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Key success factors for implementing modular integrated construction projects - A literature mining approach

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Abstract

Modular integrated construction (MiC) is an innovative construction method where components of a building are manufactured in an offsite factory, trucked to the job site in sections, set in place with cranes, and assembled together to form a whole building. Where circumstances merit, favorable conditions exist and implemented effectively; MiC improves project performance. However, several key factors need to converge during implementation to realize the full benefits of MiC. Thus, a thorough understanding of the factors which are critical to the success of MiC projects is imperative. Drawing on a systematic review of 47 empirical studies, this research identified 25 key success factors (KSFs) for MiC projects. Of these, the five topmost cited KSFs for MiC projects include *effective working collaboration and communication among project participants; standardization, optimization, automation and benchmarking of best practices*; *effective supply chain management*; *early design freeze and completion*; and *efficient procurement method and contracting*. The study further proposed a conceptual model of the KSFs, highlighting the interdependences of people, processes, and technology-related KSFs for the effective accomplishment of MiC projects. The set of KSFs is practically relevant as they constitute a checklist of items for management to address and deal with during the planning and execution of MiC projects. They also provide a useful basis for future empirical studies tailored towards measuring the performance and success of MiC projects. MiC project participants and stakeholders will find this research useful in reducing failure risks and achieving more desired performance outcomes. One potential impact of the study is that it may inform, guide, and improve the successful implementation of MiC projects in the construction industry. However, the rigor of the analysis and relative importance ranking of the KSFs were limited due to the absence of data.

Keywords: conceptual model, key success factors, modular integrated construction, review

1. INTRODUCTION

There is a global recognition that the ill-performances of the traditional construction approach engender significant threat and risks to the realization of a sustainable future of modern society and the construction industry [1]. Poor performances abound and some include lower productivity rates [2], schedule and budget overruns [3], quality problems, higher construction waste, carbon emissions [4], shortage of labor force, and the poor state of worker's health and safety [5]. However, the aggregate documentation of these ill-performances of the sector in the global context has the tendency of masking the significant regional and national differences in the magnitude of the challenges confronted [6]. Notably, the impacts of these challenges are multiplied in economies such as the Hong Kong Special Administrative Region (hereafter Hong Kong). Hong Kong is an iconic high-density metropolis with scarce developable land which drives the development of high-rise buildings. The construction sector of Hong Kong has the 2nd most expensive cost of construction in the world [3], generates a huge proportion of landfill wastes [7], and draws heavily on local labor force which is undergoing rapid aging. These collectively present a huge threat to the sustainable future of Hong Kong and the construction industry. Consistent with global transition towards industrializing and revolutionizing the construction sector [8], the Hong Kong SAR Government initiated modular integrated construction (MiC) within the Policy Addresses 2017 and 2018 as a strategic policy initiative towards enhancing innovative construction, productivity improvement, and meeting the requirements of high-rise high-density building construction in Hong Kong [9].

MiC is an innovative construction method which transforms the fragmented site-based construction of buildings into an integrated production and assembly of value-added factory-made prefabricated prefinished volumetric modules [6,9]. Drawing on the concepts of modularity, modularization, industrialized production, and lean construction, MiC represents the most complete form of off-site construction (OSC) with the greatest integration of value-added prefinished volumetric modules where 80-90% of a whole building can be completed in an offsite factory [10,11]. MiC belongs to a family of OSC techniques such as prefabricated prefinished volumetric construction, modular construction, industrialized housing construction, PPMOF (prefabricated, preassembly, modularization, and off-site fabrication), industrialized building systems, off-site manufacture, modern methods of construction, prework and off-site production [6,8,11]. Experiences with these techniques in Singapore, Canada, China, Sweden, Switzerland, New Zealand, USA, UK, Malaysia, Australia, and Japan established that achievable benefits of MiC include shortened construction time, improved working environment and site safety, improved sustainability and environmental performance, high construction quality, better management, and reduced lifecycle cost [9,12].

Despite these promises, the feasibility of employing MiC for high-rise building construction in Hong Kong currently remains cloudy [9]. Hong Kong is at the earliest stage of the MiC learning curve with few pilot projects been initiated and yet to be completed. However, MiC is associated with a unique supply chain, complex network of stakeholders, engineering, and management requirement different from those of the traditional construction approach. This means that best practices in traditional construction project management might not be directly applicable to MiC projects. As expected, countries continue to struggle with the implementation of MiC and evidences indicate that not all executed projects resulted in desirable project performance. Notwithstanding some failures, MiC projects have been successfully implemented in other countries, but an understanding of the KSFs is lacking. Such understanding is imperative in reconciling the implementation and management of MiC projects with the reality that a significant number of MiC projects do not currently succeed.

Considering that MiC has gained significant attention, a deeper understanding of the KSFs for implementing its projects is imperative. Choi et al. [13] echoed that improved understanding and prioritization of the KSFs for MiC project planning and implementation is imperative to achieve higher success. As KSFs are the few vital management areas that must receive sustained attention and commitment to ensure success [14] of MiC projects, this review study seeks to (i) identify, summarize and integrate the KSFs for MiC projects, (ii) examine the most cited KSFs for MiC projects, and (iii) propose a conceptual model of the KSFs for MiC mapping their interactions and interdependences. The output of this research is timely and relevant to Hong Kong and other countries as the construction industries attempt to benchmark best practices along the MiC learning curve. By drawing on lessons from multiple MiC project types, sizes, phases, purposes, characteristics, and environments in different countries, the framework of the KSFs forms a useful basis for future empirical studies on MiC KSFs.

2. RESEARCH METHOD AND APPROACH

This research draws on a systematic literature review methodology and systems dynamic modelling approach to examine the KSFs for implementing MiC projects. Figure 1 is a schematic of the methodological framework of the study. The study adopted a systematic review approach because it is a useful methodology for establishing the start of the art scientific knowledge of a given subject [6]. It is an established research methodology which draws on published and grey literature to delineate boundaries of existing knowledge, provide a basis for theory development and guides evidence-based policy formulation [8]. It offers an integrated perspective of scientific evidence on a given subject and brings the scientific literature closer to industry and policy decision-making. For this, it is widely used in many disciplines including the construction engineering and management research domain [6,8,15]. The systematic review was implemented based on a three stage methodological framework of literature retrieval and analysis, metatadata extraction and identification of the KSFs (see Figure 1). The literature analysis started with selection of sutiable keywords and literature search. Thus, the primary synonyms for key success factors and modular integrated construction used in the literature were identified. The implemented sets of keywords for the two phrases are shown in Table 1. These keywords were selected because they constitute the most commonly used interchangeable terminologies for MiC and KSFs in the literature. Indeed, the keywords were updated throughout the study period. These keywords were used to retrieve articles which addressed KSFs for any of the listed models of MiC. Using the keywords, structured and constrained queries were executed in Scopus and Web of Science; the two most commonly used literature databases in construction engineering and management (CEM) review studies [15].

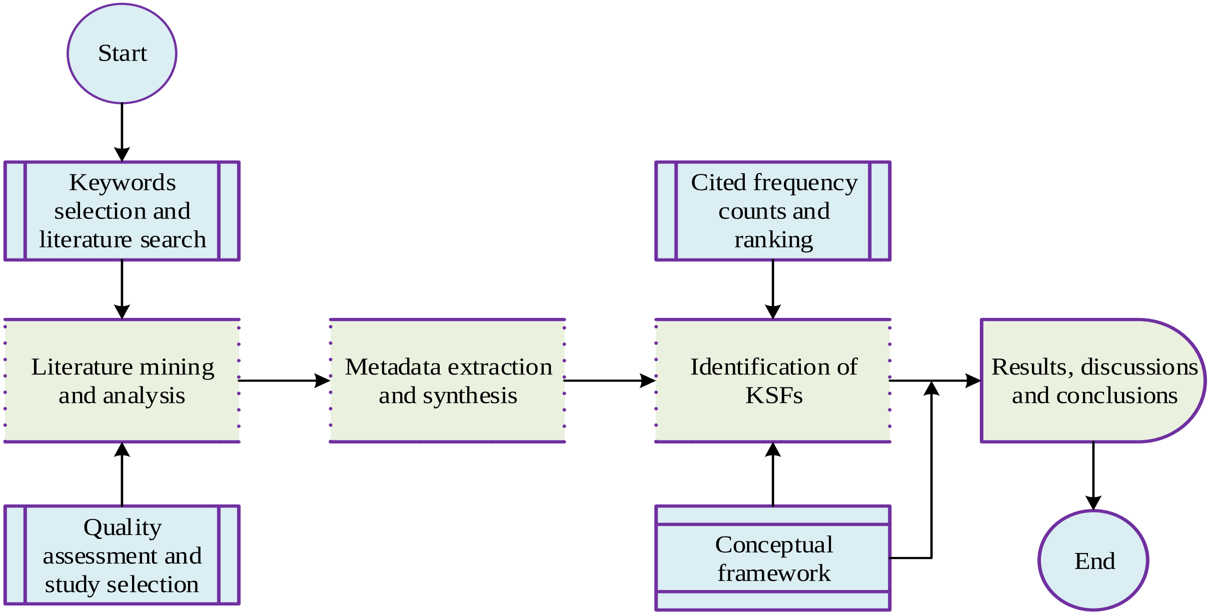

Figure 1. Methodological framework for the study

These literature search engines were selected because they index a wider spectrum of research articles within the CEM research domain [6,15]. Their wider adoption CEM systematic reviews stem from the associated higher degree of repeatability and verifiability of the search results. Using the fuzzy Boolean connector "AND", the authors search for studies containing a combination of at least one keyword each from the first and second set of keywords. No year range was defined but the language of studies was restricted to English. The authors also restricted the literature to journal articles and conference papers only. These restrictions filtered and generated 53 Scopus records (as of 4 June 2019). The authors conducted rapid screening of the titles and abstracts of these records and 30 were found to be relevant to the study.

Table 1. List of keywords used in the literature search and retrieval

Terminology	**List of keywords**
Key success factors (KSFs)	*Critical success factors; success factors; critical factors; few key areas; key results areas; decision support factors*
Fuzzy Boolean concatenator	AND
Modular integrated construction (MiC)	*Modular integrated construction; off-site construction; off-site production; off-site manufacture; prefabrication; prefabricated; industrialized building system; modular construction; industrialized construction; prework; industrialized housing construction; prefabricated prefinished volumetric construction; modular volumetric construction*

Although this sample is small but considering that MiC is relatively new, the figure indicates that researchers and practitioners are becoming interested in KSFs, highlighting the relevance of this study.

These studies were downloaded for full-text evaluation. However, the authors further conducted a general *Google* search to retrieve relevant industry reports, books and theses on the KSFs for MiC. This resulted in the retrieval of 25 relevant documents, which were also downloaded for full-text evaluation. During the full-text evaluation, articles were included if they involved empirical studies on the KSFs for MiC and thus, review articles and editorial notes were excluded. The research designs and methodologies for each study were evaluated to ascertain their overall quality and further justification for inclusion. This criterion was relaxed when considering the industry reports. After the full-text evaluation, 47 studies were found to be relevant to the aim of the study. For each study, the authors extracted the reported KSFs and recorded them in a summary table created in Excel. The number of times a KSF was reported or cited was catalogued and used as a basis for ranking the KSFs in the study. This ranking approach has been adopted in previous studies [6].

3. REVIEW FINDINGS AND DISCUSSIONS

3.1. Summary of the Included Studies

The paper synthesized research evidence from 47 empirical studies on the KSFs for MiC. The included studies comprised 32 journal articles, 7 conference papers, 7 industry reports, and 1 Ph.D. thesis. These studies were conducted in the United States (15), United Kingdom (8), Canada (5), Malaysia (4), Hong Kong (4), Australia (3), Sweden (2), China (1), Japan (1), Singapore (1), Nigeria (1), South Korea (1), and Turkey (1). These countries have some of the most successful MiC projects [8] and thus, offered useful basis for deciphering distilling information on the KSFs for MiC projects. These studies investigated the KSFs across a range of MiC project types including power plant projects, petrochemical plant projects, industrial plant projects, chemical plant projects, schools, residential building projects, and multiple projects. Thus, the sample is adequate to establish a comprehensive perspective of the KSFs for implementing MiC projects.

3.2. Evaluation and ranking of the KSFs for Implementing MiC Projects

The analysis of the 47 documents resulted in the extraction of 45 KSFs for MiC projects of which 20 were each cited once in the included studies and thus, excluded in the analysis. Table 2 shows a summary of the 25 most cited KSFs for implementing MiC, their citing sources, cited frequency counts and relative frequency ranking. Although the KSFs for MiC are sensitive to project types, project sizes, environment, and territories [13], these sets of KSFs were shared among projects and countries and thus, constitute a common framework of the KSFs for MiC projects. The number of studies which cited a KSF was computed as its cited frequency count and used to rank the KSFs in this research. The authors immediately recognize that ranking of the KSFs based on frequency counts could be misleading, but such approach is recommended and used when quantitative meta-analysis is not feasible [6]. The five most cited KSFs for MiC projects include *effective working collaboration and communication among project participants; standardization and benchmarking of best practices; effective supply chain coordination and management; early design freeze and completion*; and *suitable procurement method and contracting*. Due to space constraints, these 4 most cited KSFs are briefly discussed.

3.2.1. Effective working collaboration and communication among project participants

This KSF has been cited in 12 of the 47 studies and ranked 1st among the 25 shortlisted KSFs. Irrespective of project type and territory, MiC projects require the commitment of multiple participants and stakeholders, who have their unique goals, value systems and expectations in the project [6]. Thus, the success of MiC projects is a function of effective collaboration, information sharing, and communication among the project participants [16]. For instance, effective communication between project owners and the design team is crucial at the conceptual design stage to allow for early decision to implement MiC. There is the need for information sharing and collaboration between the design team (designer, architect, structural engineer) and fabricators or manufacturers to allow for a more precise understanding of the detailed working drawings to reduce dimensional tolerances [17]. The collaboration and communication among project participants is a necessary recipe for minimizing delays, conflicts, geometric variabilities, and reworks [6,11].

3.2.2. Standardization, optimization, automation and benchmarking of best practices

This factor ranked 2nd among the 25 shortlisted KSFs and was cited in 11 studies. Standardization is the process of implementing and developing technical standards based on the consensus of various stakeholders of MiC projects. Standardization reduces the tendency of producing unique modules to meet the specification of every implemented MiC project. It facilitates optimization and improved automation of the MiC process [18]. Warszawski [19] concurred that standardization allows for efficient allocation of resources and increases the benefits of specialization of labor in MiC projects. Through benchmarking best practices, the performance and success of MiC project can be reliably predicted based on relevant indicators and management practices. Through standardization, the production process, equipment, and labor skills can be adapted to meet the demands of the MiC project.

Table 2. Ranking of the key Success factors for implementing MiC Project

#	Key success factors	Sources	Frequency	Rank
1	Effective working collaboration and communication among project participants	[13,16,17–24, 25]	12	1
2	Standardization, optimization, automation and benchmarking of best practices	[18,19,37,29–36]	11	2
3	Effective supply chain management	[21,22,24,38–44]	10	3
4	Early design freeze and completion	[18,19,22,30,32–37]	10	3
5	Efficient procurement method and contracting	[22,28,29,31,41,44,45]	7	5
6	Early and continuous engagement of project participants throughout the project	[22,23,32,33,37,45,46]	7	5
7	Early and effective use of information technology	[22,24,25,43,47–49]	7	5
8	Adequate knowledge and experience of relevant players	[13,25,29,31,41,50,51]	7	5
9	Extensive and effective project planning, scheduling and implementation	[21,22,24,26,41,52]	6	9
10	Effective risk management	[13,22,43,50,51,53]	6	9
11	Early definition of project scope and budget	[13,20,21,26,44,51]	6	9
12	Capability and experience of modules fabricator (s)	[13,34,50,51,53,54]	6	9
13	Adequate transport infrastructure and modular installation equipment	[13,34,50,51,53,55]	6	9
14	Early advice from MiC design professionals	[27,36,53,56,57]	5	14
15	Top-management support, commitment, and involvement in the supply chain	[20,27,34,55]	4	15
16	Early involvement of fabricator	[13,50,51,53]	4	15
17	Systematic economic analysis and early decisions	[21,26,41,58]	4	15
18	Avoidance of owner delays	[13,50,51,53]	4	15
19	Module envelope limitation	[13,50,51,53]	4	15
20	Reasonable lead time to allow for prototyping and trials	[31,59]	2	20
21	Efficient logistical services	[53,60]	2	20
22	Effective coordination of on-site and off-site activities	[31,46]	2	20
23	Design compliance with relevant codes, procedures, and efficient statutory verification	[46,61]	2	20
24	Effective management of dimensional tolerances	[17,62]	2	20
25	Adequate modular design codes, specification and regulations	[46,61]	2	20

3.2.3. Effective supply chain management

MiC is associated with a complex supply chain and stages to be coordinated and managed. Effective supply chain management ranked 3rd among the 25 shortlisted KSFs and was cited in 10 empirical studies. The MiC supply chain can be reified as modular design, engineering, production, transportation, and on-site assembly. These stages are fragmented but interdependent within the supply chain. Disturbances in the upstream segments could compromise the performance of downstream supply chain segments [6]. For instance, timely delivery of modules to the site is required for continuity of the project and this also depends on the reliability of the off-site modular production and logistics efficiency. Thus, effective coordination and management of the supply chain segments, the associated stakeholders and events are critical for the success of MiC projects, irrespective of project type or territory [6,11].

3.2.4. Early design freeze and completion

This KSF was cited in 10 empirical studies and ranked 3rd among the 25 shortlisted KSFs. Considering the current lower level of standardization, each MiC project requires separate design and production of specific modules to be used in any project. Therefore, early design freeze is required prior to the fabrication and production of the modules [33]. This stage is critical because all the major downstream supply chain stages depend on the timely design freeze. Subsequent changes to the design could engender significant risk to the time and schedule of the MiC project [6,11]. Thus, developers, owners, and housing authorities need to give due consideration to this KSF to realize the time savings benefits of the MiC approach.

3.3. Conceptual Model of the KSFs for Implementing MiC Projects

To facilitate a better understanding of the nature of the KSFs for implementing MiC projects, it is useful to represent the shortlisted KSFs in a conceptual model highlighting their clusters and interactions. Following a detailed evaluation of the 25 KSFs, it is found that each KSF is associated with people (stakeholders), process (supply chain) or technology.

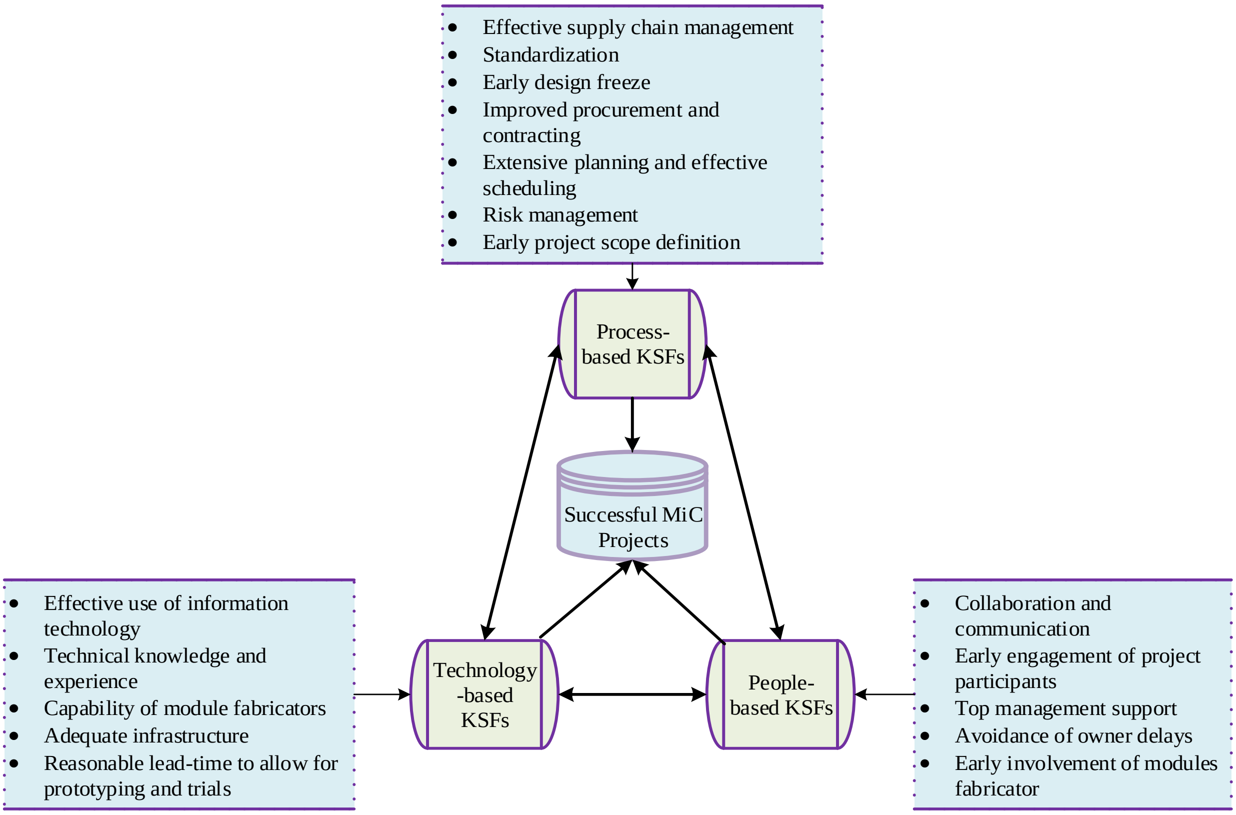

Figure 2. Conceptual model of the key success factors for MiC Projects

Although some KSFs could be well-placed under two or all these components, the authors have allocated each KSF to one cluster to facilitate improved understanding of the nature of each KSF. Figure 2 is a conceptual model showing the interactions among the people, process, and technology-related KSFs for implementing MiC projects. It is useful to highlight the complimentary KSFs because it will allow for the strategic allocation of resources to achieve a competitive advantage. It also highlights the key interactive results areas which could be prioritized to reap the benefits of other KSFs. Figure 2 shows that there are interdependencies among the people, technology and process-related KSFs. For instance, the effective use of technology such as building information modeling improves collaboration and communication among project participants [49] and facilitates the coordination and management of the MiC supply chain and associated risks [49,63]. Additionally, early engagement of participants would facilitate early design completion and freeze [33]. Early involvement of the modules fabricator could significantly reduce risk of dimensional and geometric tolerances [17,62]. Among the process KSFs, standardization improves supply chain management through reduction of the need to fabricate unique modules for each MiC project [18,19]. Among the people KSFs, top management support is required to allow for early engagement of relevant project participants in the conceptual design, planning and construction stages [27].

4. CONCLUSION AND FUTURE RESEARCH

If effectively implemented, MiC shortens construction time, improves working environment & site safety, offers improved sustainability & cleaner construction process, generate high construction quality and better management. However, several key management factors need to converge to realize the full benefits of MiC. Considering that MiC is fledgling in some economies such as Hong Kong, the construction industry can benefit from a thorough understanding of the factors which are critical to the success of MiC projects. Despite some casualties, MiC projects have been successfully implemented elsewhere. However, the KSFs for implementing MiC projects are yet to be reviewed and modelled. This research identified, summarized and integrated the KSFs for implementing MiC projects through the lens of systematic review methodology. Drawing on a sample of 47 empirical studies, the study synthesized 25 KSFs for MiC projects. Of these, the top 5 most cited KSFs are *effective working collaboration and communication among project participants; standardization, optimization, automation and benchmarking of best practices; effective supply chain management; early design freeze and completion; and efficient procurement method and contracting.* The study further proposed a conceptual model of the KSFs highlighting their interdependences in the implementation of MiC projects. Although the appropriateness of the KSFs in any context was not verified, the set of KSFs are practically relevant as they constitute a checklist of items for management to address and deal with during the planning and execution of MiC projects. The common framework of the KSFs develop would provide a useful basis for future empirical studies on the KSFs for implementing MiC. One potential impact of the study is that it may inform, guide and improve the successful implementation of MiC projects in the construction industry. However, the rigor of the analysis, relative importance ranking and systems dynamic modelling of the KSFs were limited due to the absence of empirical data. Future empirical research will (i) quantitatively evaluate and rank the KSFs using primary industry data, (ii) identify the key success processes for the KSFs, (iii) quantitatively assess and establish the interactions among the KSFs, and (iv) develop MiC project success model based on a multi-criteria decision analysis.

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