Critical success factors for modular integrated construction projects: A review

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ABSTRACT

Modular integrated construction (MiC) is an innovative construction approach which transforms the fragmented linear site-based construction of buildings into an integrated production and assembly of value-added prefabricated prefinished modules. As MiC has gained attention in the construction industry, more in-depth knowledge of the critical success factors (CSFs) for implementing MiC projects is imperative. This research reviewed studies on the CSFs for implementing MiC projects during the period 1993 to 2019. Analysis showed that the U.S., U.K., Malaysia, Australia, and Hong Kong are the largest contributors to the MiC CSFs studies. Further analysis generated 35 CSFs for implementing MiC projects. Of these, the six most cited CSFs shared between countries and MiC projects include good working collaboration and effective communication among project participants; effective supply chain management; accurate design and early design freeze; involvement of key project participants throughout the project; suitable procurement strategy and contracting; and standardization & benchmarking of best practices. These shared CSFs can be used to develop decision support systems, enabling the prediction of project success. The developed checklists and conceptual model of the CSFs could help to guide and improve the successful implementation of MiC projects and may form a useful basis for future empirical studies.

Keywords: critical success factors; implementation; modular integrated construction; review

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Introduction

Although the construction industry is conservative and slow in the adoption of innovative technologies (Ruparathna & Hewage, 2015), the sector is witnessing a paradigm shift and transition towards industrialized construction (Hwang, Shan, & Looi, 2018b; Jonsson & Rudberg, 2015). Industrialized construction offers the promises of revolutionizing the way building projects are designed, procured, engineered, constructed, and managed in the architecture, engineering, and construction (AEC) industries. The last couple of decades witnessed a renaissance of offsite construction (OSC) within the industrialized construction movement towards addressing some of the ill-performances of the stick-built construction approach. Modular integrated construction (MiC) is a typical OSC technique with the greatest integration of value-added prefabricated prefinished modules. MiC is considered as the highest order of prefabricated construction (Pan & Hon, 2018) and the most complete form of OSC where 80-90% of a whole building can be engineered in an offsite factory (Smith, 2016).

Where circumstances merit and favourable conditions prevail, MiC offers significant opportunities to improve construction project performance (Song, Fagerlund, Haas, Tatum, & Vanegas, 2005). According to the Construction Industry Council (2018), the effective implementation of MiC results in speedy construction, improved construction quality, improved working environment and site safety, reduced carbon emissions, reduced construction waste, improved sustainability and environmental performance, better project management, improved construction productivity, and reduced lifecycle cost. Although rapid advancement of MiC will continue to leverage change and innovation in the AEC industries, the lack of widespread adoption is partly linked to some complexities and uncertainties associated with its implementation (Wuni, Shen, & Mahmud, 2019). MiC is increasingly becoming a preferred construction method for most OSC projects, with concomitant commitment to its implementation, but some of the executed projects have not achieved the desired level of success and performance (Choi, O'Connor, & Kim, 2016).

The success of MiC projects is a function of the convergence of several key factors during its implementation. MiC project success means realization of project objective (s) and the expectations of project participants. These expectations may differ for owners, project managers, engineers, fabricators and contractors (Sanvido, Grobler, Parfitt, Guvenis, & Coyle, 1992) but MiC project success results from a combination of events and interactions which are associated with changing participants and processes in a constantly changing environment. Despite some problems, MiC projects have been successfully undertaken in many countries, but the factors that accounted for the successes are not entirely known. One effective mechanism for improving MiC project success is to obtain a deeper and richer knowledge of the critical success factors (CSFs) which could be prioritized in its implementation. The concept of CSFs in the management of projects emerged in the 60s (Rockart, 1982; Sanvido et al., 1992) and have proven useful in improving project success. CSFs are the few key areas that should be given sustained commitment and management attention to ensure the success of MiC projects (Martin, 1982; Mohr & Spekman, 1994; Rockart, 1982). Martin (1982) described the CSF methodology as a powerful management decision-making tool and procedure which makes clear the specific essential activities which should be benchmarked and prioritized to achieve higher project success.

As MiC has gained attention in the construction industry, a deeper and richer knowledge of the critical success factors (CSFs) for implementing MiC is imperative (Choi et al., 2016; Wuni, Shen, & Mahmud, 2019). However, despite the increased academic attention, a systematic review of the CSFs for MiC projects is not well-established. This research conducts a systematic review of the studies on the CSFs for implementing MiC projects to offer both practitioners and researchers the few key areas and set of conditions or factors that when thoroughly and completely satisfied on an MiC project results in its success. In doing so, the paper seeks to pursue the following specific research objectives: (i) to identify the annual research publications trends on the CSFs for MiC, (ii) to identify the geographical distribution of the studies on CSFs for MiC, (iii) to identify, summarize and integrate the CSFs for MiC into a checklist, and (iv) to propose a conceptual model mapping the interlinkages among the CSFs for implementing MiC projects.

The checklists of CSFs for MiC implementation would be useful to researchers in conducting further empirical research studies. Additionally, the conceptual model highlighting the interlinkages of the CSFs for MiC projects would help practitioners to further understand the few key mutually reinforcing and complimentary areas that should receive strategic resources allocation to achieve comparative and competitive advantage. Although the CSFs for MiC are sensitive to project types, project phases, and territories, a common framework and checklists will be useful to practitioners, stakeholders, and researchers, especially in areas where bespoke research is not entirely feasible or economical.

Research Background

Modular integrated construction

MiC is a revolutionary technology and construction business model which embraces and integrates the theories of modularity and modularization into the building construction process. Although there are no universal definitions for *modularity* and *modularization* in the building construction parlance (Baldwin & Clark, 1997; Gosling, Pero, Schoenwitz, Towill, & Cigolini, 2016), some comprehensive definitions are available. Baldwin and Clark (2000) defined modularity as the systematic disintegration of a complex system into discrete components, which interact with each other through standardized interfaces, rules, and specifications. A complex system is one composed of many components which may interact with each other such that the whole systems function more effectively than the sum of the individual parts in the weak (Simon, 1962). Based on this assertion, buildings are equally complex systems since the components can be designed independently but still function together as an integrated whole (Baldwin & Clark, 1997; Baldwin & Clark, 2000; Gosling et al., 2016). This partly explains why the concept of *modularity* applies to building construction. As complex systems can be better managed through breaking them up into smaller elements and looking at each separately (Baldwin & Clark, 1997), *modularity* hides the complexity of each element beyond a certain threshold through its isolation and replacement with an abstracted simpler interface (Baldwin & Clark, 2000). Haas et al. (2000) defined modularization as "*the pre-construction of a complete system away from the job site that is then transported to the site".* Modularization involves large modules which often need to be broken down into several smaller components to facilitate transportation to the job site (Haas et al., 2000). Modularization decreases the complexity of a system by integrating its smaller subsystems called *modules* (Baldwin & Clark, 1997).

Thus, MiC is defined as a construction approach "whereby free-standing integrated modules (usually completed with finishes, fixtures, and fittings) are manufactured in a prefabrication factory and then transported to site for installation in a building" (Hong Kong Buildings Department, 2018). The common types of MiC include reinforced concrete modules, steel frame modules, and hybrid modules. According to Gibb (2001), the pre-assembly degrees of the modules in MiC includes component manufacture and subassembly (e.g. bricks, windows), non-volumetric preassembly (e.g. wall panels, structural frames), volumetric preassembly (e.g. shower rooms, toilet pods) and modular buildings (e.g. complete modular building). To improve understanding of these levels of off-site assembly in MiC, Jonsson & Rudberg (2015) modified Gibb's (2001) production system classification as components manufacture & subassembly (CM&SA), prefabrication & sub-assembly (PF&SA), prefabrication & preassembly (PF&PA), and modular buildings. Thus, Jonsson & Rudberg's (2015) classification improved the differences between the volumetric preassembly and modular building echelons in Gibb's (2001) classification. However, MiC requires the total integration of all subsystems and components into an overall building system utilizing industrialized production, transportation, and assembly techniques. It has been argued that MiC, prefabricated construction, prework, modular construction, industrialized building systems, and prefabricated prefinished volumetric all constitute offsite industrialized construction techniques (Pan, 2006). However, MiC constitutes the highest order of the OSC techniques with the greatest integration of standardized units (Pan & Hon, 2018). The goal of MiC is to produce industrialized building systems where the same details generate diversified and highly individualized flexible, demountable and adaptable buildings (Richard, 2006). Thus, there are significant differences between MiC and the cast in-situ construction method (CCM). The differences are overt in the characteristics of the construction processes and the end-products (Jonsson & Rudberg, 2015). For instance, the characteristics of MiC products are inclined to higher degrees of standardization and customization than those of the CMM (refer to Jonsson & Rudberg (2015) for detailed classification of construction production systems)

Firstly, the general processes of MiC often involve project design, seeking of statutory approvals, production, transportation and job site assembly & installation of modules which significantly differ from those of the CCM. Thus, the supply chain of MiC comprises modular design, procurement, engineering, manufacturing, transportation, buffer, storage and on-site assembly (Li et al., 2016). These stages involve a complex web of multidisciplinary practitioners and stakeholders with their unique goals and value systems which needs to be managed (Luo, Shen, Xu, Liu, & Wang, 2019). The increased complexity in the management of MiC stakeholders results in various risks and uncertainties (Li et al., 2016). Secondly, as the modules are produced based on an assembly line in a factory, MiC may embrace the engineer-to-order manufacturing process (Bortolini, Formoso, & Viana, 2019), job-shop scheduling and draws on the Design for

Manufacture and Assembly (DfMA) philosophy (Hsu, Angeloudis, & Aurisicchio, 2018). In practice however, workshop production of the modules is a common approach. Another common practice is the use of both the workshop production and the mixed model assembly line production in the assembly of modules. Since the modules are usually made-to-order and designed to be used exclusively in a specific MiC project, scheduling must be configured such that the quantity of each module produced precisely matches its optimum requirement in the project so that its inventory returns to zero on completion of the project (Hsu et al., 2018). This unique scheduling requirement is different from those of the CCM, requiring entirely different management strategies.

Critical success factors

Although success and failure factors in project management were recognized earlier in the academic literature (Rubin & Seelig, 1967), it was not until the 1980s that the phrase "critical success factors" was formalized (Rockart, 1982). Rockart (1982) codified CSFs as the "few key areas of activity where favourable results are absolutely necessary for a manager to reach his/her goals". According to Martin (1982) and Mohr & Spekman (1994), CSFs constitute the key results areas which should be prioritized to achieve success on a project. CSFs constitute a powerful project management tool for minimizing project failures and as such, received a profound attention of researchers in the construction management domain (Antwi-Afari, Li, Pärn, & Edwards, 2018; Osei-Kyei & Chan, 2015). In practice, CSFs are relatively few in number and usually ranges between 5 and 10 (Freund, 1988). However, the relative importance of CSFs are unique to each project type and territory (Toor & Ogunlana, 2009). Notwithstanding, some projects share CSFs and thus, there has been increasing number of reviews on CSFs in the construction management domain (Akagi, Murayama, Yoshida, & Kawahata, 2002; Mydin, Nawi, Yunos, & Utaberta, 2015; Ojoko, Osman, Abdul Rahman, & Bakhary, 2018; Sharafi, Rashidi, Samali, Ronagh, & Mortazavi, 2018). For instance, Osei-Kyei & Chan (2015) reviewed 27 empirical studies and established a framework of 37 CSFs for implementing public-private partnership projects whereas Antwi-Afari et al. (2018) reviewed 37 articles and established a framework of 34 CSFs for implementing building information modelling.

Moreover, due to the differences between the CCM and MiC, the CSFs for the former are not directly applicable to the latter and hence, researchers have recognized the need to identify and examine the CSFs for implementing MiC projects in different countries. Over the last three decades, researchers have explored the CSFs for different MiC projects. For instance, O'Connor, O'Brien, & Choi (2014) reported that the CSFs for industrial MiC projects include timely design freeze, early recognition and planning, module envelope limitation, consensus of key players on project drivers, and adequate resources of owners. For petrochemical MiC projects, Murtaza, Fisher, & Skibniewski (1993) found that the CSFs are early design freeze, standardization, owner's resources planning and decision support systems, capability and experience of modules' fabricator, availability of local transport, early involvement of top management, and availability of trained workforce & skilled supervising team. Kamar, Alshawi, & Hamid (2009) identified the top 6 CSFs for residential MiC projects in Malaysia to include training, contractor leadership, information technology, cost management, supply chain management, and site management. In fact, researchers have identified the CSFs for MiC projects in developing and developed countries for different project types and stages.

However, these studies are wide and scattered. Thus, it is challenging for researchers and practitioners to identify the CSFs for MiC projects that are shared among project types, stages, and territories. As MiC is gaining increasing attention, it is necessary to establish a common framework of the CSFs through a systematic review and synthesis of the findings in the diverse studies across the different spatial continuums.

Research methods and approach

Research paradigm and design

This paper is situated within the realist research paradigm; a philosophical stance which is immune to the limitations of the first generation paradigms such as pragmatism and transformative stances and provides legitimacy for the use of mixed methods in a single study (Hall, 2013). Based on the epistemology of realist stance, the paper adopted a systematic review research design which deploys systematic methods to collect, critically appraise, and synthesize both qualitative and quantitative findings (Webster & Watson, 2002). The realist stance was adopted to allow for the synthesis of both qualitative and quantitative studies within the review.

Figure 1

The systematic literature review (SLR) methodology is a powerful tool which has been used in the construction engineering and management (CEM) domain to establish the boundaries of existing research and identify areas for future research considerations (Wuni, Shen, & Osei-kyei, 2019). Without systematic reviews, theory building and development in the CEM research domain will continue to be compromised as the field naturally breeds a community of strict empiricism; an entrenched convention which retards theoretical progress of the field. Thus, this paper provides a systematic review of the CSFs for MiC based on a comprehensive methodological framework comprising the selection of academic databases and literature search, the definition of inclusion and exclusion criteria, and meta-synthesis. Figure1 shows the methodological framework for the study.

Selection of academic databases and literature search strategy

According to Baker (2016), the consideration of multiple databases is imperative in a systematic review to achieve a comprehensive retrieval of the relevant articles. Prior to the literature search the authors conducted preliminary unconstrained search queries in powerful CEM databases such as Scopus, Engineering Village, Web of Science, ASCE library, Science Direct, Taylor and Francis, and Emerald Insight using the keywords “critical success factors” and “modular construction”. The aim was to identify the database with the widest coverage of the relevant articles. Xiong et al. (2015) conducted a similar preliminary query in these databases in their review of the application of structural equation modelling in construction management research. Although it is useful to consider multiple databases in a single review (Baker, 2016), this study adopted the one with the widest coverage because majority of the CEM articles are contemporaneously indexed in all these databases.

Again, the use of a single database facilitates replicability of the search process and have been widely practiced in previous CEM reviews (Wuni, Shen, & Osei-kyei, 2019). Following the preliminary search, Elsevier’s Scopus generated the highest coverage of articles and thus, it was solely adopted for the study. Considering that the algorithm-driven database search alone is not sufficient for literature retrieval in SLRs (Greenhalgh & Peacock, 2005), this study used both protocol-driven algorithm and snowballing search strategies to retrieve relevant articles. The latter allowed for the inclusion of relevant articles which were outside the scope of the predefined search keywords whereas the former allows for repeatability of the search process. Figure 2 is a flowchart of the systematic literature search process and the articles screening protocol. For comprehensive coverage, the “title/abstract/keyword” field of the Scopus search engine was deployed to search for multiple sets of keywords by deploying the Boolean concatenator “OR & AND”. The search strategy did not specify any range of years because that would have constrained the search results. However, the target documents were restricted to research articles (ar) and conference papers from top rated proceedings.

Figure 2

The full search algorithm included: TITLE-ABS-KEY (“critical success factors” OR “success factors” OR “critical factors” OR “few key areas” OR “key result areas” OR “decision support”) 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”).

Again, target journals were not specified because, from experience, relevant articles sometimes get published in journals outside the restrictions. As such, the researchers assessed each article against its merit. The search also targeted articles published in the English Language because it is the most widely used scientific language. These restrictions resulted in the retrieval of 143 Scopus records (Figure 2). Following a rapid screening of these articles, 66 articles were downloaded for full-text evaluation against the inclusion and exclusion criteria.

Specification of inclusion and exclusion criteria

In systematic reviews, the inclusion and exclusion criteria constitute the basis for reducing the retrieved population of articles to the actual sample used in the study (Wohlin, 2014). It constitutes one useful parameter for selecting quality research studies for inclusion in a systematic review. The two main inclusion criteria in the study were: (i) the article should constitute an empirical study on the CSFs for MiC and (ii) the article should be published in a peer-review journal or rated conference proceeding. As such, the authors excluded review articles, and lecture notes. After the full-text evaluation, 40 articles met the specified criteria for inclusion in the study. The initial set of articles (40) constituted useful reference sources for retrieving other relevant articles. Based on the recommendations of Wohlin (2014), the authors conducted a snowballing search on the initial set of articles. The snowballing search is an iterative manual search for relevant articles drawing on the references lists of each paper and their citing articles (Webster & Watson, 2002). The retrieved articles also constituted a further sample for the snowballing process. On reaching the saturated point (when no new articles or findings were found) of the snowballing search, an additional 15 relevant documents were found including industry reports, books and Theses. This increased the actual sample for the study to 55 articles. Table 1 shows the bibliographic summary of the included studies. This sample compares satisfactorily against previous CEM reviews such as 27 (Osei-Kyei & Chan, 2015) and 34 (Antwi-Afari et al., 2018). These articles were fully evaluated, and the relevant metadata was extracted for further analysis.

Analytical procedure and methods

The paper adopted a meta-synthesis as the analytical approach and thematic content analysis as the organizing framework. According to Baker (2016), meta-synthesis is a powerful tool which allows for the integration of qualitative and quantitative findings in a review study. Unlike meta-analysis, meta-synthesis provides a framework for synthesizing studies with disparate designs and inconsistent outcomes (Baker, 2016). Drawing on the meta-synthesis methodology, the analysis initiated with the specification of units of analysis and metadata extraction.

Table 1

Based on the research objectives, the authors extracted the year of publication, the context of the study, and the reported CSFs in each study. The study then deployed the thematic content analysis framework to resolve the variations and inconsistencies in the way similar CSFs were reported in the different studies. During the metadata extraction, the study developed a concept matrix augmented with units of analysis (Webster & Watson, 2002) to organize the CSFs. Within the concept matrix, each CSF was catalogued against the citing sources. Thus, the frequency of occurrences of each CSF was computed and ranked to ascertain the most cited CSFs.

To provide a deeper understanding of the CSFs, the research further proposed a stage-gate model and a conceptual causal loop model of the CSFs. According to Jagoda & Samaranayake (2017), a stage-gate model partitions a complex process into stages, levels and gates. It allows for detailed analysis of the distinct stages of a whole process. As a result, the stage-gate model classified the CSFs across the major stages of the construction process. Although the gates of the model could have been the distinct segments of the MiC supply chain comprising modular design and engineering, manufacturing, transportation, buffering, storage, and on-site assembly, the authors found it necessary to classify the CSFs according to the major phases of building construction. Thus, the model comprises project conception & planning stage/gate, design & procurement stage/gate, and construction stage/gate. The stage-gate model of the CSFs is shown in Figure 7.

A conceptual causal loop model was also proposed to explore the interactions and interdependences of the CSFs for implementing MiC based on systems dynamic (SD) modelling. During the mid of the 20th Century, Professor Jay W. Forrester pioneered SD as a mathematical, simulation, and dynamic modelling tool for understanding the complex behaviour of systems using feedback theory (Forrester, 1968). Traditionally, SD explores policy implications and cause-effect under different scenarios using nodes, arrows (connectors), arithmetic signs, mathematical equations, stock and flow diagrams, causal loops, and simulation models. The main stages in the development of an SD model include initial scoping, consensus building, and quantitative modelling (Costanza & Ruth, 1998). However, the conceptual causal loop model of the CSFs involved the first two stages since there was no data to support quantitative modelling. Thus, model comprises nodes and arrows which form a feedback loop of the CSFs highlighting their hypothetical linkages. Each node represents a CSF and an arrow shows the direction of influence between the two nodes. A plus sign (+) on an arrow means the incoming node (CSF) improves the performance of the second node (CSF) whereas a negative sign (-) means the incoming node (CSF) retards the performance of the receiving node (CSF). These nodes and arrows together generate feedback loops which may be balancing or reinforcing. These two foundational structures of systems thinking do not describe the behaviour of the system (Costanza & Ruth, 1998), but only highlights the hypothetical links among the CSFs for MiC projects. A reinforcing loop is one in which a CSF produces results which influences more of the same CSF, resulting in growth or decline whereas a balancing loop is stabilizing, or goal-seeking and resist change in one direction by producing a change in the opposite direction. Figure 8 is the conceptual causal loop of the CSFs for implementing MiC projects. The model was developed using Vensim PLE 7.3.4 (single precision); a powerful tool which supports system dynamic modelling.

Review Analysis and Findings

Annual publications trend on CSFs for MiC projects from 1993 to 2019

Drawing on the algorithm-driven search in Elsevier's Scopus and the snowballing search strategy, a total of 55 publications spanning between 1993 and 2019 were included in the study. The annual publications trend on the CSFs for MiC projects during the period 1993 to 2019 (years inclusive) is shown in Figure 3. These publications include journal articles (38, 69.09%), conference papers (7, 12.73%), industry reports (7, 12.73%), books (2, 3.64%) and a Ph.D. Thesis.

Figure 3

Although journal articles are usually prioritized in systematic reviews because such are deemed certified knowledge (Wuni, Shen, & Osei-kyei, 2019), the inclusion of the other documents (e.g. industry reports) in this study was intended to provide a wider perspective of the CSFs for MiC projects. It should be reiterated that the proportion of journal articles alone in the actual sample exceed the total samples in some published CEM review articles such as the cases of Antwi-Afari et al. (2018) and Osei-Kyei and Chan (2015). Figure 3 shows a sinusoidal annual publications trend on CSFs for MiC during the 26-year period (1993 – 2019) but a general increasing trend is observed in the number of annual publications, especially during the last decade (2009 – 2019). Figure 3 also highlights that CSFs for MiC projects first gained interest among researchers during the last decade of the 20th Century (1993-2000). However, articles were only published in 1993 and 1998 – 2000. During the first decade of the 21st Century (2001 – 2010), researchers became more interested in understanding the CSFs for MiC projects. During this decade, an average of 2 articles on the CSFs for MiC projects were published each year but the last decade (2009-2019) recorded a higher annual average of publications of 3 articles each. This highlights the rising interest of researchers in understanding the key few areas that should be given sustained attention to ensure the success of MiC projects in recent times. Particularly, the last decade (2009-2019) constitute the highest proportion (46, 83.6%) of the included studies. This confirms Choi et al. (2016) that there is a rising interest among researchers towards understanding the recipes for the successful planning and execution of MiC projects following the renaissance of the approach. Thus, this study is timely and relevant in contributing to the MiC implementation discourse.

Geospatial distribution of the publications on the CSFs for MiC projects

Research publications constitute one dimension in which universities and researchers contribute to industry practices, business models innovation and policy decision-making (Cohen, Nelson, & Walsh, 2002). Wuni et al. (2019) highlighted that the contribution of a country in a research domain reflects the commitment and progress of the region to that initiative. Thus, it is useful to highlight the geospatial distribution of the studies on the CSFs for implementing MiC projects. This was achieved by extracting the geographical context of each included study rather than the regional affiliations of the researchers. Figure 4 shows the geospatial distribution of the included studies. It is observed in Figure 4 that the 55 publications were conducted in 16 different countries comprising developing, transition and developed economies. Thus, the sample offers a representative coverage of the wider perspective of the CSFs for implementing MiC projects. Figure 4 further shows a parade of giants and dwarf of the territorial contributors. The least territorial contributors include Israel, Thailand, the Netherlands, Turkey, Korea, Italy, Nigeria, and Singapore with 1 publication each whereas the five giant contributors to the MiC CSFs research discourse include the U.S. (14), U.K. (11), Malaysia (7), Australia (5), and Hong Kong (4). The major contributing countries constitute a significant proportion of the front liners spearheading the promotion and development of MiC. Thus, synthesizing CSFs for MiC from these countries could reflect the international best lessons which could guide future MiC projects implementation.

Figure 4

The United States has been promoting PPMOF – prefabrication, preassembly, modularization, and offsite fabrication (prework) since the 20th century (Warszawski, 1999) and succeeded in applying the principles of modularization to several industrial projects (Choi & O’Connor, 2014; Haas et al., 2000; O’Connor et al., 2015, 2016). Similarly, the use of off-site production and modern methods of construction in the United Kingdom dates to the 20th century (Gibb, 1999). Following the renaissance of OSC, MiC has been widely promoted and implemented in China (including Hong Kong SAR) (Pan & Hon, 2018), Singapore (Hwang et al., 2018b), Australia (Blismas, Pasquire, & Gibb, 2006), Japan (Barlow et al., 2003), Malaysia (Kamar et al., 2010), Sweden (J. Lessing et al., 2005), and Korea (Lee & Kim, 2017), albeit under different brand names. Some of these include modular construction (Canada, Korea), prefabricated prefinished volumetric construction (Singapore), industrialized building systems (Malaysia), industrialized housing construction (Switzerland, Sweden, Finland), Prework or modularization (United States), Systems building (Mauritius), modern methods of construction (UK), MiC (Hong Kong), and offsite manufacture (Australia) Thus, the CSFs identified in this study reflect the findings of research works conducted in these countries with several years of experiences and lessons in the implementation of industrialized construction techniques.

Target project applications on CSFs for implementing MiC

Critical success factors (CSFs) for MiC differ across project types, objectives and stages. The differences may be more pronounced considering that not all circumstances currently merit modularization and MiC. To highlight the type of projects for which researchers examined the CSFs for MiC, Figure 5 shows the distribution of publications based on the target project applications. Figure 5 illustrates the wider usage of MiC for residential building projects (32, 58.18%). Studies that surveyed diverse stakeholders and practitioners in the construction industry without disclosing the type of project (s) were classified as multiple projects (11, 20.0%). MiC has also been used for industrial projects (5, 9.09%), especially in the United States (Choi et al., 2016; O’Connor et al., 2015, 2016; Song et al., 2005). The wider assessment of CSFs in residential MiC projects may be due to the commitment to addressing housing shortages in many countries using mass production and modularization techniques (Arif & Egbu, 2010; Kamar et al., 2010; Lessing et al., 2005; Li et al., 2018).

Figure 5

This is quite justifiable because MiC is more appealing to projects with repetitive designs and quality such as student residences, residential estates, and social housing (Hwang et al., 2018b). However, aggregating CSFs for these diverse MiC project types is theoretically plausible because lessons and best practices from one project type may be useful to several other project types. As such, a common framework of the CSFs for implementing MiC drawing on the diverse project types is quite useful. This integrated approach renders the study as a useful basis for future studies on CSFs for diverse MiC projects.

Previous research instruments used in CSFs for implementing MiC

As a guide for future studies and a highlight of the quality of the included studies, a careful analysis was conducted to ascertain the research instruments used in previous studies to examine the CSFs for implementing MiC. The metadata extraction and synthesis of research instruments revealed that previous studies used several instruments including questionnaire surveys, interviews, case studies, workshops, seminars, focus group discussions, simulations and mixed methods (refer to Figure 6). Although most of the studies deployed mixed methods, Figure 6 shows the unit counts of the individual research instruments used in previous studies.

Figure 6

Of these 7 research instruments, case study (31, 56.36%), interviews (28, 50.91%), and questionnaires (16, 29.09%) were the most used data collection instruments. These instruments (Figure 6) have been described as the most appropriate techniques for identifying CSFs for construction projects (Martin, 1982; Rockart, 1982). The wider use of case studies in previous studies is useful because it allows for an in-depth assessment of a project to identify the CSFs peculiar to that specific project. Typically, case studies are widely used for such purposes in the CEM research domain (Antwi-Afari et al., 2018; Osei-Kyei & Chan, 2015). Additionally, several studies used questionnaires surveys and interviews to solicit opinions on CSFs for implementing MiC projects from experts and practitioners. Considering that CSFs is a management decision-making tool, the use of questionnaires, interviews, workshops, group discussions and seminars in previous studies is quite appropriate. However, each of these instruments has its unique merits and demerits and their usage in future studies should be grounded on sound justification.

Analysis and ranking of the CSFs for implementing MiC projects

Drawing on the meta-synthesis of the findings in previous studies, Table 2 is a summary of the CSFs for implementing MiC projects, concomitant with the references for each CSF. For prioritization, the CSFs were integrated, analysed and ranked based on the frequency of occurrence in the 55 included studies. It is recognized that a quantitative meta-analysis or meta-synthesis is most appropriate for ranking factors in systematic reviews, but this was constrained because very few studies reported the means, standard deviations, and effect sizes of the CSFs. The basis of ranking in this study is plausible because previous reviews on CSFs have relied on the frequency of occurrence to rank the factors (Antwi-Afari et al., 2018; Osei-Kyei & Chan, 2015). Table 2 shows the ranking of 35 CSFs for implementing MiC which has been cited in at least 2 previous studies. Although this is not a standard rule, the decision to include CSFs which have been cited in at least 2 previous studies was motivated by similar practice in previous CEM reviews (see

Antwi-Afari et al., 2018; Osei-Kyei & Chan, 2015; Wuni, Shen, & Mahmud, 2019). Table 2 shows that several factors drive the success of MiC projects but the six most frequently cited CSFs for implementing MiC projects during the studied period include (i) good working collaboration, effective communication, and information sharing among MiC project participants; (ii) improved supply chain coordination, and management; (iii) accurate design, early design freeze, and timely owner's approval; (iv) fully-integrated approach and involvement of key participants throughout the project; (v) improved procurement strategy and contracting; and (vi) standardization & benchmarking of best practices. Each of these CSFs was cited between 11 and 17 times within the reviewed studies. These CSFs are geospatially insensitive and shared between countries, project stages and project types.

Good working collaboration, effective communication, and information sharing among MiC project participants

The effective and successful implementation of MiC projects requires the commitment of diverse stakeholders and the coordination of multiple trades (Haas & Fagerlund, 2002). As such, strong working relationship, communication and information sharing is paramount to the success of MiC projects (Li et al., 2018). This CSF has been cited in 17 different studies as a key result area that should be managed to ensure the success of MiC projects. At the earliest stage of MiC projects, structural designs including detailed specifications of connections, interfaces, and components need to be communicated between the engineering designer and fabricators to ensure accurate and forgivable dimensional and geometric tolerances between modules (Shahtaheri, Rausch, West, Haas, & Nahangi, 2017). Rentschler et al. (2016) indicated that a joint team of engineering designer, owner, and fabricator at the earliest stage is crucial because sometimes, the modules fabricators have the best design ideas. Thus, it is a risky practice for fabricators to manufacture modules based on design specifications and set of drawings to which they were not privy or involved. The collaboration and effective communication between the design team and the construction team is also crucial because in the absence of this collaboration, the latter will be involved in the assembly of modules to which they were not privy to the design decision-making. Communication and information sharing between logistics company, manufacturers and assembly contractor is paramount to ensure that every participant is abreast of the progress at every stage of the supply chain. The use of real-time radio frequency identification (RFID) and building information modelling-enabled platform allows for progress monitoring and information exchange among project participants in MiC projects (Li et al., 2018; Zhong et al., 2017). Considering that MiC projects involve a complex web of stakeholders with their unique goals and value systems (Luo et al., 2019), effective collaboration is required because the success of the MiC project is largely a function of a team effort rather than the contribution of individual players.

Improved supply chain coordination, and management

Improved coordination and management of the MiC supply chain was cited in 14 of the 55 publications as a key result area which should receive management commitment to improve the success of MiC projects. The MiC supply chain involves fragmented but interdependent segments comprising modular design, engineering, manufacturing, transportation, storage, buffer, and on-site assembly, resulting in several uncertainties which could derail the success of MiC projects (Li et al., 2017). Hwang et al. (2018a) noted that the success of MiC projects requires extensive coordination of these linked supply chain segments prior to and during the construction process. Thus, MiC project planning and control will have to develop strategies to configure, coordinate, optimize and manage the various stages of the supply chain and the associated stakeholders to ensure smooth delivery of the project (Li et al., 2018).

Table 2

This extensive coordination becomes mandatory in regions where the supply chain is incomplete, instructing the engagement of overseas suppliers and expertise (Pan & Hon, 2018). In cases of limited local manufacturing capability and supply of modules, the cross-border procurement of modules will have to be well-planned, coordinated and managed because inefficiencies and anomalies will result in complicated and expensive transportation requirement (Pan & Hon, 2018). Rentschler et al. (2016) recommend that enough time be allocated during upfront planning to assess supply chain options, vulnerabilities, potential disturbances and possible strategies for resilience.

Accurate design, early design freeze, and timely owner's approval

Early design freeze was cited in 11 publications as a critical recipe for the success of MiC projects. According to Gibb and Isack (2003), timely approval of the design by owners and early design freeze generates reasonable lead time and offers the opportunity for mock-ups testing and pre-site prototyping. Considering that MiC projects have shorter lead times (Blismas et al., 2006), accurate design, early design freeze, and owner's approval is necessary to get the next stage (production/manufacturing) of the supply chain hierarchy started. The discipline of contractors and timely approval of the designs are required to allow for the early design freeze to make room for the operations of the modules fabricator (Choi & O'Connor, 2014). As design changes are particularly costly, risky and schedule-sensitive in MiC projects, specification, concept and detailed design freezes should be made early to ensure smooth delivery of the projects. Early design freeze could avoid the risks associated with design changes since it organizes and compiles the design process, control changes, and forces the completion of modular design stages on time. However, the need for the early design freeze should not ignore the design inputs of the relevant project participants. Choi (2014) argued that such accurate and early design freeze should be grounded on best design principles. Akagi et al. (2002) recommend reduced interdependency between elements, controlled design variants, and allowances for changes in the design sequences. This study further recommends the allocation of reasonable allowable tolerance in the robust design selection.

Fully-integrated approach and involvement of key participants throughout the project

Involvement of owners, designers, vendor, and contractors throughout the project phases was also cited in 11 publications as critical to the success of MiC projects. The services and roles of these project participants are not one-off and do not end immediately after their first involvement in the MiC projects. Although this factor appears like the first CSF, the emphasis here is the involvement of the key project participants at all stages of the MiC project. For instance, modular fabricators or manufacturers could support assembly contractors during on-site installation of modules because they engineered the interfaces and are well-informed of the allowable tolerances between the modules than the contractors (Rentschler et al., 2016). Additionally, the involvement of fabricators during the design stage offers the opportunity for the fabricator to establish a prior relationship with the design before actual engineering and production of the modules. The involvement of owners and contractors at the modular design and fabrication stages will allow them to appreciate some technical components of the MiC value chain. The fully-integrated approach will allow clarifications to be offered to project players within the upstream supply chain and create a collaborative and supportive climate for MiC project implementation.

Improved procurement strategy and contracting

One critical consideration in the implementation of MiC is procurement and contracting strategy for module fabrication (Rentschler et al., 2016). It is therefore not surprising that 11 publications cited improved procurement strategy and contracting as a CSF for implementing MiC projects. Pan et al. (2007) argued that irrespective of the strategy adopted, procurement in MiC projects could be improved through the improved cooperation between project parties and effective integration of manufacturers and suppliers in the project decision-making process as early as a possible. Tam et al. (2007) expounded on virtues of using the design-build delivery method for residential MiC projects and highlighted the necessity of involving contractors at the design stage of MiC projects. This assertion is plausible because the design-build procurement method is a proven procurement system for residential housing projects (Toor & Ogunlana, 2009). Unlike the design-bid-build procurement method, the design-build delivery method brings both design and construction function as one team in a single contractual entity to the owner. This procurement strategy creates a team of collaborative problem solvers, allowing the team and the owner to work together from the design through to the successful completion of the MiC project. The design-builder is accountable for the entire project and thus, encourages effective pricing and scheduling throughout the project. This improves workflow continuity, efficiency and effectiveness of the entire MiC project. Essentially, the use of the design-build delivery method in MiC projects is associated with benefits such as reliable expertise, professional guides, owner involvement, collaboration, time savings, cost savings, and effective communication among project participants. These benefits themselves are CSFs for implementing MiC projects. Furthermore, Rentschler et al. (2016) recommended that module fabricators should be offered a greater scope of buying all production materials and manufacturing of the modules in a case where the schedule is critical to avoid the emergence of hindrances to performance. Typically, the success of MiC projects largely depends on the performance of the modules manufacturer (Rentschler et al., 2016). Thus, it is prudent to exercise due diligence in the selection of module fabricators. Of critical importance in the selection of fabricators include past performance in MiC projects, manufacturing capabilities and the scope of work to be subcontracted. However, once fabricators are selected, there should be less interference in their work since the modules constitute the primary driver in the overall MiC project.

Standardization & benchmarking of best practices

One of the biggest constraints which render MiC projects less competitive is the acclaimed higher direct cost of construction (Hwang et al., 2018a). This reality is partly due to the lower level of standardization in the modules and the diseconomies of scale in fledgling MiC markets (Barlow et al., 2003; O'Connor et al., 2015). Indeed, Jonsson & Rudberg (2015) documented that the mismatch between the market requirements and degree of modular design standardization constraints the realization of the full benefits of MiC. Thus, standardization and benchmarking of best practices was cited in 11 publications a CSF for MiC projects. Standardization of the design and modules for MiC projects involves maintaining their uniformity and consistency. This standardization will not generate monotonous design and products because the outputs of MiC are industrialized systems which are customizable. Thus, same design details and standardized modules could generate highly individualized and diversified MiC projects (Richard, 2006). Standardization reduces the tendency of producing unique modules to meet the specification of each MiC project. Warszawski (1999) concurred that standardization of the design and modules allow for efficient allocation of resources. Traditionally, standardization results in cost reduction since bulk quantities are produced from same materials, equipment and processes. It improves the efficiency of producing the modules due to mass manufacturing, specialization of labour, and automation of the production processes. Effectively, standardization allows for the adaptation of labour skills, equipment and production process to meet the demands of the MiC project. Through benchmarking best practices, the success of MiC can be significantly improved (Hwang et al., 2018b; Murtaza et al., 1993).

Stage-gate framework of the CSFs for implementing MiC projects

The construction of MiC projects does not involve a single discrete event. It involves a series of phases which collectively determine the success of the final project outcome. Effective management of the distinct phases and stages of the project are crucial to the success of MiC projects. Thus, it is useful to attempt to delineate and classify the CSFs across the distinct stages of the MiC project. Figure 7 is a stage-gate framework which allocates the CSFs across the different phases of the MiC project. The framework comprises the conception & planning stage/gate, design & procurement stage/gate, and the construction stage/gate. In this paper, the conception & planning stage includes project conceptualization, planning and conceptual design; the design & procurement stage include programming & feasibility, schematic design, modules design & engineering, and contract documentation; and the construction stage include modular production, transportation, storage, and on-site assembly/installation.

Figure 7

From Figure 7, the first phase involves the conception & planning gate. This is an important phase in the MiC projects and its success may influence the total success of the MiC project. Management of the early stages of the MiC project life cycle is essential because empirical evidence of MiC project performance has consistently demonstrated that ultimate project success and failure can often be traced back to decisions at and management of the early stages of the project life cycle (Hwang et al., 2018b; Murtaza et al., 1993). This is particularly important because not every condition and circumstance renders MiC as a competitive construction approach (Wuni, Shen, & Mahmud, 2019). From Figure 7, a prominent CSF at this stage is the realistic systematic economic analysis (CSF#26). This will allow the owner and relevant players to ascertain the benefits of using MiC in the project and whether the project lends itself to modularization (Choi & O’Connor, 2014; Murtaza et al., 1993). This could be achieved through intensive early research on modularization (CSF#31) and early advice on modularization consideration from MiC design experts and professionals (CSF#18). During this phase, it is essential and useful to clearly define the project engineering scope, planning and budget (CSF#14), critically align the MiC project drivers (CSF#17), and ensure that key decisions are understood by all involved parties and made as early as possible (CSF#30). The success of this phase also requires good working collaboration and effective communication among project participants (CSF#18), top management support and involvement (CSF#13) and effective management of the involved stakeholders (CSF#10).

The second phase is very critical in MiC projects because there is little flexibility after the design is completed and frozen (Hwang et al., 2018b; Song et al., 2005). Availability of modular design codes and specifications (CSF#35) is critical to the success of this phase because it will ease the permitting and statutory approval process (Murtaza et al., 1993). Owner delay avoidance

(CSF#24) is required to ensure early design freeze (CSF#8). The success of this phase also requires good working collaboration, effective communication and information sharing between designers, architects, engineers and fabricators (CSF#1). This will resolve the common problem of design information gap (Li et al., 2017) and reduces dimensional tolerance risks (Shahtaheri et al., 2017). The use of information and communication technology such as building information modelling (Li et al., 2017) will allow design sharing and visualization among all involved parties. Design robustness, flexibility and system integration (CSF#27) may improve the overall success of the MiC project.

The construction phase is the stage where the concept and design generate an actual MiC project and is linked to the success of the previous phases. For instance, effective coordination and management of all the linked segments of the MiC supply chain (CSF#2) and effective management of stakeholder, supply chain & project execution risks (CSF#10) are both critical to the success of MiC projects (Choi et al., 2016; Luo et al., 2019). The use of experienced workforce and supervising team with technical capabilities (CSF#29) will ensure effective on-site installation of the modules to the desired standard of quality. The success of this stage also requires effective coordination of the factory production and job site activities (CSF#33) to meet schedule. Effective communication between the on-site, logistics, and the factory teams is also critical to the success of the MiC project. The availability of local transport infrastructure will facilitate effective conveyance of the factory-produced modules to the job site for installation and job site transport equipment will be required to set the modules in place and facilitate final assembly of the modules.

Conceptual causal loop model of the CSFs for implementing MiC projects

There are various factors that contribute to the success of MiC projects. However, the CSFs are not static and do not exist in isolation. Improvement in one CSF could have positive influence on the performance of another CSF (s). Thus, Figure 8 is a conceptual causal loop model of the CSFs based on systems dynamic modelling. The model was developed based on the evidences reported in the literature and plenary discussion of the authors to ascertain how each CSF may influence another. This dynamic model is crucial because it highlights the hypothetical links and interdependences of the CSFs. Since CSFs are usually between 5 and 10 in practice (Freund, 1988), it is useful to highlight the complimentary CSFs because it will allow for the strategic allocation of resources to achieve competitive and comparative cost advantage. The model also highlights the key interactive results areas which could be prioritized to reap the benefits of other CSFs.

Figure 8

As CSFs have positive influence on the performance of MiC projects, their interactions are generally positive in nature (Figure 8). It can be observed that Figure 8 depicts only reinforcing loops. Thus, a major aspect of the causal loop model (Figure 8) constitutes a virtuous cycle. There are three types of CSFs in the model. Those that only influence others and are not influenced by others (e.g. early and effective use of information technology); those that do not influence others but are influenced by others (e.g. reasonable lead time to allow for prototyping and trials); and those that influence and are influenced by others (e.g. systematic economic analysis, effective working collaboration and communication among project participants, etc.) The third category are the most important CSFs because their implementation will result in the achievement of other CSFs. From Figure 8, several interdependences and interactions of the CSFs can be observed. For instance, effective working collaboration, well-informed leadership of contractors, use of information technology, and effective logistical services are all critical to the effective management of the MiC supply chain.

It can also be observed that effective working collaboration and communication among project participants are useful recipes for effective risk and stakeholder management. Particularly, collaboration and information sharing between designers and fabricators could reduce dimensional tolerance risks of the produced modules (Shahtaheri et al., 2017). The model also illustrates that early advice from MiC experts will strengthen systematic economic analysis and early decisions which would improve planning of the project and selection of a suitable procurement method to meet the project objectives. Particularly, early advice from MiC experts may improve the client's understanding of project scope and budget (Blismas, 2007; Hjort et al., 2014; Hofman et al., 2009) which would reduce delays from the owner, leading to early design approval and freezing (Gibb & Isack, 2003; Pan et al., 2008). The foregoing brief description highlights the interactions and interdependences among the CSFs for implementing MiC projects and may help practitioners to make strategic investment in management areas which will offer the most mutually reinforcing benefits towards achieving higher MiC project success.

Discussions of key findings

This research identified 35 CSFs for implementing MiC projects. These success factors were investigated in previous research studies involving diverse project types such as residential, industrial, petrochemical, commercial, schools, among others. Thus, this research is the first exclusive attempt at benchmarking and establishing a common framework of the CSFs for implementing MiC projects. The research highlighted the relevance of good working collaboration, effective communication and information sharing to the success of all MiC projects. This reflects reality because irrespective of project type, the success of MiC projects requires the services, expertise and knowledge of diverse players. Although these project participants play their distinct roles at different stages of the project, their collaboration and information sharing are imperative to ensure that succeeding participants are well-informed of previous decisions and accomplishments. The research also highlights the importance of supply chain coordination and management to the success of all MiC projects. Irrespective of the supply chain configuration of a project, the success of any MiC project requires effective coordination of the modules' design, production, transportation and on-site assembly activities. The other most cited CSFs within the framework include early design freeze, involvement of key players throughout the project, selection of a suitable procurement method and contract documentation, standardization, extensive project planning, effective use of information and communication technology (especially in large and complex projects), effective stakeholder management, and risk management. These indicate that the success of MiC projects may require multiskilled management and supervising teams.

Furthermore, Figure 7 distributes the CSFs across the major phases of the MiC project implementation process. The stage-gate framework highlights the necessity of making early decision to implement MiC in a project. This is crucial because not every design is suitable for modularization and some circumstances render MiC less competitive. Thus, it is found that commitment should be made at the conception and planning stages to seek advice from MiC experts. The use of such professional advice and systematic analysis will highlights whether the project lends itself to modularization. The framework also highlights the need for key decisions to be understood by all involved parties because previous decisions have influence on future decisions and project phases. The stage-gate framework also highlights the CSFs to be given special consideration at the design & procurement and the construction phases. Thus, the research makes a useful contribution to theory and practice because it benchmarked the key results areas to emphasise at the different phases of the project life cycle. Finally, Figure 8 is a systems dynamic model of the CSFs for implementing MiC projects. The model reveals that the most influential CSFs include extensive and effective project planning and scheduling; systematic economic analysis and early decisions; early design freeze, effective stakeholder management, good working collaboration and information sharing, effective supply chain management and risk management. These CSFs have bidirectional influences on the success of MiC projects because they significantly influence and are influenced by other CSFs. The developed conceptual causal loop model encourages management and project participants to adopt a systems perspective of viewing and analysing the interrelations and interdependences of the CSFs for implementing MiC projects. Such analysis is realistic and makes a useful contribution to the practice and praxis of MiC project implementation because the CSFs do not exist in isolation.

Conclusions and future research directions

MiC is a disruptive construction approach which transforms the fragmented site-based building construction into the production and assembly of value-added prefabricated prefinished modules. The disruptive nature of MiC engenders several changes to the traditional processes of building construction. As MiC continues to gain increasing attention in engineering, procurement and construction industries, researchers have been keen on understanding the CSFs for implementing the approach. However, a systematic review and a common framework of the CSFs for implementing MiC projects is not well-established. In response, this research identified and ranked the CSFs for MiC projects, developed a stage-gate framework for the CSFs and modelled the CSFs for MiC projects using a systems dynamic approach.

As a result, the findings of the research make some distinct contributions to the MiC and OSC literature. Firstly, the review findings are instructive to researchers and practitioners in identifying the trends of studies on MiC CSFs. The study offers a useful common reference point to researchers and provides a broader understanding of the CSFs for implementing MiC projects. Secondly, the developed checklist of CSFs for MiC projects contributes to the theoretical checklists of CSFs for OSC projects and may form a useful basis for future empirical studies. Thirdly, this study will generate a significant positive impact on the MiC implementation discourse because the identified CSFs could form a useful basis for real life planning and implementation of diverse MiC projects. Moreover, the proposed common framework and conceptual model of the MiC CSFs could facilitate more realistic planning and improve the measurement of MiC project success by researchers and practitioners. Furthermore, the proposed conceptual model of CSFs for MiC can be used to develop decision support systems, enabling the prediction of project success. As such, one potential impact of this research is that it will guide and inform the successful implementation of MiC projects. However, the review has the following limitations. Firstly, although the search strategy was comprehensive in scope, it is possible some relevant studies may have been missed. Secondly, aggregating the CSFs of several MiC project types into a common framework overlooks their differences and geospatial sensitivities. However, it is often theoretically useful to overlook these differences and sensitivities as they become unquestionably necessary when such analysis is geared towards a recommendation for real-life projects. Moreover, the ranking of CSFs based on a frequency of occurrences may be flawed because it might not necessarily reflect their criticality in projects. However, such ranking was plausible in this study because quantitative meta-analysis was constrained by the non-availability of effect sizes and quantitative parameters in preponderances on the studies. Furthermore, the causal loop model of the CSFs was not calibrated and simulated in a real project due to the absence of data. However, it does highlight the dynamic behaviour of the CSFs. Based on the documented limitations, futures studies will (i) conduct quantitative assessment of the CSFs for specific MiC projects, (ii) develop a set of strategies, critical success processes and key performance indicators for the MiC CSFs, and (iii) develop MiC project success model based on (i) and (ii).

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

#	Reference	#	Reference
1	Azhar, Lukkad, & Ahmad (2013)	29	Murtaza et al. (1993)
2	Choi et al. (2016)	30	Pan, Gibb, & Dainty (2012)
3	Toor & Ogunlana (2009)	31	Barlow et al. (2003)
4	Li, Xue, Li, Hong, & Shen (2018)	32	Warszawski (1999)
5	Triumph Modular Corporation (2019)	33	Tam, Tam, & Ng (2007)
6	Ojoko et al. (2018)	34	Bryan (2019)
7	Xue, Zhang, Su, & Wu (2017)	35	Li, Li, Wu, & Li (2018)
8	Nawi, Lee, Kamar, & Hamid (2012)	36	Pan, Gibb, & Dainty (2008)
9	Haas & Fagerlund (2002)	37	Benjaoran & Dawood (2006)
10	Lau (2011)	38	Demiralp, Guven, & Ergen (2012)
11	Rashidi & Ibrahim (2017)	39	Sharafi et al. (2018)
12	Pan, Gibb, & Dainty (2007)	40	Zhong et al. (2017)
13	Ismail, Yusuwan, & Baharuddin (2012)	41	O’Connor et al. (2014)
14	Kamar, Hamid, & Alshawi (2010)	42	Choi (2014)
15	Jerker Lessing & Brege (2017)	43	Choi & O’Connor (2014)
16	Blismas (2007)	44	Mydin et al. (2015)
17	O’Connor, O’Brien, & Choi (2016)	45	Hwang et al. (2018b)
18	Carriker & Langar (2014)	46	Akagi et al. (2002)
19	Hsu et al. (2018)	47	Hofman, Voordijk, & Halman (2009)
20	Kamar et al. (2009)	48	Blismas & Wakefield (2009)
21	Lessing, Stehn, & Ekholm (2005)	49	Lee & Kim (2017)
22	Haas et al. (2000)	50	Song et al. (2005)
23	Hjort, Lindgren, Larsson, & Emmitt (2014)	51	Marchesi & Matt (2017)
24	Rentschler, Mulrooney, & Shahani (2016)	52	Gibb (1999)
25	Arashpour et al. (2017)	53	Gibb & Isack (2003)
26	Gibb & Isack (2001)	54	Youdale (2009)
27	Burke & Miller (1998)	55	Wong, Zwar, & Gharaie (2017)
28	O’Connor, O’Brien, & Choi (2015)		

Table 2. Critical success factors (CSFs) for implementing MiC in previous studies

#	Critical success factors (CSFs)	Reference	Total	Rank
1	Good working collaboration, effective communication, and information sharing among MiC project participants	[1–17]	17	1
2	Improved supply chain coordination and management	[9,11, 13–16, 18–25]	14	2
3	Accurate design, early design freeze and timely owner's approval	[11,14, 16,26–34]	11	3
4	Fully-integrated approach and involvement of key participants throughout the project	[10,11,13,14,16,26,30,33–36]	11	3
5	Suitable procurement strategy and contracting	[5,7,8,11–14,16,23,24, 36]	11	3
6	Standardization, optimization, and benchmarking of best practices	[5,16,26–34]	11	3
7	Extensive MiC project planning, scheduling and control	[3,9,11,13–15,17,21,23,37]	10	7
8	Early and effective use of information and communication technology	[4,11,14,15,20,21,38–40]	9	8
9	Effective stakeholder MiC management starting with clearly defined goals and priorities of all involved stakeholders	[1–9]	9	8
10	Effective management of stakeholder, supply chain and project execution risks	[2,11,13,14,20,23,41–43]	9	8
11	Adequate relevant experience and knowledge of contractor, designer, and manufacturer of MiC projects	[2–5,16,23,42–44]	9	8
12	Adequate resources of owner, planning, team support and decision support systems	[2,3,29,41–43,45]	7	12
13	Top management support and early involvement of in the MiC supply chain	[1,6,11, 13, 14, 29,45]	7	12
14	Early and precise definition of MiC project engineering scope, planning and budget	[1,2,9,17,24,43]	6	14
15	Fabricator infrastructure, experience, and capabilities in modules design and production	[2,29,41–43,46]	6	14
16	Availability of local transport infrastructure, equipment, heavy lift, and site transport capabilities	[2,29,41–43,45]	6	14
17	Alignment of modules architecture and long -term collaboration among fabricators, suppliers, designers, subcontractors, and contractors	[11,13–15,21,47]	6	14
18	Early advice and modularization consideration from MiC design professionals and experts	[6,30,41,48,49]	5	18
19	Alignment on MiC project drivers	[2,17,41–43]	5	18
20	Owner-furnished long-lead equipment specification	[2,41–43]	4	20
21	Module envelope limitations	[2,41–43]	4	20
22	Early completion and cost savings recognition	[2,41–43]	4	20
23	Well-informed contractor leadership	[2,41–43]	4	20
24	Owner delay avoidance	[2,41–43]	4	20
25	Lead time & space hedging and transport delay avoidance	[2,41–43]	4	20

26	Realistic systematic economic analysis and early decisions	[9,17,23,50]	4	20
27	Design robustness, flexibility and system integration	[10,20,32,51]	4	20
28	Continuous improvement and learning	[11,14–16]	4	20
29	Availability of experienced workforce and supervising team with technical capabilities	[11,14,29,45]	4	20
30	Key decisions should be understood and made as early as possible between all parties involved	[11,14,52]	3	30
31	Intensive early research on modularization and commitment from owners	[5,16,29]	3	30
32	Reasonable lead time to allow for pre-site prototyping and trial assembly or stacking of modules in the factory	[16,53]	2	32
33	Effective coordination of off-site and on-site construction activities	[16,35]	2	32
34	Systematic performance measuring and re-use of experiences	[15,21]	2	32
35	Adequate modular design code, specification, regulations and performance management systems	[35,55]	2	32

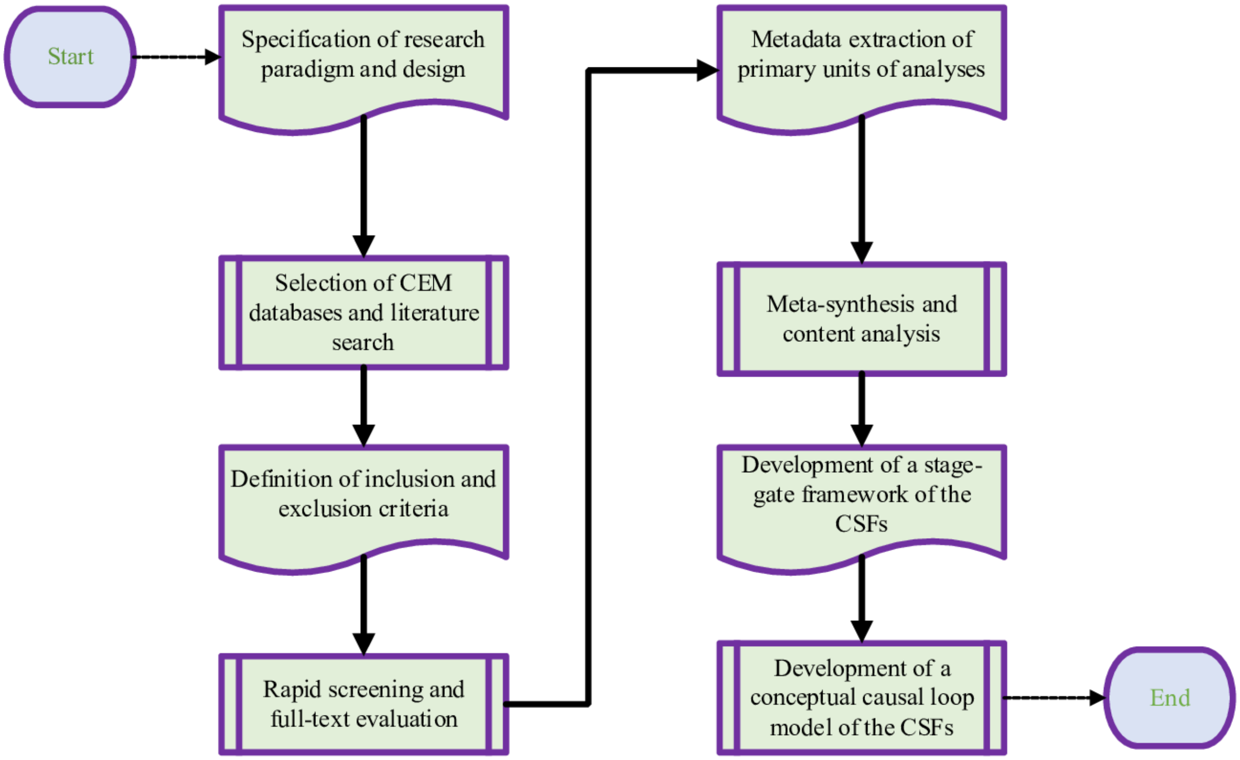


Figure 1. Methodological framework for the study

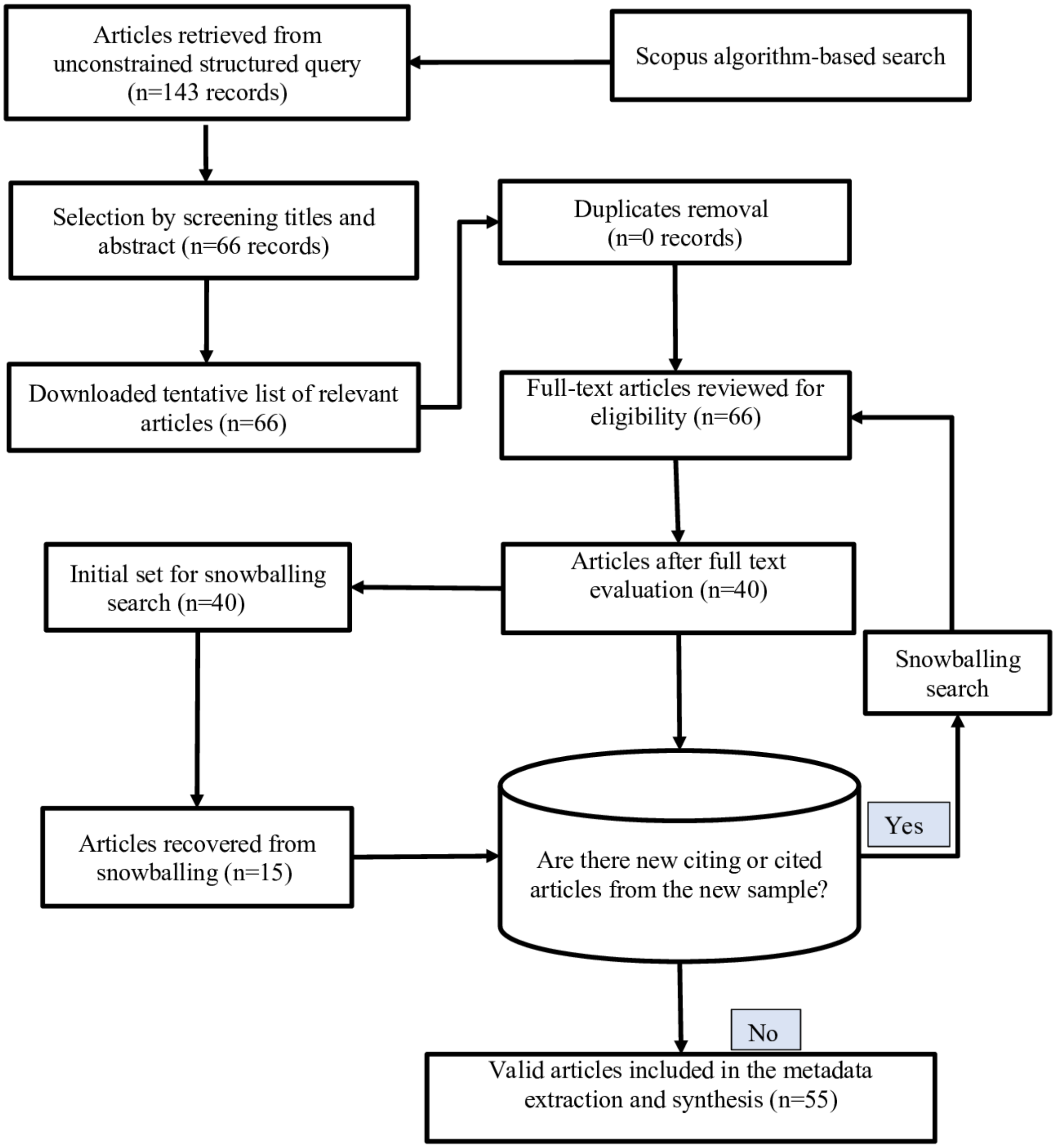


Figure 2. A flowchart of systematic literature search and article selection protocol

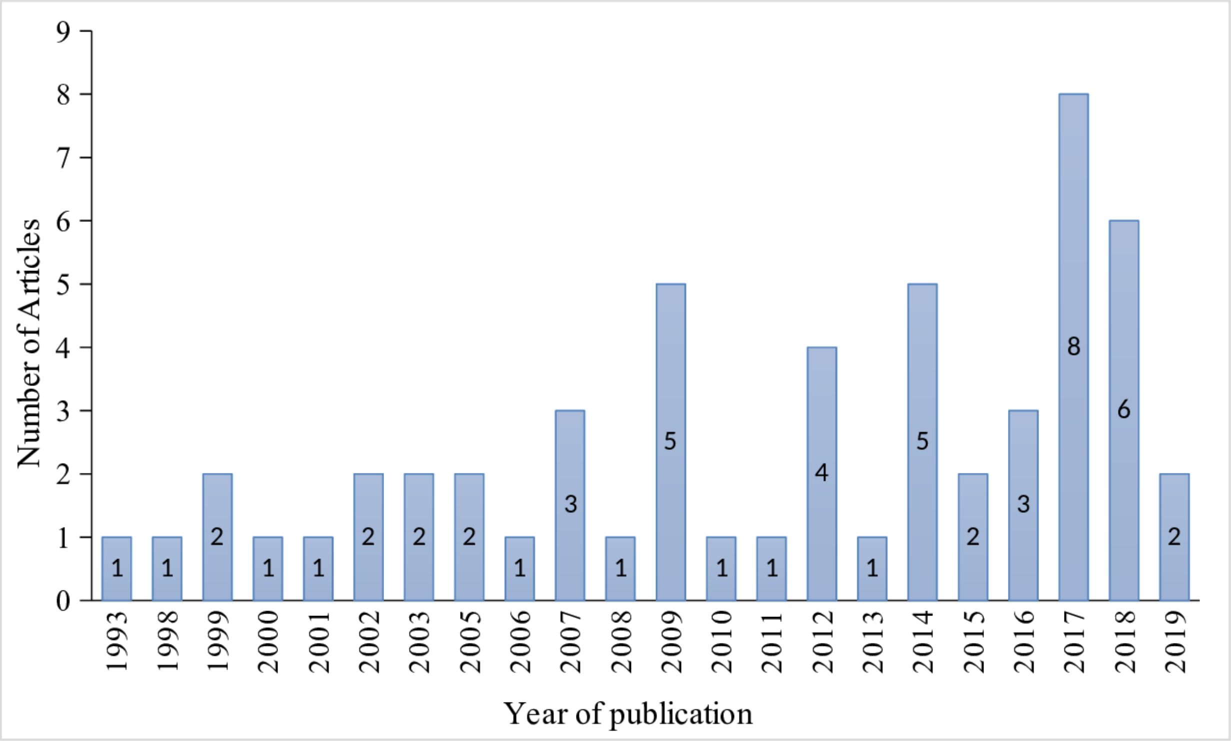


Figure 3. Annual publications trend on the CSFs for MiC from 1993 to 2019

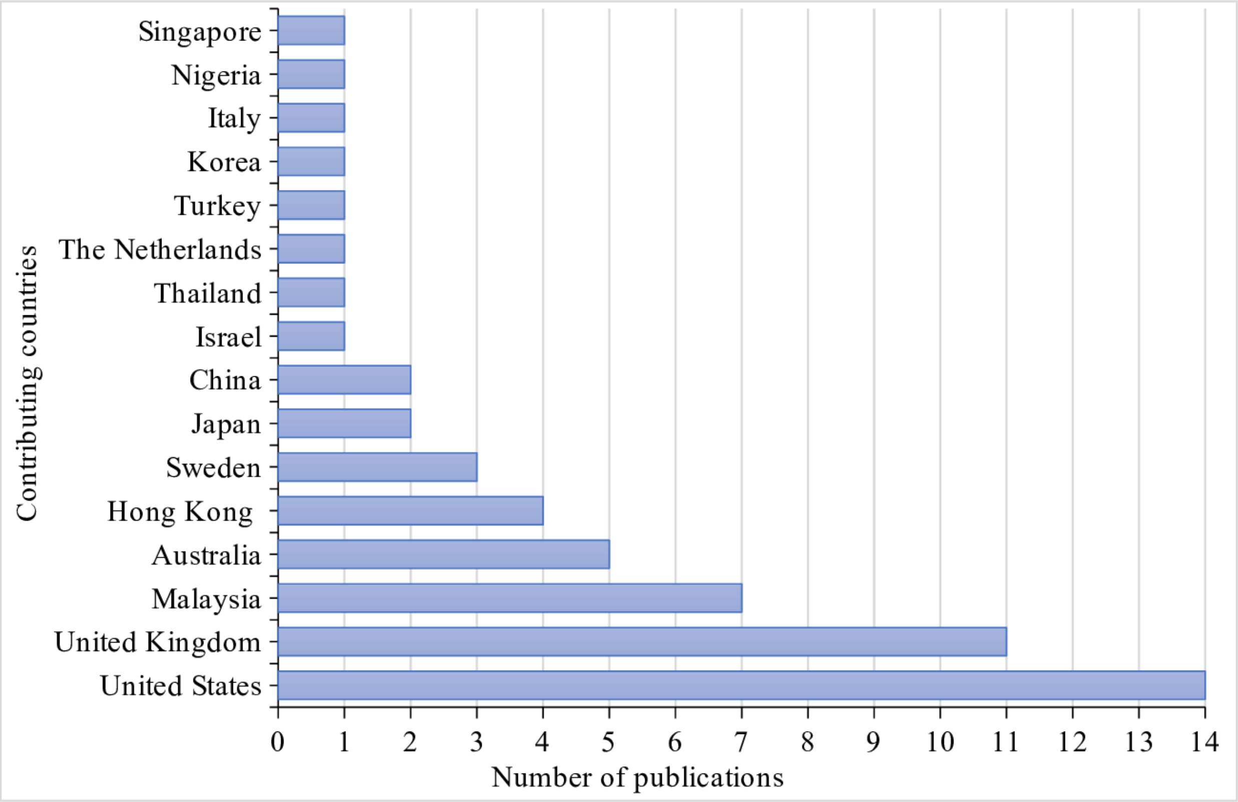


Figure 4. Geospatial distribution of the included publications

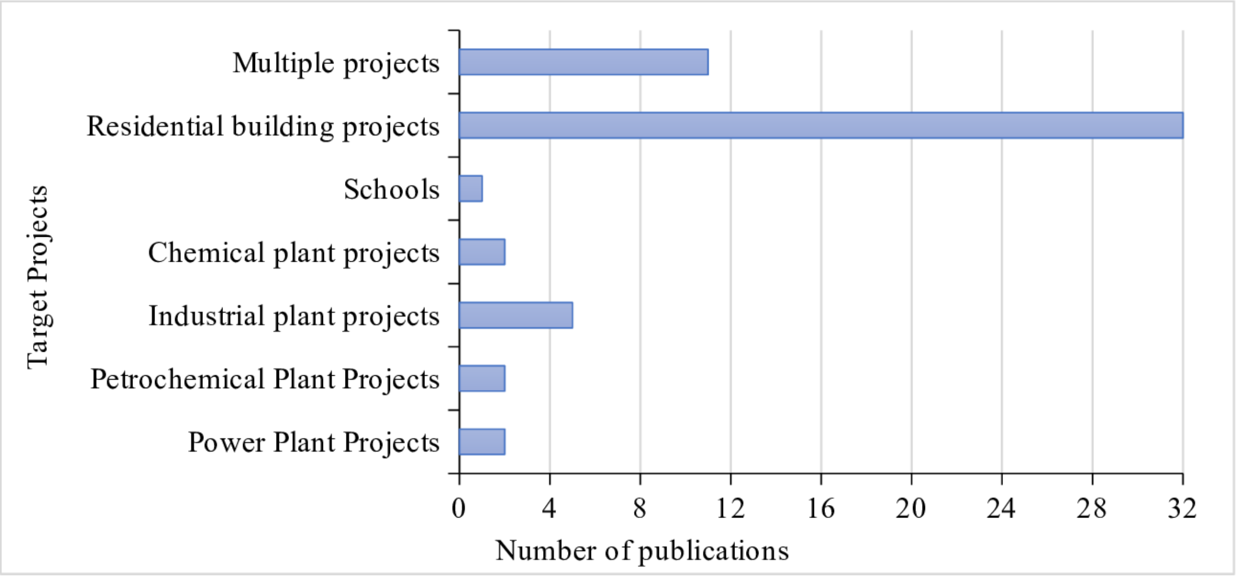


Figure 5. Distribution of MiC target projects in studies on CSFs

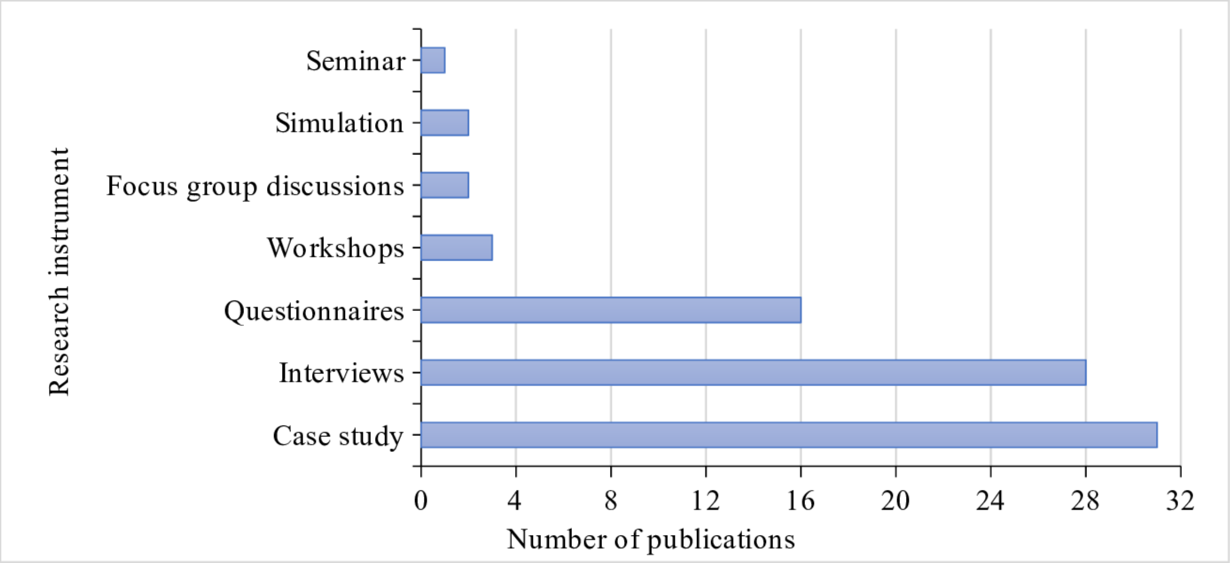
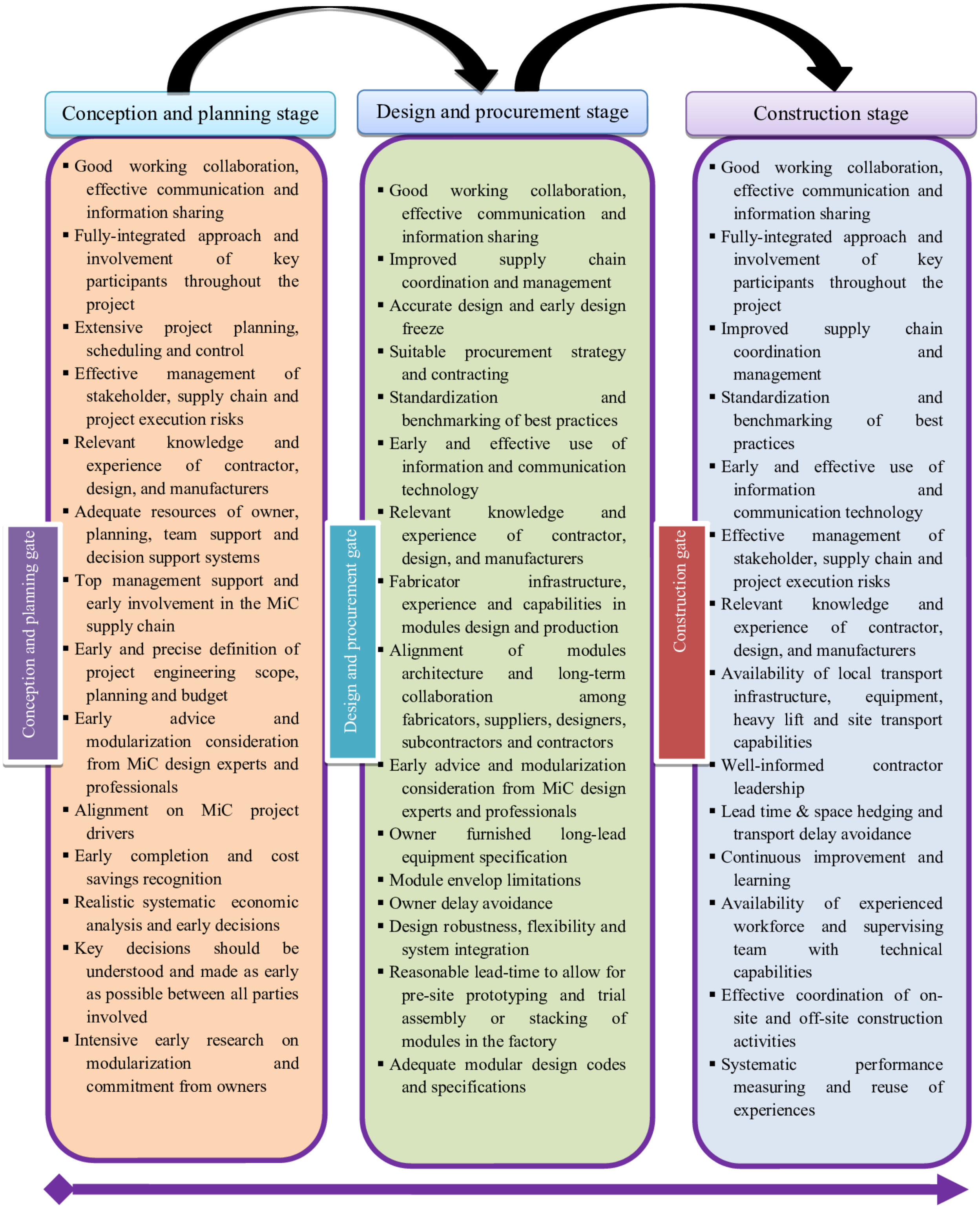


Figure 6. Distribution of research instruments used in previous studies on MiC CSFs



Conception and planning stage

- Good working collaboration, effective communication and information sharing
- Fully-integrated approach and involvement of key participants throughout the project
- Extensive project planning, scheduling and control
- Effective management of stakeholder, supply chain and project execution risks
- Relevant knowledge and experience of contractor, design, and manufacturers
- Adequate resources of owner, planning, team support and decision support systems
- Top management support and early involvement in the MiC supply chain
- Early and precise definition of project engineering scope, planning and budget
- Early advice and modularization consideration from MiC design experts and professionals
- Alignment on MiC project drivers
- Early completion and cost savings recognition
- Realistic systematic economic analysis and early decisions
- Key decisions should be understood and made as early as possible between all parties involved
- Intensive early research on modularization and commitment from owners

Conception and planning gate

Design and procurement stage

- Good working collaboration, effective communication and information sharing
- Improved supply chain coordination and management
- Accurate design and early design freeze
- Suitable procurement strategy and contracting
- Standardization and benchmarking of best practices
- Early and effective use of information and communication technology
- Relevant knowledge and experience of contractor, design, and manufacturers
- Fabricator infrastructure, experience and capabilities in modules design and production
- Alignment of modules architecture and long-term collaboration among fabricators, suppliers, designers, subcontractors and contractors
- Early advice and modularization consideration from MiC design experts and professionals
- Owner furnished long-lead equipment specification
- Module envelop limitations
- Owner delay avoidance
- Design robustness, flexibility and system integration
- Reasonable lead-time to allow for pre-site prototyping and trial assembly or stacking of modules in the factory
- Adequate modular design codes and specifications

Design and procurement gate

Construction stage

- Good working collaboration, effective communication and information sharing
- Fully-integrated approach and involvement of key participants throughout the project
- Improved supply chain coordination and management
- Standardization and benchmarking of best practices
- Early and effective use of information and communication technology
- Effective management of stakeholder, supply chain and project execution risks
- Relevant knowledge and experience of contractor, design, and manufacturers
- Availability of local transport infrastructure, equipment, heavy lift and site transport capabilities
- Well-informed contractor leadership
- Lead time & space hedging and transport delay avoidance
- Continuous improvement and learning
- Availability of experienced workforce and supervising team with technical capabilities
- Effective coordination of on-site and off-site construction activities
- Systematic performance measuring and reuse of experiences

Construction gate

Figure 7. A stage-gate framework of the CSFs for implementing MiC projects

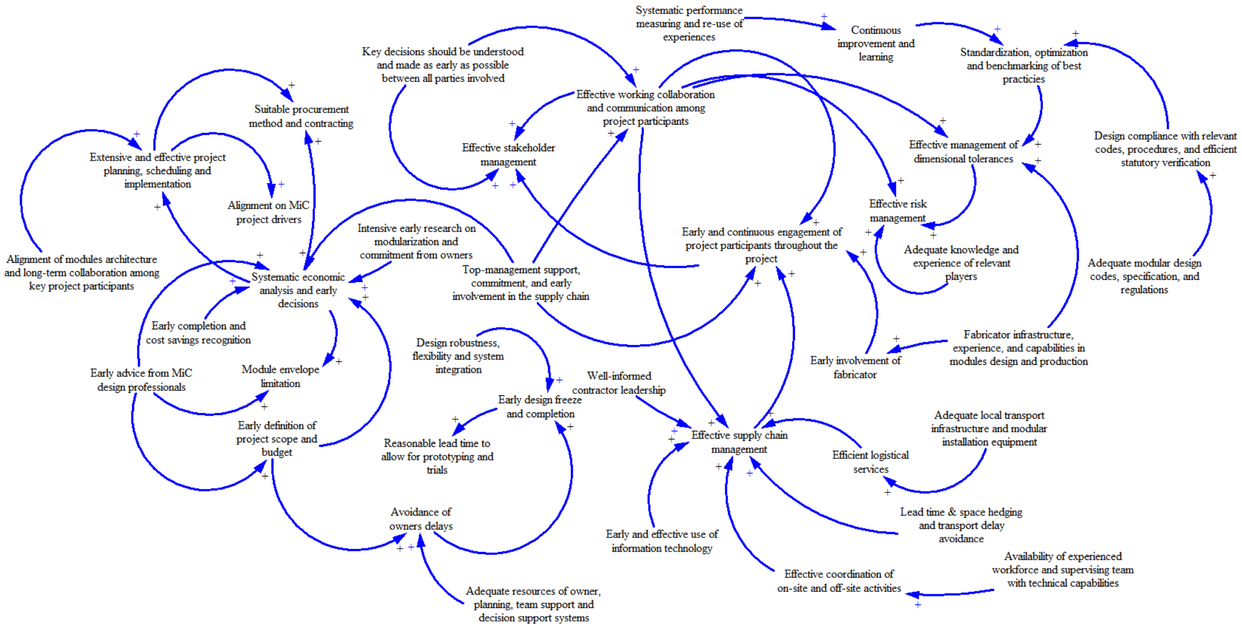


Figure 8. Conceptual causal loop model of the CSFs for implementing MiC projects