Risks of Modular Integrated Construction: A Review and Future Research Directions

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Abstract: Despite the extensively documented benefits of modular integrated construction (MiC), stakeholders continue to remain sceptical in its adoption due to the associated risks and uncertainties. The unique business model of MiC nurtures several risks and uncertainties different from those of the conventional construction approach. Although MiC is gaining attention with its market expansion, there is no systematic evaluation of the research progress. This research conducted a systematic review and synthesis of published studies on the risks of MiC from 1992 to 2019 inclusive. The analysis reveals that the research publications on risks of MiC witnessed a steady growth, with significant progress occurring in the last decade. This implies that the risk of MiC has gained more attention in the construction engineering and management domain in recent times. Existing empirical studies have focused more on *perceived implementation risks; supply chain risks; schedule risks; investment risks; structural risks; ergonomic risks; and MiC risk management strategies,* which indicates that MiC is associated with a host of risk events. The paper further identified the critical risk events (CREs) in the application of MiC based on frequency of occurrence. The identified CREs contribute to the checklists of risk events in the implementation of offsite construction, which may be useful in risk planning especially where the MiC market is still fledgling, and fewer or no bespoke risk assessment exist. The paper highlighted research gaps in existing studies and proposed areas for further studies. Thus, the paper makes a useful contribution to the scholarly literature on the risk of OSC and maybe useful to offsite construction researchers, industry practitioners, and project managers.

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

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1. Introduction

Industrialization of construction is pursued to address the manifold ill-performances of the traditional business model of the construction sector. Richard (2005) argued that industrialized construction could increase the efficiency and productivity of the construction industry like those of the manufacturing industry. Offsite construction (OSC) is one of the approaches to industrialize the construction sector. OSC is a construction production process which shifts preponderances of the trades in the traditional cast-in-situ construction (TCC) approach to an offsite factory, resulting in the fabrication of building components which are then transported to a construction site for final assembly and installation (Gibb 2001, Pan and Goodier 2012). Modular integrated construction (MiC) is a distinctive form of OSC where 80-95% of a whole building can be manufactured in an offsite factory environment (Smith 2016). MiC reduces construction time due to the concurrent offsite and onsite activities, minimizes labor cost owing to the stable factory labor force, quickens the learning curve due to the repetitive works (Murtaza *et al.* 1993), reduces project lifecycle cost (Blismas *et al.* 2006), improves project adaptability, supports change without demolition (Richard 2005), reduces construction waste and water footprint (Jaillon and Poon 2008, Jaillon *et al.* 2009), and reduces greenhouse gas emissions (Mao *et al.* 2013). Thus, MiC is considered a cleaner, innovative and sustainable construction approach (Quale *et al.* 2012).

Due to these benefits, models of MiC are promoted in Australia, Canada, USA, UK, Singapore, Sweden, Korea, China, and Malaysia such as off-site manufacture, modular construction, prework, off-site production, prefabricated prefinished volumetric construction, industrialized housing construction, and industrialized building systems. However, MiC is associated with a unique supply chain, stakeholder composition, procurement model, engineering process and management requirement (Wuni, Shen, and Mahmud 2019) resulting in significant risks and uncertainties different from those of the TCC (Li *et al.* 2013). For instance, the application of MiC demands modular design, manufacturing, transportation, storage, and onsite installation. These segments of the MiC supply chain are currently fragmented but substantially interdependent, resulting in manifold uncertainties which could derail the success of MiC projects (Li *et al.* 2016). As these linked segments constitute nearly a fixed and unique linear sequence with minimal overlapping, disturbances in upstream segments may affect the continuity of downstream segments or the entire

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supply chain (Wang *et al.* 2018a). For instance, too early delivery of modular components requires storage space whereas delays in the delivery of modules to the site may halt the entire installation process (Li, Hong, *et al.* 2018). Also, failure of modular production plants may directly translate into delays in modular delivery and a shortage of modular components on the construction site since third-party modular manufacturers cannot complement the deficit with different components.

Again, problematic dimensional and geometric variabilities in modular elements in MiC projects abound and constitute recipes for defects and expensive reworks (Shahtaheri *et al.* 2017). According to the Bureau of Labor Statistics (Bureau of Labor Statistics 2009), construction workers in residential MiC projects in the United States are exposed to higher rates of injuries and risk of work-related musculoskeletal disorders (WMSDs), compared to the rates in the TCC. These uncertainties and risk events translate into barriers to the adoption of MiC as some of them are counterproductive to the benefits of the approach. Despite these uncertainties and risks events, MiC is gaining attention with its market expansion in the Architecture, Engineering, and Construction (AEC) industry. As risk is inevitable in construction projects (Baloi and Price 2003), there is a growing body of studies seeking to understand the risks and uncertainties associated with MiC. However, a systematic review of these empirical studies has not been well established, although it is essential to monitor the progress of studies on the risk of MiC and to bridge the gap between empirical studies, and practical risk management. Hosseini et al. (2018) conducted a scientometric review of studies on OSC and Li et al. (2014) offered a critical review of studies on the management of MiC projects. However, these studies were generic and offered very little or no documentation of the risks of MiC.

Thus, this research conducts a systematic review and synthesis of empirical studies on the risk of MiC. Specifically, the study aims to: (1) examine the research publications trend on the risks of MiC, (2) identify the emerging salient research areas on the risk of MiC, (3) highlight the critical risks events (CREs) in MiC, (4) propose a risk breakdown structure of MiC, and (5) highlight the areas that require further studies. By doing so, the paper makes a useful contribution to the scholarly literature on OSC as it represents the first exclusive review and synthesis of studies on the risk of MiC. Particularly, the paper delineates the knowledge boundaries in existing studies,

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highlights some research gaps and proffers directions for future studies. The paper highlights some critical risk events in MiC. These contribute to the checklists of the risk events in OSC and may be prioritized in the implementation of MiC, especially in countries where bespoke MiC risk assessment are not available. A risk breakdown structure is also developed to offer a bird's eye view of the risk structure of MiC. As such, this paper is relevant to OSC researchers, developers, project managers, teaching staff, policymakers, and industry practitioners. The remainder of the paper is structured as follows. The next section offers an overview of MiC, followed by a description of the research methodology. The paper then offers discussions of the review findings and finally, draws logical conclusions based on the findings.

2. Overview of modular integrated construction (MiC)

Modular integrated construction (MiC) is a construction technique whereby "free-standing integrated 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). Smith (2016) describes MiC as the most complete form of OSC. Based on the degree of modularization, Gibb (1999) describes the four (4) levels of MiC as components manufacture and subassembly (e.g. windows), non-volumetric preassembly (e.g. cladding panels), volumetric preassembly (e.g. toilet pods and complete modular building (e.g. modular home). Fig. 1 shows the major stages in the modular integrated construction process.

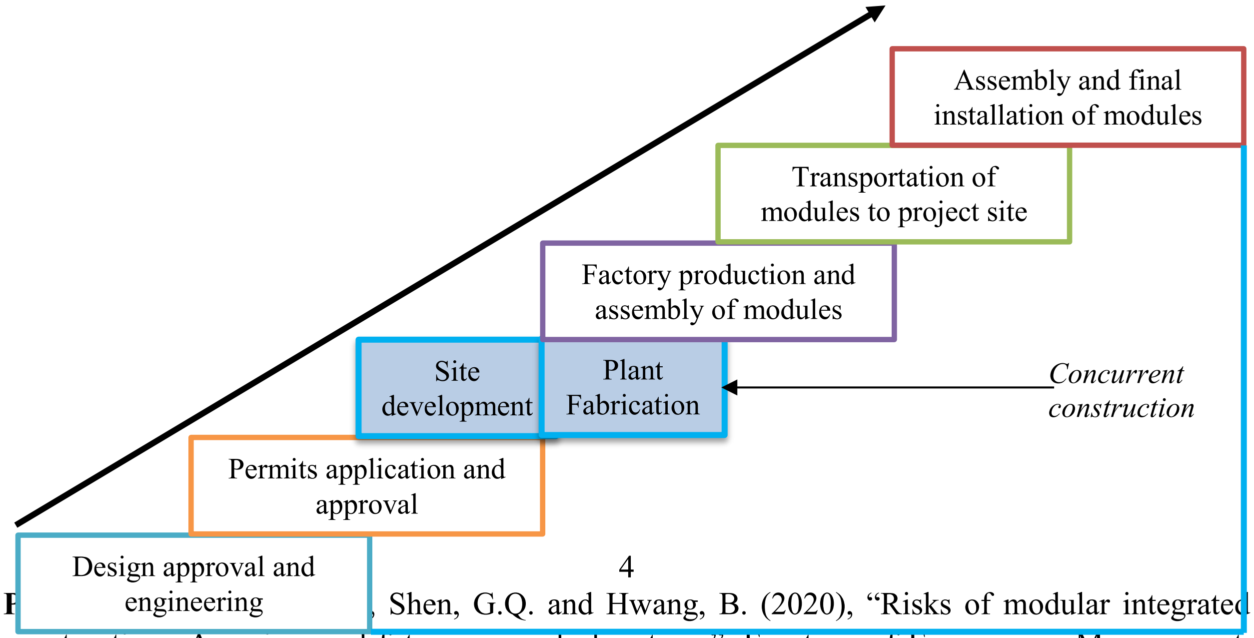

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Fig. 1. Stages of the modular integrated construction process

The supply chain of MiC can be simplified as modular design, engineering, manufacturing, transportation, storage (and/or buffer) and onsite installation (Li *et al.* 2016). These involve several stakeholders including main contractors, assembly subcontractors, manufacturers, suppliers, architects, engineers, site engineer, developers, housebuilders, designers, clients, consultants, academics, transporters, logistics managers, project coordinators, and local government (Li *et al.* 2016, Bortolini *et al.* 2019). Nam and Tatum (1997) described these stakeholders as leaders and champions of construction innovation. These multidisciplinary practitioners and professionals have their unique goals and value systems within the MiC supply chain, engendering increased complexity in coordinating and managing the involved stakeholders in MiC projects (Luo *et al.* 2019).

MiC often follows the design for manufacturing and assembly (DfMA) philosophy (Hsu *et al.* 2018), and engineer-to-order manufacturing process (Dawood 1995a, 1995b, Bortolini *et al.* 2019). Typically, modular components are made-to-order and designed to be used exclusively in a specific project. As such, the quantity of each manufactured modular component is engineered to precisely match the optimum quantity demanded to complete the MiC project and thus, the inventory must return to zero at the end of the project (Hsu *et al.* 2018). Due to this, the onsite modular demand deficit cannot be satisfied by a third-party manufacturer. This unique production scheduling individuates the MiC supply chain from that of the TCC, resulting in layers of new uncertainties in the construction process. The resulting MiC project could be permanent or temporary (Smith 2016). However, the products are industrialized building systems rather than standardized buildings. Richard (2005) indicated that the goal of MiC is to manufacture industrialized building systems where the same details generate diversified and adaptable individualized buildings which can be situated in different areas. Models of MiC include prefabricated prefinished volumetric construction in Singapore, industrialized building systems in

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Malaysia, and PPMOF- prefabrication, preassembly, modularization, and off-site fabrication in North America, etc.

3. Research methods

This paper adopted a pragmatist research paradigm to review empirical studies on the risks of MiC. The pragmatist stance allowed for the synthesis of both empirical qualitative and quantitative studies. In doing so, the systematic literature review (SLR) methodology was deployed. SLR is a powerful scientific method which adopts a systematic, and objective protocol in synthesizing knowledge on a subject (Webster and Watson 2002, Levy and Ellis 2006). Due to the organic attribute of literature, SLR is widely adopted to delineate the boundaries of scientific knowledge in the construction engineering and management (CEM) research domain (e.g. Wuni and Shen 2019, Wuni, Shen, and Mahmud 2019). Similarly, this paper adopted the SLR to review studies on the risks of MiC based on a comprehensive methodological framework comprising systematic literature search, critical appraisal, meta-synthesis, and content analysis.

3.1 Database selection and literature search

An SLR must be underpinned by a thorough, and unbiased search for relevant studies (Evans 2004). To ensure wider coverage of the relevant studies, this research initiated the search process by specifying databases rather than journals. As such, the most powerful CEM databases and libraries comprising Elsevier's Scopus, Clarivate Analytics' Web of Science, ASCE library, Engineering Village, Taylor and Francis, and Emerald Insight were examined to identify the one with the widest coverage. Preliminary searches revealed that preponderances of the articles were contemporaneously indexed in nearly all the databases, but Scopus had the highest coverage. Wuni et al. (2019) made a similar observation in a scientometric review. As such, Scopus was mainly adopted in the literature retrieval process. Prior to the search query in Scopus, synonyms for 'risk' and 'MiC' were extracted from the extant literature. The keywords were updated and refined throughout the review process to ensure the widest possible coverage. The implemented full Scopus search algorithm is shown below.

(TITLE-ABS-KEY (risk OR hazard 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 prefabrication OR prefabricated OR prefab OR pre-fabricated) OR TITLE ("industrialized building system" OR "modular construction" OR modular OR "precast construction" OR "off-site fabrication" OR "prefabricated prefinished volumetric construction" OR "modern method of construction" OR "industrialized construction")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ip")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))

Some of the keywords for MiC has been repeated in the algorithm but spelled differently because such spelling variations were observed during the review process. The algorithm is a structured but constrained search string. The *Document type* was restricted to *"Article" and "Article in Press";* the *Source type* was restricted to only "*journals*" and the *Language* was limited to only "*English*". These restrictions generated 1,164 Scopus records (as of 15 February 2019). These were screened to identify relevant articles. Also, the Scopus search was repeated immediately prior to submission (9 April 2019) to retrieve new relevant articles. As a result, three (3) additional articles were retrieved, evaluated and included.

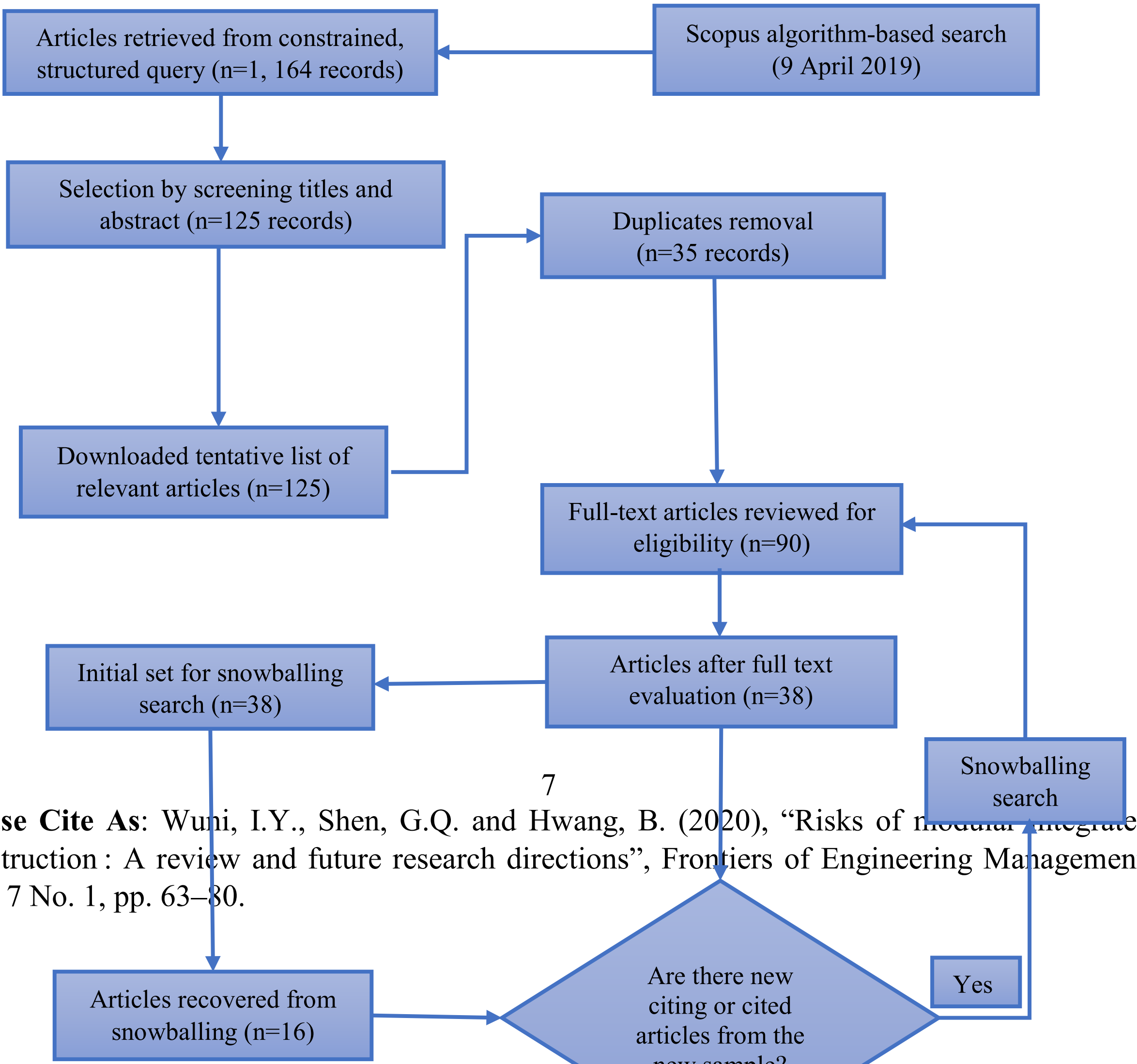

Fig. 2. Flowchart of systematic search and article selection protocol

3.2 Inclusion and exclusion criteria

Wohlin (2014) noted that inclusion and exclusion criteria constitute the benchmarks used in an SLR for filtering the actual sample size from the universe of articles in search queries. As such, the research specified some inclusion and exclusion criteria to screen the articles. The inclusion criteria were: (i) the paper should be an empirical study on the risks of MiC, and (ii) published in a peer-reviewed journal. Conference papers were not included since they do not go through a rigorous peer-review process. Articles were selected based on metadata (title and abstracts) screening and full-text evaluations.

Table 1. Bibliographic summary of the included studies

S.N.	Reference	S.N.	Reference
1	Gustavsson *et al.* (1992)	28	Li, Shen, *et al.* (2017)
2	Dawood (1995a)	29	Li, Zhong, *et al.* (2017)
3	Dawood (1995b)	30	Li, Li, *et al.* (2017)
4	Gibb and Neale (1997)	31	Love *et al.* (2017)
5	Chiang *et al.* (2006)	32	Salama *et al.* (2017)
6	Hassim *et al.* (2008)	33	Shahtaheri *et al.* (2017)

7	Polat (2008)	34	Jiang *et al.* (2017)
8	Hassim *et al.* (2009)	35	Xue *et al.* (2017)
9	Nahmens and Ikuma (2009)	36	Jiao and Li (2018)
10	Blismas and Wakefield (2009)	37	Jiang *et al.* (2018)
11	Kim *et al.* (2011)	38	Lin *et al.* (2018)
12	Ikuma *et al.* (2011)	39	Li, Hong, *et al.* (2018)
13	Kim *et al.* (2012)	40	Li, Xu, *et al.* (2018)
14	Azman *et al.* (2013)	41	Havinga and Schellen (2018)
15	Chiu *et al.* (2013)	42	Hwang *et al.* (2018)
16	Li *et al.* (2013)	43	Ji *et al.* (2018)
17	James *et al.* (2014)	44	Gan *et al.* (2018)
18	Rahman (2014)	45	Hsu *et al.* (2018)
19	Zhai *et al.* (2014)	46	Taghaddos *et al.* (2018)
20	Mao *et al.* (2014)	47	Xue *et al.* (2018)
21	Luo *et al.* (2015)	48	Wang *et al.* (2018a)
22	Li *et al.* (2016)	49	Wang *et al.* (2018b)
23	Segura *et al.* (2016)	50	Li *et al.* (2019)
24	Adekunle and Nikolopoulou (2016)	51	Luo *et al.* (2019)
25	Fard *et al.* (2017)	52	Wu *et al.* (2019)
26	Hong *et al.* (2017)	53	Bortolini *et al.* (2019)
27	Lee and Kim (2017)	54	Enshassi *et al.* (2019)

Following a rapid screening of the 1,164 Scopus records, 125 articles were deemed valid for full-text evaluations. After the full-text evaluation, 38 articles were included. Fig. 2 is a flowchart of the article screening process. Although the sample size (38) compares favorably with previous CEM reviews such as 16 (Newaz *et al.* 2018) and 32 (Saieg *et al.* 2018), the snowballing search strategy was adopted to further locate relevant articles.

The 'snowballing' search strategy was adopted as Wohlin (2014) noted that the algorithm-driven search string alone is not adequate due to the impracticality of specifying exhaustive keywords in the search string. Snowballing search refers to a strategy of using reference lists and citations of a paper to locate additional studies (Wohlin 2014). It involves searching the references (backward snowballing) and tracking the citations (forward snowballing) of an article to locate additional studies. Based on the recommendations of Levy and Ellis (2006) and Wohlin (2014), the 38 articles constituted the sample set for the snowballing search. The authors conducted backward, and forward snowballing searches using these articles. Given the iterative nature of the

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snowballing search, Webster and Watson (2002) and Levy and Ellis (2006) suggested that the search should be aborted when: (i) new findings are not emerging from the newly retrieved articles, (ii) no different citations are discovered in the newly retrieved articles, and (iii) the articles cited in newly retrieved articles have been evaluated. Thus, the authors aborted the iterative search based on these realizations. This resulted in the inclusion of ten (12) additional relevant articles, increasing the actual sample size to 54. Table 1 shows a bibliographic summary of the included studies.

3.3 Meta-synthesis and content analysis

The paper adopted meta-synthesis as the organizing framework for extracting and integrating the metadata of the 54 empirical studies. Meta-synthesis is a mixed method of conducting SLR which draws on both qualitative and quantitative studies (Baker 2016). It starts with the specification of units of analyses and extraction of metadata (Finfgeld-Connett 2014). For each study, year of publication, journal name, research focus and limitations of the study were extracted and cataloged. These were organized into an excel file as a summary table based on the units of analyses. Webster and Watson (2002) described this summary table as a concept matrix augmented with units of analyses. A systematic approach was further used to cluster the studies into various research themes based on the emphasis of each study. This method is described as a content analysis (Finfgeld-Connett 2014). It provides an organizing framework to identify emerging trends from larger volumes of literature. The content analysis formed the basis of identifying the main research topics in previous studies and was relied upon in developing the current and future research framework.

4. Review findings and discussions

4.1 Annual research publications trend on the risks of MiC

The articles included in the review spanned from 1992 to 2019, although there was no 'date range' restriction during the search. This suggests that risk of MiC has been recognized in the CEM field since the last three decades. Fig. 3 shows the annual research publications trend on the risks of MiC from 1992 to 2019. No trend is observed between 1992 and 2009 since an average of 1 article was published annually. However, the period 2009-2019 recorded a steady growth of publications on the risks of MiC. Notably, the highest number of articles (14) was recorded in 2018. This is expected because the last decade witnessed a renaissance of the OSC movement and a concomitant renewed commitment to the promotion of MiC in many countries (Wuni and Shen 2019). The rising trend suggests that the risk of MiC is gaining increasing research attention in the AEC industry (Li *et al.* 2014). As such, this study is timely and useful because when risks become reality, they can derail the performance of MiC projects (Baloi and Price 2003, Jiang *et al.* 2018).

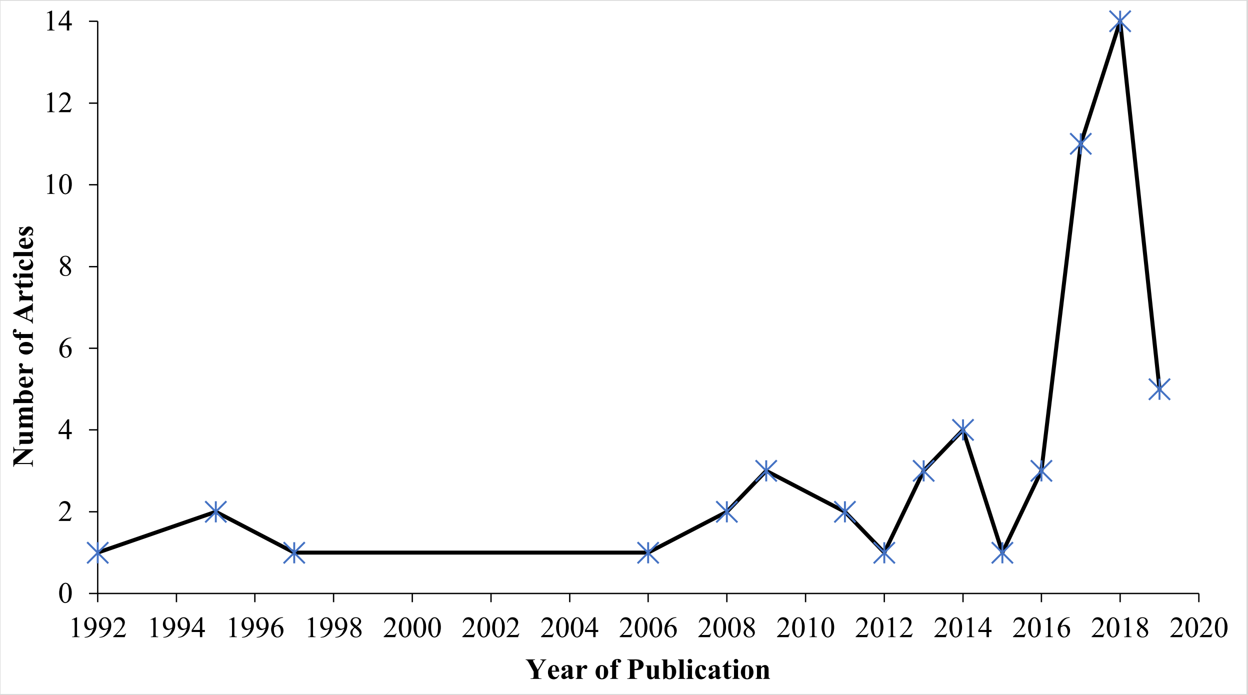

Fig. 3. Annual publications trend on the risk of MiC from 1992 to 2019 inclusive

4.2 Journal distribution of the included studies

The included studies were published in 27 journals. Table 2 shows the journals with publications on the risk of MiC. It is useful to highlight the active journals involved in the publication of studies on the risk of MiC as this will offer a cursory view of the quality of studies included in the review. These journals may also serve as a reference point to researchers when deciding to submit future studies on the risks of MiC for publication. Of twenty-seven journals, nine contributed at least 2 articles. These included *Journal of Cleaner Production* (20.4%), *Automation in Construction* (13.0%), *Journal of Management in Engineering* (7.4%), *Building and Environment* (5.6%), *Journal of Construction Engineering and Management* (5.6%), *Journal of Architectural*

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Engineering (3.7%), *Journal of Civil Engineering and Management* (3.7%), *Construction Management and Economics* (3.7%) and S*ustainability* (3.7%). These journals cumulatively published 36 (66.7%) of the 54 included studies. The rest of the journals contributed 1 article each and collectively contributed 18 (33.3%) of the included studies. Owing to the environmental friendliness of MiC (Quale *et al.* 2012, Mao *et al.* 2013), it is not surprising that a superior contribution is made by the *Journal of Cleaner Production* since sustainability is one of its core missions.

Table 2. Active journals on the risk of MiC studies

Name of Journal	Number of Articles (N=52)
Journal of Cleaner Production	11
Automation in Construction	7
Journal of Management in Engineering	4
Building and Environment	3
Journal of Construction Engineering and Management	3
Journal of Architectural Engineering	2
Journal of Civil Engineering and Management	2
Construction Management and Economics	2
Sustainability (Switzerland)	2
Construction innovation	1
American Journal of Applied Sciences	1
American Journal of Industrial Medicine	1
Applied Sciences (Switzerland)	1
Applied Ergonomics	1
Archives of Civil Engineering	1
Buildings	1
Canadian Journal of Civil Engineering	1
Engineering, Construction and Architectural Management	1
Ergonomics	1
European Journal of Social Sciences	1
Habitat International	1
International Journal of Advanced Manufacturing Technology	1
International Journal of Injury Control and Safety Promotion	1
Lean Construction Journal	1
Journal of Performance of Constructed Facilities	1
KSCE Journal of Civil Engineering	1

Also, MiC improves possible automation in the construction process (Richard 2005, Shahtaheri *et al.* 2017) and thus, it is justifiable that a relatively higher number of the articles have been published in A*utomation in Construction*. Finally, articles related to ergonomic exposure and risks of WMSDs (Kim *et al.* 2011), low back injury (Kim *et al.* 2012) and safety of construction workers in MiC projects (Fard *et al.* 2017) were published in journals such as *Ergonomics, Applied Ergonomics, and the International Journal of Injury Control and Safety Management,* respectively.

4.3 Analysis of the salient research topics in existing studies

It is recognized that the classification of studies into major research areas is subjective However, it was observed that preponderances of the studies identified, and assessed risk events in MiC. The main difference in the studies was the category of risks the authors investigated. As such, it was deemed prudent to cluster the studies based on the forms of risks. Although useful, the classification is for reference only. Some articles discussed more than one identified theme and in such a case, the paper is discussed according to the best-fit research area. The content analysis revealed seven major research themes: (i) implementation risks, (ii) supply chain risks, (iii) schedule risks, (iv) investment risks, (v) structural risks, (vi) ergonomic risks, (vii) risks management strategies. Table 3 shows the seven major themes, the associated sub-themes and percentages of the articles addressing each theme.

4.3.1 Implementation risks

MiC is considered innovation because it involves significant changes to the traditional project design, procurement, scope and interfaces of the construction process (Slaughter 1998). These changes introduce new layers of uncertainties in the construction process and expose decision makers to new challenges (Luo *et al.* 2015). As an innovative technology, MiC is facing significant resistance from industry practitioners as it requires changes to entrenched construction practices (Lovell and Smith 2010). Studies have shown that MiC is stereotyped by stakeholders as a risky approach owing to the perceived increased complexity in project delivery resulting from the manifold trades and stakeholders to be coordinated (Lovell and Smith 2010, Xue *et al.* 2018).

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Hassim et al. (2008) found that contractors in Malaysia associated the perceived riskiness of MiC to insufficient experience, design complexity, and contractor performance failure.

Table 3. Percentages of paper addressing the seven major research themes

Research theme	**Sub-themes**	**% of papers**
Implementation risks	MiC adoption risks; risks perceptions; sources of risks; implementation uncertainties; perceived barriers; project failures; MiC project management problems	9
Supply chain risks	Stakeholder management risks; fragmented and complex network of stakeholders; complex coordination of supply chain stages; supply chain management constraints; complexity in optimal supply chain configuration; supply chain disturbances	19
Schedule risks	MiC project delays; modular components delivery delays; scheduling uncertainties; schedule delays risk events; components assembly challenges	10
Investment risks	Higher setup capital; longer break-even periods; market demand for modular homes; volatile economic conditions; public consumption habits	6
Structural risks	Complexity in structural design for high risk MiC projects; structural integrity issues; vertical connections of modular components; complex multi-interfaces; dimensional and geometric tolerances; multi-hazard design; stable seismic performance; structural resilience; gravitational load of floor slabs; eccentricities; deterioration of components; dampness	13
Ergonomic risks	Health and safety of factory workers; fall injuries; low back pains; awkward working postures; spinal comprehensive and shear forces; fatigue; work-related musculoskeletal disorders	15
Risks management strategies	Time and space hedging; integrated building information modelling platforms; smart construction monitoring; integrated project delivery; stakeholder collaborative management; optimal supply chain configuration; tolerance risk management; automated ergonomic risk management; lean production and management	29

Hassim et al. (2009) further reported that work changes, defective design, changes in government regulation, contractor inexperience, and payment problems represent the top five (5) sources of risks in MiC in Malaysia. Some of these risk perceptions (e.g. complex project delivery) may be due to inexperience and insufficient knowledge of the MiC business model because the goal of the

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approach is to simplify the construction process (Richard 2005). Notwithstanding, Nussbaum et al. (2009) opined that due to the complex parade of trades, and the extensive fragmented discrete events, MiC is associated with manifold risks and uncertainties. Luo et al. (2015) reported that poor cooperation between multi-interface, inadequate design codes and standards, lack of best management practices, higher initial capital cost, and lack of quality monitoring mechanisms constitute the five (5) critical risk factors that breed the reluctance to adopt MiC in China. As the MiC industry is still fledgling in some countries (e.g. China), Jiang et al. (2018) found that failure of demonstration projects, limited capacity of modular manufacturers and inexperience account for the perceived riskiness of MiC. Essentially, these risk perceptions make MiC unattractive to stakeholders.

4.3.2 Supply chain risks

The supply chain of MiC involves modular design, manufacturing, transportation, storage, and onsite assembly. These linked segments are currently fragmented, resulting in uncertainties at each level of the continuum (Li *et al.* 2013). Hwang et al. (2018) stated that the application of MiC requires extensive coordination of the supply chain segments and involved stakeholders prior to and during the construction process. As such, several decisions and trade-offs are made under uncertainties at various segments of the supply chain. At the initial design phase, the justification to apply MiC in a project is grounded on multiple factors, which are also project and context-dependent (Murtaza *et al.* 1993). For example, the decision to adopt MiC in the One Ludgate Place in London was based on cost, time, past experience, design, structural interface, weather joints, performance tests, site logistics and safety (Gibb and Neale 1997) whereas a decision to apply MiC in a power plant project was based on plant location, labor, environmental consideration, project characteristics and risk profile (Murtaza *et al.* 1993). These differences in decision factors introduce bespoke uncertainties, which are unique to a project during the feasibility and economic analysis. Meanwhile, these decisions at the conceptual design stage of MiC projects are indispensable because changes are obscure to implement during construction (Shahtaheri *et al.* 2017).

Again, modular manufacturing operations are often based on engineer-to-order owing to the uniqueness of each MiC project (Bortolini *et al.* 2019). The bidding decisions of modular manufacturers require a precise valuation of the optimal mark-up on price based on design and production planning of every MiC project (Dawood 1995a). Such decisions are made in the context of uncertainties. Even the selection of a location for a modular production factory depends on multiple factors such as costs, transportation, land accessibility, availability of raw materials and infrastructure (Azman *et al.* 2013). Essentially, the optimal configuration of the entire supply chain is required to minimize extreme uncertainties, disruptions, and disturbances during the construction process (Shahtaheri *et al.* 2017). As modular components are specific to a project and made-to-order, logistical planning in MiC must ensure that the quantity of components produced in a factory precisely match the onsite modular demand, allowing the inventory to become empty on completion of the project (Hsu *et al.* 2018). This unique scheduling and procurement configuration require the consideration of multiple schedule deviation factors and disturbances along the entire supply chain. Owing to the interdependences of the supply chain segments (Li, Hong, *et al.* 2018), disturbances within one segment could compromise the reliability of the entire supply chain. For instance, modular production system failure, and defects in modular components may halt the onsite installation process, especially when there is no safety stock (Wang *et al.* 2018a). The impacts of these supply chain disturbances are pronounced because their causes cannot be anticipated until they occur (Wang *et al.* 2018a).

Furthermore, the MiC supply chain is dominated by multidisciplinary stakeholders such as designers, architects, engineers, manufacturers, transporters, logistics managers, main contractors, assembly subcontractors, site engineers, project managers and local government (Li *et al.* 2016, Bortolini *et al.* 2019). Each practitioner or stakeholder has an exclusive motive and value system within the supply chain. Coordination of the interests and value systems of the multiple involved parties introduces new layers of uncertainties and risks in the construction process (Li, Shen, *et al.* 2017). The fragmented and complex MiC stakeholder composition may result in poor resources planning and scheduling, workflow control, and information sharing among project stakeholders (Luo *et al.* 2019). For instance, the separate dominance of different stakeholders in the planning and control of each of the linked supply chain segments may increase the lead time of MiC projects

(Bortolini *et al.* 2019). Again, failure in upstream segments of the supply chain has detrimental implications on the reliability of downstream segments.

4.3.3 Schedule risks

Project delay occurs when a completion date of a project extends beyond the stipulated contractual duration (Assaf and Al-Hejji 2006). project delays are inevitable in the construction sector (Egan 1998). Ji et al. (2018) found that inadequate worker experience, inefficient modular components connection, poor stakeholder management, and low productivity constitute some of the most critical causes of delays in MiC projects. It should be reiterated that schedule delays constitute one of the causes of MiC project delays (Li, Hong, *et al.* 2018). As modular components are made-to-order, modular production often requires job shop scheduling to optimize the allocation of resources and facilitate timely modular delivery (Dawood 1995b). However, job shop scheduling is sensitive to fluctuations in sales, cost, and volume of modules, cost of changeovers, margins of profit and curing time (Dawood 1995b). These also depend on modular plant characteristics, attributes of modules, scheduling shift patterns, demand forecast, and dispatch information (ibid). These nurture multiple uncertainties and risks in the modular scheduling process. Beyond the scheduling stage, there are several events which may cause schedule delays in MiC projects. For instance, wind disruptions resulted in 18 days lost time during the installation of complex prefabricated cladding in the One Ludgate Place in London (Gibb and Neale 1997).

Similarly, Hsu et al. (2018) found that weather disruptions, delays in modular delivery, and crane failure resulted in significant schedule delays in MiC projects in the UK. Moreover, design information gap between designer and manufacturer, inefficient design approval, ineffective design data transition, inefficient verification of modules, delays in modular delivery, low information interoperability between different information management tools, modular installation errors and tower crane malfunction were found to be the most critical schedule delay risk factors in residential MiC projects in Hong Kong (Li *et al.* 2016, Li, Shen, *et al.* 2017, Li, Hong, *et al.* 2018). These information and stakeholder-driven risk events resulted in 200-300min delays in the six-day cycle assembly of MiC projects in Hong Kong (Li, Xu, *et al.* 2018). Although the schedule

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risk factors may differ across projects and regions, the review reveals that there a host of events which could trigger schedule delays in MiC projects.

4.3.4 Investment risks

The application of MiC in a project requires reliable production and supply of modular components. Thus, the adoption of MiC in a country requires significant investment from stakeholders. Huge capital is required to purchase land for the offsite factory, the manufacturing plant, production equipment, raw materials, and labor (Zhang *et al.* 2014). The capital-intensive profile of MiC exposes investors to manifold uncertainties and risks, as it could take several years to break-even. Studies have identified some MiC investment risk factors. Li, Li, et al. (2017) found that high price of modular components, conservative public consumption habit, inadequate modular codes and lack of cutting-edge modular production technologies constitute the most critical investment risk factors in China. Li et al. (2013) found that volatile economic conditions and sociopolitical climate are the most important investment risk factors in Canada. Lee and Kim (2017) identified insufficient modular design expertise, poor cost estimation, unstable modular production rate, and errors in structural designs to be the most critical cost-increasing risk factors in MiC projects in Korea. Essentially, critical investment risk factors differ across countries and projects. However, the findings suggest that MiC is associated with a host of investment risk factors. Particularly, it may take a relatively longer period for investors to break-even or achieve commensurate returns on the higher initial capital investment, especially in countries where the MiC market is at the fledgling stage (Dawood 1995b, Richard 2005).

4.3.5 Structural risks

Climate change-driven hazards such as typhoons, earthquakes, progressive collapse, landslides, cyclones, flooding, and severe marine environment is changing the structural requirement of construction projects (Lin *et al.* 2018) and have spurred research on structural risks of projects in the construction and civil engineering domain. The higher complexity in structural design for high-rise MiC projects which can accommodate strong wind load constitutes a significant challenge in high-density cities and neighborhoods (Wuni, Shen, and Mahmud 2019). Meanwhile, the structural integrity of MiC projects is paramount to overcome the historic stigma of prefabricated buildings such as the 1968 collapse of the 22-story Ronan Point Apartment Tower in East London. Structural integrity and operational capability of MiC projects have an influence on cost, quality and clients' satisfaction (Shahtaheri *et al.* 2017). However, due to the complex multi-interfaces in MiC projects, intolerances of modular components engender defects in MiC projects and render them vulnerable to structural failure (Gibb and Neale 1997, Shahtaheri *et al.* 2017).

Shahtaheri et al. (2017) noted that amid the precise methods of modular production (e.g. 3D fixturing, laser cutting, robotic assembly, etc.) and cutting-edge modular inspection technologies (e.g. laser scanning), problematic dimensional and geometric variabilities abound in MiC projects owing to modular geometric conflicts during production; and between modules & site interfaces. Additionally, incompatibility between process capabilities and desired levels of tolerance trigger a significant challenge in dealing with the excessive geometric variability risks in modular components and assembly (Enshassi *et al.* 2019). The accurate specification of allowable tolerances in MiC projects is indispensable because imprecision may result in less clemency between manufacturing and onsite erection tolerances (ibid). Dimensional and geometric tolerances in MiC are sensitive to modular production errors, the variability of components, measurement imprecision and discrepancies between modular interfaces and thus, failure to specify allowable variability and control tolerances could incubate an obligatory need for reworks (Shahtaheri *et al.* 2017). Existing geometric variability management practices mostly involve trial and error solutions, ad hoc strategies, and the application of strict tolerances which have often resulted in quality problems, schedule delays, budget overrun and increased site-fit reworks (Shahtaheri *et al.* 2017, Enshassi *et al.* 2019). Optimum geometric variability solution may require the combination of both relaxed and strict tolerance approaches to minimize quality and problematic dimensional tolerances (Enshassi *et al.* 2019).

During the onsite assembly process of multi-story MiC projects, there are potential events which may breed detrimental eccentricities. Construction errors and a gravitational load of floor slabs are recipes for eccentricities which could complicate the installation of upper floors (Hong *et al.* 2017). These complications translate into low productivity, schedule delays, and cost overruns. Thus, the selection of an effective modular connection method is required to avoid eccentricities. Lin et al. (2018) noted that the structural performance and safety of high-rise MiC projects could be enhanced if they are designed to be multi-hazard resistant. Of critical considerations are seismic actions and progressive collapse (Chiu *et al.* 2013, Lin *et al.* 2018). The multi-hazard design (structural seismic + progressive collapse design) is required to resist lateral forces from seismic actions and unbalanced vertical loads induced by localized failure (Lin *et al.* 2018). The multi-hazard MiC project should achieve stable seismic performance, structural resilience and infinitesimal deformation following hazards (ibid).

Also, studies have explored the structural risk of MiC projects at the operations stage. Segura et al. (2016) reported that a cooling tower for a thermal power plant constructed of precast concrete suffered a severe deterioration within 3 years of its service-life following a severe exposure to marine conditions. Although the early deterioration was associated with the wetting-drying cycles and chloride-induced corrosion, it demonstrates the potential weaknesses of MiC under severe marine conditions. Adekunle and Nikolopoulou (2016) found that 67% of 116 modular (timber) houses in the UK suffered poor indoor thermal conditions and summertime overheating. Apparently, the low thermal mass of timber exposes such houses to the risk of summertime overheating. Havinga and Schellen (2018) reported mold growth and condensation in 144 Airey houses in the UK amid internal insulation. This highlights the need to carefully select insulation materials for panelized residential MiC projects to prevent early deterioration. Jiao and Li (2018) also reported severe dumpiness in the external walls of MiC projects in China.

4.3.6 Ergonomic risks

The construction industry is one of the most dangerous sectors which expose its workforce to several health threats due to falls, and awkward working postures (Newaz *et al.* 2018). Thus, a higher incidence of fall injuries, low back pains, and risk of WMSDs are common among construction workers (Bureau of Labor Statistics 2009, Valero *et al.* 2016). Owing to the controlled factory environment, reduced onsite activities, fewer construction workers on site and the minimized requirement to work from heights, MiC improves the safety and health of construction workers (Blismas *et al.* 2006, McGraw Hill Construction 2013). In a survey, the majority of general and specialty contractors in the UK indicated that MiC improves the safety performance of projects (McGraw Hill Construction, 2013). However, the Bureau of Labor Statistics (2017) reported that the total injury and incidence rates (10.2 per 100 workers) were higher in manufactured housing compared to the rates (5.2 per 100 workers) in the onsite residential construction and both of which were above the 4.2 per 100 workers national average of the United States (US). In lean construction parlance, poor safety constitutes a significant cost due to human suffering, worker's compensation cost, lost productivity and higher employee turnover (Nahmens and Ikuma 2009).

Different construction workers are exposed to safety risks at various segments of the MiC supply chain. Gustavsson *et al.* (1992) reported that 16 of 1068 workers exposed to artificial mineral fibers, asbestos, combustion fumes from furnaces and arsenic in a Swedish manufactured housing factory died of lung cancer. In the US, construction workers in a modular home manufacturing plant sustained several injuries following exposure to sawdust, excessive noise and volatile organic compounds and forceful exertion during cutting and assembly of heavy components (Ikuma *et al.* 2011). Similarly, Kim *et al.* (2011) found that construction workers were subjected to awkward working postures during the erection of prefabricated panelized wall systems as they exceeded their action limits for spinal comprehensive (34%) and shear forces (77%).

These ergonomic exposures and biomechanical risk events abound because construction workers still engage in the manual (team) handling of modular components such as wall panels in residential MiC (Kim *et al.* 2012). Although manual team handling is appropriate where mechanical aids are unfeasible, the heavy masses of modular components engender risks to the safety of the workers. Nussbaum et al. (2009) found that residential carpenters in the manufactured housing in the US were involved in the lifting, carrying and erecting panelized walls in the range of 1.2-6.0m wide and about 250kg. This exposed the workforce to fall injuries, arm, lower and upper back pains (ibid). Similarly, Fard et al. (2017) found that out of 125 accidents during modular production and onsite installation, fatalities (38.4%), hospitalized injuries (50.4%) and non-hospitalized injuries (11.2%) resulted from 'falls', being struck by a tilt-up roof, falls from roofs, and being struck by objects during hoisting and rigging of large items. Essentially, the manual handling and operations during modular production and on-site assembly are the recipes for the safety risks. Hsu et al. (2018) found that construction workers in the UK reported severe fatigue as they manually inspected, unpacked, lined-up, unfastened, screwed, welded modules and enabled crane lift upon the arrival of modules to a construction site.

4.4 Critical risk events (CREs) in the implementation of MiC

Following risk identification and assessment, the next level on the risk management hierarchy is risk prioritization (Project Management Institute 2017). Risk events abound in MiC projects, but their impact varies. It is just not economical and practical to deal with all risk events and thus, risk management often prioritizes the (critical) risk events as they can derail the performance of projects. Critical risk events (CREs) are the risk events with the most 'violent or aggressive' impact on MiC project's objectives. Table 4 shows the nineteen most cited risk events. The study recognizes that a quantitative assessment is required to identify the CREs and that the CREs would differ across countries and projects. However, the CREs in this paper represent risk events which were frequently cited and reported in the literature. The frequency column of Table 4 depicts the number of articles that reported the associated risk event. These were extracted and synthesized whiles conducting the full-text evaluation and review of the included studies. The rank of each individual risk event is based on the number of times (frequency) it was cited in the literature.

Table 4. Critical risk events in the application of MiC

Critical risk event	Freq.	Rank
Delay in modular components delivery	9	1
Supply chain disruptions and disturbances	9	1
Inefficient scheduling	8	3
Defects in design, change order and change in project scope	7	4
Complex stakeholder composition	6	5
Crane breakdown and malfunction	6	5
Insufficient information coordination among project participants	6	5
Modular installation error	6	5
Weather disruptions	6	5
Exposure to fumes, noise and toxic compounds in modular production plant	5	10
Flexing, warping, and damage from transportation and handling	5	10

Manual inspection, unwrapping, lining-up, unhooking, screwing and welding of modular components	5	10
Modular production materials and components shortages	5	10
Insufficient capacity of modular manufacturers and suppliers	4	14
Complex interfacing between modules	3	15
Geometric conflicts between components during manufacturing and between modules & site interfaces	3	15
Longer distance between modular production plant and construction site	3	15
Dimensional and geometric variabilities	3	15
Modular production system failure	2	18

4.5 Risk Management Strategies

Several studies proposed strategies to avoid, reduce or mitigate the impact of some of the MiC risk events discussed in the previous sections. However, it is useful to present a risk structure of MiC prior to synthesis of the risk management strategies. One useful tool in facilitating the comprehensive management of risk is the Risk Breakdown Structure (RBS). RBS depicts a hierarchical structure of the risks associated with a project. Fig. 4 shows the RBS of MiC based on the review. For simplicity, only two levels are presented. The aim is to illustrate the risk associated with the approach and its business model. The various proposed risk management strategies in the extant literature are discussed below.

Towards addressing the supply chain and schedule risk events, Zhai et al. (2015) proposed lead-time (T), space (S) and L+S hedging techniques to create a buffer against unforeseen delays, upstream supply, and modular delivery uncertainties. These hedging techniques are aimed at improving the reliability of modular supply to reduce schedule delays. However, as modules are made-to-order (Bortolini *et al.* 2019), advance production, transshipping, and dual sourcing components in MiC is less feasible due to its relatively fixed supply chain once scheduled (Shahtaheri *et al.* 2017). Li, Zhong, et al. (2017) demonstrated how radio frequency identification (RFID) and building information modeling (BIM) could manage and mitigate schedule risk events. They proposed an RFID-enabled real-time BIM platform which integrates all relevant stakeholders in the MiC supply chain to allow for information sharing. The platform allows for real-time information interoperability, visibility, traceability, and exchange. Thus, it facilitates proactive risk management because stakeholders can monitor progress at all levels and could initiate timely measures to control latent events which could cause schedule delays (Li, Shen, *et al.* 2017).

However, these information-driven strategies must move in tandem with other strategies to improve schedule performance. Wu et al. (2019) proposed the adoption of the integrated project delivery (IPD) (e.g. design-build model) model to diffuse the fragmentation of the MiC supply chain and stakeholders since IPD demands multi-stakeholder collaboration (e.g. design-build team). Stakeholder collaborative management is found to have a positive influence on the cost performance of MiC projects (Xue *et al.* 2018). Bortolini et al. (2019) found that collaborative planning enhances logistics management. Additionally, Hsu et al. (2018) proposed an optimal supply chain configuration to account for onsite modular demand variations. The model aims to reduce production, operational and penalty cost through the determination of the optimal supply chain configuration based on all possible demand profiles. The optimal configuration makes a warehouse an obligatory buffer and decoupling unit between the modular manufacturing plant and the construction site (Hsu *et al.* 2018).

Towards improving the engineer-to-order manufacturing process, Wang et al. (2018b) proposed an optimization of the modular production scheduling based on operational uncertainties such as ‘process-waiting time on the flow of work’, processing time uncertainty and resources constraints.

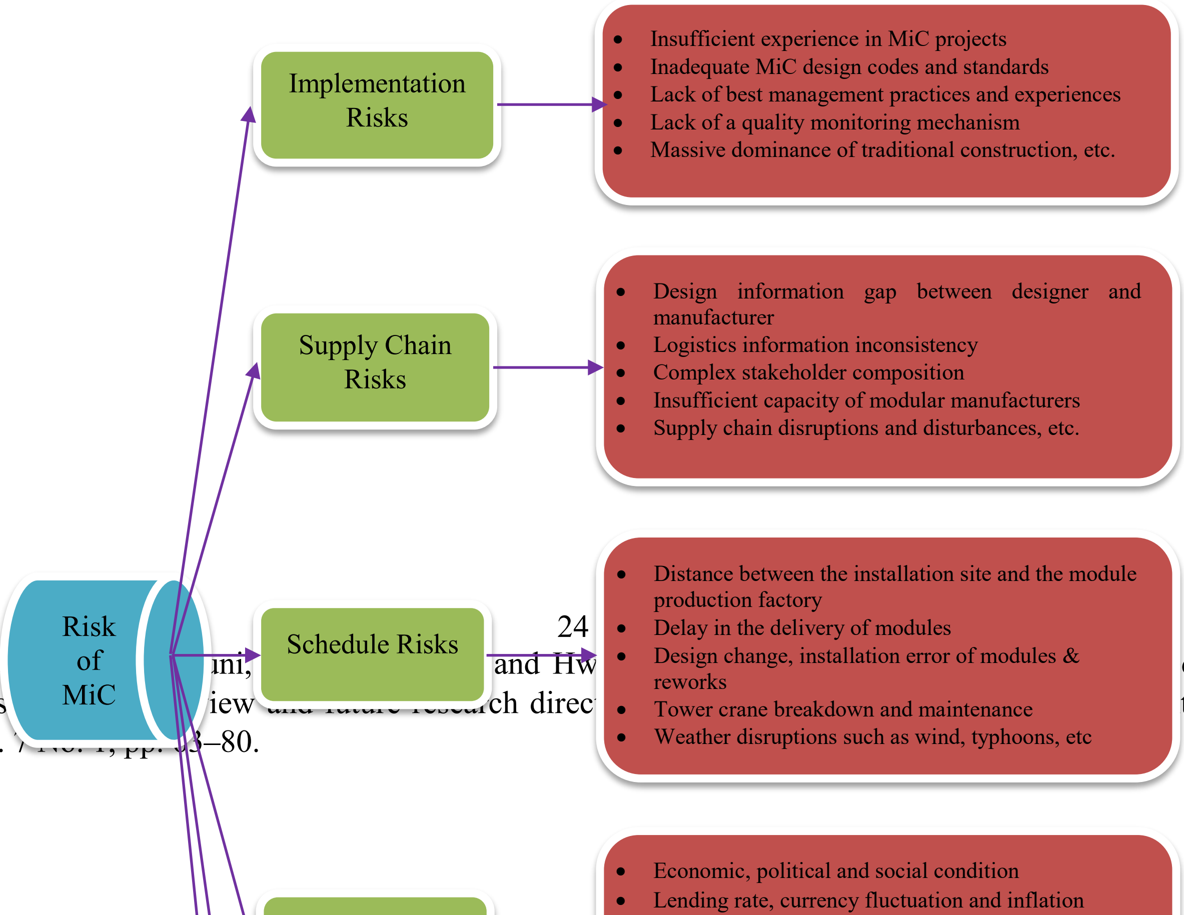

Fig. 4. Risk breakdown structure of modular integrated construction

The optimization aims at generating minimal manufacturing cost, timely delivery of modules and minimal resources wastage (Wang *et al.* 2018b). Taghaddos et al. (2018) also demonstrated how effective planning, selection, and optimization of crane configurations and lifting options improve the time, cost and safety performance of an industrial project in Alberta, Canada. As such, optimization at every stage of the supply chain could improve the schedule and cost performance of MiC projects.

In the context of structural risk, studies have proposed ways of minimizing dimensional intolerances. According to Salama et al. (2017), modular manufacturers should select an optimized configuration of modular components based on the limitations of onsite connection, transportation, and weight. The aim is to minimize the intolerance during modular production. For managing the accumulated effects of dimensional and geometric variability in MiC, Shahtaheri et al. (2017) proposed an approach of combining project risk and structural analysis (risk-based framework) to determine a Pareto-optimal structural assembly configuration with the lowest amalgamated cost of modular production and project risk. This framework is crucial at the planning and design phases of MiC as it allows for an informed trade-off to be made between modular production costs, transport cost, cost of reworks and safety of construction workers. Enshassi *et al.* (2019) proposed a systematic risk management framework to proactively manage the persistent geometric variability risks in MiC projects. The proposed framework offers decision support that allows for quantitative evaluation of modularization risks, uses either a strict or relaxed tolerance approach to identify optimum geometric variability, and generates an optimal selection of mitigation strategy-based on tolerance theory.

Moreover, some studies investigated the mitigation strategies for ergonomic exposure and safety risks. Li et al. (2019) developed ErgoSystem; an automated post-3D visualization system which supports worker-friendly workplace design based on automated ergonomic risk assessment. The system automatically assesses ergonomic exposures and allows for changes to be made to the factory layout to prevent ergonomic exposures. Nussbaum et al. (2009) proposed that panelized wall designers should eliminate ergonomic risk by incorporating ergonomic principles into the design of the wall systems. Fard et al. (2017) proposed that injuries could be minimized through stabilization of structures during lifting, storing, and permanent installation; securing fall protection systems during modular assembly while working from heights; and developing safety management initiatives in MiC projects. Studies have also investigated how a lean philosophy can minimize safety risks in MiC projects. Ikuma et al. (2011) implemented Safety and Lean Integrated Kaizen in a modular homebuilding plant and found that back strain, trip hazards and pinch points were significantly reduced. James et al. (2014) and Nahmens and Ikuma (2009) found that good scheduling practice, housekeeping, systematic workflow, production standardization and improved handling of materials minimized injuries and improved the safety of construction workers in the manufactured housing industry in the US. Similarly, Nahmens and Ikuma (2009) implemented lean principles in MiC projects in the US and observed reduced biomechanical hazards, falls and low back injuries.

4.6 Future research directions

Fig. 5 shows the current and proposed future research framework on the risks of MiC. The proposed areas for future research considerations were identified from the gaps in the reviewed studies. The review showed that most of the studies examined MiC supply chain risks events. This suggests that risk events in the supply chain constitute one of the major concerns in MiC. Notably, studies have identified the supply chain risk events (Li *et al.* 2016, Li, Shen, *et al.* 2017, Li, Hong, *et al.* 2018), and the stakeholder-associated risk factors (Li *et al.* 2016, Luo *et al.* 2019). However, there is no quantitative assessment of the supply chain risk events to identify the most critical ones. It should be reiterated that the MiC supply chain involves multidisciplinary practitioners with their unique goals and value systems (Wuni, Shen, and Mahmud 2019). Each of the stakeholders may focus on the risk associated with a segment of the supply chain. Aggregating the risks associated with the entire MiC supply chain is less likely to serve the specific needs of the disparate stakeholders.

Thus, future studies would identify and allocate critical risk events in the segments of the MiC supply chain. Furthermore, there are limited studies on the resilience of the MiC supply chain. However, the adaptive capability of the MiC supply chain which allows it to recover quickly following any disturbances is important (Wang *et al.* 2018a) to improve the performance of MiC projects. Thus, future studies would develop a risk resilience framework for the MiC supply chain. Moreover, MiC is associated with different risks and uncertainties (Li *et al.* 2013). However, the magnitude of the risks and uncertainties differ across projects and regions. As risk planning is conducted prior to and during the construction of projects (Baloi and Price 2003), a risk evaluation index is required as a decision support system to guide the selection (Murtaza *et al.* 1993) and risk-rating of MiC projects. However, there is currently no risk evaluation index and decision support for MiC projects (Wuni, Shen, and Mahmud 2019). As such, future studies would develop a risk evaluation index and decision support for MiC projects**.**

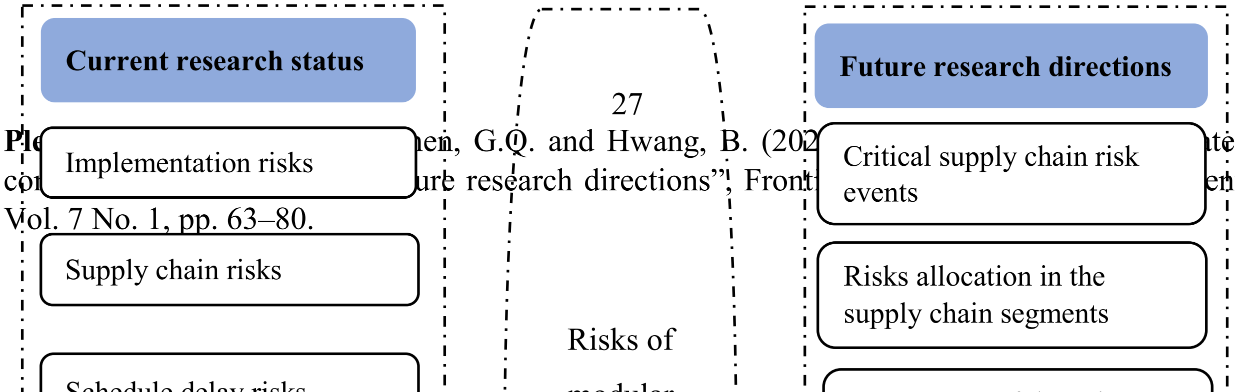

Fig. 5. Current and future research framework on the risks of MiC

Furthermore, one significant challenge in the application of MiC is the management of the geometric variabilities during the modular manufacturing and assembly due to incompatibility between process capabilities and desired levels of tolerance (Enshassi *et al.* 2019). The prevailing reactive geometric variability management practices continue to apply strict tolerances based on trial and error solutions (Shahtaheri *et al.* 2017, Enshassi *et al.* 2019). These practices have proven to be recipes for quality problems, excessive site-fit reworks, cost, and time overruns (Wuni, Shen, and Mahmud 2019). Shahtaheri *et al.* (2017) proposed a geometric and dimensional risk management framework based on strict tolerance approach whereas Enshassi *et al.* (2019) proposed a systematic proactive risk management framework and decision support based on relaxed tolerance approach. However, there are little studies on the possibility of managing geometric variability risk based on a combined strict-relaxed tolerance approach. Future studies

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will conduct a robust assessment of the impact of this combined tolerance-based mitigation strategy on quality, schedule, and cost performance of MiC projects.

Finally, studies have deployed smart construction objects and developed RFID - enabled BIM platform which integrates involved stakeholders, allowing for effective monitoring of workflow progress and information/data exchange in the manufacturing, logistics and on-site assembly segments of the MiC supply chain (Li, Zhong, *et al.* 2017, Zhong *et al.* 2017, Li, Xue, *et al.* 2018). The internet of things (IoT) – enabled BIM platform (Zhong *et al.* 2017, Li, Xue, *et al.* 2018), smart construction objects and RFID-enabled smart gateway (Li, Zhong, *et al.* 2017) work effectively in ensuring data/information traceability, interoperability, visibility, exchange and allows for proactive management of MiC schedule risks (Li, Zhong, *et al.* 2017). However, none of the developed platforms incorporated fault-tolerant techniques which allow for effective elimination errors caused by faulty operations and inputs. Thus, future studies would modify these platforms to improve their performance.

5. Conclusions

Following the growing body of bespoke literature on the risks of MiC, this research conducted a systematic review and synthesis of empirical studies on the risks of MiC from 1992 to 2019. It is found that research publications on the risk of MiC only witnessed a steady growth within the last decade. This suggests that risk of MiC is gaining attention in the CEM domain. Based on a content analysis framework, it is found that existing studies focused more on identification and assessment of perceived implementation risks, supply chain risks, schedule risks, investment risks, structural risks, ergonomic risks, and MiC risk management strategies. These multiple forms of risks suggest that MiC is associated with a host of risks and uncertainties. Based on the frequency of occurrences, the paper identified nineteen (19) critical risk events (CREs) which were reported in at least two (2) studies. The top 10 CREs include delay in modular delivery; supply chain disruptions and disturbances; inefficient scheduling; design defects and change in project scope; complex stakeholder composition; crane malfunction; insufficient information coordination among project participants; modular installation error; and weather disruptions. These should be carefully considered in the implementation of MiC.

Although significant research progress has been made on the risk of MiC, the paper identified some areas that require further research. Future studies should (i) conduct quantitative assessment and ranking of the CREs in the MiC supply chain, (ii) allocate risks among the various segments of the MiC supply chain, (iii) examine the MiC supply chain resilience, (iv) develop a risk evaluation index and decision support framework, (v) incorporate fault-tolerant techniques in the Integration of RFID and BIM for MiC supply chain management, and (vi) develop a combined strict-relaxed tolerance-based framework for management of geometric variability risk. As such, this paper makes a unique contribution to the scholarly literature on the risk of OSC as it constitutes the first exclusive review on the risks of MiC. The paper has delineated the boundaries of existing studies, highlighted the gaps and deficiencies in current studies and proffered some directions for future studies. The paper further developed an RBS of MiC and identified some CREs in the implementation of MiC. The CREs contributes to the checklists of risk events associated with OSC and may broaden the understanding of OSC researchers, project managers and practitioners on the risks associated with MiC. The checklist of CREs may also be useful in risk planning in countries where the MiC market is still fledgling, and fewer or no bespoke risk assessment exists. For policymakers, the study highlighted the need for increased commitment to making MiC more attractive as the approach continues to fight the historic stigma of prefabricated housing and risk stereotyping. Finally, the proposed research framework provides a useful foundation for future studies. However, the study has the following limitations. Firstly, a sample size of 54 is small but considering that the MiC is now gaining attention, this review is timely and useful. Secondly, although a comprehensive search was conducted, it is possible that some relevant articles may have been missed.

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