Geoffrey Qiping Shen, Clyde Zhengdao Li, and Fan Xue emerging as influential figures based on their citation frequency and interconnectedness. The document co-citation network highlights that the most frequently cited papers focus on integrating advanced technologies, such as IoT with BIM, to improve efficiency in prefabricated construction. Although the total number of citations provided insight into an article's reach, normalizing TCbY revealed which articles have had the greatest impact on the scientific community over time.

Research on OSC in housing is led by Hong Kong, China, and the UK, driven by factors of high labor costs and a focus on modular construction. Hong Kong, in particular, has successfully implemented OSC in public housing projects, aiming to enhance quality and productivity, and it stands out as a leading example with

the highest citation impact in this field. However, global collaboration in OSC research remains limited to a few key countries and institutions, and the gap between countries that have successfully adopted OSC and those facing challenges is evident. For instance, South Korea struggles with barriers such as high initial investment costs, a lack of standardized technologies, and limited availability of skilled labor, which hinder the widespread adoption of OSC. These challenges highlight the need for policy support and the development of technical infrastructure to facilitate OSC implementation. In contrast, Hong Kong and the United Kingdom have overcome these obstacles through strong policy frameworks, standardized design systems, and continuous technical education, achieving significant success in OSC adoption and expansion. This comparison underscores the importance of tailored strategies and policy approaches that account for country-specific contexts to promote OSC adoption effectively.

5.2 Implications and future trends

Based on the insights gathered in this study, several possible paths for future trends in OSC in housing can be proposed as OSC can help meet the demand for affordable housing by enabling faster delivery and public-private collaborations. One promising direction is to enhance international and institutional collaboration. By strengthening networks between countries and institutions, particularly those less represented in current research, the field can benefit from a broader exchange of knowledge and innovative practices. This collaborative approach could lead to accelerated advancements and a combined global effort in addressing challenges in OSC.

Another area for future work involves investigating emerging technologies and keywords that have not yet been executed fully. Identifying and integrating these emerging trends can open up new research opportunities and contribute to the evolution of best practices in the industry for technical integration in digital tools to enhance the precision and scalability of modular projects. For example, evaluating the impact of specific information management tools, such as BIM and IoT, is another valuable direction. Future studies can analyze how these tools enhance efficiency, cost-effectiveness, and sustainability in real-world applications of OSC. By assessing their effectiveness in practical scenarios, researchers can provide actionable insights for optimizing these technologies.

Exploring regional variations in OSC adoption is also crucial. Research could investigate why certain regions, such as Hong Kong and China, lead in this field while others lag. Understanding the factors contributing to these disparities can help develop targeted strategies to overcome barriers and promote the adoption of OSC methods in less active areas. The different regulations and practices are another key factor that creates invisible barriers in the adoption, which requires further studies for mutual advancements.

Continued focus on sustainability and lifecycle assessment is also essential. Future research should dig into how modular and prefabricated construction methods impact environmental performance and resource efficiency as they reduce waste, lower greenhouse gas emissions, and promote material reuse and energy efficiency. A suggestion could be to collaborate between OSC management and construction material studies. The OSC and manufacturing environment can offer a controlled setting to adopt, test, and implement new materials with reduced impact. Investigating these aspects will be vital for advancing green construction practices and ensuring that OSC methods contribute positively to sustainability goals.

6. CONCLUSION AND LIMITATION

The analysis in this study highlights the growing relevance of digital technologies, such as BIM, artificial intelligence, and the Internet of Things, which are expected to influence future research and practice significantly in this field. The study also identifies key areas of interest, including sustainability, circular economy, advanced manufacturing techniques, policy implications, collaboration tools, health and safety, and social impacts. By examining the most relevant keywords, influential journals, and productive authors, the study offers valuable insights into the state of research and its potential future directions.

There are still limitations to this study that must be acknowledged. First, the research relies heavily on existing publications and may not fully capture emerging trends or the most recent advancements from the OSC practices and ongoing (but not presented yet) research efforts. The scope of the review is limited to the selected publications, which might not encompass all relevant research or innovative practices. Additionally, the study's focus on academic sources may overlook practical insights and industry experiences that are not yet widely published. Future research should address these limitations by incorporating a broader range of sources, including recent industry reports and case studies, to provide a more holistic view of the field.

The study's conclusions also suggest several areas for future investigation. Future research could explore the integration of advanced technologies, such as robotics and 3D printing, in OSC and their implications for productivity and quality. The emphasis on sustainability and circular economy highlights the need for more studies on the environmental impacts and lifecycle analysis of modular housing. Additionally, the evolving regulatory frameworks and policy impacts on housing affordability warrant further exploration. Enhancing collaboration tools and knowledge management systems, along with addressing health and safety challenges in offsite environments, is also another critical area for future research. Finally, examining the global and regional trends, particularly the adoption of OSC in developing countries, will be essential for understanding the broader implications and opportunities in the field.

Acknowledgement

-

References

Agapiou, A. (2022). Barriers to offsite construction adoption: A quantitative study among housing associations in England. *Buildings, 12*(3), 283. https://doi.org/10.3390/buildings12030283

Alwisy, A., Samer BuBarkokebas, BedaBouferguene, AhmedAl-Hussein, Mohamed. (2019). A BIM-based automation of design and drafting for manufacturing of wood panels for modular residential buildings. *International Journal of Construction Management, 19*(3), 187-205. https://doi.org/10.1080/15623599.2017.1411458

Association, B. S. (2017). *Laying the Foundations for MMC Expanding the Role of Modern Methods of Construction One Potential Solution to the UK Housing Crisis*. Retrieved from London, UK:

Association, T. a. C. P. (2020). *Guide 12: Modern Methods of Construction, in: Practical Guides for Creating Successful New Communities, .* Retrieved from https://www.tcpa.org.uk/resources/guide-12-modern-methods-of-construction/

Authority, B. a. C. Prefabricated Prefinished Volumetric Construction (PPVC). Retrieved from https://www1.bca.gov.sg/buildsg/productivity/design-for-manufacturing-and-assembly-dfma/prefabricated-prefinished-volumetric-construction-ppvc

Ayinla, K. O., Cheung, F., & Tawil, A.-R. (2020). Demystifying the concept of offsite manufacturing method. *Construction Innovation, 20*(2), 223-246. https://doi.org/10.1108/CI-07-2019-0064

B.V., E. Automation in Construction. Retrieved from https://www.sciencedirect.com/journal/automation-in-construction

B.V., E. Energy and Buildings. Retrieved from https://www.sciencedirect.com/journal/energy-and-buildings

B.V., E. Journal of Cleaner Production Retrieved from https://www.sciencedirect.com/journal/journal-of-cleaner-production

Begum, R. A. S., S. K.Pereira, J. J. (2010). Waste generation and recycling: Comparison of conventional and industrialized building systems. *American Journal of Environmental Sciences, 6*(4), 383-388. http://thescipub.com/html/10.3844/ajessp.2010.383.388

Beushausen, H. D. (2002). Precast concrete technology: Research and development technology in Singapore. *Betonwerk und Fertigteil-Technik/Concrete Precasting Plant and Technology, 68*(4), 38-42.

Brissi, S. G., Luciana. (2023). Principles for adopting offsite construction in design and construction companies focused on multifamily projects in the USA. *Engineering Construction and Architectural Management, 31*(11), 4308-4329. https://doi.org/10.1108/ECAM-03-2022-0262

Cao, X. L., X.Zhu, Y.Zhang, Z. (2015). A comparative study of environmental performance between prefabricated and traditional residential buildings in China. *Journal of Cleaner Production, 109*, 131-143. https://doi.org/10.1016/j.jclepro.2015.04.120

Chiang, Y. H. T., B. S.Wong, F. (2008). Volume building as competitive strategy. *Construction Management and Economics, 26*(2), 161-176. https://doi.org/10.1080/01446190701749151

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology, 62*(7), 1382-1402. https://doi.org/10.1002/asi.21525

Daniel, E. I., Babalola, A., Oladinrin, O. T., Obi, L. I., Oshodi, O., & Konara Mudiyanselage, A. N. (2024). Where lean construction and offsite construction meet: a bibliographic scientometric analysis. *Construction Innovation*. https://doi.org/10.1108/CI-08-2023-0210

Eren, F. (2016). The Re-specification of Concepts in the Morphogenetic Approach for Property Market Research. *ICONARP International Journal of Architecture and Planning, 4*(2), 15-34. https://doi.org/10.15320/ICONARP.2016.9

Foundation, N. (2016). *Modern methods of construction: Views from the industry*. Retrieved from Milton Keynes:

Ghaleb, H., Alhajlah, H. H., Bin Abdullah, A. A., Kassem, M. A., & Al-Sharafi, M. A. (2022). A Scientometric Analysis and Systematic Literature Review for Construction Project Complexity. *Buildings, 12*(4), 482. https://doi.org/10.3390/buildings12040482

Han, Y., Yan, X., & Piroozfar, P. (2023). An overall review of research on prefabricated construction supply chain management. *Engineering, Construction and Architectural Management, 30*(10), 5160-5195. https://doi.org/10.1108/ECAM-07-2021-0668

Hao, J. L. C., B.Lu, W.Xu, J.Wang, J.Bu, W.Guo, Z. (2020). Carbon emission reduction in prefabrication construction during materialization stage: A BIM-based life-cycle assessment approach. *Science of the Total Environment, 723*. https://doi.org/10.1016/j.scitotenv.2020.137870

Herath Mudiyanselage Samadhi Nayanathara Samarasekara * , M. B. P., & Rotimi, a. F. E. (2024). Interrelations of the Factors Influencing the Whole-Life Cost Estimation of Buildings: A Systematic Literature Review. *Buildings, 14*(3). https://doi.org/10.3390/buildings14030740

Hirabayashi, R., Nakayama, H., Yahaba, M., Yamanashi, H., & Kawasaki, T. (2023). Utility of interferon-gamma releasing assay for the diagnosis of active tuberculosis in children: A systematic review and meta-analysis. *Journal of Infection and Chemotherapy, 30*(6), 516-525. https://doi.org/10.1016/j.jiac.2023.12.007

Hosseini, M. R., Martek, I., Zavadskas, E. K., Aibinu, A. A., Arashpour, M., & Chileshe, N. (2018). Critical evaluation of off-site construction research: A Scientometric analysis. *Automation in Construction, 87*, 235-247. https://doi.org/10.1016/j.autcon.2017.12.002

Hou, L., Tan, Y., Luo, W., Xu, S., Mao, C. and Moon, S., 2022. Towards a more extensive application of off-site construction: a technological review. International journal of construction management, 22(11), pp.2154-2165.

Hwang, K. E. K., I.Kim, J. I.Cha, S. H. (2023). Client-engaged collaborative pre-design framework for modular housing. *Automation in Construction, 156*. https://doi.org/10.1016/j.autcon.2023.105123

Johnsson, H. M., J. H. (2009). Defects in offsite construction: Timber module prefabrication. *Construction Management and Economics, 27*(7), 667-681. https://doi.org/10.1080/01446190903002797

Kamali, M., KasunRana, AnberAlam, M. ShahriaSadiq, Rehan. (2023). Environmental sustainability assessment of single-family modular homes using performance benchmarks of conventional homes: case studies in British Columbia, Canada. *Clean Technologies and Environmental Policy, 25*(8), 2603-2628. https://doi.org/10.1007/s10098-023-02495-2

Kamali, M. H., K.Sadiq, R. (2019). Conventional versus modular construction methods: A comparative cradle-to-gate LCA for residential buildings. *Energy and Buildings, 204*. https://doi.org/10.1016/j.enbuild.2019.109479

Karimi, R., Baghalzadeh Shishehgarkhaneh, M., Moehler, R. C., & Fang, Y. (2024). Exploring the Impact of Social Media Use on Team Feedback and Team Performance in Construction Projects: A Systematic Literature Review. *Buildings, 14*(2), 528. https://doi.org/10.3390/buildings14020528

Kedir, F., Hall, D. M., Brantvall, S., Lessing, J., Hollberg, A., & Soman, R. K. (2023). Circular information flows in industrialized housing construction: the case of a multi-family housing product platform in Sweden. *Construction Innovation, 24*(5), 1354-1379. https://doi.org/10.1108/CI-08-2022-0199

Kempton, J. S., P. (2009). Modern methods of construction: Implications for housing asset management in the RSL sector. *Structural Survey, 27*(1), 36-45. https://doi.org/10.1108/02630800910941674

Kordestani, N., Babaeian Jelodar, M., Paes, D., Sutrisna, M., & Rahmani, D. (2024). A comprehensive evaluation of factors influencing offsite construction and BIM integration in the construction industry. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-12-2023-1278

Li, C. Z., FanLi, XiaoHong, JingkeShen, Geoffrey Qiping. (2018). An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. *Automation in Construction, 89*, 146-161. https://doi.org/10.1016/j.autcon.2018.01.001

Li, C. Z., Hong, J., Xue, F., Shen, G. Q., Xu, X., & Mok, M. K. (2016). Schedule risks in prefabrication housing production in Hong Kong: a social network analysis. *Journal of Cleaner Production, 134*(Part B), 482-494. https://doi.org/10.1016/j.jclepro.2016.02.123

Li, C. Z., JingkeXue, FanShen, Geoffrey QipingXu, XiaoxiaoLuo, Lizi. (2016). SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong. *Habitat International, 57*, 74-87. https://doi.org/10.1016/j.habitatint.2016.07.002

Li, C. Z., Li, S., Li, X., Wu, H., Xiao, B., Tam, V. W., & Asiedu-Kwakyewa, C. (2022). A scientometric review of management of prefabricated construction from 2011–2021. *Buildings, 12*(10), 1515. https://doi.org/10.3390/buildings12101515

Li, C. Z., Ray Y.Xue, FanXu, GangyanChen, KeHuang, George GuoquanShen, Geoffrey Qiping. (2017). Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. *Journal of Cleaner Production, 165*, 1048-1062. https://doi.org/10.1016/j.jclepro.2017.07.156

Li, C. Z., Shen, G. Q., Xue, F., Luo, L., Xu, X., & Sommer, L. (2017). Schedule risk modeling in prefabrication housing production. *Journal of Cleaner Production, 153*, 692-706. https://doi.org/10.1016/j.jclepro.2016.11.028

Li, C. Z., Xu, X., Shen, G. Q., Fan, C., Li, X., & Hong, J. (2018). A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong. *Journal of Cleaner Production, 185*, 366-381. https://doi.org/10.1016/j.jclepro.2018.02.308

Li, C. Z., Xue, F., Li, X., Hong, J., & Shen, G. Q. (2018). An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. *Automation in Construction, 89*, 146-161. https://doi.org/10.1016/j.autcon.2018.01.001

Li, T., Yuan, L. ming, Hou, G. qiu, & Wu, Y. feng. (2022). Rapid Design and Construction Management of Emergency Hospital During the COVID-19 Epidemic. *Structural Engineering International, 32*(2), 142–146. https://doi.org/10.1080/10168664.2021.1955087

Li, X., Geoffrey QipingWu, PengFan, HongqinWu, HengqinTeng, Yue. (2018). RBL-PHP: Simulation of Lean Construction and Information Technologies for Prefabrication Housing Production. *Journal of Management in Engineering, 34*(2). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000577

Li, X., Shen, G. Q., Wu, P., & Yue, T. (2019). Integrating Building Information Modeling and Prefabrication Housing Production. *Automation in Construction, 100*, 46-60. https://doi.org/10.1016/j.autcon.2018.12.024

Lou, J., Lu, W., Xu, J., Li, X., & Wang, J. (2022). Nomenclature for offsite construction. *Building Research & Information, 50*(8), 894-908. https://doi.org/10.1080/09613218.2022.2039586

Luo, L. C., Y. (2020). Carbon emission energy management analysis of LCA-Based fabricated building construction. *Sustainable Computing: Informatics and Systems, 27*. https://doi.org/10.1016/j.suscom.2020.100405

MacAskill, S. M., S.Stewart, R. A.Sahin, O.Suprun, E. (2021). Offsite construction supply chain strategies for matching affordable rental housing demand: A system dynamics approach. *Sustainable Cities and Society, 73*. https://doi.org/10.1016/j.scs.2021.103093

Malmgren, L. J., P.Olofsson, T. (2011). Product modeling of configurable building systems - A case study. *Electronic Journal of Information Technology in Construction, 16*, 697-712. https://www.itcon.org/2011/41

Masood, R., James B. P.Gonzalez, Vicente A.Roy, KrishanuKhan, Khurram Iqbal Ahmad. (2022). A Systematic Review on Supply Chain Management in Prefabricated House-Building Research. *Buildings, 12*(1), 40. https://doi.org/10.3390/buildings12010040

Masood, R. L., J. B. P.González, V. A. (2021). Performance of the supply chains for New Zealand prefabricated house-building. *Sustainable Cities and Society, 64*. https://doi.org/10.1016/j.scs.2020.102537

Masood, R. R., K.Gonzalez, V. A.Lim, J. B. P.Nasir, A. R. (2023). Modeling relational performance of the supply chains for prefabricated housebuilding in New Zealand. *Smart and Sustainable Built Environment, 14*(1), 276-302. https://doi.org/10.1108/SASBE-01-2023-0006

MiC, C. What is MiC. Retrieved from https://mic.cic.hk/en/AboutMiC

Monahan, J. P., J. C. (2011). An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings, 43*(1), 179-188. https://doi.org/10.1016/j.enbuild.2010.09.005

Moon, S., Ham, N., Kim, S., Hou, L., Kim, J.H. and Kim, J.J., 2020. Fourth industrialization-oriented offsite construction: case study of an application to an irregular commercial building. Engineering, Construction and Architectural Management, 27(9), pp.2271-2286.

Mtech Group, L. U., Buildoffsite. (2007). *Offsite construction industry survey 2006*. Retrieved from London:

Mullens, M. A. A., R. L.Swart, W. W. (1995). The role of object oriented CAD in a generic simulator for the industrialized housing industry. *Automation in Construction, 4*(1), 29-43. https://doi.org/10.1016/0926-5805(94)00031-H

Na, S., Kim, S. and Moon, S., 2022. Additive manufacturing (3D Printing)-applied construction: Smart node system for an irregular building façade. Journal of Building Engineering, 56, p.104743.

Nations, U. (2023). *Adequate housing as a component of the right to an adequate standard of living, and on the right to non-discrimination in this context*. Retrieved from

OffsiteNZ. About Us. Retrieved from https://www.offsitenz.com/about-us

Ofori-Kuragu, J. K. O.-K., Robert; Wanigarathna, Nadeeshani. (2022). Offsite Construction Methods—What We Learned from the UK Housing Sector. *Infrastructures, 7*(12), 164. https://doi.org/10.3390/infrastructures7120164

Page, D., Hou, L., Rahnamayiezekavat, P., Antwi-Afari, M. F., Han, S., & Moon, S. (2023). Exploring effect of different resource qualities on process efficiency in construction pile installation. *Journal of Civil Engineering and Management, 29*(5), 463–474. https://doi.org/10.3846/jcem.2023.19215

Pan, W. D., A. R. J.Gibb, A. G. F. (2012). Establishing and weighting decision criteria for building system selection in housing construction. *Journal of Construction Engineering and Management, 138*(11), 1239-1250. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000543

Pan, W. G., A. G. F.Dainty, A. R. J. (2012). Strategies for integrating the use of off-site production technologies in house building. *Journal of Construction Engineering and Management, 138*(11), 1331-1340. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000544

Patil, D. A. B., S.Minde, P. R.Kulkarni, M. S. (2023). Review on comparative study of diverse wall materials for affordable housing. *Materials Today: Proceedings, 77*, 823-831. https://doi.org/10.1016/j.matpr.2022.11.489

Persson, S. M., L.Johnsson, H. (2009). Information management in industrial housing design and manufacture. *Electronic Journal of Information Technology in Construction, 14*, 110-122. https://www.itcon.org/2009/11

Pottier, P., Lagisz, M., Burke, S., Drobniak, S. M., Downing, P. A., Macartney, E. L., . . . Nakagawa, S. (2024). Title, abstract and keywords: a practical guide to maximize the visibility and impact of academic papers. *Proceedings of the Royal Society B: Biological Sciences, 291*(2027), 20241222. https://doi.org/10.1098/rspb.2024.1222

prefabAUS. What is prefab. Retrieved from https://www.prefabaus.org.au/what-is-prefab

Quale, J. E., M. J.Williams, K. W.Sloditskie, G.Zimmerman, J. B. (2012). Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States. *Journal of Industrial Ecology, 16*(2), 243-253. https://doi.org/10.1111/j.1530-9290.2011.00424.x

Rahman, M. M. (2014). Barriers of Implementing Modern Methods of Construction. *Journal of Management in Engineering, 30*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000173

Rathnasinghe, A. P., Thurairajah, N., Jones, P., & Goulding, J. (2024). The critique of sustainability discourse within the off-site construction (OSC): a systematic-scientometric review. *Architectural Engineering and Design Management, 21*(3), 379-409. https://doi.org/10.1080/17452007.2024.2386123

Sanchez-Garrido, A. J. N., Ignacio J.Garcia, JoseYepes, Victor. (2023). A systematic literature review on modern methods of construction in building: An integrated approach using machine learning. *Journal of Building Engineering, 73*. https://doi.org/10.1016/j.jobe.2023.106725

Scotland, A. D. (2020). *Using Offsite Construction for Housing Delivery in Scotland*. Retrieved from Edinburgh: https://www.ads.org.uk/sites/default/files/2022-05/case-study-using-offsite-construction-housing-delivery-2020.pdf

Singh, M. M., AnilBorrmann, Andre. (2015). Modular coordination and BIM: Development of rule based smart building components. *Procedia Engineering, 123*, 519-527. https://doi.org/10.1016/j.proeng.2015.10.104

Smith, R. S. W., J.B.; Hairstans, R. (2015). *Increasing Need for Offsite Construction and Manufactured Infrastructure in the UK Economy.* Paper presented at the CIAT Symposium Proceedings, UK.

Song, J., Zhang, H., & Dong, W. (2016). A review of emerging trends in global PPP research: analysis and visualization. *Scientometrics, 107*(3), 1111-1147. https://doi.org/10.1007/s11192-016-1918-1

Steinhardt, D. A. M., Karen. (2016). Adoption of prefabricated housing-the role of country context. *Sustainable Cities and Society, 22*, 126-135. https://doi.org/10.1016/j.scs.2016.02.008

Tanko, B. L., Zakka, W. P., & Heng, W. N. (2024). BIM in the Malaysian construction industry: a scientometric review and case study. *Engineering, Construction and Architectural Management, 31*(3), 1165-1186. https://doi.org/10.1108/ECAM-04-2021-0324

Taylor, M. D. (2010). A definition and valuation of the UK offsite construction sector. *Construction Management and Economics, 28*(8), 885-896. https://doi.org/10.1080/01446193.2010.480976

Vakaj, E., Cheung, F., Cao, J., Tawil, A. R. H., & Patlakas, P. (2023). An Ontology-Based Cost Estimation for Offsite Construction. *Journal of Information Technology in Construction, 28*, 220-245. https://doi.org/10.36680/j.itcon.2023.011

Xiao, J., WennanZhong, Ray Y. (2023). Blockchain-enabled cyber-physical system for construction site management: A pilot implementation. *Advanced Engineering Informatics, 57*. https://doi.org/10.1016/j.aei.2023.102102

Yalcinkaya, M., & Singh, V. (2015). Patterns and trends in Building Information Modeling (BIM) research: A Latent Semantic Analysis. *Automation in Construction, 59*, 68-80. https://doi.org/10.1016/j.autcon.2015.07.012

Zaalouk, A., Moon, S. and Han, S., 2023. Operations planning and scheduling in off-site construction supply chain management: Scope definition and future directions. Automation in construction, 153, p.104952.

Zhang, X., Antwi-Afari, M. F., Zhang, Y., & Xing, X. (2024). The Impact of Artificial Intelligence on Organizational Justice and Project Performance: A Systematic Literature and Science Mapping Review. *Buildings, 14*(1), 259. https://doi.org/10.3390/buildings14010259

Zhang, Z., Zou, Y., Guo, B. H., Dimyadi, J., Davies, R., & Jiang, L. (2024). Knowledge management for off-site construction. *Automation in Construction, 166*. https://doi.org/10.1016/j.autcon.2024.105632

Zhong, R. Y., Peng, Y., Xue, F., Fang, J., Zou, W., Luo, H., . . . Huang, G. Q. (2017). Prefabricated construction enabled by the Internet-of-Things. *Automation in Construction, 76*, 59-70. https://doi.org/10.1016/j.autcon.2017.01.006

Zhou, J. X., LijieShen, Geoffrey QipingWu, HengqinLuo, Lizi. (2023). Modeling stakeholder-associated productivity performance risks in modular integrated construction projects of Hong Kong: A social network analysis. *Journal of Cleaner Production, 423*. https://doi.org/10.1016/j.jclepro.2023.138699