Towards a Decision Support for Modular Integrated Construction: An Integrative Review of the Primary Decision-Making Factors

Ibrahim Yahaya Wuni and Geoffrey Qiping Shen*

Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Ibrahim Yahaya Wuni is a PhD student at the Department of Building and Real Estate of the Hong Kong Polytechnic University. Mr. Wuni is an awardee of the Hong Kong PhD Fellowship Scheme funded by the Hong Kong Research Grants Council. Mr. Wuni does research on modular integrated construction, off-site construction, risk management, decision support systems, decision science, benchmarking, and sustainable construction.

Professor Geoffrey Qiping Shen is a Chair Professor of Construction Management at the Department of Building and Real Estate of the Hong Kong Polytechnic University. Prof. Shen is the Associate Dean of the Faculty of Construction and Environment and the Academic Discipline Leader of Construction and Real Estate Management. Prof. Shen does research on construction project management, stakeholder management, industrialized construction, construction information technology, sustainable construction, collaborative working in construction, value management and partnering, prefabrication, modular integrated construction and off-site construction.

Please Cite As: Wuni, I.Y. and Shen, G.Q. (2019), “Towards a decision support for modular integrated construction: an integrative review of the primary decision-making actors”, International Journal of Construction Management, Taylor & Francis, Vol. Early Cite No. Early Cite, pp. 1–20.

Towards a Decision Support for Modular Integrated Construction: An Integrative Review of the Primary Decision-Making Factors

ABSTRACT:

Where circumstances merit and favourable conditions prevail, modular integrated construction (MiC) becomes a superior choice of construction method over the traditional approach. For many types of buildings, MiC is becoming a preferred alternative to traditional construction. However, the decision to use MiC must be made after critical analysis because several key factors and conditions need to converge to make MiC economical and feasible. As a result, this research conducted a systematic review of the determinant factors in deciding to use MiC in a project. The literature analysis identified 51 decision-making factors (DMFs) for implementing MiC. Of these, the top 5 most cited DMFs include availability of skilled and experienced factory labour force; availability of skilled management and supervising team; demanding and tight project schedule; transport infrastructure, size restrictions, and equipment availability; and need for improved construction safety. The study proposed a conceptual framework for the identified DMFs consisting of labour considerations; project characteristics; location and site attributes; and organizational factors. A stage-gate model is proposed to demonstrate the MiC implementation decision-making process. Thus, the paper contributes to a better theoretical and practical understanding of the primary DMFs for implementing MiC and will help to maximize benefits and minimize risk.

Keywords: decision support system; determinant factors; decision-making factors; modular integrated construction; review

Wordcount: 10,493 + Title + Abstract +Keywords

Introduction

Off-site construction (OSC) is a construction technique involving the planning, design, production, and assembly of building components at a location other than their final installed location to support the rapid and efficient construction of structures (Goodier and Gibb 2007). Modular integrated construction (MiC) is an innovative OSC method where building components are built in an assembly line in a factory, trucked to a job site in modules (sections), set in place with crane (s), and then joined together to form a complete building (Wuni et al. 2019a). MiC is the most complete form of OSC involving the greatest integration of factory-made value-added prefabricated prefinished volumetric modules (Pan and Hon 2018). Where circumstances merit and favourable conditions prevail, an effectively implemented MiC shortens construction time, reduces construction waste, reduces carbon emissions, improves and controls construction quality, improves working environment, reduces site labour requirement, improves productivity, and reduces whole life cost (McGraw Hill Construction 2013; McKinsey Global Institute 2017; Arcadis 2018; Construction Industry Council 2018).

For many types of buildings, MiC is increasingly becoming a preferred alternative to the traditional method in the construction industry (Hwang et al. 2018). However, one major challenge during the conceptual stage of a project is ascertaining the conditions and factors that make MiC the best choice in delivering value for money whiles meeting specific project objectives (Murtaza et al. 1993; Azhar et al. 2012). This is crucial because not all circumstances and conditions merit the implementation of MiC in a project (Song et al. 2005). For instance, the MiC technology offers profound improvements in construction projects with repetitive design such as student residences, estate apartments, hotels, prisons, and hospitals (Mao et al. 2016). MiC may also be a superior choice for projects in remote locations with harsh weather conditions and climate where construction labour with the requisite knowledge and skills is not readily available or just too expensive to warrant traditional construction (Rentschler et al. 2016). However, traditional construction may be the best choice for a project where there is the availability of skilled and experienced labour in a construction site which is considered routine.

Therefore, the decision to implement MiC in a project should be reached only after a systematic and critical analysis because several key factors and conditions need to converge to reap the full benefits of the MiC technology. Yet, the decision to implement MiC in a project in most cases is not well-informed and systematically guided. Meanwhile, the business model of

MiC encapsulates a complex combination of multidimensional knowledge requirements, systems, and process (Koskela and Ballard 2003). As such, there is always a risk that a wrong decision becomes a recipe for the poor performance of a project or its total failure (ibid). As a result, developers, construction clients, contractors, and engineers require detailed analyses of the determinant factors during the feasibility and economic analyses to ascertain the compatibility of the MiC with their projects, prior to making a final decision to use the approach in a project (Hwang et al. 2018). This is necessary and critical to the successful management of the early stages of the MiC project lifecycle because empirical evidence of project performance has consistently demonstrated that ultimate project success and failure start with the management decisions at the early part of the project lifecycle.

Meanwhile, decision-making in the context of the complex requirements and often competing project objectives during the conceptual stage of a project are possible and feasible with computer-aided decision support systems, tools, frameworks and expert systems (Murtaza et al. 1993; Hwang et al. 2018). For instance, knowledge-based decision support systems (KBDSS) are designed to allow practitioners to increase the planning rigor, stakeholder participation, and provide a sound basis for a structured decision making (Schwartz et al. 2018). KBDSS integrate, codify and transform specialist expertise and information into coherent frameworks and tools for structured decision making under complex environments (Sullivan 2002; Stoeckl et al. 2016). However, KBDSS require in-depth knowledge of the decision-making factors (DMFs). Although these DMFs are sensitive to project types, sites, objectives, and territories, many of the key decisions in MiC projects are similar in structure (Murtaza et al. 1993). As MiC has gained significant attention in the engineering, procurement, and construction (EPC) industries, a deeper knowledge and common framework of the DMFs for MiC decision support is imperative.

Despite their significance in improving the success of MiC projects, existing OSC reviews have seldom addressed the DMFs for MiC decision support. This research attempts to address the knowledge gap and contribute to the MiC implementation discourse through a systematic review of the DMFs for MiC decision support. Concomitant objectives of the review are: (i) to identify the DMFs for MiC decision support, (ii) to summarize, integrate and rank the DMFs for MiC decision support, and (iii) propose a conceptual framework of the DMFs in the implementation of MiC. The output of this research has useful theoretical and practical significance. Theoretically, this study constitutes the first exclusive review of the DMFs for MiC decision support in the literature and generates a useful checklist of the DMFs for MiC. Practically, the framework of the DMFs for MiC decision support will be beneficial to construction managers, engineering managers, operation managers, project control managers, construction site managers, project engineers, projects managers, clients and developers in determining when to use MiC in a project. The rest of paper is organized as follows. The next section offers a brief background to MiC, followed by a description of the research methods and approach adopted. The review findings are then presented and discussed and finally, conclusions and future research directions are provided.

Background and overview of modular integrated construction

MiC is an innovative construction method and a production process where free-standing prefabricated prefinished integrated modules, usually completed with finishes, fixtures, and fittings are manufactured in an assembly line in a factory, trucked to a job site in modules (sections), set in place with crane (s), and then joined together to form a complete building (Construction Industry Council 2018; Wuni et al. 2019a). The manufacturing and assembly of the building components occur in an accredited off-site fabrication factory in accordance with approved design codes and accredited fabrication method (Hwang et al. 2018). A module constitutes a building unit or component of the entire modular system (Gosling et al. 2016). A module refers to the independent building components having standardized interfaces with other parts of a building which can be integrated through the pre-planned interfaces (Baldwin and Clark 1997; Peltokorpi et al. 2018). The interfaces contain detailed preestablished engineering specifications of how to resolve potential conflicts between interacting modules (Baldwin and Clark 1997; Baldwin and Clark 2000). Essentially, modules are the basic building blocks of an MiC project which are designed to be structurally independent of one another but still function together as an integrated whole (Baldwin and Clark 2000; Gosling et al. 2016).

MiC incorporates the concepts of modularity and modularization into the building construction process. Bohn (2016) described modularity as the degree to which discrete, standardized components of a whole system can be assembled in different configurations to offer diverse options and flexibility in the final product. Modularity is an engineering concept which describes the extent to which modules can be fabricated independently, mixed and matched variously to offer flexibility and diversity of uses (Baldwin and Clark 1997). On the other hand, modularization refers to the systematic disintegration of a complex system (building) into discrete components (modules) which interact with each through standardized interfaces, rules, and specification (Gosling et al. 2016). According to Gibb (2001), the varying degrees of modularization in MiC include component manufacture and subassembly, non-volumetric preassembly, volumetric preassembly, and completely assembled modular building. MiC is considered the highest order of prefabrication and the most complete form of OSC involving the greatest integration of value-added factory-made prefabricated prefinished volumetric modules (Pan and Hon 2018).

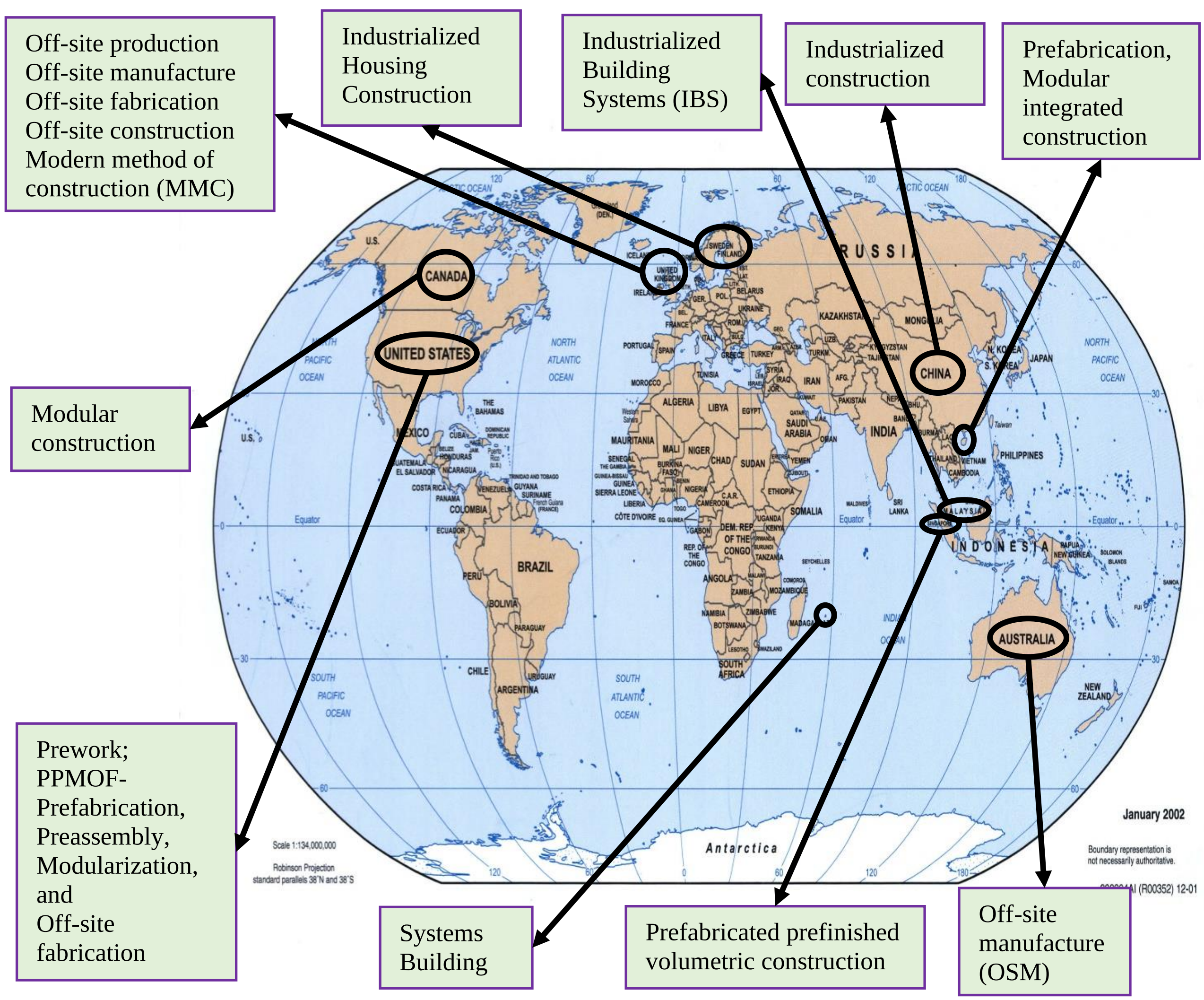

Figure 1. World map of the off-site construction techniques

MiC shares many similarities with other OSC techniques such as prefabricated prefinished volumetric construction, industrialized building systems, modular construction, and prework. Figure 1 shows a geospatial map of the OSC techniques. The general schedule of the MiC approach comprises project design, permits, and statutory approval, production of modules, transportation of modules to site, on-site installation of modules and site restoration (Modular Building Institute 2017; Construction Industry Council 2018). Figure 2 shows the major stages in the modular integrated construction process. The three main forms of MiC include reinforced concrete modules, steel frame modules, and hybrid modules.

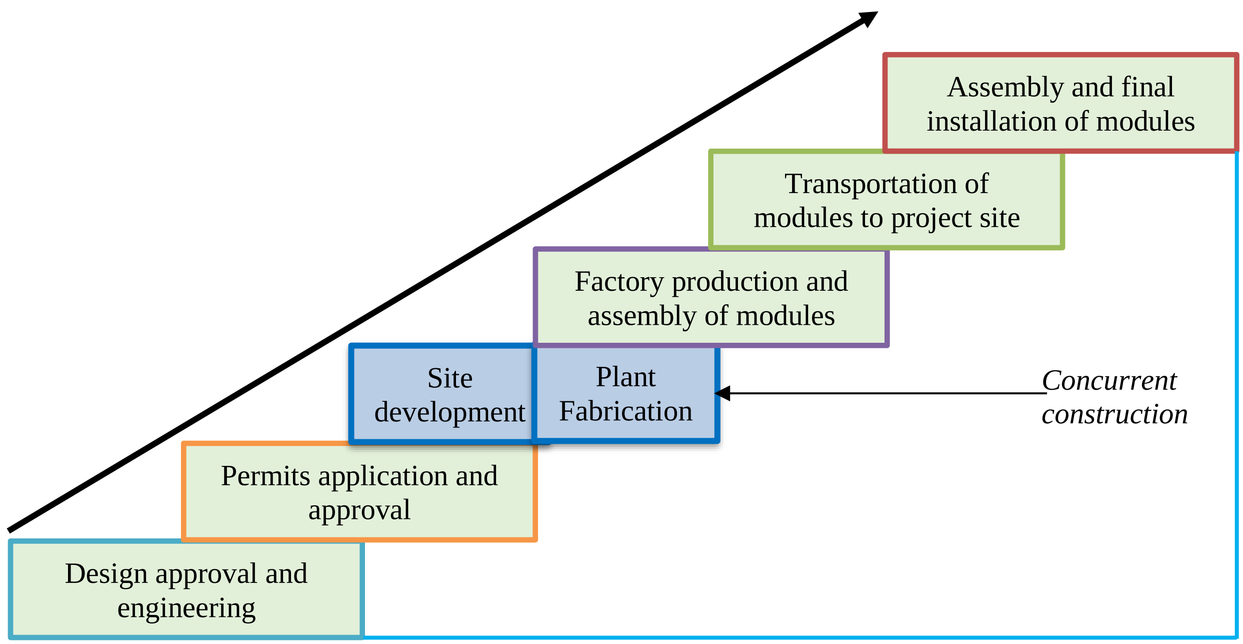

Figure 2. Stages of the modular integrated construction process

MiC is an example of the Design for Manufacture and Assembly (DfMA) philosophy; a design approach that focuses on the ease of fabrication and efficiency of modular assembly (Construction Industry Council 2018). DfMA combines the methodologies of both Design for Manufacture (DfM) and Design for Assembly (DfA). The former involves designing for the ease of fabricating modular components and concerned with the selection of the most cost-effective materials and processes to be used in minimizing the complexity of modular production operations whereas the latter involves designing the modules for ease of assembly and concerned with minimizing modular assembly cost and the number of assembly operations. DfMA operates on the principle that if the design of the modules can be simplified, then it is possible to efficiently manufacture and assemble the modular components within schedule and at a lower cost. Thus, DfMA offers the merit of speed, lower assembly cost, higher quality, shorter assembly time, increased reliability and safety in MiC projects.

Unlike the strict linear sequence of design, engineering, and construction associated with the stick-built construction approach, MiC tolerates the concurrent execution of construction trades (Peltokorpi et al. 2018). As such, it reduces the construction duration and improves productivity (McKinsey Global Institute 2017). However, the smooth implementation of MiC requires extensive coordination of the MiC supply chain and involved stakeholders, prior to and during the construction process (Hwang et al. 2018). Several factors and conditions are relevant to the successful implementation of MiC. Accuracy of the modular design and timely design freeze is required prior to the fabrication of modules (Gibb and Isack 2003). Considering that the modules are often designed to be used in a specific project and usually made-to-order, scheduling must be configured to ensure that the optimum quantity of each module is produced to avoid wastage following completion of the project (Hsu et al. 2018). Success of MiC projects also depends on good working collaboration, effective communication, and information sharing among MiC project participants (Haas and Fagerlund 2002; Li et al. 2018). These unique considerations and processes require effective decision making during the conceptual stage of a project, reinforcing the need for this study.

Research methods and approach

Research design adopted

The primary aim of the study is to identify, appraise, and summarize the relevant decision-making factors (DMFs) required to develop decision support for MiC. This involves the analysis of relevant qualitative and quantitative studies with diverse theoretical and methodological underpinnings (Whittemore and Knafl 2005). To achieve this, the study adopted an integrative systematic review design which offers a framework for synthesizing and drawing conclusions from past studies with diverse research designs (Whittemore and Knafl 2005; Torraco 2016). The research design also provides a framework for identifying important issues that research has left unresolved. Although previous reviews (Wuni et al. 2019a; Wuni and Shen 2019) have used meta-synthesis and systematic reviews to integrate qualitative and quantitative findings, such designs are best used for either synthesizing solely quantitative or quantitative studies (Webster and Watson 2002). Particularly, an integrative review constitutes a systematic review methodology deployed when meta-analysis and traditional systematic reviews are inappropriate to address a given research problem (Whittemore and Knafl 2005; de Souza et al. 2010). According to de Souza et al. (2010), integrative review is a systematic review design which emerged to address the illegitimacy of drawing conclusions from studies with diverse research designs and methods. As such, this study adopted integrative review as the research design based on a five-stage systematic review process comprising research protocol development, database selection, literature search, study selection, and data extraction, synthesis, and presentation.

Database selection and literature search strategy

A rigorous and comprehensive systematic review study must draw on the findings from a substantial number of past research, which is often facilitated through searching multiple literature databases (Baker 2016). Some of the powerful construction engineering and management (CEM) literature databases, search engines, and libraries include Scopus, Google Scholar, Web of Science, Engineering Village, Science Direct, ASCE library, Taylor and Francis, and Emerald Insight (Wuni et al. 2019a; Wuni and Shen 2019). However, Wuni et al. (2019b) noted that the same research articles are often contemporaneously indexed in these literature databases. Thus, it is imperative to select the appropriate databases which could offer a wider retrieval of the relevant literature and allows for repeatability. Preliminary searches in the databases using the keywords "off-site construction" OR "modular construction" highlighted the superior performance of Scopus and Web of Science. As a result, these two were relied upon in the literature search process. Prior to the actual search, the researchers specified the relevant keywords (which were refined throughout the study period) for the literature retrieval. Using the representative and adequate keywords in the search protocol is crucial because the abstraction and indexing process of each literature database relies on these keywords (Whitehead 2013). Two sets of keywords were defined to retrieve studies addressing the DMFs in the context of MiC. Drawing on the precedents of Wuni et al. (2019a), the full search algorithm was developed as:

TITLE-ABS-KEY (decision OR "decision support" OR choice OR selection OR comparative OR comparison OR determin OR drivers OR "success factors" OR "critical factors" OR "few key areas" OR "key result areas" OR reasons) AND TITLE-ABS-KEY ("offsite construction" OR "off-site construction" OR "offsite production" OR "off-site production" OR "off-site* *manufacturing" OR prefabrication OR prefabricated OR pre-fabricated OR "off-site fabrication" OR "industrialized building" OR "modular construction" OR "modular integrated construction" OR "modern method of construction" OR "prefabricated prefinished volumetric construction" OR "industrialized construction" OR "Industrialized housing") AND LIMIT-TO (DOCTYPE , "ar") AND LANGUAGE (“English”).*

This search algorithm was saved and re-executed in both Scopus and Web of Science during the beginning, middle and prior to submission. To restrict the retrieved studies to publications most relevant to the research topic, several search filters were used. This was necessary considering the large corpus of research literature on OSC and MiC. In the search algorithm, the Boolean concatenator “AND” filtered published documents containing at least a keyword from each of the two sets of keywords. The algorithm also filtered publications in the *English* language only and mainly *journal articles* “ar”. The search was repeated immediately prior to submission to retrieve recently indexed studies. The last search was conducted on 27th June 2019. The researchers conducted a rapid screening of the titles and abstracts of the retrieved studies for their relevance. The relevant documents were download and given a full-text evaluation for eligibility. The researchers also deployed the snowballing search strategy to retrieve other relevant studies outside the catchment of the specified keywords. To achieve this, citations (citing articles) and references (cited articles) of the shortlisted algorithm-driven retrieved publications were searched for further relevant studies using ISI Web of Science and Scopus search engine.

Study inclusion and exclusion criteria

Following the rapid screening of the titles and abstracts of the downloaded articles, duplicates were removed, and the articles were given a full-text evaluation. Although the rapid screening was the first attempt at including and excluding some studies from the review, such a cursory approach was not adequate to justify final inclusion and exclusion (Wuni et al. 2019a). During the full-text evaluation, the authors included studies which met the following criteria: (i) journal and conference papers based on empirical studies on the DMFs for an MiC decision support system and (ii) published in a peer-reviewed journal or top-rated conference proceeding. As such, the study excluded monographs, review articles, conference reviews, short surveys, conceptual papers, discussions, and unpublished/grey literature. These were excluded because they do not receive rigorous peer-review prior to publications. Figure 3 shows the articles selection process.

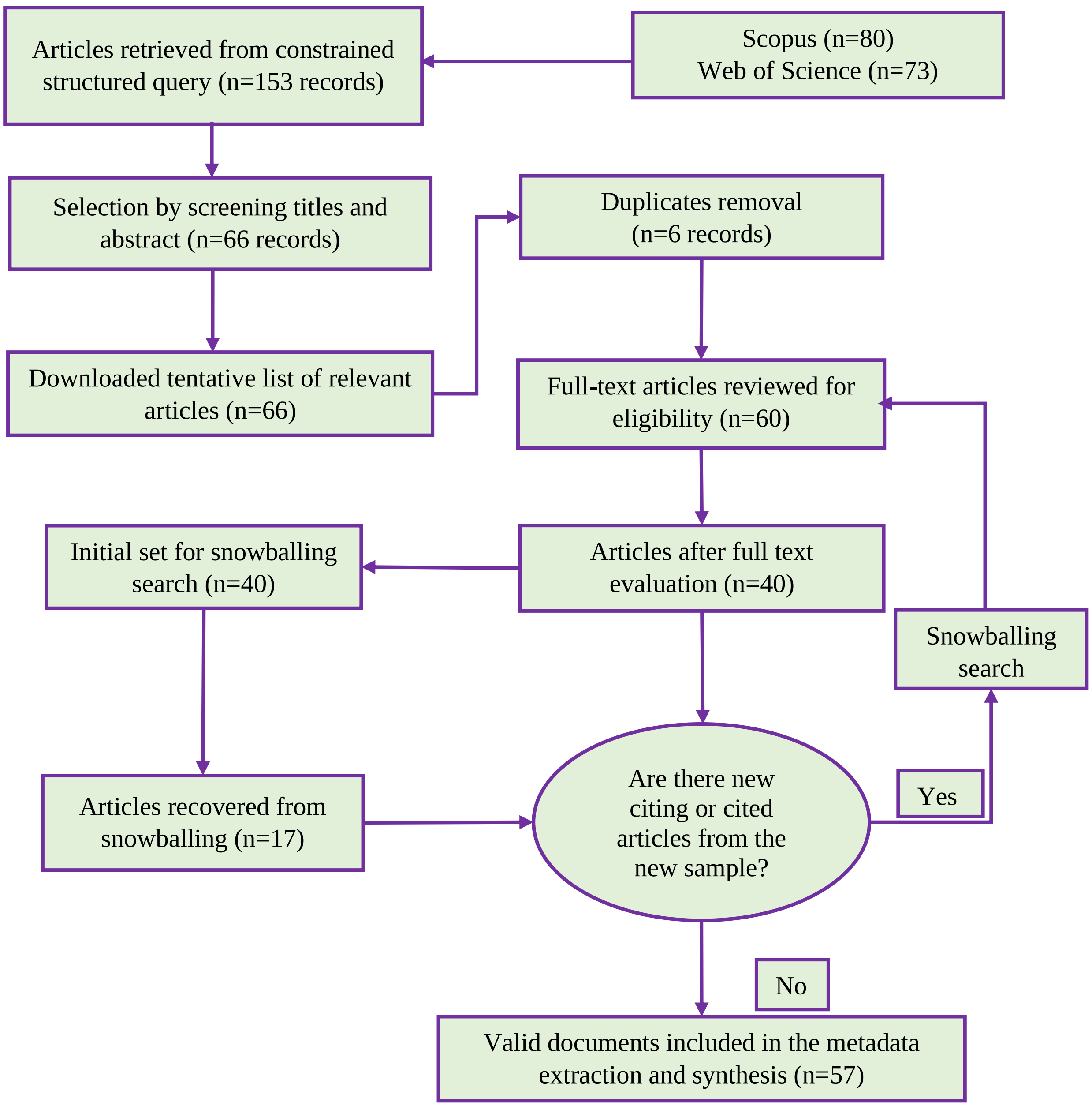

Figure 3. flowchart of systematic literature search and article selection protocol

The authors further conducted a general Google search to identify relevant industry reports and Ph.D. theses which addressed the determinant factors in deciding to use MiC. Table 1 shows a bibliographic summary and reference numbers of the included studies.

Table 1. Bibliographic summary and reference numbers of the included studies.

Ref#	Citing source	Ref#	Citing source
1	Construction Industry Institute (1992)	30	Elnaas (2014)
2	Murtaza et al. (1993)	31	Mostafa et al. (2018a)
3	Mao et al. (2014)	32	Hwang et al. (2018)
4	Liu et al. (2017)	33	Haas and Fagerlund (2002)
5	Wong et al. (2017)	34	Song et al. (2005)
6	Clement (1989)	35	Blismas et al. (2005)
7	Murtaza and Fisher (1994)	36	Koskela and Ballard (2003)
8	Polat (2008)	37	Blismas (2007)
9	Azhar et al. (2012)	38	Scofield et al. (2009a)
10	Azhar et al. (2013)	39	Pan et al. (2012)
11	Azman et al. (2013)	40	Bohn (2016)
12	Elnaas et al. (2013)	41	Rentschler et al. (2016)
13	Gibb and Isack (2003)	42	Choi et al. (2019a)
14	Hjort et al. (2014)	43	Fenner et al. (2017)
15	Choi (2014)	44	Choi et al. (2019b)
16	Carriker and Langar (2014)	45	Scofield et al. (2009b)
17	Fraser et al. (2015)	46	Gibb (1999)
18	Choi et al. (2016)	47	Pan and Sidwell (2011)
19	Lee and Kim (2017)	48	Zakaria et al. (2018)
20	Elnaas et al. (2018)	49	Mostafa et al. (2018)
21	Gao et al. (2018)	50	Triumph Modular Corporation (2019)
22	Peltokorpi et al. (2018)	51	Lessing and Brege (2017)
23	Sharafi et al. (2018)	52	Lau (2011)
24	Pan et al. (2007)	53	Wong et al. (2018)
25	Pan et al. (2008)	54	McGraw Hill Construction (2011)
26	Tam et al. (2007)	55	Bataglin et al. (2017)
27	Chen et al. (2010)	56	Hammad et al. (2019)
28	Rahman (2014)	57	Pan and Hon (2018)
29	Zhai et al. (2014)		

Literature analysis

A pre-defined data extraction sheet was developed to record the metadata of each article. The extraction sheet contained the independent data to be extracted from each article. The sheet contained sections for the year of publication, journal or conference of publication, country of study, survey instrument, reported DMFs, and target project. Discrepancies or missing data were discussed between the authors and resolved. Based on the recommendations of Webster & Watson (2002), the authors developed an Excel sheet known as concept matrix augmented with units of analysis to organize the DMFs. Each DMF constituted the primary unit of analysis in the study. Thus, the concept matrix recorded each reported DMF against the citing article. In this way, the number of times each DMF was cited in the literature was computed and formed the basis for ranking the DMFs. The resulting data were analysed in two sections. Tables and charts were used to report preliminary data such as the bibliographic summary of the included studies, geospatial distribution of the studies, and target projects. Frequency ranking was used to ascertain the critical DMFs in the literature. A conceptual framework was developed to organize and cluster the DMFs in the adoption of MiC and stage-gate model was finally proposed to demonstrate the decision-making process in MiC implementation.

Review findings, analysis, and discussions

Overview of the reviewed published studies

It is necessary to describe the characteristics and distributions of the included studies in a systematic review to highlight their quality, representativeness and relevance (Wuni et al. 2019a; Wuni and Shen 2019). The study synthesized findings from fifty-seven (57) empirical studies on the determinant factors in deciding to use MiC in a project. These studies comprised research articles (68.4%), conference papers (10.5%), industry reports (14.0%), Ph.D. Theses (5.3%) and a book (1.8%) (See Figure 4).

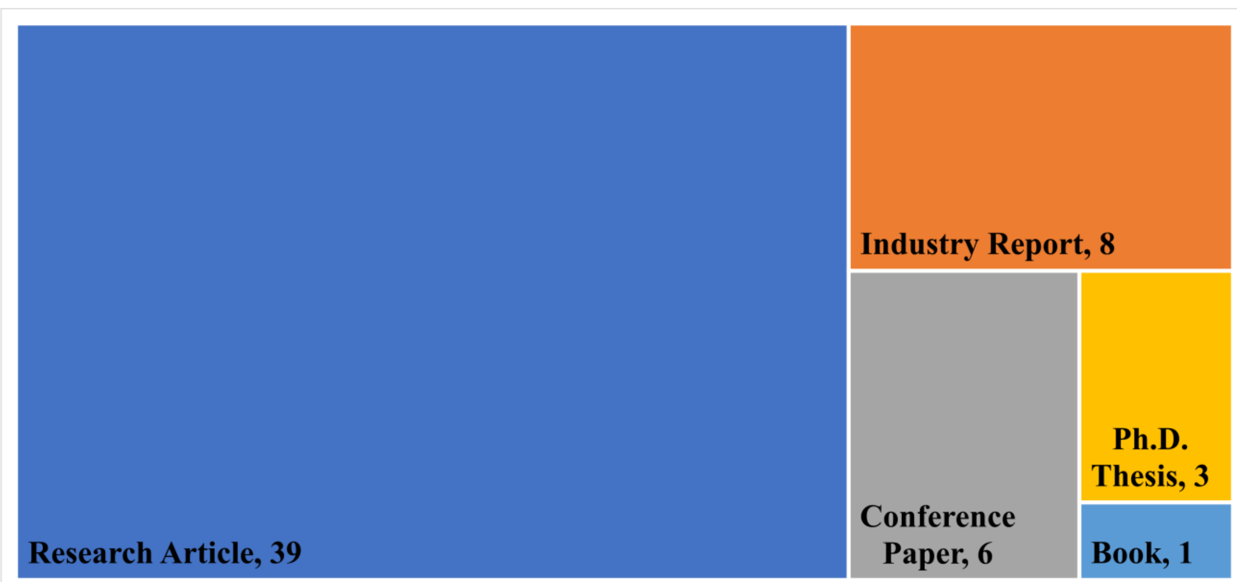

Figure 4. Distribution of the document types reviewed in the study

Although previous review studies have relied on mainly research articles (Wuni et al. 2019a), this study included several other document types to capture the DMFs from a diverse perspective. It is recognized that industry reports most often lack methodological rigor, but such industrial findings tend to offer more practical indications than most academic research articles. Additionally, considering that this study constitutes a scoping review, the sample size (57) compares favourably against samples in previous review studies (Wuni et al. 2019a; Wuni and Shen 2019). The inclusion of diverse documents could only compromise the cited ranking of the DMFs but will provide a more comprehensive set of the determinant factors in deciding to use MiC in a project.

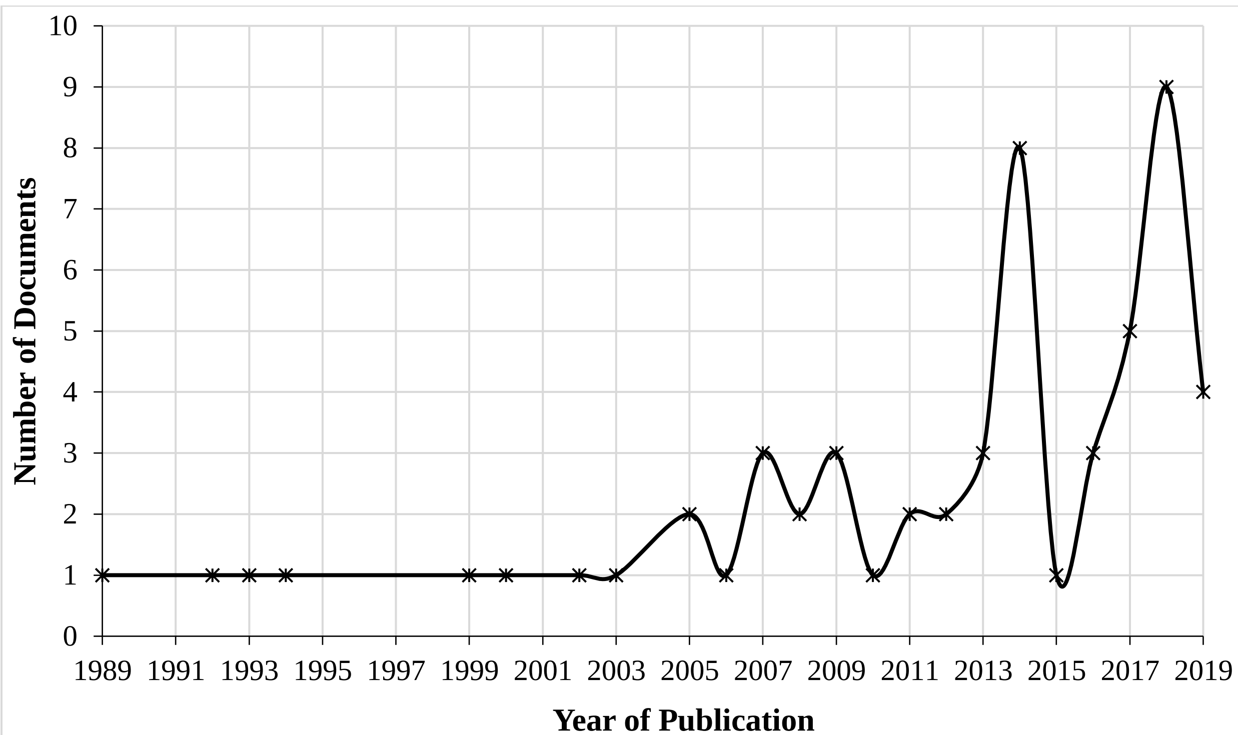

Figure 5. Annual publications trend on DMFs for MiC in a Project

The reviewed studies covered three decades spanning from 1989 to 2019. Figure 5 shows the annual publications trends on the DMFs. This year ranged covered the last decade of the 20th century and the first two decades of the 21st century; the periods which marked a significant renaissance of the offsite construction revolution (Gibb 1999; Wuni and Shen 2019). Thus, the findings of the study provide a longitudinal perspective of the earliest and most recent determinant factors in deciding to use MiC in a project which reflects the core tenets of an integrative systematic review (Whittemore and Knafl 2005; de Souza et al. 2010). From Figure 5, the first 1 decade (1989-1999) recorded an annual publication average of 1 article. This was expected because the same period marked the early renaissance of the MiC technique. During this time, researchers focused more on the drivers, benefits, and barriers to the adoption of the approach (Gibb and Isack 2001; Blismas et al. 2006; Polat 2008) in an attempt to promote the technique. The last decade (2009-2019) witnessed increased research attention on the determinant factors in deciding to use MiC in a project.

Table 2. Distribution of the included studies based on publication outlets

Journal/Conference	**No. of Documents (n=57)**
Journal of Construction Engineering and Management	7
International Journal of Construction Management	4
Journal of Management in Engineering	4
Architectural Engineering and Design Management	3
Construction Management and Economics	3
Automation in Construction	2
Building Research and Information	2
Journal of Architectural Engineering	2
Building and Environment	1
Chemical Engineering	1
Construction Innovation	1
Hydrocarbon Processing	1
International Journal of Construction Education and Research	1
Journal of Civil Engineering and Management	1
Journal of Cleaner Production	1
Journal of Computing in Civil Engineering	1
Journal of Engineering and Technology Management	1
Journal of Engineering, Project, and Production Management	1
KSCE Journal of Civil Engineering	1
Pharmaceutical Technology	1
Annual Conference of Associated Schools of Construction	2
CIB International Conference on Construction	1
Annual Conference of the International Group for Lean Construction	1
Annual ARCOM Conference	1
State-of-the-Art of Modular Construction Symposium	1
Books, Industry Reports and Theses	12

Although a sinusoidal annual pattern is observed during the period 2003 to 2019, Figure 5 shows that the last decade witnessed increased commitment from stakeholders and researchers in understanding the factors and conditions favouring the adoption of MiC. This trend renders the current study relevant because it is timely and will contribute to the effective understanding of the DMFs in deciding to implement MiC in a project. Given the dynamic construction environment and the introduction of new technologies, the DMFs in the adoption of MiC may have increased and changed within the year range (Haas and Fagerlund 2002). As such, the identified DMFs offer holistic framework of the determinant factors which are useful in evaluating the suitability of MiC and the final decision to implement the approach on a project.

The included studies were also published in high-impact CEM journals and conference proceedings (See Table 2). The reviewed documents are published in 19 journals, 4 high-rated construction management conference proceedings, and some industry websites. Furthermore, preponderances of the articles were published in reputable CEM research outlets such as *Journal of Construction Engineering and Management* (7), *Journal of Management in Engineering* (4), *International Journal of Construction Management (4), Architectural Engineering and Design Management* (3), *Construction Management and Economics* (3), *Automation in Construction* (2), *Building Research and Information* (2), and *Journal of Architectural Engineering* (2). Published articles from these influential journals collectively represented 27 (47.4%) of the included studies. Thus, high-quality articles were included in the literature analysis. The rest of the journals contributed 1 article each and contributed 12 (21.1%) of the included studies. Figure 6 shows the territorial distribution of the included studies.

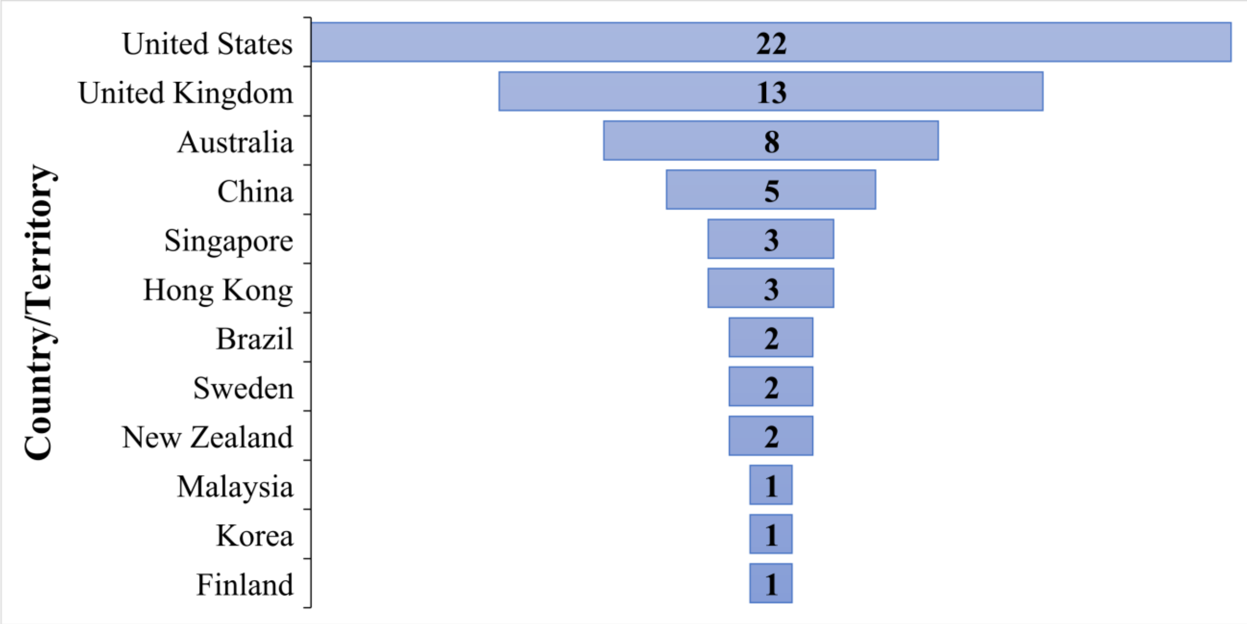

Figure 6. Geospatial distribution of the included studies

Figure 6 indicates that the reviewed studies were conducted in the context of 12 countries distributed across Europe (e.g. the United Kingdom), North America (e.g. the United States), South America (e.g. Brazil), Asia (e.g. China) and Australia. The top 5 most contributing countries included the United States (38.6%), United Kingdom (22.8%), Australia (14.0%), China (8.8%), Singapore (5.3%) and Hong Kong (5.3%). These countries constitute a major proportion of the regions with advanced levels of MiC adoption and implementation. On continental basis, the adumbrated five continents are at the tipping point of the MiC implementation and thus, the sample size may be representative of the global perspective. The absence of studies from Africa is quite justifiable because countries in the continent are still considering the adoption of MiC and the few available studies are focused on barriers, drivers, opportunities, and benefits of its adoption.

Finally, the included studies deployed six research instruments to collect data on the determinant factors in deciding to use MiC in a project (See Figure 7). It should be reiterated that some studies used mixed approaches involving a combination of two or three of the instruments, but the authors counted the number of times each instrument was used. Consequently, the total percentage of all the instruments exceeds 100%. As shown in Figure 7, the three most used instruments included case studies (52.6%), questionnaires (50.9%), and interviews (33.3%).

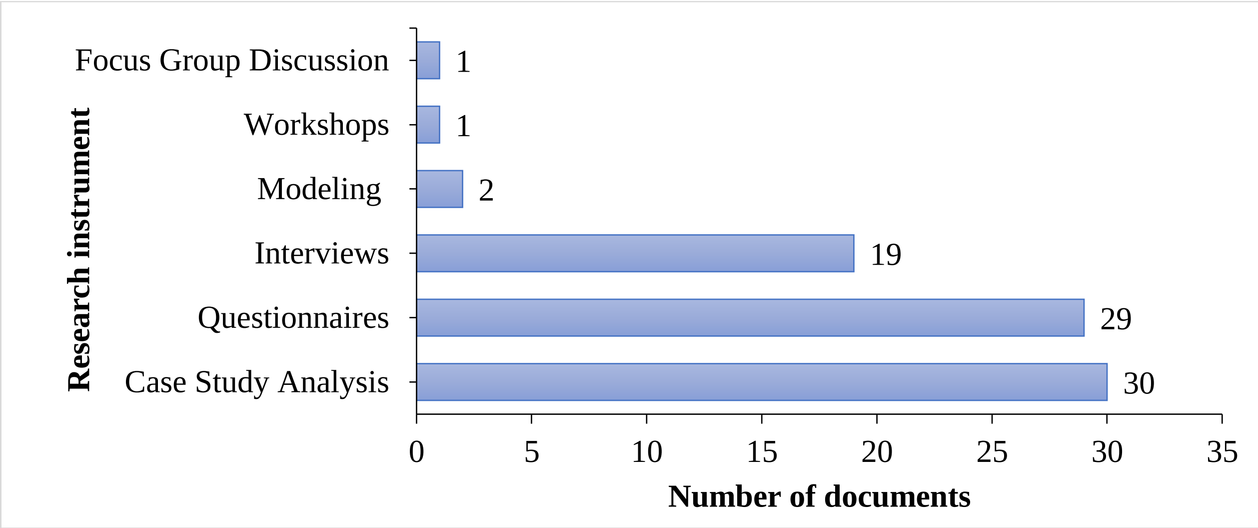

Figure 7. Frequency distribution of the research instruments used in previous studies

Although questionnaires and interviews have been widely censured for their subjectivity and data quality issues, their prominence in the previous studies is justifiable because the decision to adopt MiC in a project cannot be modelled or simulated without collecting the information from project participants, industry players, experts, and stakeholders. Thus, using these instruments to collect data on DMFs is appropriate. Moreover, the dominance of case study analysis as a data collection instrument in previous studies is impressive because the DMFs are sensitive to project type, size, location, and other characteristics. Thus, case studies offer a framework for a more detailed assessment of the DMFs within a specific project and has been widely used to collect in-depth information on a project in CEM studies (Wuni et al. 2019a; Wuni and Shen 2019). As such, the research instruments used in previous studies to collect data on the DMFs for MiC implementation decision-making are relevant and appropriate. Therefore, relevant and high-quality studies have been investigated in the current research.

Target project types for MiC implementation decision-making in previous studies

It is useful to highlight the project types for which the DMFs were extracted. This provides useful insight into the types of projects that have been involved in successful MiC implementation in previous studies. The authors extracted the project types which were used as case studies in identifying the key DMFs in MiC implementation. Figure 8 shows a distribution of twenty-eight project types which were used as case studies in previous studies and highlights that majority of project applications of MiC focused on residential projects (14), industrial projects (9), petrochemical or power plant (6), schools (5) and industrial process plants (4).

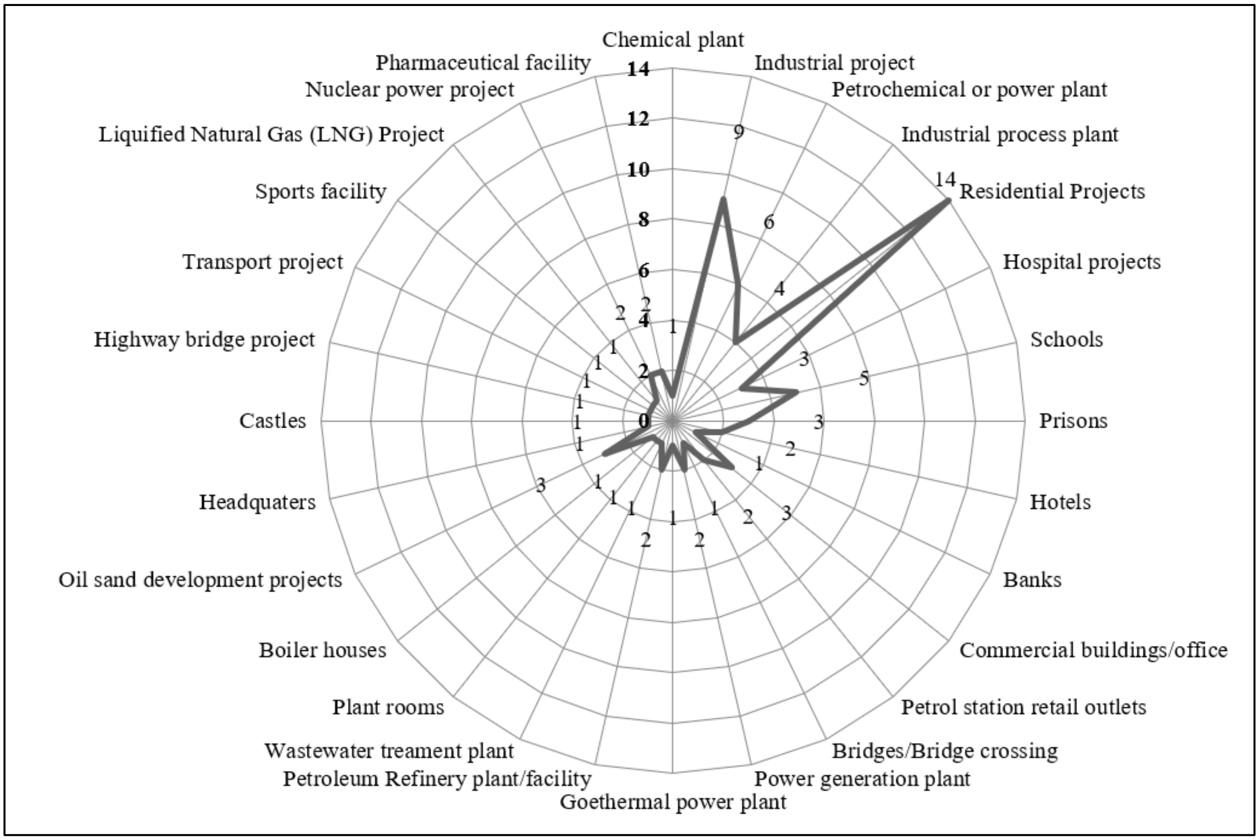

Figure 8. Distribution of the target MiC projects in previous studies

The higher frequency of deciding to use MiC in residential projects may be due to the rising global transition towards using MiC to address housing shortfalls and crises (Pan et al. 2007; Pan et al. 2012). Moreover, the need to use modular solutions in industrial projects dominated the agenda in the MiC renaissance in North America during the last decade of the 20th century (Clement 1989; Construction Industry Institute 1992; Murtaza et al. 1993; Murtaza and Fisher 1994) and may have accounted for the higher frequency of industrial projects involved in the MiC implementation decision-making. Furthermore, the use of MiC to develop school buildings have greater prominence in the literature because of the ability to construct buildings with less disruptions to academic activities (Peltokorpi et al. 2018). From Figure 8, several project types have been involved in the MiC implementation decision-making in previous studies and thus, the framework of the DMFs in this study represent the primary determinant factors in the decision to use MiC in these disparate project types. Therefore, the set of DMFs reported in the current study may serve as a useful reference in deciding to implement MiC solutions to any of the above project types.

Analysis and ranking of the DMFs in the adoption of MiC

The determinant factors in the decision to use MiC in a project were extracted from 57 research studies. A bibliographic summary of these studies and their corresponding reference numbers are presented in Table 1. Analysis of these studies resulted in the extraction of 51 DMFs for 28 project types (see Figure 8). A summary of these DMFs, their citing sources, frequency, and rankings are presented in Table 3. The various studies which cited each DMF are identified as the citing sources; the references and corresponding bibliographic information of which can be found in Table 1. The freq. in Table 3 is a measure of the cumulative number of studies which have cited a DMF and have been used to rank the identified DMFs. This indicator-based ranking approach has been implemented in published review studies (Wuni et al. 2019a).

Table 3 shows that several determinant factors need to be considered in deciding to use MiC in a project, but analysis reveals that the ten most reported DMFs which are shared among MiC projects and territories during the studied period were: (i) *availability and accessibility of skilled and experienced factory labour force*; (ii) *availability of skilled management and supervising team*; (iii) *demanding and tight project schedule*; (iv) *transport infrastructure, size restrictions, and equipment availability*; (v) *need for improved construction safety*; (vi) *strict requirement for project quality control*; (vii) *stringent project cost and strict requirement for certainty*; (viii) *availability of skilled onsite labour*; (ix) *reduced environmental impact and sustainability requirements*; and (x) *overall cost control requirement*. Due to space constraints, the first five of these DMFs are discussed below. It should be immediately indicated that the remaining DMFs are also relevant and critical depending on the project type, site, and territory. Indeed, there are some conditions in Table 3 which are not within the first ten DMFs, but for which the decision to use MiC may be highly recommended. For instance, MiC may be the best choice for projects in remote and difficult locations under harsh weather conditions and climates (Clement 1989; Construction Industry Institute 1992; Murtaza et al. 1993; Haas and Fagerlund 2002; Song et al. 2005). Moreover, MiC is highly recommended for projects with repetitive design layout (Hwang et al. 2018); when there is the need to reduce neighbourhood and business disruption during construction (Murtaza et al. 1993; Gibb 1999; Pan et al. 2007; Hwang et al. 2018) and when clients and developers propose projects with very tight schedules (Construction Industry Institute 1992; Haas and Fagerlund 2002; Rentschler et al. 2016).

Availability and accessibility of skilled and experienced factory labour force

This factor was reported in 31 of the 57 studies as a primary determinant factor in the decision to implement MiC and ranked 1st among the 51 DMFs. While this factor might not be a critical consideration in territories with developed MiC supply chain with well-established modules manufacturers and suppliers, it is a primary factor to consider because the factory-produced modules are essentially the key driver of the MiC project (Construction Industry Institute 1992; Haas and Fagerlund 2002). The production of the modules in factory environment allows for quality control and improved productivity but these are linked to the skills and attitude of the factory labour force (Egan 1998; Fraser et al. 2015). The factory labour force is required to have effective skills in production engineering, process efficiency, work area control and mechanical equipment handling (Fraser et al. 2015). Management needs to also consider whether the labour force has the ability to assemble the factory-made components, handle large building services, use the production raw materials and systems (Fraser et al. 2015). These should be given due consideration because the skills and experience of the factory labour force has implications on the quality of the modules which further have implications on the quality and performance of the overall MiC project.

Table 3. Determinant factors in the decision to implement MiC in a project

S.N.	Decision-making factor (DMF)	Citing sources (Ref#)	Freq	Rank
1	Availability and accessibility of skilled and experienced factory labour force	[1–31]	31	1
2	Availability of skilled management and supervising team	[1–5,7,8,11–14,17,19–34]	28	2
3	Demanding and tight project schedule and need for expedition	[1,2,5,7,9,10,13–18,21,22,27,30,33–42]	26	3
4	Transport infrastructure, size restrictions, and equipment availability	[1,2,7–9,11,14–18,21,24,26,29,32–35,43,44]	21	4
5	Need for improved construction safety	[1,2,25,26,28,31,32,34,37,39,44,45,5,46,7,12,15,18,20,23,24]	21	4
6	Strict requirement for project quality control	[1,2,5,7,12,13,15,18,20–22,28,31,33,35,38,39,41,42,45]	20	6
7	Stringent project cost and strict requirement for certainty	[2,3,7,13,15,18–21,24,26,28,30,31,34,35,41,42,47]	19	7
8	Availability of skilled onsite labour	[1–5,7,9,10,13–15,18,24,26,28,29,31,34]	18	8
9	Reduced environmental impact and sustainability requirements	[2,4,5,7,9,15,18,20,21,23,24,26,31,32,34,39,41,45]	18	8
10	Overall cost control requirement	[2,3,7,13,15,18–21,24,26,28,30,31,34,35,41,47]	18	8
11	Certainty of project completion date	[2,5,7,13,15,18,20,24,26,30,31,35,37,39,40,45,46]	17	11

12	Labour cost at site location	[1,3–5,13,15,18,19,24,26,28,29,31,33,46,47]	16	12
13	Availability of key MiC project team members in the earliest stages of the project	[7,9,10,14–19,21,33,34,37,42,48,49]	16	12
14	Remote and difficult site location	[2,7,16,20,24,26,29–32,38,40,41,46]	14	14
15	Need to reduce neighbourhood and business disruption and noise during construction	[2,4,5,7,15,17,18,24,26,31,32,37,40,46]	14	14
16	Labour and plant cost on site	[2,3,7,13,19,20,27,28,30,31,35,47]	12	16
17	High standard quality of both internal and external finishes	[2,5,13,24,26,28,31,35,38,39,45,46]	12	16
18	Project and contract type	[14,16,17,21,33,34,37,39,41,43,48,50]	12	16
19	Site accessibility	[6,9,10,15–18,24,26,27,35]	11	19
20	Owner's understanding, receptivity and acceptance of MiC	[2,7,9,10,14–16,18,21,51,52]	11	19
21	Site condition, constraints and attributes	[9–11,15,17,18,21,33,34,38,48]	11	19
22	Organizational readiness and familiarity with MiC	[1–4,7,9,10,14,21,32,53]	11	19
23	Overall project timescale	[2,5,7,13,20,27,28,30,31,35]	10	23
24	Need to minimize field construction cost	[9,11,12,20,22,33,34,39,41]	9	24
25	Presence of repetitive layout design and construction	[9,10,23,27,29,32,33,41,54]	9	24
26	Availability of manufacturing facility within economical transport distance	[2,3,7,8,20,24,26,30,31]	9	24
27	Early upfront support and involvement of top management	[1–4,7,9,10,16,52]	9	24
28	Severe local area condition, harsh weather and climate	[1,2,6,7,23,33,34,38,41]	9	24
29	Suitability of design for MiC	[9,10,15,16,18,27,29,32]	8	29
30	Construction equipment quality and availability	[1,2,7,24,26,29,32,35]	8	29
31	Availability and capacity of modules fabricator and suppliers	[2,7,11,15,17,18,33,34]	8	29
32	Reducing traffic movement	[2,4,5,7,20,24,26,31]	8	29
33	Availability and use of relevant information and communication technology (e.g. BIM)	[10,21,28,32,49,51,55,56]	8	29
34	Need to minimize field construction time	[14,23,32,38,40,41,46]	7	34
35	Need for inspection and supervision of modules	[2,7,10,17,23,30,32]	7	34
36	Structural stability of individual and assembled modules	[2,7,9,10,16,30,32]	7	34
37	Favourable local codes, building standards and zoning regulations	[9–11,15,18,21,39]	7	34
38	Business needs, owner requirement, and regulatory demand	[9,14,16,25,33,40,53]	7	34
39	Types and sizes of modules	[1,2,7,30,32,41]	6	39
40	Detailed and defined project scope, and budget parameters	[9,16,33,40,41,43]	6	39
41	Available of adequate lead time for modules manufacture	[2,7,10,30,32]	5	41
42	Size and type of project	[1,28,31,32,40]	5	41

43	Available of local modular design codes and specifications	[9,10,15,21,39]	5	41
44	Capability of local MiC supply chain	[11,16,17,57]	4	44
45	Complexity of project design	[9,10,12,23]	4	44
46	Project risk profile	[9,10,15,41]	4	44
47	Site layout (e.g. availability of space to unload and store modules	[2,7,32]	3	47
48	Detailed design	[15,18,52]	3	47
49	Building height (number of stories)	[32,54]	2	49
50	Module import restriction	[2,7]	2	49
51	Communication and collaborative culture	[14,48]	2	49

Availability of skilled management and supervising team

This factor was cited in 28 of the 57 studies as a critical determinant factor in deciding to use MiC and ranked 2nd among the 51 DMFs. This DMF is shared among all project types and territories because the management and supervision requirement of MiC projects demand more bespoke skills than those of the traditional construction method. The success of the MiC project largely depends on the effective management and supervision of the entire MiC process. It requires extensive coordination of the various activities, processes, and the complex web of stakeholders associated with the MiC supply chain (Haas and Fagerlund 2002; Hwang et al. 2018). Thus, the management and supervising team (MST) must be multiskilled to be able to deliver the best from the MiC project (Construction Industry Institute 1992; Egan 1998; Gibb 1999). Typically, the MST must have knowledge of the entire MiC process and skills in logistical and materials handling, supply chain coordination and management, project integration, DfMA, MiC preconstruction planning and preparation, production lead times, and possess greater technical skills in large building services installations and handling (Fraser et al. 2015). These capabilities are necessary because the MST would have to manage and supervise these activities and processes throughout the MiC process (Fraser et al. 2015; Rentschler et al. 2016). This DMF must be carefully considered in the decision-making process because the success of MiC entire depends on detailed design, effective planning, and a knowledge of the MiC supply chain capabilities which are intertwined and linked with management.

Demanding and tight project schedule and need for expediting schedules

This factor has been cited in 26 studies and ranked 3rd among the 51 identified DMFs in previous studies. The chief benefit of MiC is reduced construction time (Blismas et al. 2006; Pan et al. 2007). Therefore, projects that come with tight and demanding schedules justifies the need for

MiC. Experience has shown that MiC could result in a 50 – 70% reduction in the traditional construction schedules (Construction Industry Institute 1992). The concurrent continuity of on-site and off-site activities results in reduced construction time. Additionally, the factory-based quality control of the modules through mock-up testing/prototyping, trial assembly and stacking of modules results in lower defects during installation which reduces site-fit reworks and saves time (Construction Industry Council 2018). Thus, MiC is a superior choice for project with tight schedules.

Transport infrastructure, size restrictions, and equipment availability

This factor was cited in 21 studies and ranked 4th among the identified DMFs. In most cases, the manufacturing plant or suppliers of the modules are sited in remote locations and thus, the modules must be transported to the job site for assembly and final installation (Azhar et al. 2012). Therefore, in deciding to implement MiC, management must consider the availability of suitable transport channels, local regulatory restrictions on transportable modules sizes, availability of trucks, and the availability and capacity of on-site cranes (Carriker and Langar 2014). Moreover, the traffic situation in the neighbourhood must be given due consideration since it can trigger delays in modular delivery to job site significantly and significantly affect the tighter schedules of MiC resulting in expensive rates of hired equipment. In cases of where importation and cross-border transportation of the modules are required, this DMF must be given detailed analysis because it could result in excessive additional cost trigger (Pan and Hon 2018). The availability of transport infrastructure in good condition, favourable regulatory restrictions on modular sizes and equipment availability are suitable factors which favours the implementation of MiC.

Need for improved construction safety

Construction is one of the most dangerous activities and occupation is the world (McGraw Hill Construction 2013). As such, there has been an increasing requirement for occupational safety improvement in the sector and concomitant commitment in the industry towards improving the safety and health of construction workers. MiC is championed as one innovative approach which improves construction safety (McGraw Hill Construction 2013). Owing to the reduced requirement to work from heights, controlled factory environment, and fewer workers on site, contractors have reported improved safety in MiC projects (McGraw Hill Construction 2013).

Thus, it was not surprising that this factor was cited in 21 studies and ranked 4th among the identified DMFs. Considering that the traditional construction approach is found to be dangerous, MiC or a combination of both may be a superior choice in projects with strict requirement for improved construction safety performance. With the increasing requirements to improve safety in the sector, a critical consideration must be given to the safety benefits of MiC in deciding to implement the approach.

Conceptual framework of the DMFs in the Adoption of MiC

The foregoing discussion and the findings in Table 3 indicate that several factors must be considered before deciding to use MiC in a project. Thus, conceptual design and planning stage of MiC implementation involves a multicriteria decision-making problem. Given that not all these factors are relevant to every project, it is useful to cluster the DMFs to facilitate informed decision-making. This study conceptualizes the MiC DMFs as a multicriteria decision-making problem involving labour consideration, project characteristics, location and site conditions, and organizational factors. Figure 9 is a conceptual framework of the DMFs in deciding to use MiC in a project.

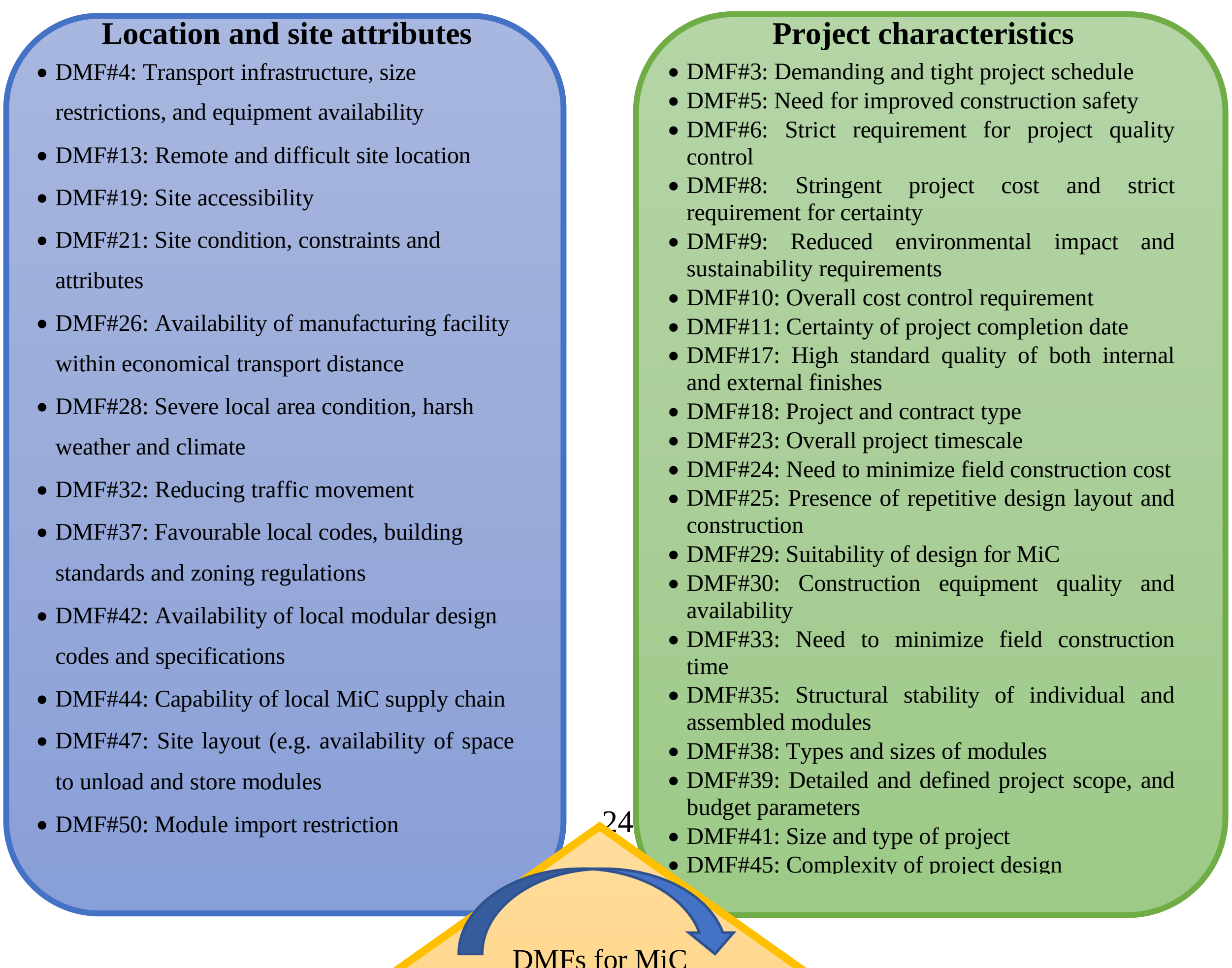

Figure 9. Conceptual framework of the DMFs for MiC implementation

Although overlaps exist, a detailed analysis of the 51 DMFs in Table 3 shows that the determinant factors are made of conditions, characteristics, and factors associated with labour, location and site, nature, and requirement of projects and organizational issues and requirements. This is consistent with the classification of Murtaza et al. (1993) and Haas and Fagerlund (2002). The conceptualized framework indicates that a combination of DMFs from each category must be analysed in deciding to use MiC in a project. Of the 51 DMFs, 22 are related to project characteristics and objectives; 12 are associated with location characteristics and site attributes; 8 are closely aligned with organizational planning and needs; and 8 are related to labour availability, capabilities, and requirements. The framework offers a more organized perspective of the nature of the DMFs and may facilitate more structured decision-making. Management may then determine the satisfactory combinations of the DMFs from each category which warrants the adoption of MiC in a project. Nevertheless, a decision to implement MiC in a project could result from the analysis of the DMFs in just one category, depending on the distinct objective of the proposed project.

Stage-gate model of the decision-making process in MiC implementation

A stage-gate model is developed in Figure10 to pictorially demonstrate the decision-making process in attempting to deploy MiC in a project. A stage-gate model divides a complex decision-making process into distinct and sequential stages and gates (Jagoda and Samaranayake 2017). Each gate denotes a distinct decision-making framework where a decision-maker could arrive at a conclusion and initiates a project or transition into another gate for further decision-making. Drawing on previous studies (Construction Industry Institute 1992; Murtaza et al. 1993; Hwang et al. 2018), the proposed stage-gate model delineates the MiC implementation decision-making process into three levels or gates comprising pre-screening, detailed feasibility analysis and economic analysis.

The schematic view of the stage-gate model is shown in Figure 10. The delineation of the decision process into stages is relevant and necessary because not all projects require all three stages in deciding to implement MiC. The information required at each stage also differs and offers a more structured perspective of the decision-making process. For instance, clients and developers may just be interested in determining a suitable method for a project based on their objectives. The pre-screening gate alone could be used to provide this information. In this gate, clients would have to evaluate the characteristics of the proposed project and the conditions and attributes of the proposed site against the primary objectives. This will offer a preliminary answer to whether MiC is the best choice (Murtaza et al. 1993).

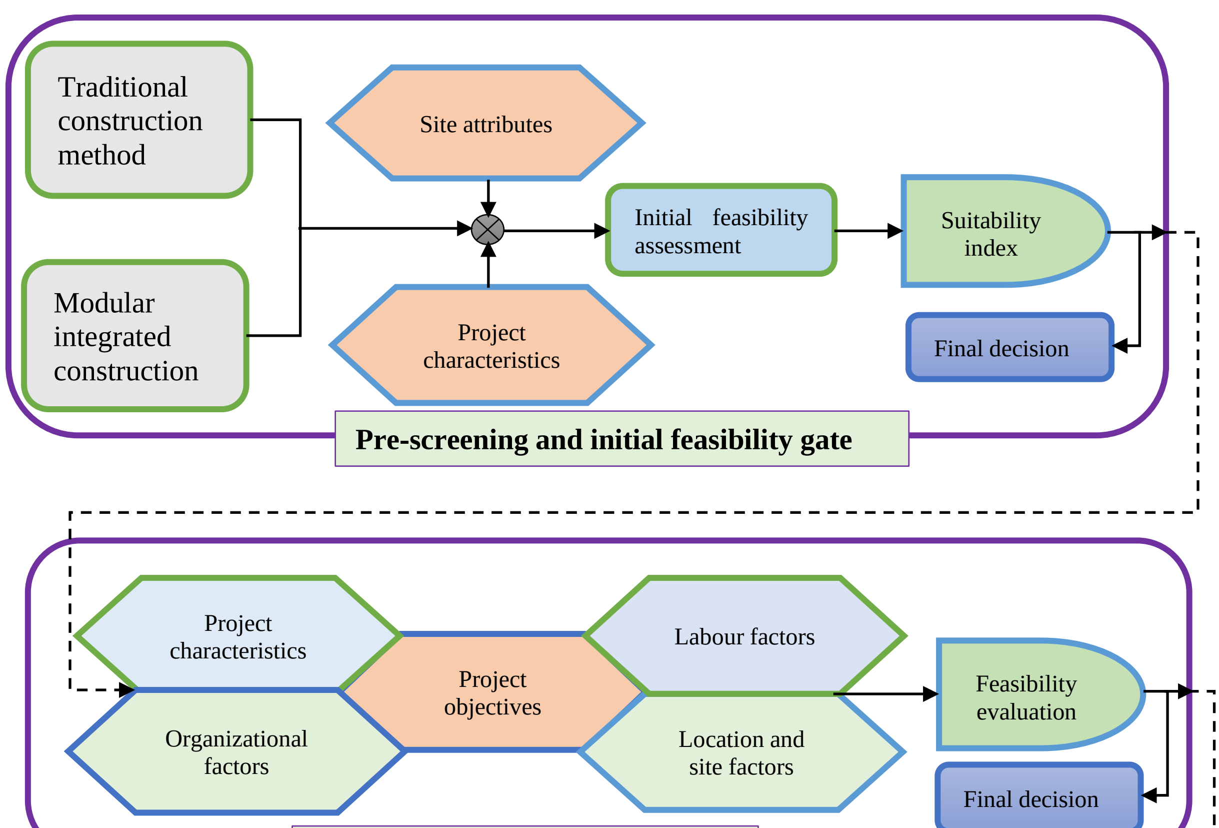

Figure 10. A stage-gate model for MiC implementation decision-making

As such, the stage-gate model conceptualizes that not all the identified DMFs (or the clusters) may be required to decide to implement MiC. Depending on the need of the client, one gate or level may be adequate to support decision-making. If a client or management finds MiC as suitable for the project, a more detailed analysis may be required to ascertain the design and construction approach which offers the highest advantage and benefits for the proposed project (Murtaza et al. 1993; Haas and Fagerlund 2002). Within the detailed feasibility gate, management would be able to also analyse the benefits and advantages of adopting MiC or a hybrid of the traditional method and MiC on a project. This stage requires more information on each category of the DMFs and may be more complex than the pre-screening gate. Additionally, the parameters of the second gate may become a starting point where a client or business dictates the adoption of MiC. Thus, the first stage loses relevance as the suitability of MiC for the project is answered within the demands of the client or the business needs.

Finally, the economic analysis gate offers the framework for management, clients or developers to ascertain the cost reduction, time savings, quality improvement, risk minimization, and sustainability performance associated with implementing MiC on the proposed project (Construction Industry Institute 1992; Murtaza et al. 1993). This would require information such as cost estimations, cash-flow patterns, safety performance simulation, among others. Essentially, the proposed stage-gate model offers a more structured and pictorial explanation of the decision-making process in MiC implementation. However, KBDSS which integrate expert systems and decision support systems (Hwang et al. 2018) is required to automate the decision-making process, but the identified DMFs in the study constitute the key input into the KBDSS.

Conclusions, limitations and future research direction

MiC is an innovative construction method which transforms the linear fragmented site-based construction of buildings into integrated production and assembly of value-added factory-made prefabricated prefinished volumetric modules. The *modus operandi* of MiC offers adopters the opportunity for improved quality control, the certainty of project cost and time, improved environmental performance, reduced business disruption, and a safer working environment. However, not every circumstance and condition warrant the implementation of MiC in a project. As a result, this research investigated the determinant factors in deciding to implement MiC in a project through the lens of systematic review methodology. The research recruited and analysed 57 studies on the DMFs published during the year 1989-2019, which covered the most significant period in the MiC renaissance in the 20th and 21st centuries.

Annual publications trend analysis showed that the MiC DMFs only gained significant and increasing attention during the last 1.5 decades. A geospatial analysis showed that the 57 studies have been conducted in the context of 12 countries distributed across Europe, North America, South America, Asia Pacific, and Australia. These continents have the most advanced levels of MiC implementation where the technology is currently at its tipping point and thus, provided a useful basis to establish a framework of the DMFs drawing on 28 successful MiC project types. Further analysis revealed that previous studies predominantly used case study analysis, questionnaires, and interviews as the data collection instruments. Analysis of the included studies resulted in the extraction of 51 DMFs for the 28 different MiC project types. Of these, the top 10 most cited DMFs were: (i) *availability of skilled and experienced factory labour force*; (ii) *readily available skilled management and supervising team*; (iii) *demanding and tight project schedule*; (iv) *transport infrastructure, size restrictions, and equipment availability*; (v) *need for improved construction safety*; (vi) *strict requirement for project quality control*; (vii) *availability of skilled onsite labour*; (viii) *stringent project cost and strict requirement for certainty*; (ix) *reduced environmental impact and sustainability requirements*; and (x) *overall cost control requirement*. These are shared among project types and territories, highlighting their significance in the decision to implement MiC. The research further conceptualized the 51 DMFs into a framework comprising labour factors, project characteristics, location and site conditions, and organizational factors. A stage-gate model is proposed to demonstrate the MiC implementation decision-making process.

Therefore, the robust analysis presented in this paper has both theoretical and practical significance. Theoretically, the paper contributes to a better theoretical and conceptual understanding of the determinant factors in deciding to implement MiC in a project. Practically, the findings of this research make a useful contribution to knowledge of the MiC implementation decision-making process. This will help clients, developers, industry practitioners, and government authorities to determine when it is feasible and appropriate to deploy MiC in a project to maximize benefits and minimized risk. For researchers, the checklist and framework of the identified DMFs would form a useful basis for developing decision support and expert systems for MiC projects in different jurisdictions.

However, the following limitations of the study are noteworthy. First, the study conducted a comprehensive literature search during the process, but some relevant studies may have been missed. Second, the rankings of the DMFs were not based on relative importance but based on frequency of citations. This may limit the relevance of the rankings. Future studies will address these limitations and improve the decision-making process through the following: (i) critically examine the decision-making process currently used in the industry; (ii) determine the most critical DMFs in the use of MiC in a project; (iii) develop a decision support system for MiC implementation; and (iv) develop guidelines to help industry practitioners effectively deploy the decision support system.

Acknowledgment

The work described in this paper is fully funded by the Department of Building and Real Estate of the Hong Kong Polytechnic University under the auspices of the Research Grants Council of the Hong Kong Special Administrative Region (PF17-00649). However, the views expressed herein are solely those of the authors and not the funding body.

References

Arcadis. 2018. Tackling Costs in the Digital Age: International Construction Costs 2018. , Amsterdam, Netherlands URL: https://www.arcadis.com/media/F/1/E/%7BF1E33F46-EA9C-4F75-A642-

E0E0F31420BD%7DInternational-Construction-Costs-2018-Arcadis-Updated_001.pdf.

Azhar S, Lukkad M, Ahmad I. 2012. Modular v. stick-built construction: Identification of critical decision-making factors. In: 48th Annual Conference of Associated Schools of Construction. Associated Schools of Construction, Fort Collins, p. 8 URL: http://ascpro0.ascweb.org/archives/cd/2012/paper/CPRT202002012.pdf.

Azhar S, Lukkad MY, Ahmad I. 2013. An Investigation of Critical Factors and Constraints for Selecting Modular Construction over Conventional Stick-Built Technique. Int J Constr Educ Res. 9(3):203–225 DOI: 10.1080/15578771.2012.723115.

Azman MNA, Ahamad MSS, Majid TA, Yahaya AS, Hanafi MH. 2013. Statistical evaluation of pre-selection criteria for industrialized building system (IBS). J Civ Eng Manag. 19(sup1):S131–S140 DOI: 10.3846/13923730.2013.801921.

Baker JD. 2016. The Purpose, Process, and Methods of Writing a Literature Review. AORN J. 103(3):265–269 DOI: 10.1016/j.aorn.2016.01.016.

Baldwin CY, Clark KB. 2000. Design Rules: The Power of Modularity. Volume 1. MIT Press, Cambridge, Massachusetts.

Baldwin CY, Clark KB. 1997. Managing in an Age of Modularity. Havard Bus Rev. 75(5):84–93.

Bataglin FS, Viana DD, Formoso CT, Bulhões IR. 2017. Application of BIM for Supporting Decision-making Related to Logistics in Prefabricated Building Systems. In: Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC). , Heraklion, Greece, pp. 71–78 DOI: 10.24928/2017/0278.

Blismas NG. 2007. Off-site manufacture in Australia : Current state and future directions. , Brisbane, AUstralia URL: http://www.construction-innovation.info/images/pdfs/Publications/Industry_publications/Off-site_manufacture_in_Australia.pdf.

Blismas NG, Pasquire C, Gibb AGF. 2006. Benefit evaluation for off-site production in construction. Constr Manag Econ. 24(2):121–130 DOI: 10.1080/01446190500184444.

Blismas NG, Pendlebury M, Gibb AGF, Pasquire C. 2005. Constraints to the use of Off-site production on construction projects. Archit Eng Des Manag. 1(3):153–162 DOI: 10.1080/17452007.2005.9684590.

Bohn E. 2016. Deciding When to Use Modular Construction. Pharm Technol. 40(6):45–46.

Carriker M, Langar S. 2014. Factors Affecting Large Scale Modular Construction Projects. In: 50th ASC Annual International Conference Proceedings. Associated Schools of Construction, Fort Collins, pp. 1–8.

Chen Y, Okudan GE, Riley DR. 2010. Decision support for construction method selection in concrete buildings: Prefabrication adoption and optimization. Autom Constr. 19(6):665–675 DOI: 10.1016/j.autcon.2010.02.011.

Choi JO. 2014. Links between Modularization Critical Success Factors and Project Performance. The University of Texas at Austin.

Choi JO, Chen X Bin, Kim TW. 2019a. Opportunities and challenges of modular methods in dense urban environment. Int J Constr Manag. 19(2):93–105 DOI: 10.1080/15623599.2017.1382093.

Choi JO, O'Connor JT, Kim TW. 2016. Recipes for Cost and Schedule Successes in Industrial Modular Projects: Qualitative Comparative Analysis. J Constr Eng Manag. 142(10):04016055 DOI: 10.1061/(asce)co.1943-7862.0001171.

Choi JO, O'Connor JT, Kwak YH, Shrestha BK. 2019b. Modularization Business Case Analysis Model for Industrial Projects. J Manag Eng. 35(3):04019004 DOI: 10.1061/(asce)me.1943-5479.0000683.

Clement R. 1989. Deciding When to Use Modular Construction. Chem Eng. 96(8):169–170.

Construction Industry Council. 2018. About Modular Integrated Construction. :1–7 URL: www.cic.hk/eng/main/mic/whatsmic/aboutmic/.

Construction Industry Institute. 1992. MODEX : Automated decision support system for modular construction. , Austin, TX URL: https://www.construction-institute.org/scriptcontent/more/29_1_more.cfm.

Egan J. 1998. Rethinking construction: The Report of the Construction Task Force. DOI: Construction Task Force. Uk Government.
Elnaas E. 2014. The Decision to Use Off-Site (OSM) Systems for House Building Projects in the UK. University of Brighton.
Elnaas H, Ashton P, Gidado K. 2013. A decision evaluation model to choose between manufacturing off-site or on-site methods for construction of house building projects. In: Smith S., Ahiaga-Dagbui D. (eds) Procs 29th Annual ARCOM Conference, 2-4 September 2013, Reading, UK,. Association of Researchers in Construction Management, Reading, pp. 59–67.
Elnaas H, Gidado K, Ashton P. 2018. Factors and Drivers Effecting the Decision of Using Off-Site Manufacturing (OSM) Systems in House Building Industry. J Eng Proj Prod Manag. 4(1):51–58 DOI: 10.32738/jeppm.201401.0006.
Fenner AE, Zoloedova V, Kibert CJ. 2017. Conference Report 2017: State-of-the-Art of Modular Construction. , Florida DOI: 10.13140/rg.2.2.18051.60960.
Fraser N, Race GL, Kelly R, Winstanley A, Hancock P. 2015. An Offsite Guide for the Building and Engineering Services Sector. , Loughborough DOI: 10.1680/mpal.13.00031.
Gao S, Low SP, Nair K. 2018. Design for manufacturing and assembly (DfMA): a preliminary study of factors influencing its adoption in Singapore. Archit Eng Des Manag. 14(6):440–456 DOI: 10.1080/17452007.2018.1502653.
Gibb AGF. 1999. Off-site Fabrication: Prefabrication, Pre-assembly and Modularization. 1st ed. Whittles Publishing, Latheronwheel DOI: 10.1680/bimpp.63693.109.
Gibb AGF. 2001. Standardization and pre-assembly- distinguishing myth from reality using case study research. Constr Manag Econ. 19(3):307–315 DOI: 10.1080/01446190010020435.
Gibb AGF, Isack F. 2001. Client Drivers for Construction Projects. Eng Constr Archit Manag. 8(1):46–58 DOI: 10.1046/j.1365-232x.2001.00184.x.
Gibb AGF, Isack F. 2003. Re-engineering through pre-assembly: Client expectations and drivers. Build Res Inf. 31(2):146–160 DOI: 10.1080/09613210302000.
Goodier C, Gibb AGF. 2007. Future opportunities for offsite in the UK. Constr Manag Econ. 25(6):585–595 DOI: 10.1080/01446190601071821.
Gosling J, Pero M, Schoenwitz M, Towill D, Cigolini R. 2016. Defining and Categorizing Modules in Building Projects: An International Perspective. J Constr Eng Manag. (04016062):1–11 DOI: 10.1061/(ASCE)CO.1943-7862.
Haas CT, Fagerlund WR. 2002. Preliminary Research on Prefabrication, Pre-assembly, Modularization and Off-site Fabrication in Construction. , Austin, TX URL: https://smartech.gatech.edu/handle/1853/10883.
Hammad AW, Akbarnezhad A, Wu P, Wang X, Haddad A. 2019. Building information modelling-based framework to contrast conventional and modular construction methods through selected sustainability factors. J Clean Prod. 228:1264–1281 DOI: 10.1016/j.jclepro.2019.04.150.
Hjort B, Lindgren J, Larsson B, Emmitt S. 2014. Success Factors Related to Industrialized Building in Sweden. In: Paper presented at the CIB International Conference on Construction in a Changing World,. School of the Built Environment, University of Salford, Kandalana, Sri Lanka, pp. 1–13.
Hsu PY, Angeloudis P, Aurisicchio M. 2018. Optimal logistics planning for modular construction using two-stage stochastic programming. Autom Constr. 94(May):47–61 DOI: 10.1016/j.autcon.2018.05.029.
Hwang B-G, Shan M, Looi KY. 2018. Knowledge-based decision support system for prefabricated prefinished volumetric construction. Autom Constr. 94(July):168–178 DOI: 10.1016/j.autcon.2018.06.016.
Jagoda K, Samaranayake P. 2017. An integrated framework for ERP system implementation. Int J Account Inf Manag. 25(1):91–109 DOI: 10.1108/IJAIM-04-2016-0038.
Koskela L, Ballard G. 2003. What should we require from a production system in construction? In: Construction Research Congress March 19-21, 2003. American Society of Civil Engineers, Honolulu, Hawaii, United States, pp. 1–8 DOI: 10.1061/40671(2003)42.

Lau AKW. 2011. Critical success factors in managing modular production design: Six company case studies in Hong Kong, China, and Singapore. J Eng Technol Manag. 28(3):168–183 DOI: 10.1016/j.jengtecman.2011.03.004.

Lee JS, Kim YS. 2017. Analysis of cost-increasing risk factors in modular construction in Korea using FMEA. KSCE J Civ Eng. 21(6):1999–2010 DOI: 10.1007/s12205-016-0194-1.

Lessing J, Brege S. 2017. Industrialized Building Companies' Business Models: Multiple Case Study of Swedish and North American Companies. J Constr Eng Manag. 144(2):05017019 DOI: 10.1061/(asce)co.1943-7862.0001368.

Li CZ, Xue F, Li X, Hong J, Shen GQ. 2018. An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. Autom Constr. 89(February):146–161 DOI: 10.1016/j.autcon.2018.01.001.

Liu G, Li K, Zhao D, Mao C. 2017. Business model innovation and its drivers in the chinese construction industry during the shift to modular prefabrication. J Manag Eng. 33(3):04016051 DOI: 10.1061/(ASCE)ME.1943-5479.

Mao C, Shen Q, Pan W, Ye K. 2014. Major Barriers to Off-Site Construction: The Developer's Perspective in China. J Manag Eng. 31(3):04014043 DOI: 10.1061/(ASCE)ME.1943-5479.0000246.

Mao C, Xie F, Hou L, Wu P, Wang J, Wang X. 2016. Cost analysis for sustainable off-site construction based on a multiple-case study in China. Habitat Int. 57:215–222 DOI: 10.1016/j.habitatint.2016.08.002.

McGraw Hill Construction. 2011. Prefabrication and Modularization: Increasing Productivity in the Construction Industry. , Bedford, MA URL: https://www.nist.gov/sites/default/files/documents/el/economics/Prefabrication-Modularization-in-the-Construction-Industry-SMR-2011R.pdf.

McGraw Hill Construction. 2013. Safety Management in the Construction Industry: Identifying Risks and Reducing Accidents to Improve Site Productivity and Project ROI. , Bedford, MA URL: https://www.cpwr.com/sites/default/files/publications/SafetyManagementinConstructionSMR-2013_0.pdf.

McKinsey Global Institute. 2017. Reinventing Construction: A Route To Higher Productivity. , New York, United States.

Modular Building Institute. 2017. Modular Advantage for the Commercial Modular Construction Industry: the Offsite Construction Issue. , Canada.

Mostafa S, Kim KP, Tam VWY, Rahnamayiezekavat P. 2018b. Exploring the status, benefits, barriers and opportunities of using BIM for advancing prefabrication practice. Int J Constr Manag:1–12 DOI: 10.1080/15623599.2018.1484555.

Mostafa S, Tam VW, Dumrak J, Mohamed S. 2018a. Leagile Strategies for Optimizing the Delivery of Prefabricated House Building Projects. Int J Constr Manag:1–15 DOI: 10.1080/15623599.2018.1494674.

Murtaza MB, Fisher DJ. 1994. Neuromodex—Neural Network System for Modular Construction Decision Making. J Comput Civ Eng. 8(2):221–233 DOI: 10.1061/(ASCE)0887-3801(1994)8:2(221).

Murtaza MB, Fisher DJ, Skibniewski MJ. 1993. Knowledgment-Based Approach to Modular Construction Decision Support. J Constr Eng Manag. 119(1):115–130.

Pan W, Dainty ARJ, Gibb AGF. 2012. Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction. J Constr Eng Manag. 138(11):1239–1250 DOI: 10.1061/(ASCE)CO.1943-7862.0000543.

Pan W, Gibb AGF, Dainty ARJ. 2008. Leading UK housebuilders' utilization of offsite construction methods. Build Res Inf. 36(1):56–67 DOI: 10.1080/09613210701204013.

Pan W, Gibb AGF, Dainty ARJ. 2007. Perspective of UK housebuilders on the use of offsite modern methods of construction. Constr Manag Econ. 25(2):183–194 DOI: 10.1080/01446190600827058.

Pan W, Hon CK. 2018. Modular integrated construction for high-rise buildings. Proc Inst Civ Eng -

Munic Eng:1–12 DOI: 10.1680/jmuen.18.00028.

Pan W, Sidwell R. 2011. Demystifying the cost barriers to offsite construction in the UK. Constr Manag Econ. 29(11):1081–1099 DOI: 10.1080/01446193.2011.637938.

Peltokorpi A, Olivieri H, Granja AD, Seppänen O. 2018. Categorizing modularization strategies to achieve various objectives of building investments. Constr Manag Econ. 36(1):32–48 DOI: 10.1080/01446193.2017.1353119.

Polat G. 2008. Factors Affecting the Use of Precast Concrete Systems in the United States. J Constr Eng Manag. 134(3):169–178 DOI: 10.1061/(ASCE)0733-9364(2008)134:3(169).

Rahman MM. 2014. Barriers of Implementing Modern Methods of Construction. J Manag Eng. 30(1):69–77 DOI: 10.1061/(ASCE)ME.1943-5479.0000173.

Rentschler C, Mulrooney M, Shahani G. 2016. Modularization: The key to success in today's market. Hydrocarb Process. 95(12):27–30.

Schwartz MW, Cook CN, Pressey RL, Pullin AS, Runge MC, Salafsky N, Sutherland WJ, Williamson MA. 2018. Decision Support Frameworks and Tools for Conservation. Conserv Lett. 11(2):1–12 DOI: 10.1111/conl.12385.

Scofield R, Potangaroa R, Bell P. 2009a. Offsite Unplugged : The Potential for Offsite Production in New Zealand. , Auckland URL: http://12219-portal.memberconnex.com/PDFs/CSA/Offsite Unplugged.pdf.

Scofield R, Wilkinson S, Potangaroa R, Rotimi F. 2009b. Driving Innovative Offsite Construction Techniques in New Zealand. , Auckland URL: http://www.hera.org.nz/PDFs/CSA/Driving Innovative Offsite Construction Techniques in NZ.pdf.

Sharafi P, Rashidi M, Samali B, Ronagh H, Mortazavi M. 2018. Identification of Factors and Decision Analysis of the Level of Modularization in Building Construction. J Archit Eng. 24(2):04018010 DOI: 10.1061/(ASCE)AE.1943-5568.0000313.

Song J, Fagerlund WR, Haas CT, Tatum CB, Vanegas JA. 2005. Considering Prework on Industrial Projects. J Constr Eng Manag. 131(6):723–733 DOI: 10.1061/(asce)0733-9364(2005)131:6(723).

de Souza MT, da Silva MD, de Carvalho R. 2010. Integrative review: what is it? How to do it? Einstein (São Paulo). 8(1):102–106 DOI: 10.1590/s1679-45082010rw1134.

Stoeckl N, Grainger D, Esparon M, Farr M, Larson S, Kennard M, Álvarez-romero JG, Cattarino L, Adams V, Douglas M, Pressey B, Pannell D. 2016. Integrated models, frameworks and decision support tools to guide management and planning in Northern Australia. , Townsville URL: https://www.nespnorthern.edu.au/wp-content/uploads/2017/04/Review_of_models_final_web.pdf.

Sullivan T. 2002. Evaluating Environmental Decision Support Tools. , Upton, NY: Brookhaven National Laboratory URL: https://www.bnl.gov/isd/documents/30163.pdf.

Tam VWY, Tam CM, Zeng SX, Ng WCY. 2007. Towards adoption of prefabrication in construction. Build Environ. 42(10):3642–3654 DOI: 10.1016/j.buildenv.2006.10.003.

Torraco RJ. 2016. Writing Integrative Literature Reviews: Using the Past and Present to Explore the Future. Hum Resour Dev Rev. 15(4):404–428 DOI: 10.1177/1534484316671606.

Triumph Modular Corporation. 2019. Critical Success Factors for Volumetric Modular Construction. :1–5 URL: https://triumphmodular.com/permanent-modular/how-to-start/critical-success-factors/.

Webster J, Watson RT. 2002. Analyzing the Past To Prepare for the Future : Writing a Literature Review. MIS Q. 26(2):xiii–xxiii DOI: 10.1.1.104.6570.

Whitehead D. 2013. Searching and Reviewing the Literature. In: Schneider Z, Whitehead D (eds) Nursing & Midwifery Research: Methods and Appraisal for Evidence-Based Practice. Elsevier - Mosby, pp. 35–56 DOI: 10.4135/9781849209892.n2.

Whittemore R, Knafl K. 2005. The integrative review: updated methodology. J Adv Nurs. 52(2):546–553 DOI: 10.1111/j.1365-2648.2005.03621.x.

Wong PSP, Whelan B, Holdsworth S. 2018. Are contractors ready for greater use of prefabrication in projects? An empirical analysis on the role of unlearning and counter-knowledge. Int J Constr Manag:1–16 DOI: 10.1080/15623599.2018.1539160.

Wong PSP, Zwar C, Gharaie E. 2017. Examining the Drivers and States of Organizational Change for

Greater Use of Prefabrication in Construction Projects. J Constr Eng Manag. 143(7):04017020 DOI: 10.1061/(ASCE)CO.1943-7862.0001309.
Wuni IY, Shen GQP. 2019. Holistic Review and Conceptual Framework for the Drivers of Offsite Construction : A Total Interpretive Structural Modelling Approach. Buildings. 9(117):1–24 DOI: 10.3390/buildings9050117.
Wuni IY, Shen GQP, Mahmud AT. 2019a. Critical risk factors in the application of modular integrated construction : a systematic review. Int J Constr Manag:1–15 DOI: 10.1080/15623599.2019.1613212.
Wuni IY, Shen GQP, Osei-kyei R. 2019b. Scientometric Review of Global Research Trends on Green Buildings in Construction Journals from 1992 to 2018. Energy Build. 190(May):69–85 DOI: 10.1016/j.enbuild.2019.02.010.
Zakaria SAS, Gajendran T, Skitmore M, Brewer G. 2018. Key factors influencing the decision to adopt industrialised building systems technology in the Malaysian construction industry: an inter-project perspective. Archit Eng Des Manag. 14(1–2):27–45 DOI: 10.1080/17452007.2017.1298512.
Zhai X, Reed R, Mills A. 2014. Factors impeding the offsite production of housing construction in China: An investigation of current practice. Constr Manag Econ. 32(1–2):40–52 DOI: 10.1080/01446193.2013.787491.