Critical risk factors in the application of modular integrated construction: A systematic review

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ABSTRACT

The business model of modular integrated construction (MiC) demands a unique design, engineering, supply chain, stakeholder composition, construction and management. These requirements engender manifold uncertainties and risks events which may derail the success of MiC projects. Empirical studies have examined the risks associated with MiC in different countries. However, the critical risk factors (CRFs) in the application of MiC have not been reviewed. This paper conducted a systematic review and synthesis of 39 empirical studies on the risks of MiC and identified 30 CRFs. Based on the frequency of occurrences, the top ten (10) CRFs in the application of MiC have been discussed. Of these, stakeholder fragmentation and management complexity; higher initial capital cost; poor supply chain integration and disturbances; delays in delivery of modular components to the site; and poor government support and regulations constitute the five (5) most CRFs. The findings are useful to countries which are yet to adopt MiC and may broaden the understanding of offsite construction researchers and practitioners on the risks of MiC. Future studies would make a quantitative ranking of the CRFs and propose management strategies.

Keywords: modular integrated construction; risk; supply chain; uncertainties

Word count: 9297 + Title + Abstract + Keywords

Introduction

The construction sector makes a substantial contribution to the progress of many economies around the globe. It is relied upon in meeting the housing and infrastructural needs of countries. As a result, preponderances of the built fabric are products of the traditional cast-in-situ construction (TCC) approach. However, the business model of the TCC has been found to be wasteful, unproductive, inefficient, and unsustainable (Kibert 2007). Studies have demonstrated that industrialization of construction is indispensable in improving the ill-performances of the TCC (Egan 1998; Richard 2005). In the context of the industrialized construction, there is the paradigm shift towards offsite construction (OSC). OSC adopts a manufacturing business model where building components are fabricated in an offsite factory and then transported to a construction site for installation (Pan & Goodier 2012).

Modular integrated construction (MiC) constitute one of the most complete forms of OSC. MiC is a construction system where free-standing volumetric building components, usually completed with finishes and fixtures are fabricated in a factory environment and then, transported to a construction site for installation (Smith 2016). Owing to its mode of operation, MiC reduces construction waste (Tam et al. 2007), greenhouse gases emissions (Mao et al. 2013), shortens construction time, reduces labour and project lifecycle costs, improves health and safety of workers (Blismas et al. 2006), facilitates change without demolition, and improves construction flexibility and adaptability (Richard 2005). Due to the diverse benefits, MiC is promoted in the United Kingdom, Hong Kong, the United States, Singapore, Canada, China, Malaysia and Australia inter alia. However, the business model of MiC is associated with a unique supply chain, construction engineering, stakeholders' composition, and management process different from those of the TCC. These unique characteristics hatch manifold detrimental uncertainties and risk events.

For instance, the application of MiC requires effective coordination of the fragmented modular design, fabrication, transportation and onsite assembly segments of its supply chain (Li et al. 2013; Li et al. 2016). Its application also requires the coordination and management of the disparate goals and value systems of the complex web of stakeholders within the entire supply chain. Modular components are made-to-order and thus, shortages cannot be complemented by third-party manufacturers (Bortolini et al. 2019). A successful application of MiC also requires a reliable & timely supply of modular components and the effective functioning of cranes (Li, Hong, et al. 2018). Besides, problematic dimensional and geometric intolerances may cause massive cost of site-fit reworks (Shahtaheri et al. 2017). Moreover, unstable economic indices may affect the prices of modular components, with a negative effect on the costs of MiC projects (Li et al. 2013). Again, the manual handling, inspection, unloading, screwing and welding of the heavy modular elements upon arrival to construction site exposes workers to injuries and risk of work-related musculoskeletal disorders (WMSDs) (Hsu et al. 2018).

These risk factors and events could derail the schedule, budget, quality and safety performance of MiC. As risks are inevitable in any construction project, it is essential to plan, identify, assess, prioritize, respond and monitor risk factors to control the potential impact of negative risks and take advantage of positive risk (Project Management Institute 2017). While every project has unique risk characteristics and requires a unique management framework, it is widely recognized that projects share some risk factors (Baloi & Price 2003). Risk is considered as an "uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives" (Project Management Institute 2017, pp.397). Empirical studies have identified and assessed risks associated with MiC. For instance, Li et al. (2013) identified and assessed risk factors that affect the cost and schedule performance of MiC projects in Canada. Li et al. (2017) investigated MiC investment risk factors in China. Li et al. (2018) analyzed schedule risk factors in the six-day cycle assembly of MiC projects in Hong Kong and Luo et al. (2019) identified and assessed stakeholder-associated risk factors in MiC projects in China.

While these and similar studies have identified and assessed several risks associated with MiC, there is no study which has reviewed all these studies to identify the critical risk factors associated with the application of MiC for prioritization in MiC risk management. As risks are manifold and abound in MiC projects, identification of the most critical risk factors could be very useful to many countries in the application of MiC. As a result, this study seeks to identify the critical risk factors in the application of MiC through the lens of a systematic review and synthesis of empirical studies on the risks of MiC. For comprehensiveness, the following research questions demand critical consideration.

RQ1. What is the annual publications trend on the risk of MiC?
RQ2. Which journals publish studies on the risk of MiC?
RQ3. In which context (country) were the studies conducted?
RQ4. What are the critical risk factors in the application of MiC?

It is hoped that answers to these questions will generate distilling information on the risks of MiC. As MiC is gain wider market expansion and the attention of OSC practitioners and researchers, multiple stakeholders of the global OSC community stand to benefit from prioritization of the risk factors. The remainder of the paper is structured as follows. The next section offers a background of MiC, followed by the research methods adopted in the study. Then, the review results are discussed, and finally, logical conclusions are drawn.

Background of modular integrated construction (MiC)

Modularity has an entrenched historical foundation in innovation management (Simon 1962). As an engineering concept, modularity denotes the degree to which units of a whole system or product can be created independently and still be integrated to generate diversified systems using same design details. It offers systems integrators multiple options of configuring and reconfiguring the independent modules to achieved diversified outcomes (Winch 1998). Slaughter (1998) described modular integrated construction (MiC) as an innovation because it involves significant changes to the design, procurement, engineering, and delivery of construction projects. MiC is a construction approach “whereby free-standing volumetric modules (completed with finishes, fixtures, and fittings) are manufactured in a prefabrication factory and then transported to site for installation in a building” (Hong Kong Buildings Department 2018). Depending on the degree of modularization, Gibb (1999) classified MiC into four stages comprising components manufacture and subassembly (e.g. windows, bricks, etc.), non-volumetric preassembly (e.g. cladding panels, structural frames, etc.), volumetric preassembly (e.g. toilet pots, shower rooms, sanitary systems, etc) and complete modular building (e.g. modular home, prison blocks, motels, etc.). The supply chain of MiC is grossly simplified as modular design, offsite production, transportation, storage, buffer, and installation. The major stakeholders within the supply chain include designers, engineers, architects, manufacturers, suppliers, logistics companies, developers, clients, contractors, project managers, academics and local government (Luo et al. 2019).

Owing to the fragmentation of the supply chain segments, these multidisciplinary stakeholders have their separate objectives and value systems within the chain. The configuration of the MiC supply chain differs across countries. Typically, a developer or client contracts an architect (or designer) and engineers (structural & service) to produce the modular designs. Usually, the designs must consider safety, buildability, constructability, and transportation requirements (regulations and convenience). The working drawings are engineered based on the principles of design for manufacture and assembly (DfMA) (Hsu et al. 2018). A manufacturer or manufacturer direct (who might not be privy to the design decision) is then arranged to produce the modules (Smith 2016). As modular components are unique to a project, the manufacturing process is engineer-to-order (Dawood 1995a). As such, the quantity of each manufactured modular component is produced to meet exactly the required demands of the MiC project (s) on site and the inventory must return to zero at the end of the project (Hsu et al. 2018). On completion, the produced modules are stored in a warehouse. Following receipt of a transport order, a logistic company conveys the modular components to another warehouse (known as a buffer) closer to the construction site or directly to the construction site (Li, Hong, et al. 2018). An assembly company (usually manufacturers or assembly subcontractors) is contracted to install the components on site following an assembly line and plan. This unique delivery process individuates the MiC supply chain from the TCC model and as such, introduces additional uncertainties and management requirements. The MiC products constitute industrialized building systems rather than standardized buildings. The goal of MiC is not only to produce standardized buildings but to deliver industrialized building systems involving the use of the same details to generate diversified and individualized buildings (Richard 2005; Richard 2006).

Research methods

This study adopted a qualitative research design and the systematic literature review (SLR) methodology to explore the CRFs in the application of MiC. An SLR is an objective, replicable and transparent tool used to examine existing studies on a subject (Levy & Ellis 2006). Considering the organic attribute of literature on a subject, SLR is the unique tool for establishing the knowledge boundaries of a given subject. Webster & Watson (2002) indicated that SLR provides a comprehensive foundation for theory development, closes areas where a plethora of research exist and uncovers areas that demand further research. Considering its relevance, SLR is widely used in the construction engineering and management (CEM) domain to synthesize published literature (e.g. Osei-Kyei & Chan 2015; Newaz et al. 2018; Saieg et al. 2018). As such, this paper implemented the SLR using a comprehensive methodological framework of systematic literature search, screening, critical appraisal, metadata extraction and content analysis (Figure 1).

Literature search protocol

Prior to the final literature search, the study examined multiple powerful CEM databases and academic libraries to identify the one with the highest coverage, accuracy, and relevance. Using the same set of keywords, preliminary searches were conducted in Elsevier's Scopus, Clarivate Analytics' Web of Science, ASCE library, Engineering Village, Taylor and Francis, and Emerald Insight.

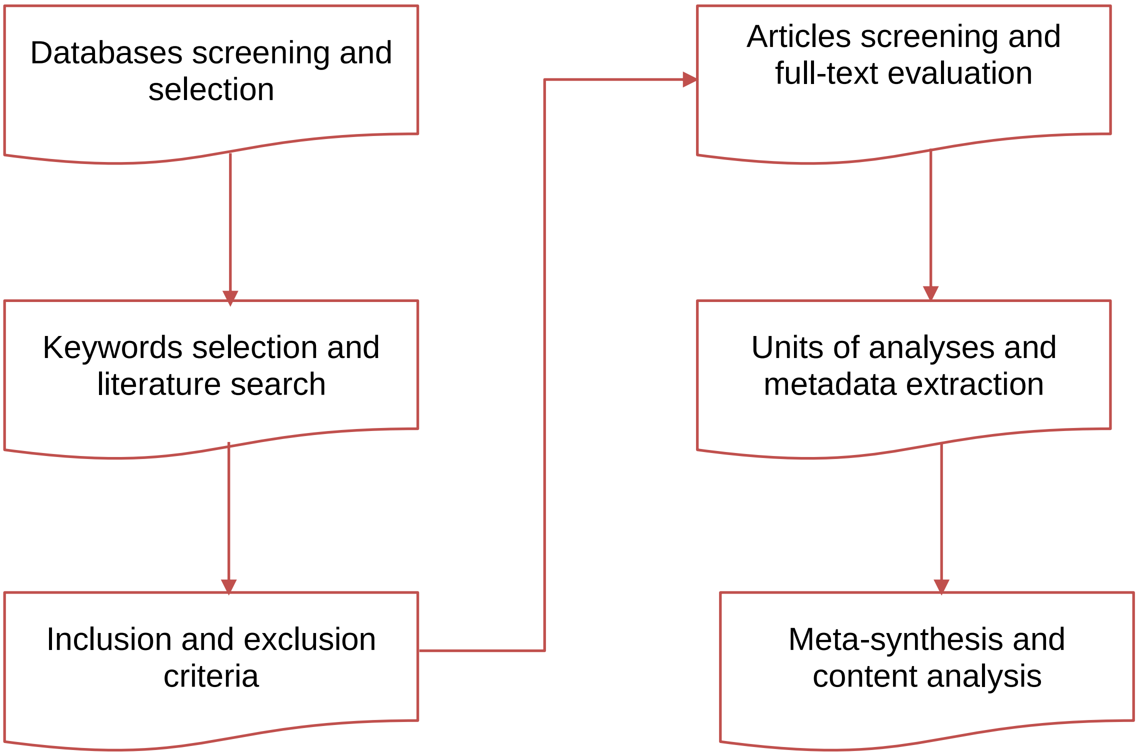

Figure 1. Methodological framework of the study

It was discovered that the majority of the retrieved articles were repeatedly indexed in all the databases and libraries, but Scopus had the widest coverage. Scopus was also found to be the most user-friendly, easiest to restrict search results and associated with advanced features such as citations and reference tracking functionalities. As such, it was solely used in the literature search process. Previous CEM reviews also relied on Scopus for article retrieval (e.g. Osei-Kyei & Chan 2015; Newaz et al. 2018; Saieg et al. 2018). Following the selection of Scopus, the most used synonyms of 'risk' and 'modular integrated construction' were identified in the extant literature. The lists of keywords were continuously refined and updated throughout the review process. The optimal set of keywords for 'risk' and 'MiC' were generated at the end of the review process. The full Scopus search algorithm is shown below.

(TITLE-ABS-KEY (risk OR hazard OR barrier OR uncertainty OR uncertainties OR safety OR delay OR "cost overrun" OR "time overrun") AND TITLE("offsite construction" OR "off-site construction" OR "offsite production" OR "off-site production" OR "offsite manufacturing" OR "off-site manufacturing" OR prefabrication OR prefabricated OR prefab OR pre-fab OR pre-fabricated) OR TITLE("industrialized building system" OR "modular construction" OR modular OR "off-site fabrication" OR modularization OR "prefabricated refinished volumetric construction") OR TITLE("modern method off construction" OR "industrialized construction")) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"ip")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))

As indicated in the algorithm, the search was constrained as follows: the *document type* was restricted to *article (ar)* or *article-in-press (ip)* only; the *language* was restricted to *English* only, and the *source type* was restricted to journals (j) only. These restrictions were generic because the study had a focus on articles only and the writers are native English speakers. There was no restriction as to the year of publication. This search query retrieved 1,308 Scopus records. The search was repeated immediately prior to submission to ensure that relevant recently published articles were included in the study. The final search contributed five (5) relevant articles to the actual sample size.

Inclusion and exclusion criteria

According to Wohlin (2014), an SLR requires explicit specification of the inclusion and exclusion criteria to facilitate verification and replication of the paper. As such, the paper specified the inclusion and exclusion criteria to screen, filter and extract the actual sample size from the 1,308 Scopus records. An article was included if: (i) it is an empirical study on the risk of MiC, and (ii) published in a peer-reviewed journal. Based on these, conference papers were excluded due to criticism that they do not receive rigorous peer-review.

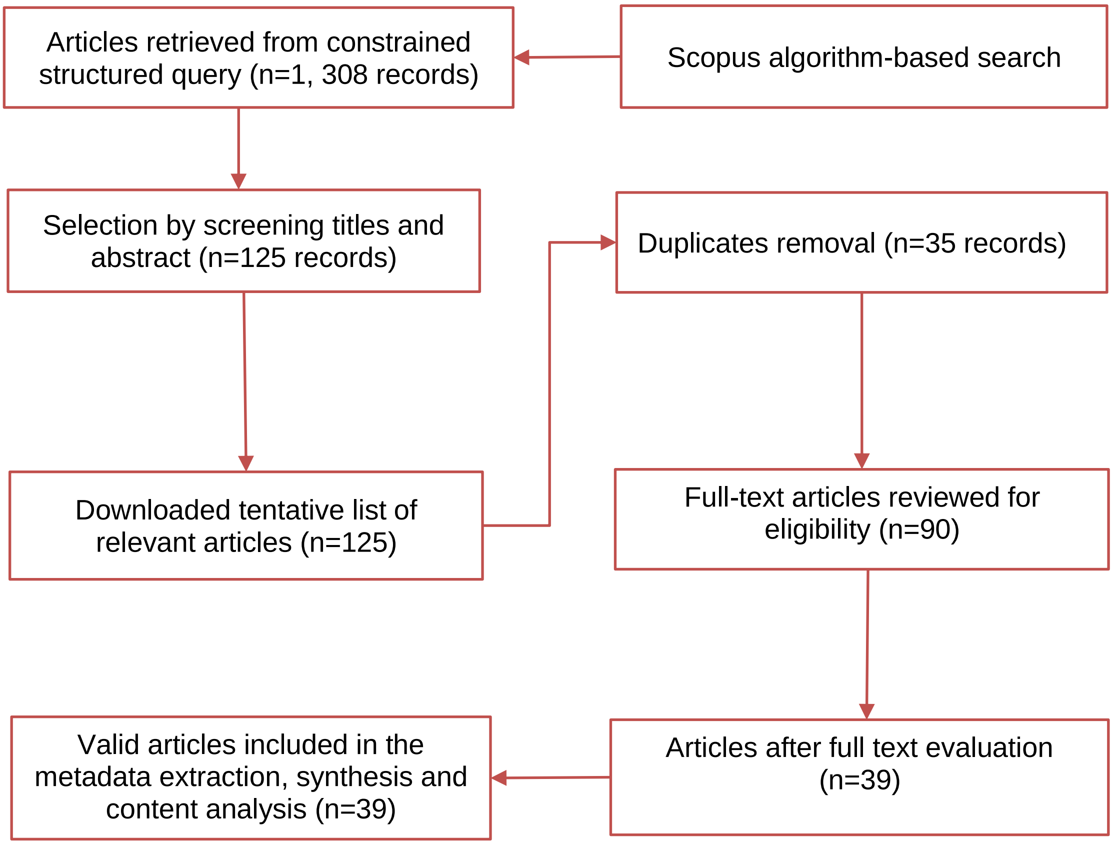

Figure 2. flowchart of systematic search and article selection protocol

Based on the adumbrated criteria, the authors screened the titles, and abstracts of the 1,308 record for preliminary inclusion. This rapid screening process resulted in the inclusion of 125 candidate articles. After full-text evaluation, 29 articles were included. A flowchart of the articles screening process is shown in Figure 2. The sample was considered relatively smaller although it compared favorably against the samples of some previous CEM reviews such as 16 (Newaz et al. 2018) and 27 (Osei-Kyei & Chan 2015). Based on the recommendations of Webster & Watson (2002), Levy & Ellis (2006), and Wohlin (2014), the authors conducted a snowballing search to increase the sample. The snowballing search is an iterative process of locating additional studies based on the reference lists (backward snowballing) and citations (forward snowballing) of the previously identified 29 articles (Wohlin 2014). Using the reference and citation tracking functionalities of Scopus, ten (10) additional articles were identified, evaluated and included. The authors screened the reference lists and citations of the newly retrieved 10 articles but found no additional articles. In all, a total of 39 valid articles were synthesized. This sample was considered adequate considering that MiC is still undeveloped in most countries. Again, the sample sized compares favorably against the recently published CEM review using 32 articles (Saieg et al. 2018). Table 1 shows the 39 included publications and their serial numbers, which are referenced in other sections.

Thematic content analysis

To facilitate the metadata extraction, the study employed meta-synthesis as the literature organizing framework. Unlike the traditional meta-analysis which draws exclusively on quantitative studies, meta-synthesis provides the framework to integrate quantitative and qualitative findings of studies in a single SLR (Baker 2016). Following the tenets of meta-synthesis, the study specified the units of analysis to guide the metadata extraction (Lachal et al. 2017). Based on the research questions, the researchers extracted the year of publication, journal of publication, context (country) of the study and the reported risk factors of each study.

Table 1. Legend of the serial numbers (SN.) of publications in Table 3

SN.	Publication	SN.	Publication
1	Dawood (1995a)	21	C.Z. Li et al. (2017)
2	Dawood (1995b)	22	Shahtaheri et al. (2017)
3	Gibb & Neale (1997)	23	M. Li et al. (2017)
4	Blismas et al. (2006)	24	C.Z. Li, Zhong, et al. (2017)
5	Chiang et al. (2006)	25	Jiang et al. (2017)
6	Polat (2008)	26	Jiang et al. (2018)
7	Hassim et al. (2008)	27	Zhang et al. (2018)
8	Hassim et al. (2009)	28	Gan et al. (2018)
9	Arif & Egbu (2010)	29	Han & Wang (2018)
10	Kim et al. (2011)	30	Ji et al. (2018)
11	Kim et al. (2012)	31	Li et al. (2018)
12	Li et al. (2013)	32	Li, Xu, et al. (2018)
13	Zhang et al. (2014)	33	Hwang et al. (2018)
14	Mao et al. (2014)	34	Hsu et al. (2018)
15	Zhai et al. (2014)	35	Wang et al. (2018a)

16	Rahman (2014)	36	Wang et al. (2018b)
17	Luo et al. (2015)	37	Gan, Chang, & Wen (2018)
18	Li et al. (2016)	38	Luo et al. (2019)
19	Hong et al. (2017)	39	Wu et al. (2019)
20	Lee & Kim (2017)		

These were organized into a summary table, referred to as a thematic content matrix augmented with units of analyses (Webster & Watson 2002). The risk factors in each study were organized and integrated based on the thematic content analysis. According to Finfgeld-Connett (2014), thematic content analysis provides a structured approach of identifying and organizing emerging trends in text-mining based on a large volume of literature. The thematic content analysis facilitated the harmonization and marriage of semantic differences in the way the risk factors were worded in the different studies. This approach has been used in previous CEM reviews (e.g. Osei-Kyei & Chan 2015; Newaz et al. 2018).

Review findings and discussions

Annual publications trend on the risk of MiC

The articles (39) included in the review spanned from 1995 to 2019 inclusive. As such, past and recent evidence have been synthesized. Figure 3 shows the annual distribution of the selected papers within the 24-year period. It is observed that no article was published in 1996, and from 1998 to 2007. Indeed, an average of 1 paper on the risk of MiC was published yearly between 1995 and 2013. This suggests that minimal attention was given to the risks of MiC within this period. In 2014, a higher number of 4 articles were published on the risk of MiC and the average declined to 1 between 2015 and 2016. However, the number of publications increased significantly between 2017 and 2019. This highlights that risks of MiC is gaining rising attention among practitioners, researchers and stakeholders. The significant increase within the last decade is expected because of the renewed commitment in the promotion of MiC (Li et al. 2014; Hosseini et al. 2018). The trend suggests that increasing effort is advanced to gain an understanding of the risks associated with MiC and thus, reinforcing the relevance and need for this paper.

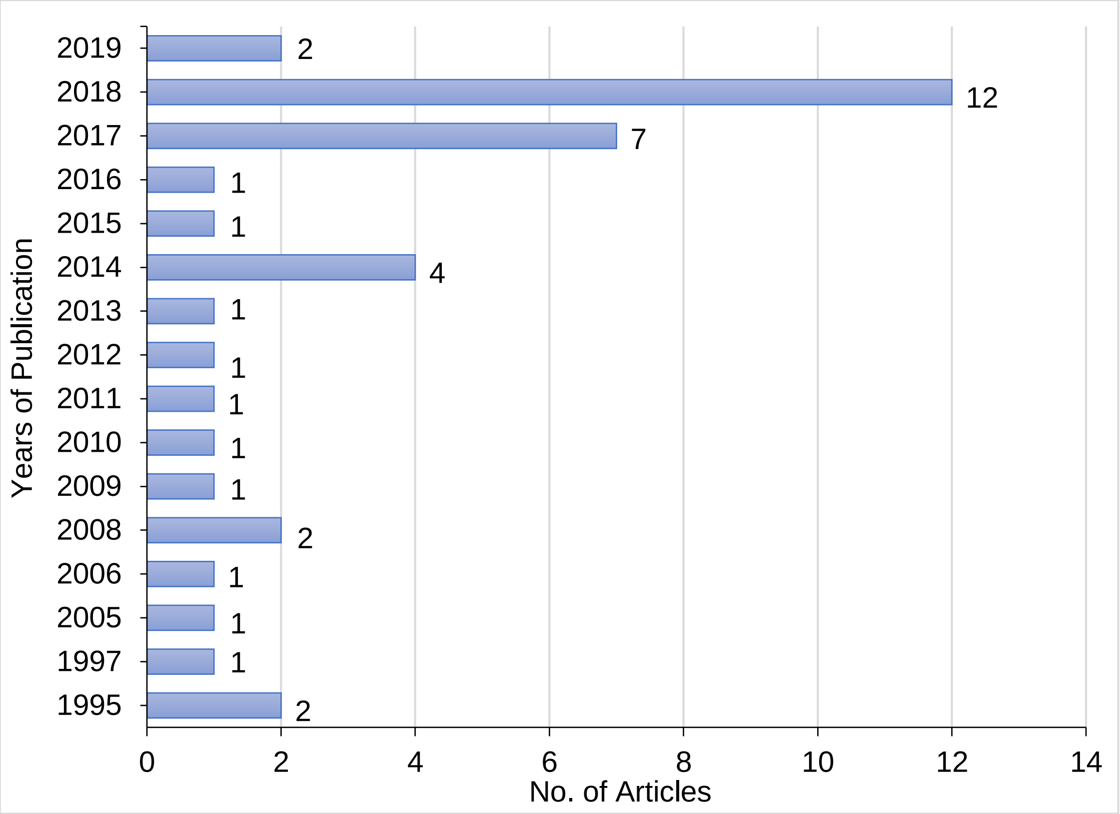

Figure 3. Annual distribution of selected articles from 1995 to 2019

Contribution of Journals in MiC risk studies

It is useful to highlight the journal distributions of the articles included in the study since it depicts the quality of the studies included in the review. Table 2 shows the frequency distribution of the studies across 20 different peer-reviewed journals. It can be observed that the majority of these journals constitute some of the top-tier construction engineering and management journals. This suggests that diverse high-quality articles were included in the review.

Table 2. Distribution of selected articles according to journals

Research Outlet	**Number of Articles**
Journal of Cleaner Production	13
Automation in Construction	3
Journal of Management in Engineering	3
Construction Management and Economics	2
Engineering, Construction and Architectural Management	2
Habitat International	2
Journal of Architectural Engineering	1

American Journal of Applied Sciences	1
Applied Ergonomics	1
Applied Sciences (Switzerland)	1
Architectural Engineering and Design Management	1
Building and Environment	1
Buildings	1
Canadian Journal of Civil Engineering	1
Ergonomics	1
European Journal of Social Sciences	1
Journal of Civil Engineering and Management	1
Journal of Construction Engineering and Management	1
KSCE Journal of Civil Engineering	1
Sustainability (Switzerland)	1

Out of the 20 journals, it is found that 6 of them contributed at least 2 articles on the risk of MiC within the 24-year period. They include Journal of Cleaner Production (33%), Automation in Construction (8%), Journal of Management in Engineering (8%), Construction Management and Economics (5%), Engineering, Construction and Architectural Management (5%), and Habitat International (5%). These journals contributed 25 (64%) of the sample size of the study and constitute some of the high-ranked CEM journals (Li et al. 2014; Osei-Kyei & Chan 2015; Hosseini et al. 2018). The superior contribution of the Journal of Cleaner Production (JCLP) is justifiable because MiC is considered a cleaner construction approach (Quale et al. 2012; Mao et al. 2013; Hwang et al. 2018) and thus, JCLP may be considered an appropriate research outlet for MiC studies. The remainder of the 14 journals contributed 1 article each and collectively contributed 14 (36%) of the actual sample of articles in the study.

Geospatial distribution of research articles on the risk of MiC

It is also useful to highlight the origin of the articles included in the study. Figure 4 shows the geospatial distribution of the selected articles in the study. The studies were conducted in four continents comprising Australia (e.g. Australia), Asia (e.g. China, Singapore, Hong Kong), Europe (e.g. UK) and North America (e.g. USA, Canada). There were no articles from Africa and South America. As Africa and South America are not advanced in the application of MiC, the absence of articles from these continents make no difference.

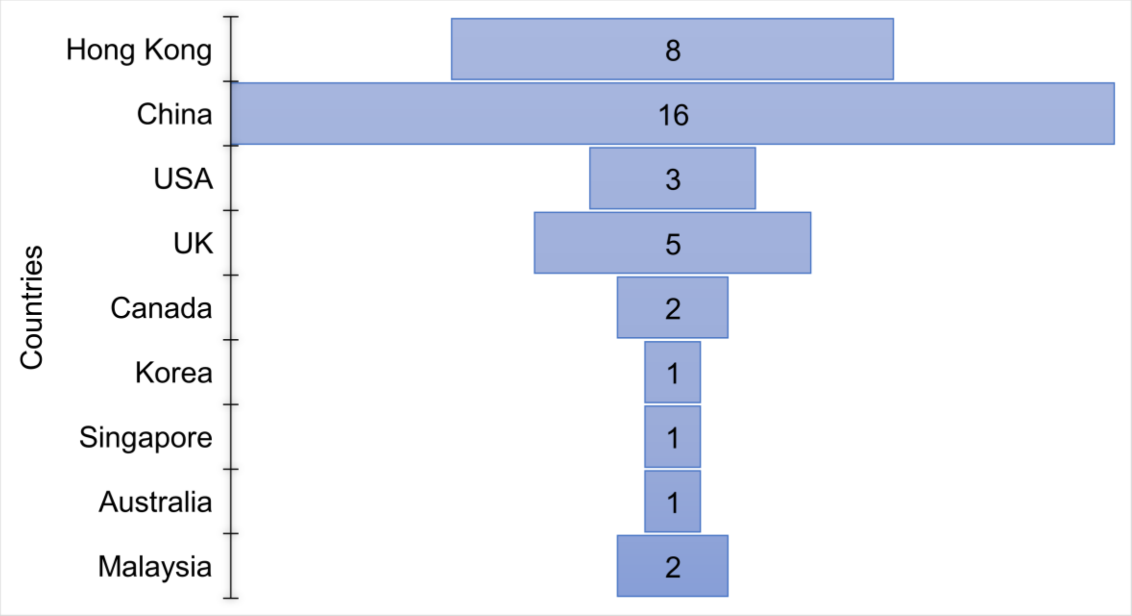

Figure 4. Geographical distribution of selected articles

Indeed, Europe, Asia, North America, and Australia are the giant continents in OSC and MiC and thus, the inclusion of articles of from all these continents highlight the quality and representativeness of the included studies. Figure 4 also shows that articles from both developing (e.g. Malaysia, China) and developed economies (e.g. Canada, USA, etc.) have been included in the study. Thus, the results will reflect the shreds of evidence in both developing and developed countries. Out of 9 countries, China (16), Hong Kong (8), UK (5), and USA (3) contributed the greatest number of articles on risks of MiC. Korea, Singapore, and Australia each contributed the least number (1) of articles. However, the top 4 most contributing countries have developed a clear vision and plans for OSC and MiC (Chiang et al. 2006; Jaillon et al. 2009; Pan & Goodier 2012). As such, the evidence synthesized in this review constitute the diverse findings from countries with both advanced and less advanced levels of MiC adoption.

Critical risk factors in the application of MiC

Risk factors in this paper refer to events, characteristics, and processes that may derail and compromise the quality, schedule, budgetary and safety objectives of MiC projects. Critical risk factors (CRFs) are the risk factors that must be prioritized as they constitute the greatest threats to the achievement of MiC project objectives (Project Management Institute 2017).

Table 3. Critical risk factors in the application of MiC

Critical risk factor (CRF)	Sources	Freq.	Rank
Stakeholder fragmentation and management complexity	[6,15,18,21,24,25,30-33,36,38]	12	1
Higher initial capital cost	[9,13-16,18,19,25-27,33]	11	2
Poor supply chain integration and disturbances	[13,15,18,26,31,32,34,35,38]	9	3
Delays in delivery of modular components to site	[18,21,24,26,31,32,34-36]	9	3
Poor government support and regulations	[12-16,25,28-29]	8	5
Lack of MiC codes and standards	[13,15,17,23,25,28-29]	7	6
Defective design and change order	[8,12,18,20,27,39]	6	7
Supply chain information gap and inconsistency	[18,21,24,31,32,38]	6	7
Inefficient scheduling	[1,2,34-35,38]	6	7
Limited MiC expertise and experience	[20,25,28,29,36,39]	6	7
Shortage of modular components	[4,8,12,34,35]	5	11
Complex interfacing between systems	[9,16,17,20,22]	5	11
Weather disruptions	[3,12,34-36]	5	11
Transportation restrictions (size & weight)	[6,15,33,34]	4	14
Inexperience of contractors in MiC	[6-9,39]	4	14
Skilled labour requirement	[13,15,16]	4	14
Modular installation errors and complex rectification	[18,20,31,32]	4	14
Poor cooperation and communication among project participants	[9,25,30,38]	4	14
Modular design complexity	[7,33,39]	3	19
Unsupportive planning and building regulations	[8,12,33]	3	19
Limited capacity of modular manufacturers/suppliers	[4,26,37]	3	19
Manual handling of heavy modular components	[10,11,22]	3	19
Absence of standard modular components	[13,28,37]	3	19
Unable to freeze design and specification early	[4,9]	2	24
Higher prices of modular components	[5,23]	2	24
Diseconomies of scale and longer break-even period	[9,17]	2	24
Modular production system failure	[12,20]	2	24
Lack of best management practices	[17,33]	2	24
Inaccurate cost estimation	[20,23]	2	24
Geometric and dimensional intolerances	[22,30]	2	24

As such, the CRFs may be considered as the direct opposite of critical success factors (CSFs). Identification of CRFs require quantitative assessments and priority ranking but since this study is a critical synthesis of empirical studies, CRFs constitute the most reported risks factors in the application of MiC. CRFs differ across projects and countries but identifying the most reported risk factors will offer useful information in risk planning and prioritization, especially in countries or projects where bespoke studies are not feasible or stakeholders are not experienced in MiC. Table 3 shows the most reported risk factors in the application of MiC. Of a preliminary 73 risk factors, these 30 CRFs constitute the most important risk factors as they have been reported in at least two (2) empirical studies. Owing to the space constraints, the top ten (10) CRFs are discussed below.

Stakeholder fragmentation and management complexity

Following the fragmentation of the segments of the MiC supply chain, the associated stakeholders in MiC projects are also fragmented (Luo et al. 2019). The diverse occupational and professional backgrounds of these project participants introduce additional layers of complexity in their management. Unlike the TCC where the diverse professionals collectively deliver and transfer the risk of a project to a client as a 'service', stakeholders in MiC are aggregated into a single 'market' responsible for continuous delivery of the project (s) (Richard 2006). Since the developer wholly initiates and finances projects in the TCC, the participating professionals virtually do not have risk beyond the period of engagement of their services. However, these professionals within the MiC market are continuously engaged throughout the project delivery process and as such, share the risk throughout the project. As each or groups of the stakeholders have their differing goals and value systems within the MiC supply chain, effective management of conflicting interests is a *sine qua non* for the success of MiC projects (Mok et al. 2015).

The fragmentation of the stakeholders and their management complexity has been reported in twelve (12) articles, highlighting it as the most CRF in the application of MiC. Particularly, the coordination and effective management of the project participants require effective communication and information sharing

(Li et al. 2016). Stakeholders such as clients, designers, main contractors, transporters, and assembly subcontractors have multilevel interdependences during the modular design, fabrication, transportation, storage, buffer and onsite modular assembly process (Li et al. 2016; C.Z. Li, Zhong, et al. 2017; Luo et al. 2019). For instance, design information needs to be shared between designers (architects or engineers) and manufacturers to ensure that the produced modules are strictly consistent with the design specification since inconsistencies may render the modular components useless in an MiC project (C.Z. Li, Shen, et al. 2017; Li, Xu, et al. 2018). There is also the need for early integration of the design and construction team to prevent ‘over-the-wall’ syndrome where the construction team is made to interpret the working drawings produced by the design team to which they were not privy. The design and logistics teams need to work closely with the highway team to ensure that modular sizes and weights are consistent with the transport regulations. Certainly, this engenders complexity in the management of stakeholders in MiC projects. Highlighting the increased network of stakeholders, Luo et al. (2019) reported that ‘poor planning of resources and schedule’, ‘poor control of working flows’, and ‘poor information sharing between stakeholders’ could increase the negative impact of the complex stakeholder composition on the performance of MiC projects. Typically, poor coordination and management of the diverse interests and value systems of the professional in MiC projects may result in schedule delays, conflicts and additional costs (Li, Hong, et al. 2018).

Higher initial capital cost

MiC is proven to be cost-effective and offers lifecycle project cost savings (Pan & Sidwell 2011). However, depending on the level of adoption in a country, the implementation of MiC is associated with higher initial capital cost. This factor occurred in 11 studies and is ranked the second (2nd) most critical risk factor. Typically, the application of MiC demands the purchase of additional land acquisition for the modular manufacturing plant, molds, equipment, casting beds, specialized factory labor, and warehouse or temporary modular storage space (Zhai et al. 2014; Zhang et al. 2014; Hong et al. 2017). As these constitute fixed cost, the average cost reduces with increasing output. However, the higher initial and capital costs constitute detrimental recipes for large spectra of risk. Particularly, the adumbrated cost elements are not borne by one party but shared among stakeholders within the MiC value chain. For instance, the limited demand for modular components prevents the early enjoy of economies of scale by modular producers and suppliers. Owing to the higher prices of modular components due to the diseconomies of scale in some countries, it takes a longer time for modular producers to break-even (Richard 2006). Also, as there are currently no fortified best management and implementation practices in MiC projects, developers stand the risk of delivering low-quality projects, which have detrimental implications on their investment. In the context of the limited market for MiC projects in some developing countries (e.g. China, Malaysia), there are reported difficulty in obtaining returns on the colossal initial capital tied to the MiC projects (Luo et al. 2015). Essentially, the longer pay-back period associated with MiC projects in some countries increases the opportunity cost and risks of the higher capital investment.

Poor supply chain integration and disturbances

Poor supply chain integration and disturbances have been reported in nice (9) articles and is ranked 3rd among the CRFs in the application of MiC. The supply chain of MiC consists of a complex and longer value chain comprising tendering, design, engineering, manufacturing, transportation, storage and assembly of modular components which require the integration and coordination of multiple parties such as the client, main contractor, designer, manufacturer, transporter, and assembly subcontractors. As the supply chain constitute linked segments (Li et al. 2016; Hsu et al. 2018), a higher degree of stability and coordination is required to facilitate the free flow of information, materials, services, and funds among project participants (Luo et al. 2019). However, the integration of the MiC supply chain linked segments are complicated, and as such, characterized by disturbances which could derail the budget and schedule performance of MiC projects (Wang et al. 2018a). The MiC supply chain is considered complex owing to the large spectrum of project participants with their unique goals and value systems; fragmentation and discontinuity of the interdependent segments within the value chain; lengthier chain due to both factory & onsite construction activities; complicated defects or error rectification and rework; and strict requirement for geometric and dimensional tolerances (Koskela 2003; Shahtaheri et al. 2017; Luo et al. 2019).

Owing to the poor integration and management of the linked segments of the MiC supply chain, disturbances have an adverse implication on the reliability of the supply chain. For example, delays in the delivery of modular components to the construction site could generate schedule delays and additional cost of labor and the hired equipment (Li, Hong, et al. 2018). Mobile and tower crane breakdown and a malfunction could halt the installation process and result in schedule delays (Li, Xu, et al. 2018). Besides, weather disruptions such as wind could compromise the use of cranes on site and may result in significant loss of installation time (Gibb & Neale 1997). Essentially, disturbances are inevitable and abound in the MiC supply chain. The supply chain disruptions and disturbances are critical risk events because they are triggered by latent factors which cannot be precisely anticipated, and their occurrence demand adjustment to original schedule and production plans which may hatch ‘operation chaos’, ‘prolonged durations’, and ‘increased supply chain cost’ (Wang et al. 2018a). As multiple disturbances can occur contemporaneously, effective supply chain disturbance management is required to minimize their impact on project objectives. This highlight the need for a resilient and flexible MiC supply chain to cope with these disturbances (Hsu et al. 2018; Wang et al. 2018a).

Delays in delivery of modular components to the site

Construction delays are a major plaque in projects management in the global construction industry (Egan 1998). Schedule delays occur when it takes a longer period to complete a project than the initially agreed contractual time (Yang & Wei 2010). Relative to the TCC, MiC shortens construction time and reduces delays (Gibb 2001; Blismas et al. 2006; Pan & Goodier 2012). However, there are several events which could trigger delays in the delivery of MiC projects. Prominent among them are delays in the delivery of modular elements to the construction site (Hsu et al. 2018; Li, Xu, et al. 2018). This has been reported in nine (9) studies as a risk factor in the application of MiC and is ranked 3rd in the current study among 30 CRFs (Table 3). Modular delivery may be delayed due to inefficient scheduling and planning, modular production system failure, road traffic congestions, weather disruptions and reproduction of components owing to defect (Gibb & Neale 1997; Li et al. 2013; Hsu et al. 2018; Wang et al. 2018a). The delays in the modular delivery have detrimental implications on the schedule and cost performance of MiC because it generates an increased cost of additional labor working hours, cost of hired equipment and time overrun. These are counterproductive to the cost and time savings benefits of MiC.

Poor government support and regulations

Government constitutes the biggest construction client in most countries. Government regulations and support are required in the implementation of innovative technology such as MiC. Lack of government support and regulations have been highlighted in eight (8) studies as a risk factor in the application of MiC and is ranked 5th among the 30 CRFs in this study. Owing to the fragmented nature of the construction industry, conservative consumption habits of stakeholders and the resistance to innovation (Blismas & Wakefield 2009; Jiang et al. 2018), the role of government in the implementation of MiC is immense. This is evident in many countries. For instance, the Hong Kong government grants gross floor area concessions to private developers who implement MiC in the projects (Tam et al. 2015). The Chinese government has a clear vision for the adoption and implementation of MiC within the National New Urbanization Plan 2014-2020 (Jiang et al. 2017). The Malaysian Construction Industry Development Board (CIDB) implemented the 2003-2010 and 2011-2015 MiC roadmaps to encourage the adoption of the technology (Kamar et al. 2014). Similar government initiatives have been implemented in Canada, Singapore, Australia, and the UK to promote the application of MiC (Gibb 2001; Blismas & Wakefield 2009; Hwang et al. 2018). The absence of these supports and regulations constitute sources of significant risk in the application of MiC as there are reported difficulties in obtaining planning permits for MiC and lower market demand for MiC projects (Mao et al. 2014; Luo et al. 2015; Gan, Chang, Zuo, et al. 2018). Again, in the absence of incentives and subsidies, investment in MiC is found to be costly in some countries (Dawood 1995b; M. Li et al. 2017).

Lack of MiC codes and standards

Buildings and construction projects have the greatest ecological footprint on the earth and as such, poor design, construction and usage have adverse implications on the welfare, satisfaction, safety and carbon emissions (Intergovernmental Panel on Climate Change 2007). Building codes and standards are the regulatory frameworks that ensure that buildings are designed and constructed to meet requirements such as indoor environmental quality, energy consumption, structural integrity, durability, sustainability, comfort, and zoning regulations. Owing to the engineering differences between the TCC and MiC, the design codes and standards of the former are not applicable to the latter. As MiC is still fledgling in some countries, lack of design codes and standards have been reported in seven (7) studies as a critical risk factor in the application of MiC. Considering that MiC involves huge capital investment, applying the approach in projects without clear and adequate regulatory guidance may result in a financial loss (Luo et al. 2015).

Defective design and change order

Defective design denotes a deficiency in modular design, materials, workmanship, production, and assembly which have detrimental implications on building components, mechanical systems and structural integrity of a project whereas change order denotes significant changes to the original design and scope of a project. Defective design and change orders have been reported in six (6) studies as a risk factor in the application of MiC and is ranked 7th among the 30 CRFs. In MiC projects, there is virtually zero tolerance for defective design since the production schedule becomes fixed once initiated (Hsu et al. 2018; Wang et al. 2018b; Wang et al. 2018a). Defects in the design mean that there will be wide geometric and dimensional variabilities between the manufacturing tolerances and assembly tolerances (Shahtaheri et al. 2017). Such variabilities may result in construction defects which require prohibitive cost rectification and reworks. The reworks will also require redesign, reproduction, transportation, and assembly of the additional modules to right the wrongs in the assembly process. Apparently, the rectification of the errors and the accompanying reworks constitute huge cost and recipes for MiC project delays (Li et al. 2013; Lee & Kim 2017). Also, changes in project scope are difficult to implement in MiC because there is decreased flexibility for late design changes and poor cooperation between multi-interfaces (Tam et al. 2007; Rahman 2014; Hwang et al. 2018). Essentially, defective design and change orders constitute significant risks to the cost, quality, schedule and structural integrity of MiC.

Supply chain information gap and inconsistency

As noted earlier, the effective integration of the MiC supply chain and associated stakeholders require adequate communication and information sharing (C.Z. Li, Shen, et al. 2017; C.Z. Li, Zhong, et al. 2017; Li, Xu, et al. 2018). Supply chain information gap and inconsistency was ranked 7th out of the 30 CRFs. Owing to the interdependence of the segments of the MiC supply chain, consistency of information is crucial for smooth delivery of the projects. Poor information sharing within the chain may result in significant delays in MiC projects. In Hong Kong, Li, Xu, et al. (2018) found that “inefficient design data transition”, “design information gap between designer and manufacturer”, “logistics information inconsistency”, and “low information interoperability between different enterprise resource planning systems” resulted in between 200 and 300min delays in the six-day cycle assembly of residential MiC projects. Considering the shorter schedules and the higher hourly rate of the hired assembly equipment, this loss of time constitutes a significant cost.

Inefficient scheduling

Modular manufacturing scheduling constitutes a crucial parameter in the application of MiC. Inefficient scheduling has been noted in six (6) studies as a critical risk factor in the application of MiC. Unlike the TCC, scheduling in the precast construction industry is made-to-order (Dawood 1995b). As a result, the modular manufacturing process conforms to the engineer-to-order enterprise resource planning. This demands that the quantity of each manufactured modular component produced precisely matches its optimal quantity demanded in the MiC project and thus, the inventory must return to zero at the end of the project (Hsu et al. 2018). Since the modules are designed to meet the specifications and design of a single project, shortages cannot be supported using modules from other manufacturers, unless they are designed using the exact same specification. This highlights the host of uncertainties and risks associated with inefficient scheduling. Indeed, the scheduling must consider demand variations, operational uncertainties such as ‘process-waiting time on the flow of work’, processing time uncertainty and resources constraints (Wang et al. 2018a; Wang et al. 2018b). Dawood (1995b) indicated that job shop scheduling of modular plant must consider arrival patterns, number of machines, work sequence and continuous performance evaluation. All these events come along with uncertainties which may increase the cost of inefficient scheduling.

Limited MiC expertise and experience

As an innovative technology, special skills and expertise are required to enhance the success of applying MiC. The immature nature of MiC in some countries, especially developing countries leave the approach to the mercy of inexperienced professionals (Jiang et al. 2018). Limited expertise and experience in the application of MiC have been noted as a risk factor in six (6) studies. This is crucial because the level of expertise and experience have implications on the quality and performance of MiC projects. For instance, based on experience, developers could optimize some processes to create more value for money. Adequate experience may ensure safer investment in the form of a higher quality of the projects and fewer defects/reworks. Pan & Sidwell (2011) highlighted the positive effect of experience and expertise on cost savings in MiC projects. As such, the expertise and experience of professional must be given due consideration in the application of MiC.

Conclusions and implications

The application of MiC is associated with lifecycle cost savings, shortened construction time, reduced construction waste, improved adaptability, reduced carbon emissions and simplification of the construction process. However, the unique design, engineering, supply chain, stakeholder composition and management requirements of MiC engender wider spectra of risks and uncertainties which could compromise the adumbrated benefits of MiC. In response, empirical studies have examined the various risk associated with MiC in different countries. As most of the studies focused on different risk components of MiC, there is the need to synthesize the empirical research findings to generate a research framework of the critical risk factors (CRFs) associated with MiC. This paper conducted a systematic review of 39 empirical studies on the risks of MiC.

The analysis showed that risks factors of MiC are gaining increasing attention in the CEM research domain, especially within the last decade with about 12 publications recorded in 2018. Out of the 20 journals, Journal of Cleaner Production (33%), Automation in Construction (8%), Journal of Management in Engineering (8%), Construction Management and Economics (5%), Engineering, Construction and Architectural Management (5%), and Habitat International (5%) contributed the most publications with each contributing at least 2 articles on the risks of MiC. The superior contribution of the Journal of Cleaner Production (13) may be due to the cleaner nature of MiC. Out of 9 countries, China (16), Hong Kong (8), UK (5), and USA (3) contributed the greatest number of articles on the risks of MiC. However, the 9 countries are in four continents comprising Europe, North America, Australia, and Asia. These continents are noted for their advanced levels and clear vision in the adoption of MiC which highlights the quality and representatives of included studies. The literature synthesis resulted in the extraction of 73 risk factors, of which 30 were considered CRFs as they were reported in at least two studies.

Of the 30 CRFs, stakeholder fragmentation and management complexity; higher initial capital cost; poor supply chain integration and disturbances; delays in delivery of modular components to site; poor government support and regulations; lack of MiC codes and standards; defective design and change order; supply chain information gap and inconsistency; inefficient scheduling; and limited MiC expertise and experience were the top 10 CRFs in the application of MiC. Although the study is an SLR, the findings have substantial implications for practice and future studies. Firstly, the CRFs identified may be useful to countries which are yet to adopt MiC and may be used to guide MiC project risks planning. Secondly, the findings may broaden the understanding of offsite construction researchers and practitioners of the CRFs in the application of MiC. Thirdly, the identified CRFs contribute to the theoretical checklist of risks factors associated with OSC techniques. Finally, the identified CRFs may be investigated and prioritized in other countries prior to the application of MiC and thus, may reduce the impact of the risk factors on project objectives. Despite the relevance of the study, the following limitations are worth highlighting. First, the study used the number of occurrences in studies to determine the criticality of the risk factors which is not effective enough. As such, a quantitative assessment is required in future studies. Second, albeit adequate, the sample of articles is small, and the review should be updated in subsequent years to capture new findings on the risks factors as MiC mature and gain wider market expansion in many countries. Finally, no mitigation strategies were identified for the CRFs and thus, future studies may investigate management strategies and their effectiveness in addressing the CRFs.

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