https://doi.org/10.1016/j.jclepro.2020.124044

A Study of Literature on Modular Integrated Construction - Critical Review and Future Directions

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A B S T R A C T

Modular integrated construction (MiC) has been an attractive research topic in the last decade. The adoption of this technology has increased in several countries worldwide, which shows the need for exploring its main research themes, characteristics, benefits, and challenges. Through a three-step research process integrating bibliometric search, quantitative analysis, and qualitative analysis, the literature of MiC was extensively analyzed. The aim was to identify ongoing research trends and current gaps that will benefit future research in this vital domain. The quantitative analysis of literature showed that almost 50% of research in MiC was conducted in only four countries. Science mapping of author keywords showed the connection between MiC and topics, such as simulation, sustainability, and scheduling, which indicated the diverse nature of the existing literature. The qualitative analysis of the literature showed that the categories of building design and management aspects were dominating the research in the area. Gaps in MiC research encompassed lack of quantitative analysis to assess the benefits of various innovative design proposals, lack of cost analysis for MiC to measure its savings, and lack of analysis to adopt the appropriate project delivery method in MiC projects. Future research directions comprise developing models to analyze stakeholder relationships during the design stage, examining contractual relationship among participants, investigating cost comparisons with different construction methods, and assessing the methods for introducing MiC into the curriculum of future engineers. This study provides a road map for future research projects and raise the practitioners' awareness of the latest methodologies and trends in global MiC research.

1. INTRODUCTION

Modular Integrated Construction (MiC) is a method of manufacturing 3D-volumetric fully finished modules at off-site facilities and hauling them to the site for installation. This technology is part of the Off-Site Construction (OSC) methods, such as prefabrication, panelized, and hybrid-construction. Prefabrication in general goes back to the 17th century. For instance, prefabricated parts are built in England and then shipped to a village named

"Cape Ann" in the United States of America (USA). Similarly, components are shipped from England to build hospitals and cottages in Australia (Boafo et al., 2016). Furthermore, cast iron prefab components for a portable colonial cottage named "Manning's" back in 1830 are manufactured in Glasgow and then shipped to the colony (Taylor, 2010). The evolution continues in prefabrication, and buildings, such as "Crystal Palace" by Sir Joseph Paxton, and "House of Tomorrow and Crystal House" by George Fred Keck, highlight a new era in the construction industry. Utilization of prefabrication has been flourishing due to its increasing demand. This is clearly seen after the World War II due to the high demand for houses as a consequence of the destruction of multiple cities (Taylor, 2010). In 1971, "Northwest Homes of Chehalis" company invents the term "modular homes" to describe the modular residential structures it builds. Each wooden module or unit, termed "one big box beam", is 50 ft. long and is shipped to the University of Alaska in Fairbanks (Lucas, 1971). Pre-cast 3D concrete modules have also been used in an 18-story building project back in 1973 in the United States (Anon, 1973). Those modules, named "Shelley System", form part of an experimental program launched by the Department of Housing and Urban Development, USA, in 1969. The modules are box-like, and have lengths and weights varying from 42 to 44 ft. and 48 to 53 tons, respectively. In 1988, MiC is used to build luxury private homes and commercial buildings. At this stage, MiC begins to provide better quality and more flexibility in design. The private homes, called "Modular Mansion", comprise 5,700 sqft houses and are built out of only nine modular units (Wolfman, 1988). MiC is reported to save around USD 20 per sqft in those projects.

To this end, modern 40-story residential towers have been built using concrete MiC modules in Singapore. The project towers rising to 140 meters are the highest MiC concrete towers worldwide (The Clement Canopy, 2019). A similar 135-meter high tower in Croydon, England, is the second-highest MiC tower in the world (Tall Building Conference, 2019). In recent years, more markets are becoming interested in this technology. For instance, Hong Kong has launched several MiC projects around the city since late 2018 (Construction Industry Council, 2019). Attraction to MiC and its increasing utilization are due to to its numerous benefits. It promotes overlap between on-site and off-site works, lowers risk of delays, removes 90% of on-site activities (Jabar et al., 2013), and reduces accidents by 80% (Kamali and Hewage, 2016). Additionally, it reduces capital cost by 10% (Navaratnam et al., 2019), decreases wastage by 76% (Kamali and Hewage, 2016), and provides better construction quality. However, this modern technique suffers from several challenges, such as high initial investment cost due to the uncertainty of demand (Chai et al., 2019; Ferdous et al., 2019), transportation and logistics of the modules due to project constraints (Hwang et al., 2018a), and lack of codes and standards (Rahim and Qureshi, 2018).

The literature on different aspects of 3D fully finished volumetric MiC modules has been growing in the last decade. Typical examples include modular building connections design and load transfer problems (Srisangeerthanan et al., 2020), and environmental performance of MiC buildings (Kamali et al., 2019). Some others are on measurements of the impact of government policies adopted to promote MiC (Li et al., 2018a), assessment of the productivity of MiC modules' installation (Liu et al., 2019), and development of advanced control panels for the manufacturing machines of MiC modules (Tamayo et al., 2018). The vast amount of literature in this field necessitates a systematic literature review. MiC, being part of the OSC, has been collectively reviewed with other construction methods such as prefabrication, panelized construction, and hybrid construction (Jin et al., 2018). However, the review does not explore the research themes and trends in MiC. The current status and importance of MiC requires differentiating its literature from other research carried out in OSC.

MiC literature has been reviewed from specific aspects, such as sustainability performance (Kamali and Hewage, 2016), critical success factors (Wuni and Shen, 2019), and critical risk factors (Wuni et al., 2019). Other studies on MiC have appraised barriers preventing its adoption (Wuni and Shen, 2020a), high-rise building application (Pan et al., 2018), and general performance in a specific location (Navaratnam et al., 2019). However, the existing literature has not assessed the numerous knowledge areas that are integrated with MiC. Besides, the aforementioned reviews fail to evaluate the current state-of-art research in MiC technology, neither did the inclusion of MiC in reviews that focus OSC generally. Consequently, the literature on MiC needs to be studied on an intermediate level to provide a more detailed view than that presented in general OSC reviews. Besides, more grounds and knowledge areas may be incorporated to extend the coverage provided in existing MiC reviews. This study, therefore, aims to harmonize the fragmented research conducted on MiC. In this study, the specific objectives are to 1) quantitatively assess MiC literature and its different bibliometric parameters; 2) develop science maps for MiC bibliometric parameters; 3) identify the themes and ongoing trends in MiC research; 4) uncover the gaps in the existing MiC literature; and 5) provide future research directions in MiC. These objectives are fulfilled through a three-staged research. The first is a bibliometric search of the literature, followed by a quantitative analysis using scientometric tools, and finally, a systematic, qualitative analysis of the literature. Following this introduction, the remainder of the study comprises section 2 (methodology), section 3 (quantitative analysis), section 4 (qualitative analysis), section 5 (discussion of results), and section 6 (conclusion).

2. METHODOLOGY

2.1 Multi-Stage Critical Literature Review

Literature review is considered a viable tool in defining the domain of a certain knowledge area, allows for the identification of knowledge gaps and generation of future recommendations (Greene, 1989). A literature review paper may consider different time intervals based on multiple factors. These include topic, scientific branch, awareness of existing literature, depth of the literature review and purpose of the literature review (Harden, 2010; Johnson and Onwuegbuzie, 2004; Zou et al., 2014). In addition, scholars in the field of construction have used the review method to assess the literature (Azhar et al., 2013; Kamali and Hewage, 2016; Yin et al., 2019). In this study, a multi-stage method was adopted to assess literature from quantitative and qualitative points of view. Figure (1) explains the several stages of this research work. To find the required literature, a set of key words were used as inputs in multiple search engines (*Web of Science* and *Scopus*). The best results were recovered from *Scopus*, as recommended by some scholars (Aghaei Chadegani et al., 2013; Mongeon and Paul-Hus, 2016).

Keywords selection was based on skimming articles to locate the proper jargons and expressions that must be used, as well as those to be eliminated. An iterative search process was done to find the best combination that produced the most accurate results, and accordingly a reliable analysis. The initial keywords used were *"TITLE-ABS-KEY("modular construction" OR "modular integrated construction" OR "MiC" OR "prefabricated prefinished volumetric construction" OR "PPVC" OR "prefabricated modular building" OR "modular home" OR "modular building" OR "modular building system" OR "prefabricated modular unit" OR "industrialized building system" OR "IBS").*

The term "modular" is common to other scientific branches, so enhancement of keywords was required. The following part was added to the search engine "*AND TITLE-ABS-KEY("offsite construction" OR "off-site construction" OR "prefabricated" OR "prefab" OR "pre-fab" OR "prefabricated construction" OR "pre-fabrication" OR "prefabrication" OR "pre-fabricated" OR "preassembly" OR "pre-assembly" OR "pre-assembled" OR "preassembled" OR "on site assembly" OR "on-site assembly")"*. The search was conducted in late ***November 2019*** and resulted in 478 documents (see Figure 2). Further filtration was performed to limit the result to the intended area of study. Non-related documents, such as Tozawa et al. (2009), were skimmed for common keywords that should be removed from the search. Consequently, the following keywords were added *"AND NOT TITLE-ABS-KEY (organic OR molecular OR atomic OR chemistry OR "chemical reaction" OR nuclear OR paperfluidics)"*. Afterwards the results were limited to "Journal Articles, Conferences Papers and Review Papers", as adopted in similar studies (Yin et al., 2019). In addition, the title, abstract and even full paper, when required, were studied to ensure that unrelated documents were removed to increase confidence in the results of the analysis.

2.2 Quantitative Analysis Stage

Following from the literature search, 237 papers were extracted from *Scopus*. These formed the input of this stage, i.e. the statistical analysis of the bibliometric features of literature using *VOSviewer* (Cobo et al., 2011; Van Eck and Waltman, 2009, 2010; Van Eck and Waltman, 2019), and *Ghephi* (Heymann and Le Grand, 2013; Lucaciu et al., 2016). *VOSviewer* is a free software used to produce scientific maps and links between various bibliometric parameters, such as keywords' co-occurrence, co-authorship visualization, location, institutions, most cited articles, and so on. By analyzing these parameters, the structure of the literature and inter-relationship between various scientific domains were visualized. It also provides the relationships and links between various elements according to the chosen analysis. In this study, the occurrence of the keywords and their cluster were analyzed. Statistical analysis of the journals, top authors, location of research, type of documents and top citied articles were also analyzed. To develop further statistical features of the literature, sample files were exported from *VOSviewer* and used as inputs in "*Gephi*", a software used for bibliographic analysis. Therefore, more statistical features of the files were calculated and analyzed.

2.3 Qualitative Analysis Stage

The third stage of this research, as shown in Figure (1), is the qualitative assessment of literature. This practice is also known as a systematic analysis. The aim is to build an in-depth discussion on the identified research themes and to uncover the knowledge gaps. Afterwards, future directions and recommendations will be developed to guide and help the research community, and to add to the body of knowledge. Screening of the selected 237 articles was done to ensure that all the documents included in theme analysis were of good quality and related to the scope of MiC. This practice is common in qualitative systematic analysis of literature, and was used in some previous studies (Jin et al., 2018; Yin et al., 2019).

3. QUANTITATIVE ANALYSIS

3.1 General Features of the Literature

The selected 237 papers were analyzed to determine the characteristics of the sample. The year range used when searching in *Scopus* was not limited, which resulted in documents published from 1969 to 2020. The selected sample contained three types of documents: journal papers (59%), conference papers (35%) and review papers (6%). The reason behind including conference papers was due to their effect on the quantitative analysis of keywords repetition (Lopez and Froese, 2016), which is indicative of the sample and the trends within the literature, and this way a broader realization for MiC research was built.

Despite that the implementation of MiC dates back to the 1960s, interest in MiC fluctuated over the years. Hence, very few papers were published between 1980 and 1990. However, MiC regained momentum in the new millennium, particularly in 2005, as shown in Figure (3). Furthermore, interest in MiC increased in the last six years, resulting in the publication of 39 papers in 2018 only. The idea of MiC originated in the USA (Anon, 1973; Lucas, 1971). Therefore, quantitative analysis indicated that MiC research leaders were from the USA with 40 publications. Following the USA, Canada, Australia, and the United Kingdom (UK) published 34, 29 and 23 articles, respectively, as shown in Figure (4). These four countries produced almost 50% of the whole literature sample considered in this study. Scholars from other countries also contributed, as depicted in Figure (4).

3.2 Scientometric Analysis

The second part of the quantitative analysis was the scientometric analysis. The top journals, co-authors, repetition of key words, most cited articles and active countries researching in MiC were analyzed. These five core aspects were adopted as the main elements of scientometric analysis, as reported in previous literature review articles (Jin et al., 2018; Oraee et al., 2017; Song et al., 2016). *VOSviewer* for visualizing science maps and quantifying bibliometric parameters (Van Eck and Waltman, 2019) was used for this analysis. Besides, *VOSviewer* was adopted in several literature review papers in similar study areas (Park and Nagy, 2018; Wu et al., 2019; Yin et al., 2019). VOSviewer was utilized to produce importable files to "Gephi", which was used to analyze certain factors, such as average citations per year, and average publication year, as shown in Table (1).

3.2.1 Active Countries

The chosen type of analysis was "citation" and "countries", and both were limited by setting the number to 3 and 15, respectively. Although there are no standard ways of selecting these thresholds, some previous review articles that used *VOSviewer* recommended them (Hosseini et al., 2018; Oraee et al., 2017). Besides, multiple attempts were attempted to identify the most suitable range of the number of countries that could form the proper clusters. Consequently, 15 countries of 38 exceeded the set thresholds. These two arguments were applied to select all the thresholds in other scientometric analyses. Table (1) provides details of each country in terms of total citations, average citations, total link strength, and so on. Figure (5) is the mapping of these countries, where variances at font and node size indicate where more articles are published. USA published the highest number of documents, which is an agreement with the claim that MiC originated from the USA. All other bubbles were connected with that of the USA's. Similarly, Australia and UK had the same number of links as the USA but with different total link strength. This indicated the extent of the influence of research produced in USA on other locations. However, Australia had more links and total link strength, which suggested that Australian articles had a higher influence than those of the USA's. All the four countries that formed 50% of the sample are presented in Figure (5). In terms of citations, research studies based in USA achieved the highest number of citations, while the lowest was found in the Netherlands. Some countries not included in Figure 4 featured in the map due to their high number of citations and links compared to the number of documents produced (e.g. the Netherlands). Interestingly, the ranking of countries in our study was quite different from that reported in a recent study on critical success factors in MiC (Wuni and Shen, 2019). Our analysis identified the USA, Canada, Australia, the UK, China, Malaysia, and Singapore as the most influential countries in MiC research. However, Wuni and Shen's rank produced the USA, the UK, Malaysia, Australia, Hong Kong, Sweden, and Japan. The reason behind this difference could be attributed to the basis selected for each ranking. While Wuni and Shen focused on ranking countries researching on critical success factors of MiC, the focus of our study was much broader. We ranked all the countries that participated in MiC research as a whole. This means that a country like Canada, which did not assess the critical success factors of MiC, focused on another knowledge domain in MiC research.

3.2.2 Analysis of Sources

Second element resulting from the scientometric analysis was the analysis of sources publishing research work in MiC. Table (2) lists the sources that published the highest number of papers in MiC. To generate the table, "citation" analysis for "sources" was selected in *VOSviewer* and the threshold was set to a minimum of three documents.

Afterwards Gephi was used. The analysis performed on *VOSviewer* and *Gephi* showed that *Automation in Construction* came on top, with nine articles out of 238. These nine articles received 185 citations an average of 20.6 citation per document.

Journal of Cleaner Production was in second place with seven articles and 119 citations. The citations of *Journal of Construction Engineering and Management* for only six articles reached 168, which was substantial indication of its quality and impact on MiC work. Similarly, *Journal of Management in Engineering*, which received 138 citations for four articles, averaged 34.5 citations per article. Other important journals that published MiC research works are listed in Table (2). Scholars can use such list in their search for articles related to MiC.

3.2.3 Analysis of Co-Authors

As the sample consists of 237 documents, an extensive list of authors was expected. Table (3) presents prolific authors in MiC research. To conduct the analysis in VOSviewer, "co-authorship" was selected as the type of authors, whereas the thresholds were set to three documents and 20 citations. The output showed 23 co-authors matching these requirements. The table contained the number of documents where every author was mentioned, and the number of citations gained in total for these documents. Furthermore, the analysis provided the average year of publication, which indicated the prolificacy of each author and the time interval where he/she produced the most articles. It is worth mentioning that the impact of a certain author could be assessed based on the number of citations gained on a certain number of documents.

For instance, "Al-Hussein, M.", whose average publication year was 2016, authored 9 articles and had 124 citations (average citation of 13.8 per article). Such result indicated the quality of his work and how it added to the body of knowledge. Moreover, the peak working years for him were between 2014 and 2018. Furthermore, Table (3) provides the research focus of each author. The first author was found to be specialized in on- and off-site construction operations. The data produced from this analysis can guide scholars working on MiC to identify the top authors in this field so as to keep up with the updates in the field. Besides, the data provides a good background for future collaboration between different research teams.

3.2.4 Top Cited Articles

Part of the quantitative analysis was to analyze the top cited articles in MiC. Table (4) includes the documents extracted from *VOSviewer* with more than 30 citations. Additionally, the research methods used in each article were identified, and normal citation for each paper were obtained from *Gephi*. Many articles used simple methods, such as questionnaires, comparisons, and literature review. Due to the substantial number of articles (25 articles), the table was limited to articles with 35 or more citations (20 articles). The number of total citations indicated the influence of each article The top cited paper, which examined the concept of pre-assembly and how various project participants accepted that concept, was published by Gibb and Isack (2003) Another conceptual paper was published by Richard (2005), who discussed the various levels of construction manufacturing, and they could be advanced. Sustainability of MiC on the performance of MiC building was discussed in several articles(Begum et al., 2010; Kamali and Hewage, 2016, 2017). Other scholars focused on the structural design of MiC projects (Lawson and Ogden, 2008; Loss et al., 2016; Manalo, 2013). The construction management aspect was examined in other studies that focused on success factors, scheduling and market assessment (Lu, 2009; O'Connor et al., 2014; Taghaddos et al., 2014). Comparing the citation of older articles with newer ones may be defective; therefore, normalization of citation was evoked to uncover the most influential articles. Ferdous et al. (2019), received the highest normalized citation, ranking it as the most influential work in the sample. Therefore, researchers can use these data to identify the top articles and topics in MiC. Additionally, it was observed that researchers engaged in different aspects of MiC research in the last 15 years.

3.2.5 Co-occurrence of Author Keywords

Keywords represent the knowledge areas found in a certain field of research. It can indicate the boundaries of the research domain, offer some relationships and trends among the research domains. The patterns shown in Figure (6) reflect the themes that have been studied in MiC. This has been presented in keywords map as shown in some earlier studies (Jin et al., 2018; Van Eck, 2014). The science mapping of keywords was created by selecting "co-occurrence" analysis and author keywords. The occurrence threshold was set to 3 and resulted in 29 keywords out of 560, after accumulating repeated words (i.e., BIM with Building information modeling and Modular Building with Modular Buildings). The resulting map contained six clusters, with each representing a domain that is connected or relevant in concept.

1. Cluster one *"Red"* (construction, modular construction, lean construction, design, productivity, manufacturing, scheduling, simulation,). It represented the strong focus on simulation, productivity and scheduling (Goh and Goh, 2019; Taghaddos et al., 2014).
2. Cluster two *"Green"* (modular building, energy efficiency, off-site construction, sustainability, life cycle assessment). Sustainability became a major trend in research in the last few years, and modular buildings were assessed on their overall life cycle to ensure or quantify their performance in this regard (Hammad et al., 2019; Liu and Qian, 2019b; Rodrigues et al., 2016).
3. Cluster three *"Blue"* (building systems, industrialization, modularization, prefabricated construction). The various concepts of modularization and building

systems were studied as researchers were digging for the optimum modular building system (Choi et al., 2019; Jensen et al., 2012; Salama et al., 2017b).

4. Cluster four *“Yellow”* (prefabrication, preassembly, modular). MiC has always been associated with preassembly and manufacturing, both representing the core features of MiC that promote productivity (Afifi et al., 2016; Jang, 2018; O'Connor et al., 2014).
5. Cluster five *“Light Purple”* (cold-formed steel, seismic design, shear walls). One of the main challenges for MiC was structure analysis i.e. its response to seismic loads. Many scholars focused this area to enhance the adoption of high-rise modular buildings (Innella et al., 2018; Yu et al., 2019).
6. Cluster six *“Turquoise”* (BIM, construction management). MiC required a great deal of coordination and communication, which made it a fertile ground for the implementation of BIM and construction management studies (Bonenberg et al., 2019; Isaac et al., 2016).
7. Cluster seven *“Orange”* (Singapore, prefabricated prefinished volumetric construction). Singapore appeared among the keywords because researchers in Singapore listed the city’s name in the keywords. Three out of 10 articles originating from Singapore mentioned the city’s name. This action emphasizes that the researchers produce output that is for the development of MiC particularly in Singapore. In addition, MiC in Singapore is named PPVC which explained the link between the two keywords.

The link between the keywords defined the complexity of the network and the total link strength defined the interrelatedness between keywords (Jin et al., 2018). Statistical details of the keywords can be found in Table (5). The most repeated keyword was “Prefabrication”, followed by “Modular Construction” and “Modular Building”. The identified keywords reflected the main knowledge areas existing in the literature, while keywords which were repeated less than 3 times covered a broader span of knowledge areas. However, lower repetition of keywords could be interpreted as a gap in the literature. For instance, the keywords identified lacked important and critical keywords, such as supply chain, risk, contractual relationship, and disputes. Others included optimization, internet of things, blockchains, hybrid simulation, automation, smart buildings, repair and maintenance, project control, and life cycle cost. A detailed qualitative analysis will unlock the actual themes existing in literature, but at this point, these knowledge areas are believed to be lacking.

4. QUALITATIVE ANALYSIS

In this section, theme analysis was conducted to understand the ongoing trends in MiC research. A categorization based on themes was created and represented in Figure (7). Diverse research directions were in the sample. But only 107 papers out of 237 were used in the quantitative analysis and the time span covered 2003 to 2020. These articles were carefully selected to reflect the overall sample. It was also ensured that they contained valuable research outputs and relevant to this literature review study. Overlaps between categories existed and were settled based on the core objective of each study. For example, if a study proposed a new structural design and used BIM, then it was categorized as a structural design study and not information management technologies study.

4.1 Sustainability

4.1.1 Sustainability in Operations

The sustainable benefit of MiC was a major concern for a lot of researchers. Begum et al. (2010) compared material wastage between two construction projects; one used a conventional cast in-situ method, while the other utilized precast elements (i.e., 3D precast). The study showed that MiC produced less waste and 94% of its waste was reused or recycled. The MiC execution operations took place in two places at the same time; on-site and off-site. Xie et al. (2018) addressed the consumption of energy in MiC manufacturing facilities. The study focused on reducing the cycle time inside the facility through identifying non-value-added activities that caused wastage, and accordingly enhanced energy consumption (EC). The literature also included a review of sustainable/lean methods that could be implemented throughout project processes. In the manufacturing stage, facility layout, multiskilled workers, and pull driven control systems were recommended to improve sustainability in this stage. In addition, just-in-time (JIT) deliveries with buffered stock for two days were considered optimum results in the on-site assembly stage (Innella et al., 2019). The literature lacked analysis of key decisions that should be taken at MiC on- and off-site locations to guarantee project's sustainability. In addition, the literature lacked a comparison between several project sizes and achieved wastages.

4.1.2 Sustainability Assessment

Measuring the impact of MiC from the point of view of sustainability is important. This has encouraged researchers to study this subject and search for a conclusion. Review papers were carried out to identify the status of the body of knowledge in this area. Marjaba and Chidiac (2016) discussed sustainability and resiliency metrics for buildings and studied the various sustainability certificates for buildings. The review concluded that MiC had a potential in this area but lacked the metrics for performance assessment. Another review article by Kamali and Hewage (2016) examined sustainability and future directions in MiC. Gaps in social and economic life cycle analyses of MiC were identified and life cycle sustainability assessment was suggested as a decision-making tool. This article ranked amongst the top cited articles in MiC. Quale et al. (2012) compared environmental impacts of modular houses and conventional houses in the USA. The comparison was made in four main points: material production and transport, off-site and on-site energy use, workers transportation and waste management. Results showed that the impacts of MiC were below average.

Another performance measurement conducted through surveys to identify sustainability performance indicators (SPI) of MiC buildings by assessing environmental, economic, and social aspects. This SPI allowed for a clear and reliable comparison between MiC and traditional methods (Kamali and Hewage, 2017). The results showed that the economic dimension was still the main concern of practitioners. Furthermore, Kamali et al. (2018) formulated some performance criteria for assessing the sustainability of modular buildings. Using interviews and questionnaire, a list of criteria was created and then analyzed using Analytical Hierarchy Process (AHP), Multi Criteria Decision Analysis method (MCDA), and Elimination and Choice Translating Reality (ELECTRE). The top environmental criteria concluded were energy performance, efficiency strategies and waste management, while the top economic criteria concluded were design and construction time and design and construction costs. Finally, the concluded top social criteria included workforce health and safety, and safety and security of building. Validation of proposed performance measurement framework was carried out using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and case studies. However, the limitations of the study comprised limited sample size, and scarcity of experts with knowledge in MiC and conventional methods. Furthermore, only one case study was used for validation and potential users of the framework may require calibrating the SPIs to consider site specific socio-economic and geographical conditions.

Similarly, Liu and Qian (2019a) developed a tool for assessing the social impact of MiC buildings through their life cycles. The research used stakeholder categorization to earmark sustainability indicators. AHP method was used for analysis, and a comparison between two projects was developed. Results showed that PPVC projects performed better. The stakeholder related indicators however, needed continuous investigation, and a maintenance stage could be added to the comparison. Another study (Kamali et al., 2019) studied the influence of life cycle assessment on the environmental performance (global warming potential) of MiC and other methods. A conventional project and two other MiC projects formed the basis of the study and data collection was through questionnaire surveys. Weightings of each alternative were measured through AHP. The first modular building had the lowest environmental impacts. However, the second modular building was the worst performing, which indicated that MiC was not the absolute optimum environmentally friendly construction technique. Enhancements like optimal design, reduced material, and minimum transportation distances were required in MiC. A different sustainability assessment research about summer heating of a hospital built using MiC was performed in the UK (Fifield et al., 2018). The hospital consumed less energy but suffered from overheating risk in summer. The study proved that the building design contributed to overheating in summer, thus calling for design modifications in upcoming projects. MiC projects were not studied during the operation and maintenance stage to assess their energy reliability and to link the performance with certain parameters in design.

4.2 Construction Operations

4.2.1 On-Site Operations

Conventional construction operations are different from construction operations in MiC, as MiC relies on crane operations. Olearczyk et al. (2012) developed a method for crane selection and utilization for multi-lifts using algorithms that could adapt and react to dynamic site conditions. The method required inputs from the crane and restrictions or conditions of the lifting process. The authors, in another work, developed another crane selection model using mathematical rules. The study included constraints, such as crane capacity check, crane placement location, outrigger clearance, and boom clearance. The model was tested using a case study (Olearczyk et al., 2014). Further simulation was carried out by Liu et al. (2019) through developing a DES model for MiC project using mobile crane. The unique aspect of the study was the incorporation of weather and transportation delays in the model to make it more realistic. The output of the model provided utilization percentages for resources and it was compared with previous models. The results showed lower utilization percentage which validated the impact of weather conditions and transportation delays.

Application of 3D visualization tools is trending in the construction industry. For instance, lifting operation was presented through 3D scenarios to allow the project stakeholders to visualize the project assembly operations during the design stage. This eliminated uncertainties, enhanced communication and decision making, and assisted practitioners in critical lifting (Han et al., 2015). The visualization concept (3D Studio Max) was also combined with simulation models (Simphony.Net) to produce a full visualization for the whole construction process of a 34-story MiC building (Moghadam et al., 2012a).

Furthermore, a discrete event simulation (DES) model was built for a construction process, and then Value Stream Mapping (VSM) was used to determine the points where lean concepts could be applied. Total Quality Management, E-Kanban JIT system, labor cross-training, construction robotics, and development of lean (To-Be) models were applied (Goh and Goh, 2019). Simulation was also used to combine safety with productivity factors in a simulation model named “Human-In-The-Loop” (HITL). The technique considered human factors, such as operator competency, and communication among lifting crew. The model was built to minimize risks and enhance productivity. The whole process was also visualized using BIM, laser scanned point cloud, and virtual reality (Goh et al., 2019). Moving further towards safety aspects, Fard et al. (2017) studied the causes of accidents in MiC/prefabricated projects (125 accidents). Results showed that the most common injury was “fracture”, which took place due to “falling” because of “unstable structures”.

Moving to logistics, Hsu et al. (2018) developed a model that could adapt to demand changes in the construction site to optimize the logistics process in manufacturing, storage and assembly stages. The stochastic programming model, which was tested using a case study, captured all possible variations in demand at the construction site Additional future works may focus on other features, such as location and number of warehouses, outsourcing, more manufacturing activities, and possible disruptions. From the existing literature, knowledge gaps exist in the limited studies conducted on on-site construction operations and lack of integration between safety and simulation models. Also, only one model addressed transportation and supply chain in MiC, which is a critical managerial aspect in on-site operations. In addition, quantification of safety impacts when adopting MiC should also be studied.

4.2.2 Off-Site Operations

Manufacturing concepts in construction began with components prefabrication, which later evolved to complete prefabrication, full assembly, and pre-finished 3D modules. Richard (2005) provided an extended concept of manufacturing, incorporating “reproduction”, which represented the fifth step after prefabrication, mechanization, automation, and robotics. The concept, borrowed from printing technology, discussed enhancement of manufacturing by producing the same output with simpler techniques. In manufacturing, robots are utilized extensively. The dominant application of robots was in the manufacture of MiC homes, which started in Japan in the seventies. However, robots are utilized in other activities in the construction industry, such as installing finishes, plastering, and hauling of materials. (Bock, 2007). Another element in manufacturing is pre-assembly, which was covered by two studies. Gibb and Isack (2003), the top cited article in the sample, addressed how clients perceived pre-assembly. Through surveys and interviews, it was found that clients agreed on the benefits of pre-assembly and that they should involve suppliers early on during the design stage. Conversely, Rausch et al. (2016) addressed pre-assembly differently, where optimum assembly planning of various parts was targeted, whether it is volumetric or non-volumetric.

To enhance decision making in MiC production lines, modern technologies were incorporated into manufacturing operations through using visualizations. This idea was carried out using Value Stream Mapping (VSM), Maxscript and 3D Studio Max (Han et al., 2012). Furthermore, linear time complex algorithms were utilized to design control panels for automated MiC machines, which enhanced the manufacturing process and minimized safety hazards (Tamayo et al., 2018). More enhancements were suggested through using a software named MCMPro, a computer tool for drafting, that could integrate BIM and Lean concepts by providing drawings and takeoff lists for components automatically (Moghadam et al., 2012b). Moving to lean concepts, Yu et al. (2013) studied the application of lean concepts (the 5S- sort, straighten, shine, standardize, and sustain) in a production line for a company that owned MiC modules production lines. The hardest part of applying lean concepts on the production line was the challenge encountered in convincing the middle managers and the frontline workers to adopt the idea. However, this case study reported the success of the pilot trial. In the same context, discrete and continuous simulation model for the production lines of MiC modules were built to promote lean production, increase productivity, and remove some unnecessary activities within the production cycle. The production line was enhanced using automated stations and parallel stations (Afifi et al., 2016). Another important aspect of the modular off-site facilities was the noise levels within the facility and the healthy work environment, Dabirian et al. (2020) built a stochastic model that assessed the acoustic conditions within the facility to evaluate the noise risk and measure the noise exposure levels for workers.

This part of the literature concentrated on production lines and manufacturing operations. It was noted that the objective of these studies was to enhance productivity in a way or another using different approaches. Automation proposals were noted in multiple articles. Nevertheless, this aspect could be improved to increase the reliability of MiC. Technical issues related to assembly were not addressed, and wastage control within the manufacturing facilities was not explored. The difference between the manufacture of concrete and steel MiC modules was not highlighted. It is expected that different monitoring and control systems are required within each facility.

4.3 Building Design

4.3.1 Structural Design

Structural performance of MiC buildings is an important aspect in MiC. It is believed that this aspect is the reason behind the widespread of MiC, as scientists have provided structural solutions that allowed for high-rise MiC buildings. In the literature, a proposal was found for new steel-timber composite structural system that enhanced cost and time (Loss et al., 2016). Creative materials were also proposed to serve as the walls of modules. Basically, the cross-section comprised two layers of HDPE and a filling of polyurethane foam (PUF) (Sharafi, P. et al., 2018b). Another new material, made of fiber-reinforced rigid PUF and magnesium oxide (MgO) boards, was tested for various sorts of loading (Manalo, 2013). In addition to materials, a new structural system was proposed that discussed shifting the “elevator shafts” without affecting the building (Gunawardena et al., 2016b). Moving to another aspect of MiC building structure, a new proposal for steel connections was provided and contained intermediate plug-in device that made the installation more convenient and eliminated welding (Chen et al., 2017). Innovations continued in connections with a proposal to use interlocking system between modules. This provided a hanging mechanism and allowed the building to resist various sorts of loading (Sharafi, P. et al., 2018a). Through an experimental investigation, a reinforced concrete column with steel beam composite joint was proposed for modular buildings. The column was tested using three samples representing three sorts of connections. It was testing concluded that the seismic performance of the proposal offered ductility coefficients and equivalent viscous damping coefficients within limits. Further finite element analysis was conducted using ABAQUS and satisfactory results were realized after validation (Wu et al., 2020). In addition, the connection between modules and foundations was studied by Lacey et al. (2018), while Chua et al. (2020) proposed to enhance the connection between floor slabs and vertical elements to resist lateral loads. Their results showed that vertical connections between modules using a rod, and the horizontal connection between modules, using tie plate and shear keys, were very important in lateral load resisting. A spring joint proposed to make up for these connections also produced same stiffness. After analysis it was concluded that this new joint offered a linear link and multi-linear links with elements, which enhanced the stiffness of the building. Lastly, the inter-module connections were reviewed for its performance requirements through proposing solutions for the two key issues in inter-module connections: lateral load transfer and lack of high-performance inter-module connectivity (Srisangeerthanan et al., 2020).   The article offered an assessment of all existing connections identified through critical review against the required performance, the results showed that automatic and semi-automatic connections were the most suitable to meet the structural, constructional, and manufacturing requirements. However, the current state-of-the-art connections only achieved partial satisfaction (Srisangeerthanan et al., 2020).

Moving to special structural loads, a special loading type was highlighted by Godbole et al. (2018), who studied dynamic movement of modular units during hauling from one place to another. From a different perspective, Chua et al. (2018) used bay pushdown analysis to assess the robustness of MiC buildings in case of progressive failure due to element removal. The famous seismic loads were discussed by Gunawardena et al. (2016a), where the authors discussed its effect on several elements and connections, and provided explanation to the behavior of the system. Fire performance of tubular steel columns was studied using various proofing materials; fiber reinforced calcium silicate (FRCS) boards, rock wool and aluminum silica (Fiberfrax), to check the fire rating in hours (Zhang et al., 2018). Further exploration of the benefits and challenges of using cold-formed steel sections as the main structure components were explored in the literature, particularly in Hong Kong. The main benefits of these steel sections were their applicability as wall supporting structures and the possibility of being used as the main column structure. The main disadvantage was, however, that no rigorous research have been conducted on these sections to enhance its usability (Andy Prabowo, 2019).

The progress in the structural aspect of MiC is huge. Many inventions were created, and various innovative ideas were proposed. These included use of composite sections, light weight material, fast and easy connections, and utilizing BIM to promote automated fabrication of structural elements (Liew, 2020). However, the literature did not assess the impact of these new inventions on architectural aspects, such as spatial design and acoustic performance. For instance, using material such as HDPE, PUF and MgO will have an impact on acoustic performance and fire safety of the whole building. Thus, these materials need more vigorous testing. In addition, studies on concrete modules were not very intensive as most researchers focused on steel modules. This despite that the world's highest modular building was made of concrete and not steel (The Clement Canopy, 2019).

4.3.2 Architectural Design

Scholars focused on modules dimensions after conforming to all the requirements and conditions of design. Modular Suitability Index (MSI) was proposed to represent all the constraints and conditions that affected module dimensions, and accordingly, the architectural conditions (Salama et al., 2017b). Similarly, unified matrix technique was utilized to fulfill the architectural, structural and constructional constrains that exist, as well as to optimize the cost of spatial design (Sharafi et al., 2017). A different method was used to determine optimal modularization with interchangeable and replaceable interfaces. This conferred flexibility on the architecture design (Isaac et al., 2016). Similar modularization concept was tested for applicability in the design of health care facilities. Analysis was conducted to test the applicability of a user-centric and participatory design in modular health care facilities. However, the results showed that time pressure and lack of end-user involvement hindered the application (Lahtinen et al., 2020). Another study assessed the effect of structural requirements on architectural design in high-rise buildings. The process of staking modules around concrete shafts were discussed and solutions were proposed (Lawson et al., 2012). Likewise MiC performed better than conventional buildings on comparison of their architectural and acoustic performances, thermal behavior and energy consumption (Boafo et al., 2016). The concept of MSI and taking multiple considerations in deciding the sizing of modules were the core issues explored in MiC. Indices are required to be validated against their applicability for various MiC building projects, yet a unified standard method for assessing the optimality of module size is lacking. Simulations were not utilized to test the performance of modules after it was sized using MSI or the unified matrix technique, leaving a gap in the literature.

4.3.3 Sustainable Design

Sustainability is trending globally in all aspects and the best way to guarantee sustainability is by starting with the design itself. In this context, parametric design software was utilized in MiC building design. With the aim of reducing waste, Rhino and Grasshopper software packages were utilized and linked with BIM, and algorithms to achieve this (Banihashemi et al., 2018). A similar study supported decision making in the design stage by assessing the life cycle of modular buildings and determining which stage required enhancements (Faludi et al., 2012). Nowadays, adaptation of buildings to climate changes is important. Buildings must consume minimum energy through determining the configuration of each unit and appropriately adjusting them to achieve minimum total energy consumption. Aspects like optimal window ratio, defining proper orientation and using different materials were studied (Košir et al., 2018). Concurrently, Li et al. (2018b) studied the responsiveness of MiC building envelope to climate and how the needs of the occupants could be satisfied. Such needs included comfort, flexibility, and energy-saving. The same sustainability goal was also addressed by Rodrigues et al. (2018), who worked on optimizing the design of lightweight steel frame modules. The study proposed a correlation relationship between some geometrical indices of the building and its energy performance. Lau et al. (2019) proposed converting the building envelop in MiC to solar panels to save energy and decrease CO_2 emissions. The proposal was named building-integrated photovoltaics (BIPV), and BIM was used as the platform for testing its implementation. Results showed that this method was reliable and promising. However, the hardware required was expensive and using PV on building envelopes is not very common in the industry.

Sustainable design is an extension or improved way of realizing architectural design. It can also be a way to incorporate the impacts of the structural system on the overall performance of the building. Parametric design is the new trend in architecture, and it optimizes the usability and reliability of a design. Each proposal in design should be vigorously studied using sustainability simulation tools to assess its performance. This existed in the literature but the need for further improvement will always be required. Finally, the design of MiC buildings should follow the concept of Design for Manufacturing and Assembly (DfMA). By reviewing the literature regarding this concept, it was found that the concept was adopted to satisfy three main objectives. First of which was to enable a holistic design process that encompassed the manufacture and assembly of a structure or an object. The second objective was to provide an evaluation system of the efficiency of manufacturing and assembly that could work with virtual design and construction (VDC). Lastly, DfMA was adopted to embrace the ever-changing prefabrication and modular construction technologies. However, DfMA still lacked design guidelines, multidisciplinary team coordination and lean principles(Gao et al., 2019).

4.4 Management Aspects

4.4.1 Feasibility through Benefits and Challenges

The benefits and challenges (B&C) of MiC have been addressed to enlighten the construction industry when adopting MiC. These (B&C) vary according to location, market status, and official support and encouragement provided by the government. Rahim and Qureshi (2018) discussed the adoption of MiC in Singapore and how it was favored over prefabricated buildings. Nevertheless, a lot of challenges militated against the adoption of MiC, hence they suggested that knowledge of MiC be incorporated into the educational system. Four articles addressed the (B&C) of MiC through ranking and prioritization. The first study, which focused on the Mainland China market, aimed to identify factors affecting the growth of MiC. Fuzzy set theory was used, and the identified factors were scored and ranked (Zhang et al., 2014). The second study targeting Mainland China and UK markets identified 26 challenges. For both markets, the results varied according to type of stakeholders (e.g. client, contractor, etc.), previous experience in MiC projects, and size of the company (Rahman, 2014). The third study focused on the Singaporean market. Constraints of adoption were identified and mitigation strategies were proposed from the literature and verified using interviews. Thereafter, the authors statistically analyzed the data to identify the top five constraints along with the top three mitigation strategies (Hwang et al., 2018a). The fourth study addressed the execution of MiC in dense, urban environments, like Hong Kong. The study identified the benefits, barriers, and opportunities through questionnaires, and concluded that modularization offered better productivity and quality to clients in dense, urban environments. However, the main barriers were transportation and site access (Choi et al., 2019). Furthermore, a study developed comparison between the performance of PPVC and Individual Panel System (IPS) based on some case studies. Results suggested that PPVC achieved higher productivity and quality with reduction in time, cost, site hazards, noise, and dust. Thus, the benefits of MiC in comparison with panelized system were established (Hossain, 2019).

It is important to emphasize that B&C varies according to the existing level of adoption in a certain market. A market that has recently adopted MiC may not realize many benefits. However, a high-level of adoption may guarantee more benefits, since the stakeholders are likely to be more aware of its challenges. Further B&C research studies are expected to emerge as MiC design and construction methodologies develop. New inventions are always accompanied by quantification for B&C.

4.4.2 Construction Management

Starting with the methods of delivering MiC projects, the owner should take advantage of his superior position and partner with suppliers or contractors to enhance coordination, communication, and planning. Furthermore, construction management (CM) or design-build (DB) project delivery method was recommended due to complexity of the project (Molavi and Barral, 2016). Contractors began to adopt MiC by creating a subsidiary company that specialized in MiC. Through two case study projects (DB and design bid build- DBB), cost comparison ranked DB as more effective as it allowed the involvement of the contractor in design stage (Dakhli et al., 2015).

In terms of managing early project stages, an international online questionnaire survey was conducted on 9 critical success factors in the concept, planning, and design stages of a project. It was concluded that the most influential factors included robust design specifications, accurate drawings and early design freeze, good working collaboration, effective communication and information sharing among project participants. Others involved effective stakeholder management, extensive project planning and scheduling, and early engagement of key players. Small sample size, data quality and reliability risks were the main limitations of this online questionnaire (Wuni and Shen, 2020b).

Planning and scheduling are important aspects of construction management and represent a key role in MiC due the presence of on- and off-site activities. A previous study suggested building a time schedule that included on-site construction, manufacturing process, transportation and installation. A genetic algorithm was used to optimize resources and decision making. Furthermore, the schedule addressed conditions like multiple projects at the same manufacturing facility (Lee and Hyun, 2019). Similarly, Liu and Lu (2018) developed an optimization model for material logistics and labor crews. The goal was to optimize project budget. Integration of linear schedules of on-site and off-site activities with BIM was proposed to offer synchronization and visualization. Constraints like storage areas and number of trucks were addressed. This proposal identified the critical control points that connected on- and off-site schedules (Salama et al., 2017a). A productivity model for all the project phases in MiC was developed using System Dynamics (SD). The productivity was calculated through cost per tonnage of module, while the productivity factors were taken from the key performance indicators in each phase. For each phase Causal Loop diagram was developed and all stages were linked together using Stock and Flow diagram. The results showed that productivity varied greatly with poor labor performance. The core benefit of the model was that it could give an early warning at the design stage on the impacts of variability on subsequent project stages (Manouchehri, 2019).

MiC is presented as a cost-effective solution. However, when adopted, some additional costs are incurred. Accordingly, the reasons behind cost increase required some investigations. Hong et al. (2018) created a cost breakdown to determine the items responsible for a cost increase or decrease. Afterwards, a cost-benefit analysis (CBA) was developed. It was concluded that the increase in cost when adopting OSC could range from 26.3% to 72.1% subject to changes based on different market location and project conditions. Another CBA was carried out to compare cost per ft^2 for MiC and panelized system. MiC provided a marginal cost saving. However, as the saving was not guaranteed, selection should be based on a more reliable study. In addition, case studies used in comparison were not identical (Lopez and Froese, 2016). Addressing planning and cost aspects required elaboration on uncertainties and risks that could affect them. Li et al. (2013) identified the risks in MiC and assessed the impact on cost and time using fuzzy AHP. Weightings were given based on expert opinions and fuzzy AHP. The study also built a simulation model using Simphony NET 4.0 to incorporate the identified risks. It was concluded that a contingency reserve be set aside for cost and time plus a classification for risks to general, off-site, and on-site risks.

A literature review was developed to identify the critical risk factors that affected MiC. The study found 30 factors, and the top 10, based on frequency of occurrence were discussed in detail. High initial cost, delays in the delivery of modules, and lack of government support were the top risks (Wuni et al., 2019). Furthermore, the barriers to adopting MiC were identified through a holistic international review and meta-analysis of literature. The study identified 120 barriers in 15 countries, which were classified into knowledge, attitudinal, financial, technical, aesthetic, industry, process, and policy barriers. The barriers were mapped, and clusters were formed to build an ecosystem for barriers and how they hindered the uptake of MiC. The recommendation was to tackle several barriers at a time using strategies, such as integration. As an example, to solve the stakeholders attitudinal barrier, the government should be the main initiator and implementer of MiC (Wuni and Shen, 2020a).

Decision making is critical in construction management. Its tools support all stakeholders in making the right decisions based on the information given. Key areas were benchmarked for stakeholder management in MiC through a structured questionnaire with international MiC experts. The results showed that the top three areas were effective working collaboration, communication and information sharing among participants, effective coordination of the PPVC supply chain segments, and early involvement of relevant stakeholders (Wuni and Shen, 2020c). Song et al. (2005) identified some of the factors affecting the adoption of modularization in industrial plants. However, the list of factors affecting the decision making was used later in several studies related to MiC. The work was considered a very good reference as it was one of the top cited in this field.

Decision making on the adoption or otherwise of MiC is also important. Azhar et al. (2013) reviewed the literature to identify these factors, and then performed interviews, questionnaires and focus group meetings to analyze the critical decision-making factors. Their findings identified six major ones. A second study with similar objective utilized interviews to identify and rank the decision making factors. Several statistical analyses were performed and a decision making software was then developed using Microsoft Excel and Microsoft Visual Basic Applications (VBA) (Hwang et al., 2018b).

Decision making on the degree of modularization for a certain project was reported in an earlier study based on multiple criteria that exist in the project, and the degree of modularization includes adopting MiC as the highest level of modularization (Sharafi, P. et al., 2018). In another direction, the preparedness of an organization to adopt MiC within its scope of work is important, which drove a research toward studying the organizational readiness and the features that must be present in an organizations before adopting MiC (Musa et al., 2016). In the context of ensuring successful adoption of MiC, O'Connor et al. (2014) identified success factors and their enablers for any MiC project.

Early contractor involvement is key in MiC projects. However, this could be achieved through multiple project delivery methods such as DB, integrated project delivery, EPC, BOT, and so on. However, existing literature failed to present the best project delivery method. Likewise, the impact of proper planning and scheduling in decreasing the cost of MiC projects could not be found. Cost is critical in MiC and off-site operations are technically costly. However, factors such as mass production and economies of scale may be incorporated with planning and scheduling to deliver a cost-effective project control proposal. Decision-making on the degree of modularization, feasibility of MiC, and readiness to adopt MiC have not been integrated. Rather each of these factors were addressed separately, while the practical case is that all these aspects are related.

4.5 Information Technology Management

The way information is communicated within a project is crucial to the success of the project. The most common information-based concept in construction is Building Information Modeling (BIM), which offers a database, tools, and options that can help project participants in various aspects. Scholars have studied BIM from three main perspectives, which included extending/enhancing the database, applying BIM to various operations, and identifying the benefits and challenges of adopting BIM. In extending the BIM standards and database, Nawari (2012) studied three components of BIM standards and extended them to match the requirements of OSC in general, including MiC. The components were: Information Delivery Manual (IDM), Model View Definition (MVD), and Industry Foundation Classes (IFC). Similarly, Ramaji and Memari (2018) focused on modifying (MVDs) to comply with multi-story modular buildings. The same author published two articles that focused on building a product oriented towards information delivery framework using BIM (Ramaji and Memari, 2016; Ramaji et al., 2017). In the first article the concept of Product Architecture Model (PAM) was developed and built to match the requirements of MiC projects. The study addressed the extended use of BIM to apply this concept. The second article combined PAM and BIM together in an application for multi-story modular buildings, which required modifications to some standards.

Many applications of BIM can be found in MiC, starting with the design process. Solnosky et al. (2014) addressed the application of BIM and how it promoted coordination in different design stages and enhance the structural performance. Conversely, Yeoh and Jiao (2019) focused on constructability and how the module dimensions fulfilled the transportation and installation constraints. In manufacturing, Alwisy et al. (2012) addressed the production of shop-drawings and take-off lists using BIM to enhance the process. They also applied some lean concepts by combining a CAD model with BIM technology. In facility management of MiC buildings, Valinejadshoubi et al. (2019) utilized BIM to visualize the damage or distress in the structure of MiC building using sensors. Zhai et al. (2019) developed an Internet of Things-enabled BIM platform (IBIMP) for a MiC project. IBIMP promoted decision-making, communication, information collection, and progress control through all the project stages. Besides, it also removed the barriers that prevented the adoption of BIM in MiC. For general utilization, Bonenberg et al. (2019) discussed the application and benefits of BIM to various project stages. In addition, the study addressed problems that already existed in MiC, which BIM could solve. Furthermore, Lu and Korman (2010) discussed the benefits and challenges of implementing BIM in MiC. The cost of implementing BIM and lack of BIM knowledge among sub-contractors were the main challenges facing the adoption of BIM in MiC. The minimum required level of details (LOD) in MiC projects was not specified. Proposals for solving the adoption problems of BIM in MiC projects are lacking. Extending the database of BIM and building new frameworks for adoption adds a lot to the literature. However, the extension of BIM database needs to be standardized and generalized to fit different sorts of MiC projects.

4.6 Others

In this section articles that did not match any category are presented. For instance, an article that covered the history of prefabrication and how it evolved over time (Ågren and Wing, 2014). Furthermore, MiC market analysis was discussed in four articles; the first discussed the valuation of OSC market inside the UK (Taylor, 2010), the second analyzed the impact of a policy issued in 2017 by the Chinese government (Li et al., 2018a), the third assessed the readiness of Indian construction organization for OSC as a whole (Bendi et al., 2020). Finally, the fourth considered the role of government in increasing the adoption of prefabricated housing, including using MiC (Steinhardt and Manley, 2016).

Review articles which studied multiple aspects in the same study were allocated to this category as well. Navaratnam et al. (2019) discussed the structural performance, fire resistivity, acoustic performance, and seismic performance of MiC/prefab buildings in Australia. In another review paper the focus was on high-rise MiC buildings and how they developed in different countries (Pan et al., 2018). Ferdous et al. (2019) reviewed the technical advancements, opportunities and challenges in MiC. Results indicated that MiC was at a satisfactory level in terms of structural performance. Additionally, MiC was recognized as a sustainable solution from the triple bottom line perspective of sustainability. It was also found that MiC could be crippled by a lack of design guidelines, scarcity of skilled workers, and transportation problems. The article concluded that the future opportunities in MiC structural system should be through replacement of timber by FRP, improving fire safety and sound insulation of currently used material, and development of innovative interlocking systems. Another literature-based study focused on comparing MiC practices in three major markets: Hong Kong, Singapore, and the Mainland China. The results showed that Singapore developed an effective policy system while all of them did not issue any authoritative specifications. Furtherly, MiC was found to be in need of government support to mitigate the technical issues and promote innovation (Xu et al., 2020). From a distinct perspective, a literature review was developed to assess the interaction between lean construction, automation, and modularization. The result showed that potential research could be carried out to satisfy the three paradigms through robotics, integrated project delivery, and parameterization (Brissi and Debs, 2020). The last two papers in this review are unique in nature. The first one discussed the strategies behind adopting MiC and the need to highlight the end goal of a project at the very beginning, through optimizing either design or construction or operations stage of the project (Peltokorpi et al., 2018). The last paper tested MiC building to measure its shielding ability against radioactive fallout scenarios (Hinrichsen et al., 2018).

5. DISCUSSION

In this section, trends and future directions are discussed. Trends were based on the categorization made in the previous sections. The analysis included critically identifying the reasons behind these trends and summarizing the highlights of the trend. Future directions comprised the gaps found in literature and ways to address them.

5.1 Trend Analysis

In the light of the categorization made in the previous section, the literature understudied was divided into six main categories (Figure 7) and nine sub-categories. These branched from four of the six categories created and each category contained a number of articles, as indicated in the given percentages in Figure (7). The six main categories considered the main trends of research in MiC, the focus on these topics is highly expected for this emerging construction technique. In addition, our classification is coherent with the science mapping of key words presented in Figure (6). The linkages between the identified trends and the developed keywords map are established as follows.

Building design and management aspects of MiC constitute almost 50% of the whole sample understudied. The reason behind this high percentage is that the design of MiC buildings is completely different from conventional buildings, thus it attracts researchers to participate in this new area of research. In addition, the height of the tallest MiC building is about 140 meters (Clement Canopy in Singapore), which is completely dwarfed by the heights of the skyscrapers existing in major cities. Besides, design aspects of MiC is also covered in the science mapping of keywords in clusters four and five. The trend in MiC building design includes developing new materials for the structural systems (e.g. HDPE & PUF), creating interlocking systems to connect modules together, and testing modules under dynamic transportation loads. Other identified trends are determining optimum model dimensions, optimizing spatial design, measuring acoustic performance, utilizing parametric design to build more sustainable MiC design, and assessing the responsiveness of the building to climate. All these trends are geared towards realizing optimum designs for MiC buildings from the three core perspectives of design structure, architecture, and sustainability.

The other part of the 50% is the management aspects that explore feasibility analysis and construction management. Both have been represented in clusters one and six, respectively, in the science mapping of keywords. Scholars are interested in critically analyzing this new technique in terms of identifying its benefits and challenges for various markets and investigating and proposing new scheduling techniques for the overlap between on-site and off-site activities of projects. Other motives cover measuring cost effectiveness through cost-benefit analysis and analyzing how the industry can convert from traditional methods to such a modern method.

Furthermore, cluster number two (execution of MiC) arises from the science mapping of keywords. As a logical result, the execution aspect of MiC projects, on- and off-site, has the third highest percentage (17.8%). This is a strong indication of scholars' interest in exploring the optimum ways of properly executing on- and off-site activities. From on-site related studies, the research trends include crane selection and utilization, crane location optimization, and 3D visualization for MiC lifting activities through VSM and BIM. In addition, DES models for modules installation and adjusting logistical plans according to site demands are other trends. Likewise, in off-site related studies, utilization of robotics, optimization of assembly planning of module parts, and visualization of the manufacturing process are important research trends. Besides these, others are building simulation models for the manufacturing process and adoption of lean production principles to increase productivity.

Apart from execution, the interest in information technology management, which has been presented in cluster six, is covered by 10.3% of the sample. This is in consonance with trend of digitalization which has been going on in the entire world. In addition, MiC projects are very hard to execute without utilizing BIM. Research trends in this aspect include analysis of benefits and challenges of using BIM, extending and enhancing BIM database to fit specific MiC project needs, and exploring various applications of BIM in MiC project lifecycle. The last part of the sample is sustainability, with a share of 10.3%. This agrees with the the global trend of adopting sustainable methods. MiC is a sustainable construction method that needs to be examined and assessed to measure and quantify its impact. Sustainability falls in line with the keywords science mapping, and it includes comparing wastage in MiC with other construction methods, reducing energy consumption in off-site facilities, developing sustainability metrics and assessing sustainability certificates. Others are developing sustainability performance indicators and measuring energy performance in different operation stages.

5.2 Future Directions

In this section, ideas for future research are presented based on the gaps found in the literature. In relation with construction processes, visualization of simulated installation (Moghadam et al., 2012a) has been discussed, productivity enhancement through lean approach (Goh and Goh, 2019) has been presented, and safety aspects (Goh et al., 2019) have been treated. A comprehensive study that combines lean concepts, visualization, and safety will result in a more comprehensive conclusion on ways to enhance on-site MiC construction processes. In addition, advanced simulation methods, such as agent-based simulation and hybrid simulation are recommended. The extensive factors that affect the construction processes on the managerial and strategic level can be incorporated to can give a more solid conclusion.

Time and cost evaluations for new proposed designs are needed in order to support the ideas and increase its validation (Chen et al., 2017; Gunawardena et al., 2016b; Isaac et al., 2016; Loss et al., 2016; Sharafi, P. et al., 2018a). In addition, large scale case studies for innovations and pilot testing of developed innovative materials (Manalo, 2013; Sharafi, P. et al., 2018b) are needed. Further integration between the three discussed types of design (architectural, structural, and sustainable) can be performed to optimize the design of MiC buildings. However, the strategic concepts of delivering MiC projects (Peltokorpi et al., 2018) and applying DfMA principles as well , must be taken into account. An in-depth research may provide a solution that balances between the optimality in design, construction, and operation. Furthermore, the concept of standardization and the development of standards and codes for the design of MiC modules are needed. Besides, the incorporation of changeable and replaceable interfaces can add a lot of value to these standards (Isaac et al., 2016).

As MiC stands for Modular Integrated Construction, the word integration is key to the success of this technology. Research studies with profound impact will be the ones containing the better integration of multiple aspects in the analysis and containing verification from different perspectives. The concept here is to provide ideas that solve multiple problems at the same time, and has a lot of positive impact in various directions. The innovations reviewed in the qualitative section of this work could have provided better integration if the cost and time impacts were inspected. This is necessary for encouraging the adoption of these innovations and offering construction participants a deep insight into them.

The critical stage in MiC is the design stage. Its management in terms of coordination and collaboration between stakeholders requires a special design management style. The contractor or supplier should be involved from the beginning and accordingly, shall share in the design liability. Furthermore, the influence of stakeholders and how they affect each other during the design stage requires a stakeholder analysis model. This point is highly affected by the project delivery method which has only been discussed two studies (Dakhli et al., 2015; Molavi and Barral, 2016). Finally, there is no in-depth analysis of the optimum project delivery method from the perspective of construction professionals.

The project delivery method also affects the reimbursement of the contractor for his work at each stage of the project, as contained in the contract conditions. Therefore, a potential knowledge gap is identified as none of the consulted literature has addressed the contractual relationship between various project participants in MiC projects. Accordingly, several questions beg for adequate answers. For instance, will the advance payment for the contractor be adjusted due to the increased initial amount of money required for materials? How will the employers deal with the issue of early fixed design? How can the variation order procedures be adjusted to suit this new construction method? How the contractor’s care for the works will be addressed during the transportation of modules? Will there be an additional insurance policy for modules transportation in the contract?

In the same manner, the literature has not covered cases of disputes between project stakeholders, even though it is hardly believable that all MiC projects around the world were completed without conflicts. Lessons learnt from dispute resolution can be useful for ensuring a smooth application of MiC. Furthermore, risks in MiC projects have been adequately addressed in the literature (Li et al., 2013; Wuni et al., 2019). Nevertheless, no risk allocation to has been clearly discussed, which is expected to be included in the contract conditions. Standard forms of contract (FIDIC, NEC, etc.) are formed based on risk sharing. However, the literature is yet to assess the suitability of applying these forms in MiC projects.

The benefits and challenges of MiC can change according to the adaptability of participants and the extent of MiC adoption in a certain market. Therefore, keeping track of these challenges and enhancing the benefits are future research directions. In addition, market analysis of how a certain market is shifting towards MiC has been addressed (Taylor, 2010), therefore, assessing the growth factors may also form a future research study. Moreover, cost-analysis studies that focus primarily on MiC and investigations that assess the cost of a project that has been converted from stick built to MiC are still lacking in the literature. In addition, clear comparison between MiC and other OSC methods in terms of cost effectiveness needs to be established to enhance decision making.

Regarding decision making, several factors that affect choosing MiC over traditional methods have been identified (Azhar et al., 2013) and advanced decision making tools have been developed (Hwang et al., 2018b). However, decision making on a strategic level and information on a market's adoption of MiC, are still lacking. We propose that a readiness index for cities be created. This index should include all the internal factors related to a project and the external factors related to a market (e.g. infrastructure, day and night traffic conditions, government regulations, and society awareness). It is expected that this index will provide a useful guide to investors that intend to venture into MiC. Another proposal for enhancing MiC research is to spread this knowledge through educational programs. This can be achieved through proposing schemes and courses for the undergraduate and graduate levels. Such programs will bequeath the concept of MiC onto the new generations and enhance their problem-solving skills. From the foregoing, the existing research gaps from the surveyed literature have been presented. Figure 8 summarizes this whole section and presents the ideas in two parts; enhancements and innovative ideas.

6. CONCLUSION

In this study, the research objective was aimed at systematically analyzing the features of the MiC literature. To do so, research was carried out in three stages. First, appropriate literature was sourced; secondly, the literature was quantitatively analyzed; and thirdly, qualitative analysis of the sample articles.

Articles were sourced from the Scopus database and subjected to multiple iterations and manual screening. This resulted in 238 papers, which were further analyzed. Quantitative analysis revealed that more than 50% of the MiC literature was produced by only four countries, USA, the UK, Canada, and Australia, with the USA leading the pack. Furthermore, the top publishing sources were identified to be Automation in Construction, Journal of Cleaner Production, Journal of Construction Engineering and Management, Procedia Engineering, and Engineering Structures. Likewise, the top-cited journal sources were Automation in Construction, Journal of Construction Engineering and Management, Journal of Management in Engineering, and Journal of Cleaner Production.

“Al-Hussien M.” and “Mendis P.” were identified as the top researchers participating in MiC research. “Al-Hussien M.” topped the list in all comparison parameters i.e. the number of publications, total citation, and average normalized citation where he achieved 9 publications, 124 citations and 1.6 average normalized citations, making him the most influential researcher in this field, with research focus on MiC construction operations on and off-site. The most influential articles were Gibb and Isack (2003), and Kamali and Hewage (2016), which were 181 and 91 times, respectively. However, the normalized citation for Kamali and Hewage's article was higher than Gibb and Isack's, which made their article the most influential. The last element in the qualitative analysis was the author's keywords analysis. Using a science mapping tool, seven clusters were inter-related and connected. The most repeated keywords were prefabrication, modular construction, and modular building. The keywords reflected the diverse knowledge areas covered in the samples. However, the absence of certain words is an indication of a gap in the literature. Examples of such missing keywords included risks, supply chain, contractual relationships, and optimization.

Qualitative analysis was performed on 107 of the 237 articles to identify trends and make categorization. Six main categories and nine subcategories were identified. The number of papers that fell into each category formed the trends in MiC research, as presented in Figures (7). Building design and management aspects categories were the two dominating categories in the literature. Next in line were construction operations. The qualitative analysis of literature showed that no previous study compared project sizes with sustainability benefits during operations. Besides, the sample of participants taken during sustainability assessments was too small to build enough confidence in the results. The research in construction operations did not address the context of the operation in any way and did not quantify the safety benefits of MiC in terms of decrease in accidents and lower expenses of safety equipment. Furthermore, the research in building design did not address the benefits of proposed designs in terms of cost and time, and there is a need for large scale case studies for proper assessment. The research in management aspects lacked solid recommendations for project delivery methods and proper cost assessment when MiC is compared with other construction methods. The main research trend was building design, which was justifiable bearing in mind that the world is pushing to adopt MiC in high-rise buildings.

The most important output of the current research is the future directions in MiC research. Figure 8 summarized the analysis for future directions, and the core points are given as follows;

- Testing innovative MiC building design ideas in large scale applications.
- Actual trials of new construction materials proposed in the literature.
- Keeping track of the challenges facing MiC in each market after and before adoption.
- Keeping track of how to increase the benefits of MiC.
- Studying the contractual relationship between project parties in MiC and uncovering lessons learned from disputes.
- Integrating lean concepts with safety in the MiC construction processes.
- Development of standards and codes that promote standardization.
- Comparison between MiC and other OSC methods regarding cost-effectiveness.
- Development of plans that involve spreading knowledge regarding MiC in the educational sector at the tertiary level.
- Development of assessment indices for sustainability, resilience, and readiness for MiC.

MiC is the future of buildings and the world is interested in this modern method. Some countries are pushing to produce better MiC buildings due to the benefits of MiC. This study can support researchers interested in MiC to build plans and proposals for their research works and help them imagine the future fusion between MiC and other knowledge fields. Furthermore, this work can guide researchers in their collaboration with the industry. Finally, it is important to mention that this study could be further enhanced by adding the literature found in government reports, thesis outputs, and other literature produced in languages other than the English language.

ACKNOWLEDGEMENT

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Sharafi, P., Rashidi, M., Samali, B., Ronagh, H., Mortazavi, M., 2018. Identification of Factors and Decision Analysis of the Level of Modularization in Building Construction. Journal of Architectural Engineering 24(2), 04018010, doi:10.1061/(ASCE)AE.1943-5568.0000313, https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29AE.1943-5568.0000313 %X In the majority of ordinary housing development projects, instead of using complex multicriteria decision-making systems, companies still rely on expert knowledge, checklists, or similar tools to decide on an appropriate level of modularization. Generally, in these types of projects the level of modularization is mainly driven by site constraints, such as accessibility and harsh weather conditions. Because of the lack of appropriate decision support tools, it is very hard for decision makers to include factors, such as lifecycle costs, quality, productivity, efficiency, and design complexity, into their decision, even if they are willing to do so. Simple decision support tools are required to provide practical assistance to the decision makers to adopt an appropriate level of modularization for such projects. This study, as a part of a broad ongoing research project on the optimum level of modularization in building construction, has compiled the expert knowledge for decision support that enables the decision makers to perform an easy initial feasibility study on the use of an appropriate level of modularization in their construction projects. First, a list of critical decision-making criteria is created. These criteria are obtained from an extensive literature review, qualitative survey questionnaires, and semistructured interviews with researchers and professionals in the construction industry as well as modular manufacturers. Then, using the results, a simple multicriteria decision analysis (MCDA) approach is developed as a practical decision support system to facilitate the decision-making process for selecting appropriate construction systems as well as determining the proper level of modularization for building construction projects. The validation of the study is demonstrated through a local actual case study.

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Table 1: Countries where MiC researchers are based

Countries	Links	Total Link Strength	Documents	Citations	Norm. Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
United States	12	58	40	566	42.4	2013	14.2	1.1
Canada	10	59	34	489	40.6	2016	14.4	1.2
Australia	13	95	29	353	42.8	2017	12.2	1.5
United Kingdom	12	63	23	431	26.2	2012	18.7	1.1
China	7	46	19	129	14.5	2018	6.8	0.8
Malaysia	5	9	12	97	7.6	2016	8.1	0.6
Singapore	9	43	12	90	15.5	2019	7.5	1.3
Hong Kong	7	43	11	37	16.1	2019	3.4	1.5
Germany	5	12	8	88	6.8	2012	11.0	0.8
South Korea	4	9	7	71	6.5	2015	10.1	0.9
Sweden	1	1	7	100	7.5	2016	14.3	1.1
India	4	9	6	38	2.8	2008	6.3	0.5
Italy	3	12	6	155	11.6	2016	25.8	1.9
Finland	5	10	5	20	5.3	2003	4.0	1.1
Netherlands	3	3	3	68	3.0	2014	22.7	1.0

Table 2: Analysis of sources publishing research work in MiC

Name	Documents	Citations	Norm Citations	Avg. Citations	Avg. Norm. Citations
Automation in Construction	9	185	17.6	20.6	2.0
Journal of Cleaner Production	7	119	20.2	17.0	2.9
Journal of Construction Engineering and Management	6	168	10.9	28.0	1.8
Procedia Engineering	6	79	5.2	13.2	0.9
Engineering Structures	5	68	12.9	13.6	2.6
Construction and Building Materials	4	104	6.0	26.0	1.5
Journal of Computing in Civil Engineering	4	72	5.0	18.0	1.3
Journal of Management in Engineering	4	138	13.3	34.5	3.3
Energy and Buildings	3	47	4.7	15.7	1.6
Journal of Architectural Engineering	3	30	2.4	10.0	0.8
Journal of Building Engineering	3	57	8.8	19.0	2.9
Structural Engineer	3	17	1.8	5.7	0.6

Table 3: Analysis of co-authors

Authors	Documents	Citations	Norm. Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations	Research Focus
Al-Hussein M.	9	124	14.3	2016	13.8	1.6	Construction operations on-site & off-site
Mendis P.	6	99	12.8	2017	16.5	2.1	Structure building design & fire performance
Ngo T.	6	83	9.0	2017	13.8	1.5	Structure building design & fire performance
Choi J.O.	4	84	8.2	2017	21.0	2.0	Modularization for various projects
Gunawardena T.	4	60	7.3	2016	15.0	1.8	Structural design & performance
Aye L.	3	29	2.1	2016	9.7	0.7	Structure building design & fire performance
Bai Y.	3	48	10.8	2019	16.0	3.6	Structural design & performance
Dodoo A.	3	45	4.2	2017	15.0	1.4	Sustainability Assessment
Fernando S.	3	29	5.1	2019	9.7	1.7	Structural design & performance
Gad E.	3	29	5.1	2019	9.7	1.7	Structural design & performance
Gustavsson L.	3	45	4.2	2017	15.0	1.4	Sustainability Assessment
Hermann U.	3	55	3.8	2017	18.3	1.3	Construction operations on-site
Hewage K.	3	148	10.6	2017	49.3	3.5	Sustainability Assessment
Kamali M.	3	148	10.6	2017	49.3	3.5	Sustainability Assessment
Lawson R.M.	3	66	5.1	2008	22.0	1.7	Structural design
Lu N.	3	89	6.7	2010	29.7	2.2	Building design using BIM
Moselhi O.	3	22	2.2	2018	7.3	0.7	On-site operations, building design, & structural assessment
Nguyen Q.T.	3	33	2.4	2017	11.0	0.8	Structure building design & fire performance
O'connor J.T.	3	72	5.3	2016	24.0	1.8	Modularization for various projects
Ogden R.G.	3	66	5.1	2008	22.0	1.7	Structural design & performance
Taghaddos H.	3	55	3.8	2017	18.3	1.3	Construction operations on-site
Telyas A.	3	75	3.3	2012	25.0	1.1	Construction operations on-site
Tran P.	3	33	2.4	2017	11.0	0.8	Structure building design & fire performance

Table 4: Top cited Articles in MiC

Document	Title	Citations	Norm. Citation	Methods Used
Gibb and Isack (2003)	Re-engineering through pre-assembly: Client expectations and drivers	181	1.0	Interviews
Kamali and Hewage (2016)	Life cycle performance of modular buildings: A critical review	91	5.7	Literature review
Song et al. (2005)	Considering prework on industrial projects	68	3.1	Case studies, site visits, MODEX & Neuromodex
Macillo et al. (2017)	Seismic response of CFS shear walls sheathed with nailed gypsum panels: Experimental tests	60	4.8	Seismic response testing of full-scale shear walls
Rahman (2014)	Barriers of implementing modern methods of construction	60	3.4	Questionnaire
Quale et al. (2012)	Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States	60	3.1	Case studies & comparisons
Kamali and Hewage (2017)	Development of performance criteria for sustainability evaluation of modular versus conventional construction methods	55	4.4	Questionnaire
Yu et al. (2013)	Lean transformation in a modular building company: A case for implementation	54	2.3	Lean principles, 5S, VSM & case study
Richard (2005)	Industrialised building systems: Reproduction before automation and robotics	50	2.3	Analogical Model
Hwang et al. (2018a)	Key constraints and mitigation strategies for prefabricated prefinished volumetric construction	47	6.3	Literature review & questionnaire
Lawson and Ogden (2008)	'Hybrid' light steel panel and modular systems	47	3.9	Review & case studies
Taghaddos et al. (2014)	Simulation-based multiagent approach for scheduling modular construction	46	2.6	Agent Based Simulation
Lacey et al. (2018)	Structural response of modular buildings – An overview	45	6.0	Review
Loss et al. (2016)	Connections for steel–timber hybrid prefabricated buildings. Part II: Innovative modular structures	44	2.8	Finite element analyses & Comprehensive Experiments
Lu and Korman (2010)	Implementation of Building Information Modeling (BIM) in Modular Construction: Benefits and challenges	44	2.8	Review & case studies
O'Connor et al. (2014)	Critical success factors and enablers for optimum and maximum industrial modularization	43	2.4	Discussion & Brainstorming
Lehmann (2013)	Waste generation and recycling: Comparison of conventional and industrialized building systems	41	1.7	Literature review & comparison
Bock (2007)	Construction robotics	39	2.3	Review
Manalo (2013)	Structural behaviour of a prefabricated composite wall system made from rigid polyurethane foam and Magnesium Oxide board	37	1.5	Experimental Investigation
Ferdous et al. (2019)	New advancements, challenges and opportunities of multi-storey modular buildings – A state-of-the-art review	36	8.6	Review

Table 5: Quantitative details of keywords

Keyword	Cluster No.	Link	Total Link Strength	Occurrences	Average Pub. Year	Avg. Citations	Avg. Norm. Citations
Prefabrication	7	24	61	41	2015	19.2	1.6
Modular Construction	1	15	29	39	2017	12.0	1.0
Modular Building	5	8	15	21	2016	14.0	2.0
BIM	4	6	9	14	2016	9.5	0.8
Modularization	6	10	20	13	2015	28.9	1.2
Off-site Construction	2	12	19	11	2018	24.9	2.7
Modular	7	1	1	7	2014	18.0	1.3
Productivity	1	8	13	7	2015	21.3	1.0
Lean Construction	1	10	14	6	2017	14.3	1.1
Construction	1	6	7	5	2016	4.4	0.8
Sustainability	3	5	7	5	2017	28.4	1.8
Building Systems	6	5	7	4	2010	35.0	2.2
Industrialization	6	4	5	4	2011	32.3	1.8
Life Cycle Assessment	5	5	6	4	2015	33.8	2.2
Prefabricated Construction	6	3	4	4	2013	12.5	0.8
Prefabricated Prefinished Volumetric Construction	8	4	6	4	2019	18.8	2.7
Automation	4	5	6	3	2018	7.0	0.4
Barriers	2	5	5	3	2018	33.7	6.2
Cold-Formed Steel	3	3	5	3	2018	26.0	2.4
Construction Management	4	4	4	3	2012	32.0	1.6
Design	1	4	4	3	2012	5.0	0.5
Energy Efficiency	5	2	2	3	2014	10.3	0.5
Manufacturing	1	4	4	3	2010	24.3	1.1
Preassembly	2	5	7	3	2016	36.3	2.4
Scheduling	1	3	5	3	2016	18.3	1.1
Seismic Design	3	4	6	3	2018	29.7	2.9
Shear Walls	3	4	6	3	2017	38.7	3.1
Simulation	1	5	5	3	2014	21.0	1.2
Singapore	8	4	7	3	2018	23.3	3.1

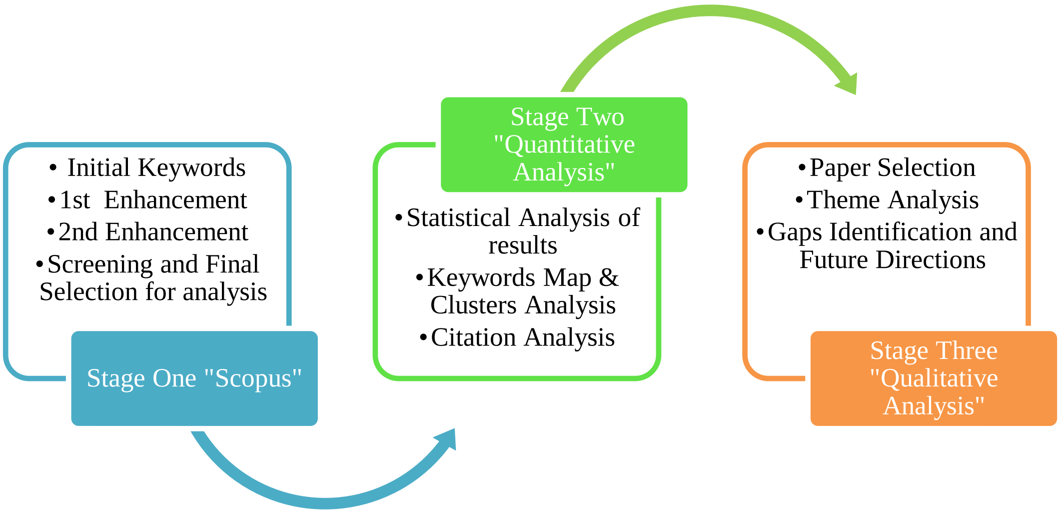

Figure 1: Stages of research in this study

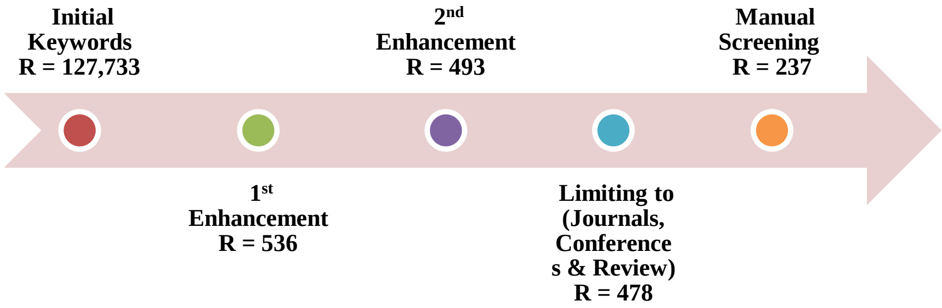

Figure 2: Steps of the search stage and the results of each step

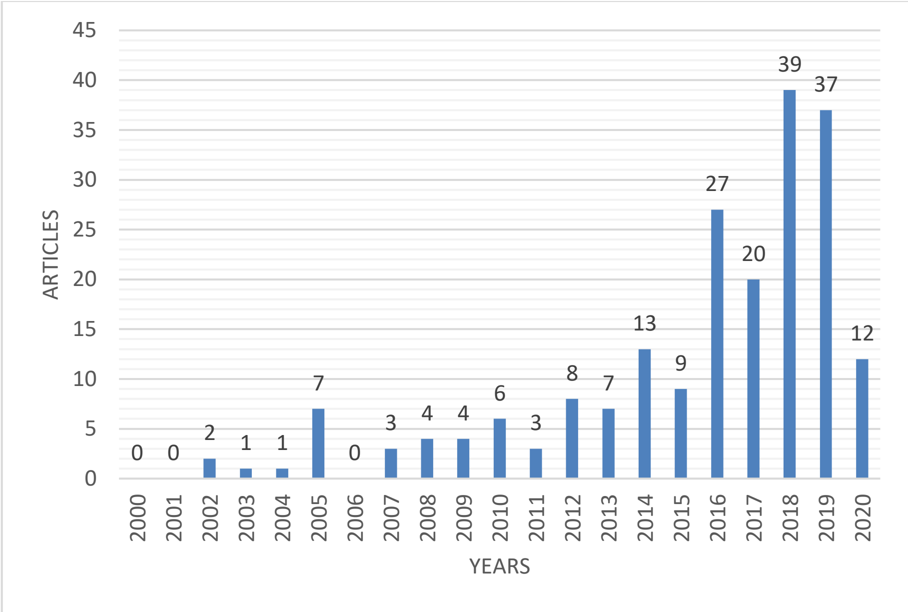

Figure 3: No. of papers per year (2000 ~ 2020)

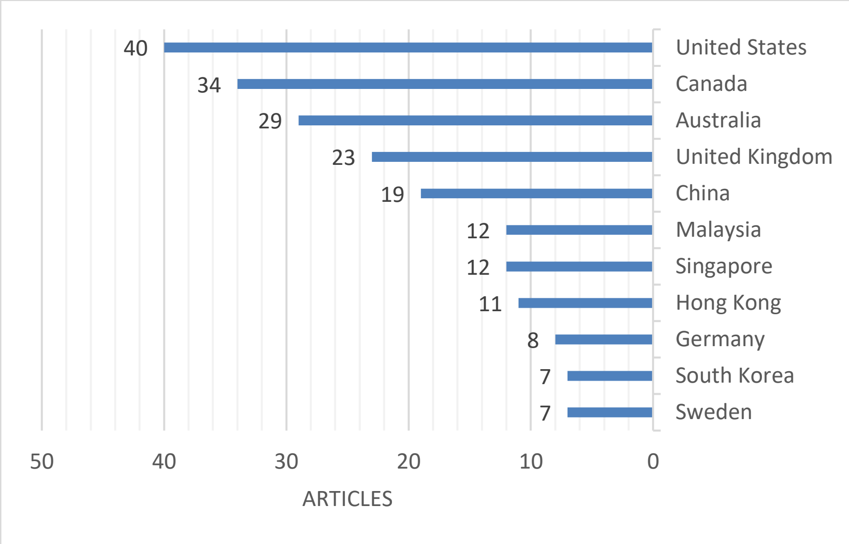

Figure 4: Locations of publications

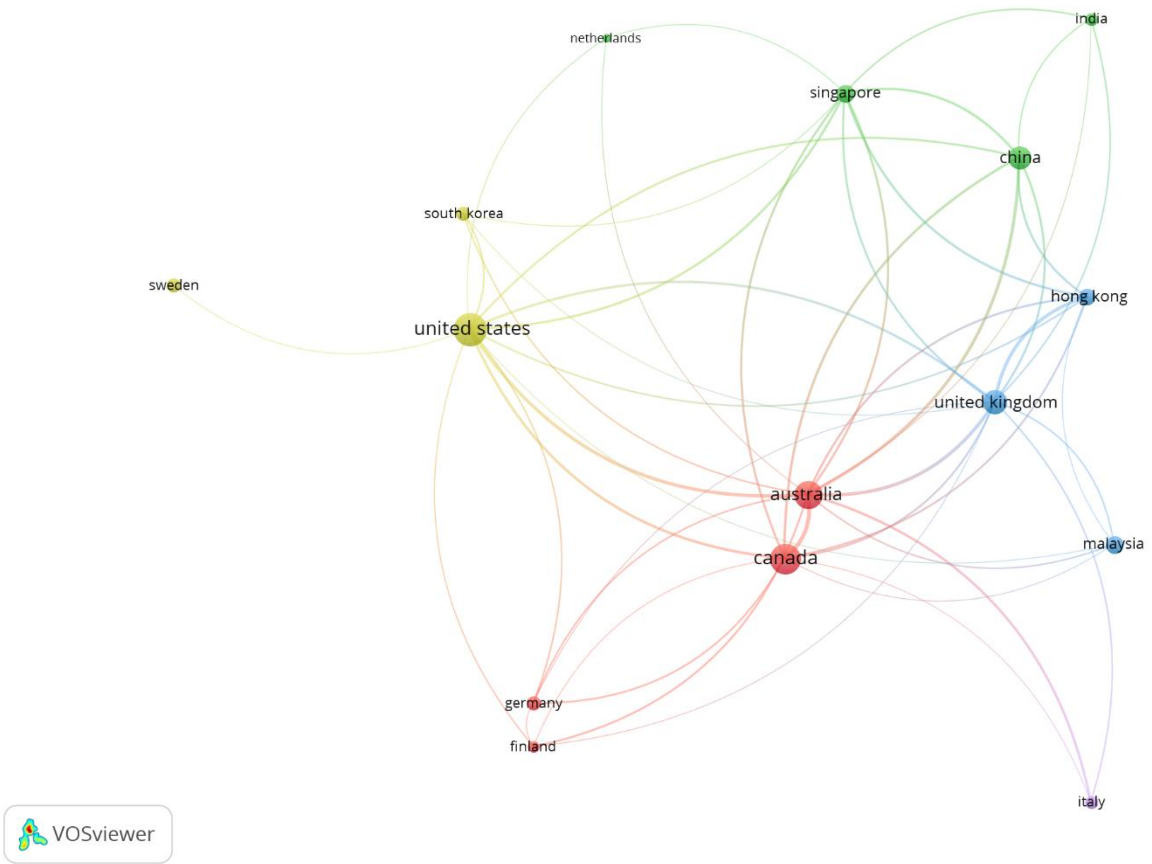

Figure 5: Map of countries where MiC research studies are produced

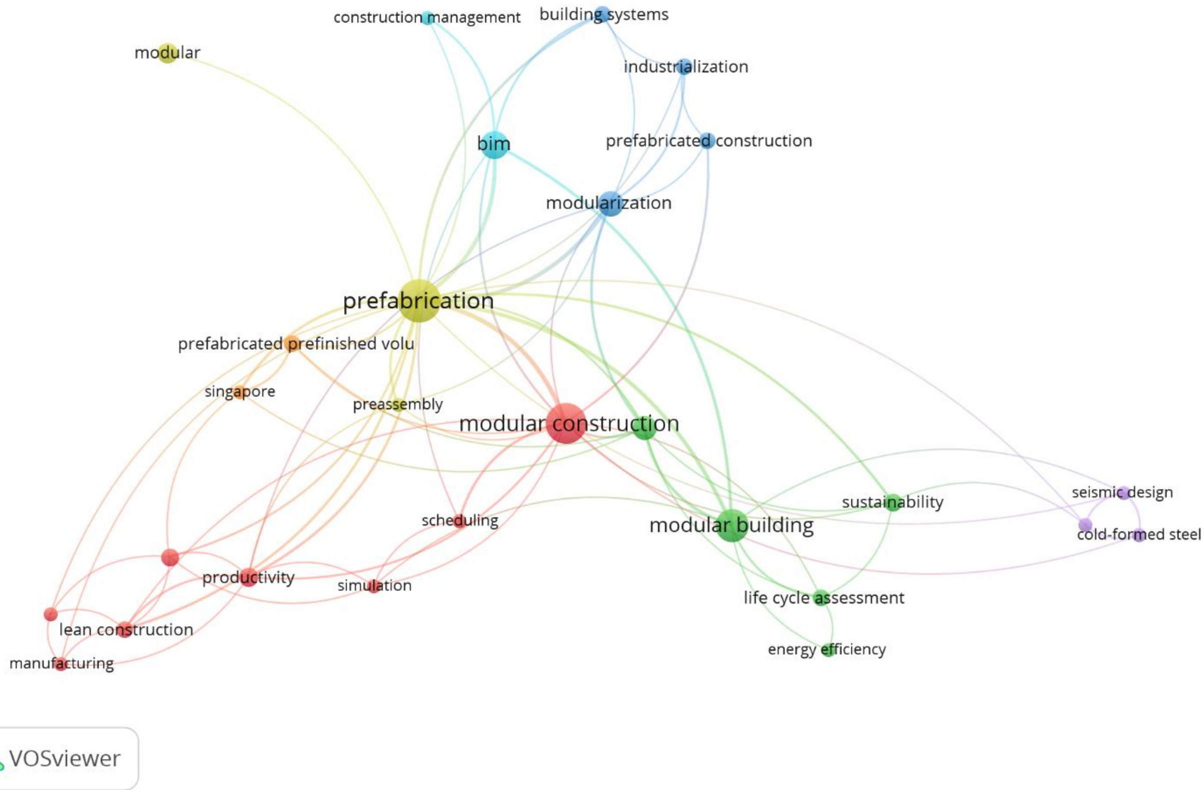

Figure 6: Scientific analysis map of author keywords in MiC

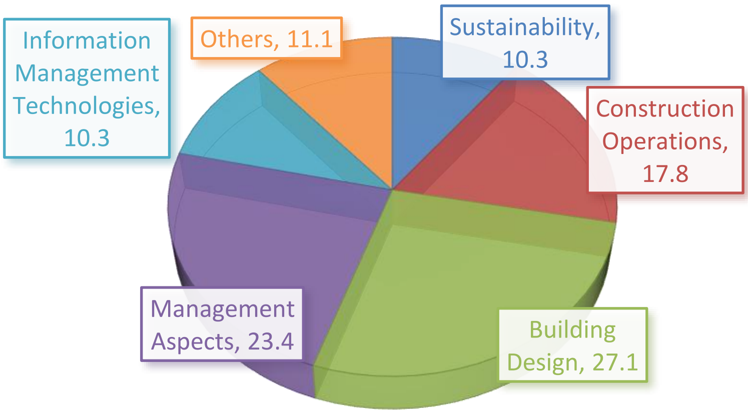

Figure 7: Percentage of each literature category

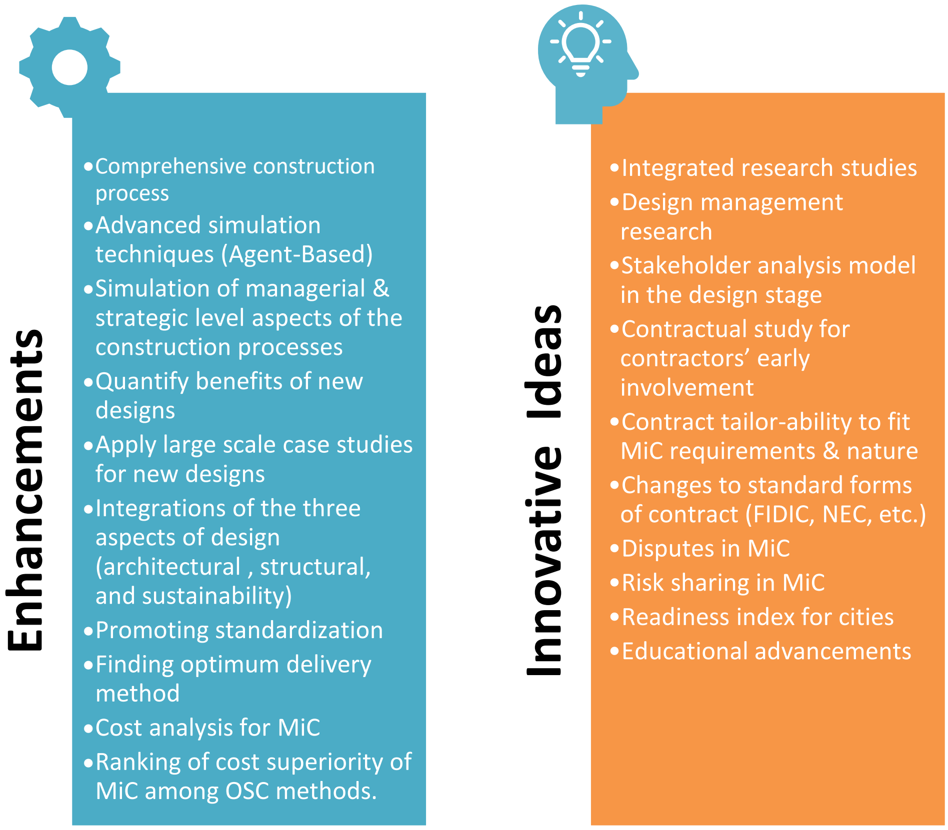

Figure 8: Summary of gaps and future directions