Quantitative evaluation and ranking of the critical success factors for modular integrated construction projects

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Abstract

Modular integrated construction (MiC) is becoming a preferred construction approach for many types of building projects. However, several factors and conditions must converge to determine the success of MiC projects. This research identified and evaluated 25 critical success factors (CSFs) for implementing MiC projects. The dataset was generated through a structured questionnaire survey and analysed using robust statistical techniques. Based on the mean scores, the top five CSFs for MiC projects include fabricator experience and capabilities in modules design and production; robust drawing specifications and early design freeze; good working collaboration, communication and information sharing among project participants; standardization and mass production; and effective coordination of the supply chain segments. An exploratory factor analysis generated four principal success factors (PSFs), comprising adequate technical capability and infrastructure; effective stakeholder and supply chain management; early commitment; and standardization and benchmarking. A fuzzy evaluation revealed that all the 4 PSFs are paramount to the success of MiC projects. As a contribution, the research has identified and prioritized the CSFs which may help MiC project managers and stakeholders in the appropriate allocation of limited resources. These shared CSFs may constitute forecasting and diagnostic tools for progressively measuring success along the MiC project lifecycle phases.

Keyword: Critical success factors; fuzzy synthetic modelling; modular integrated construction; off-site manufacturing

1. Introduction

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Within the sustainable construction paradigm shift, the construction industry is pursuing offsite manufacturing (OSM) of buildings to address many of the intractable challenges of the traditional cast-in-situ construction approach (Wuni and Shen 2020a). OSM is a sustainable production technology whereby building components (modules) are manufactured off-site in a specialized factory or workshop and then transported to a construction site for final assembly and installation (Goodier *et al.* 2019). Modular integrated construction (MiC) is the most complete form of OSM where 80-95% of a whole building can be engineered and manufactured an off-site factory or workshop (Smith 2016). According to Pan and Hon (2018), MiC is a disruptive construction technique which transforms the fragmented site-based construction of buildings into an integrated production and assembly of value-added factory-made prefabricated prefinished volumetric modules.

Drawing on the concepts of design for manufacture and assembly (DfMA), MiC is disrupting the construction and real estate ecosystem through delivery of industrialized systems rather than projects (Bertram *et al.* 2019, Wuni and Shen 2019a, Wuni *et al.* 2019). MiC leverages significant gains construction project performance in terms of schedule, cost, quality, and sustainability (Mills 2018, Wuni and Shen 2019b). Where circumstances merit and favourable conditions prevail, MiC shortens construction time, improves productivity, minimizes construction waste, improves working environment and site safety, improves project quality control, and reduces carbon emissions (Building and Construction Authority 2017, Construction Industry Council 2018). For many types of projects in the architecture, engineering and construction (AEC) industries, MiC is increasingly become a preferred method of construction over the traditional site-based construction approach.

However, as Choi et al. (2016) noted, several conditions and factors need to converge to achieve success in any project. Success of MiC projects involves meeting the planned objectives of the project and the expectations of key stakeholders (Wuni and Shen 2019a). The success of MiC projects requires the contributions of multidisciplinary stakeholders with their unique goals and value systems (Luo *et al.* 2019, Wuni *et al.* 2019). These stakeholders have unique expectations and thus success is interpreted differently (Chan and Chan 2004). According to Choi et al. (2016), not all implemented MiC projects have met planned objectives and the expectations of stakeholders. Nonetheless, several MiC projects have been successfully executed in some countries but the reasons that accounted for the successes are not well-established.

One effective mechanism for understanding the factors that predicate success in MiC projects is to obtain an in-depth knowledge of the critical success factors (CSFs) for MiC projects. According to Wuni and Shen (2019a), CSFs constitute the key few areas which must be given sustained attention and resources commitment to achieve success in a project. The CSFs methodology provides a common framework for tracking and measuring progress towards success of a project. Several studies have examined the CSFs for OSM techniques such as industrialized building systems (Yunus and Yang 2012), Prework (O'Connor *et al.* 2014, Choi *et al.* 2016), and prefabricated construction (Li *et al.* 2018). However, there is limited research on the factors and conditions which facilitate the success of MiC projects (Wuni and Shen 2019a). As a result, this research aims to identify and evaluate the critical success factors for MiC projects. Considering that MiC is gaining increasing attention in the AEC industries, this research will contribute to the practice and praxis of MiC implementation. It constitutes the first exclusive research on the generic CSFs for MiC projects and makes a useful contribution to literature on the management of MiC projects.

2. Theoretical background

2.1 Overview of modular integrated construction

MiC is an innovative construction approach whereby "free-standing volumetric modules usually completed with finishes, fittings and fixtures are manufactured and assembled in an accredited fabrication facility, in accordance with any accredited fabrication method, and then installed in a building under building works" (Building and Construction Authority, 2017, p.8). The three common types of MiC include reinforced concrete modules, steel frame modules, and hybrid modules (Construction Industry Council 2018). Although the value chain of MiC shares several stages with the traditional site-based construction approach, the former has unique processes which require different sets of conditions to achieve success.

The supply chain of MiC involves project design, statutory approval of design, off-site fabrication of modules, transportation of modules to site, and on-site installation. These stages of the MiC supply chain involves multidisciplinary stakeholders such as architects, designers, engineers, building authorities, fabricators, suppliers, contractors, project managers, logistics companies, highway authorities, developers and clients (Luo *et al.* 2019, Wuni *et al.* 2019). The success of MiC projects depends on effective coordination and management of the various stages of the MiC supply chain and the associated stakeholders.

The effective implementation of MiC requires some key considerations. Prior to applying MiC in a project, the developer needs to ascertain whether the design of the project is suitable for modularization (Murtaza *et al.* 1993, Hwang *et al.* 2018b). This is crucial because not all projects lend themselves to modularization. The analysis is required at the earliest stages of the MiC project because early commitment is a prerequisite for reaping the full benefits of MiC projects (Wuni and Shen 2019b). During the project design, there is the need to engage the fabricator and local contractor (Building and Construction Authority 2017). This provides the opportunity to incorporate the input of these players into the project design and familiarize the actors with the project. Early completion and freezing of the project design are required to facilitate the fabrication of the modules. Considering that there is very little flexibility for design changes after freezing, it is imperative to make robust engineering specification and accurate drawing of the designs.

During the factory production of the modules, mock-ups and prototypes are produced, checked and tested before mass production (Construction Industry Council 2018). The Building and Construction Authority (2017) recommends trial assembly or staking of the modules in the factory to ascertain of the ease of assembly during on-site installation. This stage often operates concurrently with on-site activities such as foundation works, eternal underground utility works among others (Construction Industry Council 2018). The fabricated modules are then transported to the construction site for direct installation or buffering (Wuni *et al.* 2019). The Construction Industry Council (2018) recommends special traffic arrangement for transporting modules with width larger 2.5m in high-density metropolis such as Hong Kong and Singapore. The modules on site are then systematically staked and connected based on an assembly plan. The craned building system is then completed and finished to generate a liveable structure.

2.2 Success factors for modular integrated construction projects

Given the limited amount of published research on MiC projects, bespoke success factors can hardly be retrieved directly from the literature (Wuni and Shen 2019a). However, there are some relevant studies on the success factors for other OSM techniques such as industrialized building systems (IBS), prefabricated prefinished volumetric construction (PPVC), modular construction, prefabrication, prework, and volumetric modular construction which are relevant to MiC projects (Hwang *et al.* 2018a). This is because MiC has many similarities with the *modus operandi* of these OSM techniques. Thus, the research conducted a comprehensive review of the relevant literature to identify the success factors which may be applicable to MiC projects.

Song et al. (2005) found that the prominent CSFs for prework on industrial projects include realistic economic analysis, early commitment to the approach, availability of skilled management team, and availability of sound infrastructure network for transporting the modules to site. Tam et al. (2007) identified suitable procurement strategy and contracting to be a CSF for prefabricated construction projects. Blismas (2007) summarized the CSFs for modular construction projects to be robust design specification and early design freeze, effective supply chain management, early involvement of key participants, suitable procurement strategy, and relevant experience and knowledge of key players. Blismas and Wakefield (2009) conducted a questionnaire survey and identified that early commitment is CSF for OSM projects. Pan et al. (2012) conducted a questionnaire survey in the UK and found that robust engineering specification, design robustness and early design freeze constitute CSFs for industrialized housing projects. Choi et al. (2016) concluded that timely design freeze, long lead equipment specification, fabricator/supplier involvement, and effective risk management are the four prominent CSFs for industrial modular construction projects.

Li et al. (2018) conducted a questionnaire survey in China and found that the prominent CSFs for planning and control of prefabricated construction projects include involvement of key players at the earliest stages of the project, adequate knowledge and experience of key participants, effective communication and information sharing among project participants, efficient use of information and communication technology, and proper coordination between onsite and off-site trades. Even though a plethora of research have expounded on the CSFs for various OSM techniques, there is no specific empirical study on CSFs for MiC in the extant literature (Wuni and Shen 2019a). Nonetheless, the comprehensive review of the literature provided a good framework and reference point to identify the CSFs which may be relevant to MiC projects. Table 1 is the summary of the potential success factors for MiC projects from the literature review.

Table 1. Potential success factors for MiC Projects

Success factors	Reference
Robust drawing specification and early design freeze	Gibb and Isack (2001); Wuni and Shen (2019a)
Adequate experience and knowledge of key players	Li et al. (2018); Wuni and Shen (2019a)
Standardization and mass production	Gibb and Isack (2001); (Blismas 2007)O’Connor et al. (2015)

Extensive project planning, scheduling and control	Lessing and Brege (2017); Li et al. (2018)
Good working collaboration, communication and information sharing	Pan et al. (2007); Choi et al. (2016)
Effective coordination of the supply chain segments	Blismas (2007); Wuni and Shen (2019a)
Fabricator experience and capabilities in modules design and production	Akagi et al. (2002); Wuni and Shen (2019a)
Suitable procurement strategy and contracting	Blismas (2007); Tam et al. (2007)
Early advice from experts and consideration of MiC	Blismas and Wakefield (2009); Wuni and Shen (2019a)
Experienced workforce and technical capability	Murtaza et al. (1993); Hwang et al. (2018)
Effective coordination of on-site and off-site trades	Li et al. (2018); Wuni and Shen (2019a)
Alignment on MiC project drivers and modules architecture	Choi et al. (2016); O'Connor et al. (2016)
Availability of sound local transport infrastructure	Hwang et al. (2018); Wuni and Shen (2019a)
Early completion and cost savings recognition	Choi et al. (2016); Wuni and Shen (2019a)
Availability of skilled workforce, management and supervision team	Murtaza et al. (1993); Hwang et al. (2018); Wuni and Shen (2019a)
Realistic economic analysis, early decision and definition of project scope	Song et al. (2005); Blismas and Wakefield (2009)
Availability and active involvement of key project team members from the earliest stage of the project	Pan et al. (2012); Wuni and Shen (2019a)
Effective supply chain and execution risk management	Choi et al. (2016); Wuni and Shen (2019a)
Support and early involvement of top management in supply chain decision-making	Hwang et al. (2018); Wuni and Shen (2019a)
Appreciation of key early decision and their implication between all parties involved	Blismas and Wakefield (2009); Wuni and Shen (2019a)
Effective use of information and communication technology (e.g. BIM)	Li et al. (2018); Wuni and Shen (2019a)
Effective coordination and management of stakeholders	Choi et al. (2016); Wuni and Shen (2019a)
Module envelope limitations	Choi (2014);Choi et al. (2016)
Early involvement of modules suppliers and fabricators	Choi et al. (2016); Wuni and Shen (2019a)
Continuous improvement	Choi (2014);Choi et al. (2016)
Owner delay avoidance	Choi (2014);Choi et al. (2016)

3. Research Methods and Approach

This research adopted a quantitative research design where international data formed the basis for evaluating the CSFs for MiC projects. A multistage methodological framework was employed involving a comprehensive literature, pilot survey, questionnaire design and administrations, pre-testing of data for reliability, mean score analysis, and a fuzzy synthetic evaluation analysis of the CSFs for MiC projects (Figure 1). These methodological components are described below.

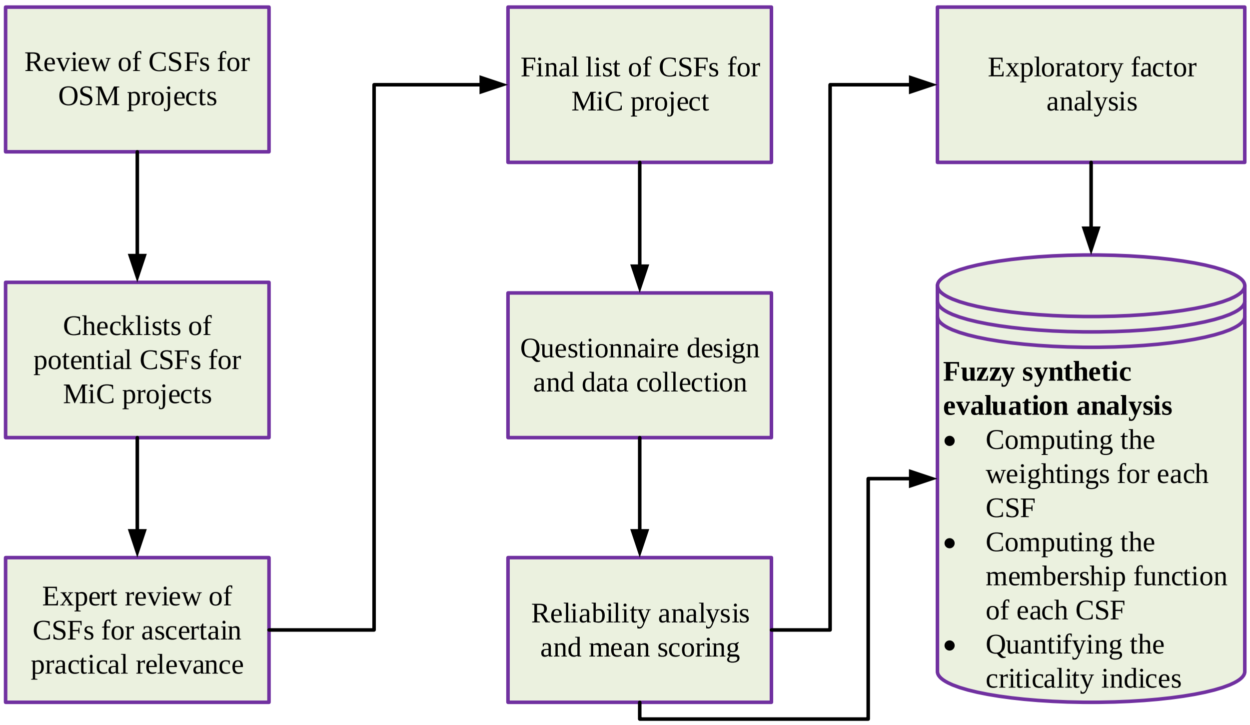

Figure 1. Overall methodological framework of the research

3.1 Data collection and measurement instrument

Following the literature review, three MiC experts from Australia, Hong Kong, and Canada were contacted to evaluate the applicability of the identified CSFs to MiC projects. It is a best practice in the survey-based construction management research to use odd-number of experts during the pilot review (Wuni and Shen 2020b). When the experts have a difference regarding the relevance of a given management practice, the dominant view is adopted. Three experts were adopted because it is the lowest odd number and has been used in existing published studies (Wuni and Shen 2020b). The pilot survey outcome resulted in the removal of the last CSF in Table 1. The rest of the CSFs were confirmed by the experts to be applicable to MiC projects. The modified list formed the basis for the data collection. A questionnaire was designed to collect quantitative data on the CSFs. Questionnaire is widely used to collect quantitative data in the construction engineering and management (CEM) research domain (Hwang *et al.* 2018b, Li *et al.* 2018). This research was based on a questionnaire survey of international experts. This approach was adopted because the study aims to establish a generic framework of the CSFs which may be relevant to different MiC project types and geographical areas. The study recognizes the sensitives of the CSFs to different project types and territories, but the survey of international experts is widely used in the CEM research domain to evaluate key project management issues based on the rich and hands-on experiences of experts from different countries (Ameyaw and Chan 2015, Osei-Kyei, Chan, Javed, *et al.* 2017). The international questionnaire survey approach generates rich data within a short period.

Consistent with Osei-Kyei et al. (2017), the researchers identified the international experts from the published articles on the CSFs for different OSM techniques. Industry MiC experts were also identified from construction industry councils' databases in most countries. Overall, an excel database containing the emails of 400 experts was created. A purposive sampling technique was adopted to identify the relevant MiC experts because there is no central database for global MiC experts. The questionnaire consisted of two sections. The first section solicited background information of the respondents. Considering that data quality is a major drawback of international surveys, the background information requested during the survey acted as a reality check to ensure that relevant experts participated in the study. Table 2 shows the background information of the respondents. Information regarding the sector of work, years of hands-on work experience in MiC projects, and country/region of working experience were collected.

Table 2. Background information of the surveyed experts

Attribute	Sub-attribute	Responses	% Responses
Years of MiC work experience	Below 10 years	40	71.4
	11 - 20 years	7	12.5
	Above 20years	9	16.1
	Total	***56***	***100.0***
Regions	North America	18	32.2
	Asia and Pacific	19	33.9
	Australia	5	8.9
	Europe	11	19.6
	South America	1	1.8
	Africa	2	3.6
	Total	***56***	***100.0***

The second section required the experts to evaluate the importance of the success factors for MiC projects using a 5-point rating scale comprising 1=Not critical, 2=Fairly critical, 3=Critical, 4=Very critical, and 5=Extremely critical. Based on the measurement scale adopted, the linguistic terms dictated that success factors with mean scores of at least 3.0 were considered critical. The criticality threshold varies (e.g. ≥3.5 or 4) but the minimum of 3.0 adopted in the study is because the linguistic variable 'critical' was assigned to 3 on the 5-point grading scale. The final questionnaire was used to create an online survey link using "Survey Monkey". The researchers combined MS Word, Excel, and Outlook to write personalized invitation emails (with the survey link attached) to all the 400 experts. The experts were given 4 weeks to complete the online survey. After two rounds of reminders, a total of 56 valid responses were retrieved from the "Survey Monkey" platform. Although small, the sample was considered adequate for statistical analysis because it exceeded the minimum requirement 30 for the central limit theorem. Indeed, smaller sample sizes are characteristics of the published international survey studies in the CEM research domain such as 42 (Osei-Kyei, Chan, Javed, *et al.* 2017) and 27 (Sachs *et al.* 2007).

3.2 Statistical Pretesting of Dataset

Statistical analysis of the dataset was conducted with the aid of the Statistical Package for the Social Sciences (SPSS v.20). The research analysed the dataset for internal consistency and reliability. The reliability analysis was conducted using the Cronbach's Alpha. According to Tavakol and Dennick (2011), the Cronbach's Alpha ranges between 0 and 1, where 0 indicates no reliability of research instrument and 1 denotes absolute reliability of the dataset. A threshold of 0.7 is the acceptable level of reliability. A reliability analysis of the dataset generated a Cronbach's Alpha of 0.900, indicating excellent internal consistency of the responses of the experts and validity of the survey instrument. This outcome rendered the dataset reliable for further analysis.

3.3 Mean scoring of the success factors

The mean scores (MS) of the success factors for MiC projects were computed to obtain their average assessment on the 5-point grading scale adopted. The MS (μ_i) were computed using the formula.

$$MS = \frac{\sum(E \times F)}{N}, \qquad (1 \leq MS \leq 5) \qquad (1)$$

Where, E denotes a score given to each success factor by an expert, ranging from 1 to 5 (1= not critical and 5=extremely critical); F denotes the frequency of each rating (1-5) for each success factor; and N represents the total number of responses for a given success factor. Drawing on Osei-Kyei et al. (2017), the MS of the success factors were interpreted on an interval scale where a success factor with an MS of $\mu_i \leq 1.4$, $1.5 \leq \mu_i \leq 2.4$, $2.5 \leq \mu_i \leq 3.4$, $3.5 \leq \mu_i \leq 4.4$, and $\mu_i \geq 4.5$ was considered "not critical", "fairly critical", "critical", "very critical", and "extremely critical", respectively. The MS formed the basis for ascertaining the ranking and prioritizing the success factors.

3.4 Factor analysis of the CSFs for MiC projects

Factor analysis is a factor reduction statistical method which has the power to group correlated variables into clusters. It is widely used to conduct structure detection in research involving the quantitative evaluation of several factors (Zhang 2005, Osei-Kyei, Chan, Javed, *et al.* 2017). However, some conditions must be satisfied before factor analysis can be used for a dataset. These conditions were tested in the current research. The first requirement is reliability of the dataset. A Cronbach's Alpha of 0.900 indicated that the first criterion was satisfied. Based on the recommendations of Chou et al. (1998), the normality of the dataset was investigated using the Shapiro-Wilk test. The test generated p-values less than 0.000 for all CSFs, indicating that the dataset is not normally distributed (Hwang *et al.* 2018b). This further imposed the use of non-parametric statistical techniques for further analysis of the dataset.

The Kruskal–Wallis test was conducted to determine whether there are significant variations between the responses of the experts from academia and industry at a confidence level of 95%. The test generated p-values greater than 0.05 for all CSFs, indicating that there are no significant differences in the responses of the different experts. The Kaiser-Meyer-Olkin (KMO) Test for Sampling Adequacy was conducted on the dataset. The analyses generated a statistic of 0.681 which is higher than the 0.6 threshold adopted in previous studies (Osei-Kyei, Chan, Javed, *et al.* 2017). This means the dataset is suitable for structure detection. The Bartlett's test of sphericity was conducted to determine whether the CSFs are related and suitable for structure detection. The analyses generated an approximate Chi-square of 736.839 and a p-value less than 0.000, indicating that the correlation matrix is not an identity matrix. Hence, the null hypothesis is rejected, and the dataset is suitable for factor analysis.

Although several other techniques are used to measure the suitability of a dataset for factor analysis, the consistent affirmative results of the above statistical indicators are considered adequate to justify suitability of the dataset for factor analysis. As a result, an exploratory factor analysis was conducted using Principal Component Analysis as the factor extraction method and Promax with Kaiser Normalization as the factor rotation method. The rotation converged in 12 iterations and a generated a 4-factor solution, which formed the basis for the fuzzy synthetic evaluation analysis. Hereafter, the factor groupings are referred to as principal success factors (PSFs) in the study. The CSFs were grouped into PSFs because it reduces the cognitive complexity associated with managing the numerous CSFs and provides a systematic framework for implementing them during project implementation.

3.5 Fuzzy synthetic evaluation analysis of the CSFs for MiC projects

Evaluation of the success factors for MiC projects by the experts involves the use of linguistic variables such as 1=not critical and 5=extremely critical. Assessment in this form is subjective and associated with uncertainties (Ameyaw and Chan 2015). The evaluation using linguistic variables is fuzzy in nature because it draws on the judgement of the experts. Boussabaine (2014) established that fuzzy set theory is most appropriate for analysing data clouded with such fuzziness. As a result, this research conducted a fuzzy synthetic evaluation (FSE) analysis of the CSFs for MiC projects. FSE is a branch of fuzzy set theory (Zadeh 1965) which uses weightings and membership functions to facilitate objective assessment of the subjective judgements of experts (Zafar *et al.* 2019). Several studies have used FSE in the CEM research domain to evaluate project management issues. Ameyaw and Chan (2015) used FSE to evaluate risk factors in public-private partnership (PPP) water projects in developing countries and Osei-Kyei et al. (2017a) used FSE to evaluate operational management CSFs in PPP projects. Similarly, the current research employs the FSE technique to evaluate the CSFs for MiC projects. The FSE was implemented based on a comprehensive methodology comprising computation of the membership functions of the CSFs and PSFs, calculating the weightings of the CSFs and PSFs, and quantifying the impact of the PSFs using criticality indices.

3.5.1 Computing the membership functions of the CSFs and PSFs for MiC projects

FSE uses the grading alternatives to generate the membership functions of the CSFs and PSFs for MiC projects. Based on Ameyaw and Chan (2015), the two-dimensional five-point grading scales was defined as E = (1, 2, 3, 4, 5), where E_1= not critical, E_2= fairly critical, E_3= critical, E_4= very critical, and E_5= extremely critical. Based on the responses of the experts, the membership function (MF) of each CSF is computed as follows:

$$\mathrm{MF}_{u_{in}} = \frac{X_{1u_{in}}}{E_1} + \frac{X_{2u_{in}}}{E_2} + \frac{X_{3u_{in}}}{E_3} + \frac{X_{4u_{in}}}{E_4} + \frac{X_{5u_{in}}}{E_5} \quad (3)$$

Where u_{in} denotes the nth CSF in a given PSF; $\mathrm{MF}_{u_{in}}$ represents the MF of a given CSF; $X_{j_{u_{in}}}$(j= 1, 2, 3, 4, 5) denotes the percentage of the experts who scored j for the significance of a specific CSF, which measures the degree of membership; and $\frac{X_{j_{u_{in}}}}{E_i}$ denotes the relation between $X_{j_{u_{in}}}$ and its grade alternative; and " +” denotes a notation in fuzzy set. Using equation (3), the MF of a specific CSF can be expressed as:

$$MF_{u_{in}} = \left(X_{1_{u_{in}}}, X_{2_{u_{in}}}, X_{3_{u_{in}}}, X_{4_{u_{in}}}, X_{5_{u_{in}}}\right) \quad (4)$$

The MFs were computed from the collective assessment of a CSF by the experts using equation (4). For example, 1.8% of the experts rated *"CSF9 - Early involvement of modules suppliers and fabricators"* as *not critical*, 3.6% rated CSF9 as *fairly critical*, 37.5% rated CSF9 as *critical*, 37.5% rated it *very critical*, and 19.6% rated CSF9 as *extremely critical*. Hence, the MF for CSF9 is derived using equation (3) as follows:

$$MF_{SF9} = \frac{0.018}{\text{not critical}} + \frac{0.036}{fairly\ critical} + \frac{0.375}{\text{critical}} + \frac{0.375}{\text{very critical}} + \frac{0.196}{\text{extremely critical}}$$

Alternatively, the MF for CSF9 is written as: (0.02, 0.04, 0.38, 0.38, 0.20) as shown in Table 6. Using the same approach, the MFs of the remaining CSFs in Table 6 were computed. The MFs of the CSFs are further used to compute the MFs of the PSFs. However, the MFs of the PSFs require data of the weightings of the CSFs.

3.5.2 Calculating the weightings of the CSFs and PSFs for MiC projects

From the works of Hsiao (1998), Lo (1999), and Ameyaw and Chan (2015), the weightings of the CSFs can be computed using the analytic hierarchy process, tabulated judgement, and normalized mean. As recommended by Lo (1999), this research adopted the normalized mean method because it is simple and uses the mean scores of the CSFs and PSFs. The weightings were computed through normalization of the mean scores of the CSFs and PSFs as follows:

$$W_i = \frac{MS_i}{\sum_{i=1}^{5} MS_i}, \ 0 < W_i < 1 \text{ and } \sum_{i=1}^{5} W_i = 1 \quad (5)$$

Where W_i denotes the weighting function of a CSF/PSF i, and MS_i is the mean score of a CSF/PSF i based on the survey. Thus, the weighting function set is given as:

$$W_i = (w_1, w_2, w_3, \ldots\ldots\ldots\ldots, w_n) \quad (6)$$

From Table 5, PSF1 contains 5 CSFs, including CSF1, CSF8, CSF12, CSF10, and CSF16. Considering that CSF1 has a mean score of 3.91, the weighting of CSF1 is computed using equation (5) as follows:

$$W_{CSF1} = \frac{3.91}{3.91+3.71+3.68+3.63+3.50} = 0.212 \text{ (as shown in Table 5)}$$

Using the same approach, the weightings of the remaining CSFs were computed and shown in Table 5. The sum of the mean scores of the CSFs within each PSF was used to derive the total mean score for a given PSF. From Table 5, the total mean scores of PSF1, PSF2, PSF3, and PSF4 are 18.43, 32.35, 28.31, and 10.80, respectively. Hence, the weighting for PSF3 was computed using equation (5) as follows:

$$W_{PSF3} = \frac{28.31}{18.43+32.35+28.31+10.80} = 0.315 \text{ (as shown in Table 5)}$$

Using the same approach, the weightings of the remaining PSFs were computed and shown in Table 5. Based on Hsiao (1998), the weighting function set of the CSFs within each PSF was used develop the final fuzzy evaluation matrix (D_i) as follows:

$$D_i = W_i \bullet R_i = (w_1, w_2, w_3, \ldots\ldots\ldots\ldots\ldots, w_n) \bullet \begin{bmatrix} X_{1_{u_{i1}}} & X_{2_{u_{i1}}} & X_{3_{u_{i1}}} & X_{4_{u_{i1}}} & X_{5_{u_{i1}}} \\ X_{1_{u_{i2}}} & X_{2_{u_{i2}}} & X_{3_{u_{i2}}} & X_{4_{u_{i2}}} & X_{5_{u_{i2}}} \\ X_{1_{u_{i3}}} & X_{2_{u_{i3}}} & X_{3_{u_{i3}}} & X_{4_{u_{i3}}} & X_{5_{u_{i3}}} \\ \ldots. & \ldots. & \ldots. & \ldots. & \ldots. \\ X_{1_{u_{in}}} & X_{2_{u_{in}}} & X_{3_{u_{in}}} & X_{4_{u_{in}}} & X_{5_{u_{in}}} \end{bmatrix} \quad (7)$$

$$= (d_{i1}, d_{i2}, d_{i3}, \ldots\ldots\ldots\ldots\ldots, d_{in})$$

Where D_i represents the final evaluation matrix; W_i denotes the weightings of the CSF within a PSF; R_i denotes the fuzzy evaluation matrix; "●" is a fuzzy composition operator; X_1 to X_5 are membership functions of the CSFs in any given PSF as shown in Table 6; and d_{in} denotes the degree of membership of the grade alternative. For example, the fuzzy evaluation matrix and weighting function of PSF1 can be extracted from Table 6 and Table 5, respectively as follows:

$$R_{PSF1} = \begin{bmatrix} 0.00 & 0.02 & 0.30 & 0.43 & 0.25 \\ 0.00 & 0.07 & 0.34 & 0.39 & 0.20 \\ 0.00 & 0.14 & 0.29 & 0.38 & 0.20 \\ 0.02 & 0.09 & 0.29 & 0.41 & 0.20 \\ 0.00 & 0.11 & 0.38 & 0.43 & 0.09 \end{bmatrix} \text{ and } W_{PSF1} = (0.212, 0.201, 0.200, 0.197, 0.190)$$

Hence, the MF of PSF1 (known as final fuzzy evaluation matrix) is computed as follows:

$$MF_{PSF1} = D_{PSF1} = W_{PSF1} \bullet R_{PSF1}$$

$$= (0.212, 0.201, 0.200, 0.197, 0.190) \times \begin{bmatrix} 0.00 & 0.02 & 0.30 & 0.43 & 0.25 \\ 0.00 & 0.07 & 0.34 & 0.39 & 0.20 \\ 0.00 & 0.14 & 0.29 & 0.38 & 0.20 \\ 0.02 & 0.09 & 0.29 & 0.41 & 0.20 \\ 0.00 & 0.11 & 0.38 & 0.43 & 0.09 \end{bmatrix}$$

= (0.00, 0.08, 0.32, 0.41, 0.19) as shown in Table 6

Using the same approach, the MFs of PSF2, PSF3, and PSF4 were derived and shown in Table 6. The MFs of the PSFs and grade alternatives on the 5-point grading scale formed the basis for computing the impact of the PSFs.

3.5.3 Quantifying the criticality of the PSFs for MiC projects

The criticality indices of the PSFs were computed using the grade alternatives and the MFs of the PSFs (Ameyaw and Chan 2015, Zafar *et al.* 2019). The criticality indices of the PSFs were derived using the formula:

Criticality index (CI) = $\sum_{i=1}^{n}(D_i \times E_i)$ (8)

Where; D_i denotes the fuzzy evaluation matrix of a given PSF and E_i denotes the grade alternatives of the 5-point rating scale. From the Table 6, the following outcomes can be derived:

D_{PSF1} = (0.00, 0.08, 0.32, 0.41, 0.19)

D_{PSF2} = (0.01, 0.09, 0.36, 0.39, 0.16)

D_{PSF3} = (0.02, 0.12, 0.33, 0.39, 0.15)

D_{PSF4} = (0.01, 0.10, 0.30, 0.45, 0.14)

Hence, the criticality indices of the CSFs are computed as follows:

$PSF1_{CI}$ = D_{PSF1} * E_i = (0.00, 0.08, 0.32, 0.41, 0.19) * (1, 2, 3, 4, 5) = **3.691**

$PSF2_{CI}$ = D_{PSF1} * E_i = (0.01, 0.09, 0.36, 0.39, 0.16) * (1, 2, 3, 4, 5) = **3.595**

$PSF3_{CI}$ = D_{PSF1} * E_i = (0.02, 0.12, 0.33, 0.39, 0.15) * (1, 2, 3, 4, 5) = **3.543**

$PSF4_{CI}$ = D_{PSF1} * E_i = (0.01, 0.10, 0.30, 0.45, 0.14) * (1, 2, 3, 4, 5) = **3.597**

4. Results of data analysis

4.1 Mean ranking of CSFs for MiC projects

It is a textbook logic to use mean scores to establish the average quantitative narrative of the relative importance of the CSFs based on the grading point adopted. Table 3 shows the mean scores of 25 CSFs for MiC projects. The general observation is that each CSF obtained a mean index greater than the critical threshold of 3.0 (Zafar *et al.* 2019) on the 5-point grading scale used. These indicate that all the 25 success factors can be considered as critical. Although CSFs are usually few ranging from 5 to 8 (Freund 1988), the 25 CSFs in the current study is not overambitious because it is simply obscure to have 5 to 8 CSFs shared by all countries and project types. The huge number of CSFs represents a useful framework to identify bespoke CSFs for a given project type in a specific territory.

Based on the mean scores, the top CSFs for MiC projects include fabricator experience and capabilities in modules design and production (3.91), robust drawing specifications and early design freeze (3.89), good working collaboration, communication and information sharing among project participants (3.86), standardization and mass production (3.84), and effective coordination of the supply chain segments (3.79). These five CSFs highlight the profound importance of capabilities, design accuracy, collaboration, standardization and supply chain management to the success of MiC projects. This finding is consistent with works of Wuni and Shen (2019a) who found these CSFs to be among the top most cited CSFs for MiC projects. However, Blismas (2007) found that CSF1 is not critical in Australia.

Table 3. Mean scores of the CSFs for MiC projects

S.N.	Success Factors	MS	Rank	Wilk-Shapiro test (p-value)	Kruskal -Wallis test (p-value)
CSF1	Fabricator experience and capabilities in modules design and production	3.91	1.00	0.000**	0.291
CSF2	Robust drawing specifications and early design freeze	3.89	2.00	0.000**	0.908
CSF3	Good working collaboration, communication and information sharing among project participants	3.86	3.00	0.000**	0.534
CSF4	Standardization and mass production	3.84	4.00	0.000**	0.023
CSF5	Effective coordination of the supply chain segments	3.79	5.00	0.000**	0.736
CSF6	Availability and active involvement of key project team members from the earliest stages of the project	3.77	6.00	0.000**	0.605
CSF7	Extensive project planning, scheduling and control	3.71	7.00	0.000**	0.958
CSF8	Experienced workforce and technical capability	3.71	7.00	0.000**	0.874
CSF9	Early involvement of modules suppliers and fabricators	3.70	9.00	0.000**	0.816
CSF10	Availability of skilled workforce, management and supervising team	3.68	10.00	0.000**	0.697
CSF11	Early advice and consideration from MiC design experts and professionals	3.66	11.00	0.000**	0.453
CSF12	Availability of sound local transport infrastructure and site equipment capabilities	3.63	12.00	0.000**	0.504
CSF13	Realistic economic analysis, early decision and definition of MiC project scope	3.55	13.00	0.000**	0.239
CSF14	Effective coordination and management of stakeholders	3.52	14.00	0.000**	0.488
CSF15	Effective coordination of on-site and off-site trades	3.52	14.00	0.000**	0.559
CSF16	Adequate experience and knowledge of key players	3.50	16.00	0.000**	0.108
CSF17	Alignment on MiC project drivers and modules architecture	3.48	17.00	0.000**	0.856
CSF18	Continuous improvement	3.48	17.00	0.000**	0.767
CSF19	Suitable procurement strategy and contracting	3.46	19.00	0.000**	1.000
CSF20	Support and early involvement of top management in supply chain decision making	3.46	19.00	0.000**	0.518
CSF21	Appreciation of key early decisions and their implication between all parties involved	3.46	19.00	0.000**	0.015
CSF22	Effective use of information and communication technology (e.g. BIM)	3.38	22.00	0.000**	0.708
CSF23	Effective supply chain and execution risk management	3.34	23.00	0.000**	0.213
CSF24	Early completion and cost savings recognition	3.34	23.00	0.000**	0.296
CSF25	Module envelope limitations	3.25	25.00	0.000**	0.417

Their finding is entirely expected because Australia has a developed MiC market with some suppliers of modules. Thus, the significance of fabricator experience on the success of MiC projects may not be critical in such a circumstance but same cannot be concluded for countries with a fledgling MiC market.

4.2 Principal groupings of the CSFs for MiC projects

The factor analysis (FA) detected 4 structural components of the CSFs for MiC projects as shown in Table 4. FA is useful to reduce a long register of the CSFs into a systematic framework of fewer components. It reduces the cognitive complexity associated with handling and prioritizing the long list of CSFs for MiC projects (Ameyaw and Chan 2015) and may provide decision-support in the strategic allocation of scarce resources.

Table 4. PSFs for MiC Projects

S.N.	PSFs	Factor loadings	Eigen-value	% of variance explained	Cumulative % of variance explained
PSF1	**Adequate technical capability and infrastructure**		**7.233**	**28.934**	**28.934**
CSF1	Fabricator experience and capabilities in modules design and production	0.862			
CSF8	Experienced workforce and technical capability	0.787			
CSF12	Availability of sound local transport infrastructure and site equipment capabilities	0.680			
CSF10	Availability of skilled workforce, management and supervising team	0.594			
CSF16	Adequate experience and knowledge of key players	0.577			
PSF2	**Effective stakeholder and supply chain management**		**5.938**	**23.753**	**52.687**
CSF19	Suitable procurement strategy and contracting	0.925			
CSF7	Extensive project planning, scheduling and control	0.831			
CSF5	Effective coordination of the supply chain segments	0.795			
CSF15	Effective coordination of on-site and off-site trades	0.784			
CSF3	Good working collaboration, effective communication and information sharing among project participants	0.782			
CSF25	Effective use of information and communication technology (e.g. BIM)	0.762			
CSF14	Effective coordination and management of stakeholders	0.698			
CSF6	Availability and active involvement of key project participants at the earliest stages of the project	0.528			
CSF22	Effective supply chain and execution risk management	0.498			
PSF3	**Early commitment**		**4.508**	**18.033**	**70.720**
CSF21	Appreciation of key early decisions and their implication between all parties involved	0.807			
CSF9	Early involvement of modules suppliers and fabricators	0.715			
CSF11	Early advice and consideration from MiC design experts and professionals	0.626			
CSF2	Robust drawing specification and early design freeze	0.583			

CSF24	Module envelope limitations	0.570			
CSF23	Early completion and cost savings recognition	0.473			
CSF13	Realistic economic analysis, early decision and definition of project scope	0.673			
CSF20	Support and early involvement of top management in supply chain decision making	0.681			
PSF4	**Standardization and benchmarking**		**1.143**	**4.571**	**75.291**
CSF18	Continuous improvement	0.759			
CSF17	Alignment on MiC project drivers and modules architecture	0.537			
CSF4	Standardization and mass production	0.467			

The FA generated a 4-factor solution comprising PSF1 – adequate technical capability and infrastructure; PSF2 – effective stakeholder and supply chain management; PSF3 – early commitment; and PSF4 – standardization and benchmarking (Table 4). These PSFs have stronger association with MiC project success and explain about 75.29% of the variation in the success of MiC projects. A framework of the CSFs and PSFs are shown in Figure 2.

4.3 Weighting function of the CSFs and PSFs for MiC projects

The weightings of the CSFs and PSFs constitute indicators of the relative importance of each CSF and PSF and the accuracy of the weighting functions largely determines the reliability of the FSE analysis of the CSFs (Hsiao 1998, Lo 1999). Table 5 shows the weighting functions of the CSFs and PSFs for MiC projects based on the mean scores. PSF2 obtained the highest total mean and weighting of 32.35 and 0.360, respectively, followed by PSF3 with total mean and weighting of 28.31 and 0.315, respectively.

Table 5. Weighting functions of the CSFs and PSFs for MiC Projects

S.N.	CSF/PSF	Mean for CSF	Weightings for each CSF	Total Mean for each PSF	Weightings for each PSF
CSF1	Fabricator experience and capabilities in modules design and production	3.91	0.212		
CSF8	Experienced workforce and technical capability	3.71	0.201		
CSF10	Availability of skilled workforce, management and supervising team	3.68	0.200		
CSF12	Availability of sound local transport infrastructure and site equipment capabilities	3.63	0.197		
CSF16	Adequate experience and knowledge of key players	3.50	0.190		
PSF1	**Adequate technical capability and infrastructure**			**18.43**	**0.205**
CSF3	Good working collaboration, effective communication and information sharing among project participants	3.86	0.119		
CSF5	Effective coordination of the supply chain segments	3.79	0.117		
CSF6	Availability and active involvement of key project participants at the earliest stages of the project	3.77	0.117		
CSF7	Extensive project planning, scheduling and control	3.71	0.115		

CSF15	Effective coordination of on-site and off-site trades	3.52	0.109		
CSF14	Effective coordination and management of stakeholders	3.52	0.109		
CSF19	Suitable procurement strategy and contracting	3.46	0.107		
CSF25	Effective use of information and communication technology (e.g. BIM)	3.38	0.104		
CSF22	Effective supply chain and execution risk management	3.34	0.103		
PSF2	**Effective stakeholder and supply chain management**			**32.35**	**0.360**
CSF2	Robust drawing specification and early design freeze	3.89	0.137		
CSF9	Early involvement of modules suppliers and fabricators	3.70	0.131		
CSF11	Early advice and consideration from MiC design experts and professionals	3.66	0.129		
CSF13	Realistic economic analysis, early decision and definition of project scope	3.55	0.125		
CSF21	Appreciation of key early decisions and their implication between all parties involved	3.46	0.122		
CSF20	Support and early involvement of top management in supply chain decision making	3.46	0.122		
CSF23	Early completion and cost savings recognition	3.34	0.118		
CSF24	Module envelope limitations	3.25	0.115		
PSF3	**Early commitment**			**28.31**	**0.315**
CSF4	Standardization and mass production	3.84	0.356		
CSF18	Continuous improvement	3.48	0.322		
CSF17	Alignment on MiC project drivers and modules architecture	3.48	0.322		
PSF4	**Standardization and benchmarking**			**10.80**	**0.120**

PSF1 obtained the third highest total mean and weighting of 18.43 and 0.205, respectively and tailed by PSF4 with the lowest total mean and weighting of 10.80 and 0.120, respectively. The weightings of the CSFs formed the basis for computing the membership functions of the PSFs.

4.4 Membership functions of the CSFs and PSFs for MiC Projects

The MFs of the CSFs in Table 6 were computed using equation (3) and presented in the form of equation (4). The weightings of the CSFs within each PSF in Table 5 and their corresponding MFs in Table 6 formed the basis for computing the MFs for the PSFs (Table 6) using equation (7). Table 6 shows the MFs of the CSFs and PSFs for MiC projects. The MFs of the PSFs for MiC projects formed the basis for computing the criticality indices of the PSFs for MiC projects.

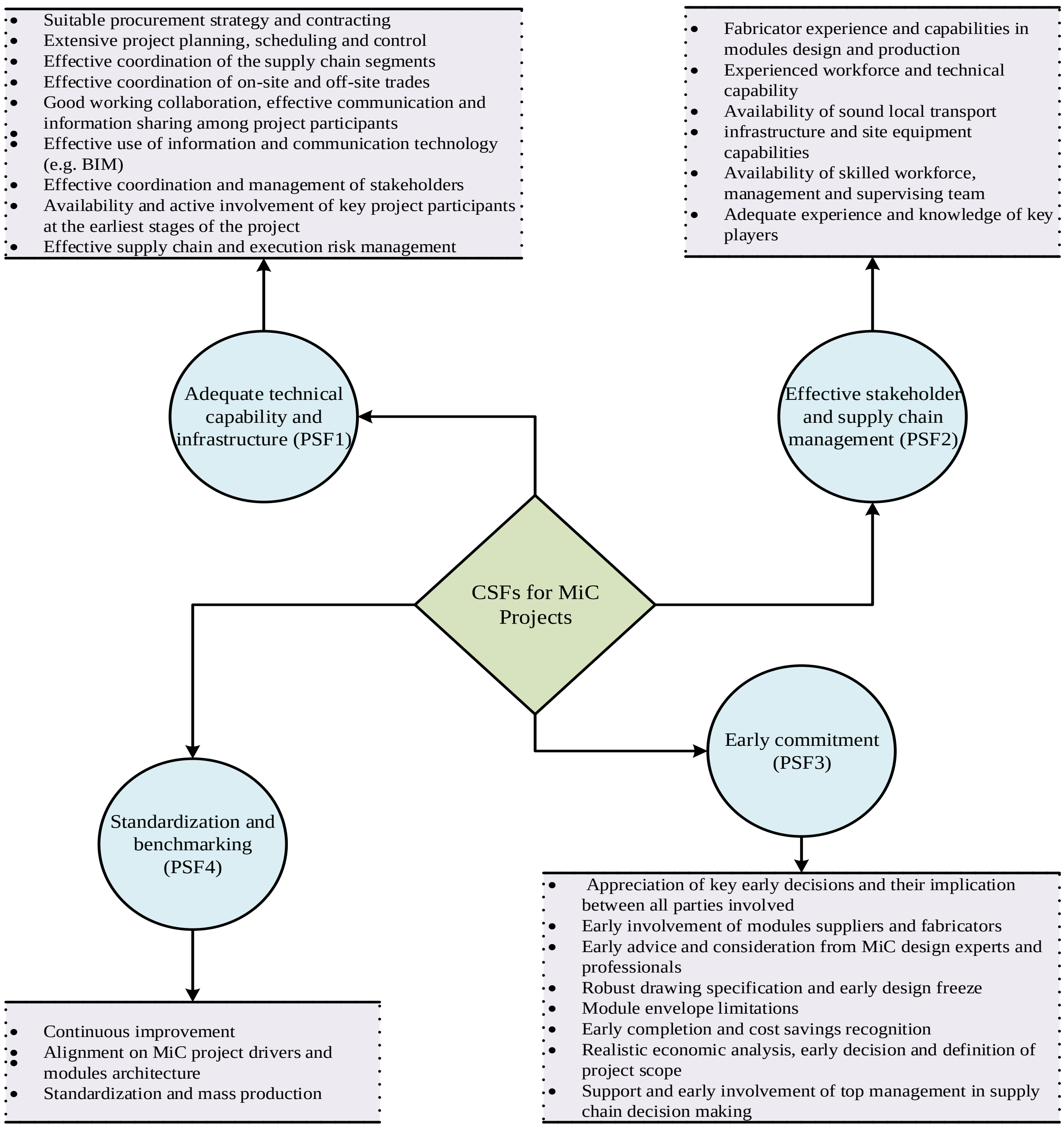

Figure 2. Conceptual framework of the CSFs for MiC projects

Table 6. MFs of the CSFs and PSFs for MiC Projects

S.N.	CSF and PSF	Weightings for CSF	Membership Functions for CSFs	Membership Function for PSFs
PSF1	**Adequate technical capability and infrastructure**			**(0.00, 0.08, 0.32, 0.41, 0.19)**
CSF1	Fabricator experience and capabilities in modules design and production	0.212	(0.00, 0.02, 0.30, 0.43, 0.25)	
CSF8	Experienced workforce and technical capability	0.201	(0.00, 0.07, 0.34, 0.39, 0.20)	

CSF12	Availability of sound local transport infrastructure and site equipment capabilities	0.200	(0.00, 0.14, 0.29, 0.38, 0.20)	
CSF10	Availability of skilled workforce, management and supervising team	0.197	(0.02, 0.09, 0.29, 0.41, 0.20)	
CSF16	Adequate experience and knowledge of key players	0.190	(0.00, 0.11, 0.38, 0.43, 0.09)	
PSF2	**Effective stakeholder and supply chain management**			**(0.01, 0.09, 0.36, 0.39, 0.16)**
CSF19	Suitable procurement strategy and contracting	0.119	(0.02, 0.07, 0.46, 0.32, 0.13)	
CSF7	Extensive project planning, scheduling and control	0.117	(0.00, 0.11, 0.27, 0.43, 0.20)	
CSF5	Effective coordination of the supply chain segments	0.117	(0.00, 0.04, 0.30, 0.50, 0.16)	
CSF15	Effective coordination of on-site and off-site trades	0.115	(0.02, 0.13, 0.38, 0.29, 0.20)	
CSF3	Good working collaboration, effective communication and information sharing among project participants	0.109	(0.00, 0.04, 0.29, 0.46, 0.21)	
CSF25	Effective use of information and communication technology (e.g. BIM)	0.109	(0.02, 0.11, 0.45, 0.34, 0.09)	
CSF14	Effective coordination and management of stakeholders	0.107	(0.00, 0.14, 0.34, 0.38, 0.14)	
CSF6	Availability and active involvement of key project participants at the earliest stages of the project	0.104	(0.00, 0.09, 0.23, 0.50, 0.18)	
CSF22	Effective supply chain and execution risk management	0.103	(0.00, 0.13, 0.50, 0.29, 0.09)	
PSF3	**Early commitment**			**(0.02, 0.12, 0.33, 0.39, 0.15)**
CSF21	Appreciation of key early decisions and their implication between all parties involved	0.137	(0.02, 0.14, 0.36, 0.32, 0.16)	
CSF9	Early involvement of modules suppliers and fabricators	0.131	(0.02, 0.04, 0.38, 0.38, 0.20)	
CSF11	Early advice and consideration from MiC design experts and professionals	0.129	(0.00, 0.18, 0.18, 0.45, 0.20)	
CSF2	Robust drawing specification and early design freeze	0.125	(0.00, 0.07, 0.27, 0.36, 0.30)	
CSF24	Module envelope limitations	0.122	(0.04, 0.16, 0.41, 0.30, 0.09)	
CSF23	Early completion and cost savings recognition	0.122	(0.04, 0.13, 0.34, 0.46, 0.04)	
CSF13	Realistic economic analysis, early decision and definition of project scope	0.118	(0.00, 0.13, 0.32, 0.43, 0.13)	
CSF20	Support and early involvement of top management in supply chain decision making	0.115	(0.02, 0.09, 0.38, 0.45, 0.07)	
PSF4	**Standardization and benchmarking**			**(0.01, 0.10, 0.30, 0.45, 0.14)**
CSF18	Continuous improvement	0.356	(0.02, 0.11, 0.38, 0.38, 0.13)	

CSF17	Alignment on MiC project drivers and modules architecture	0.322	(0.00, 0.13, 0.36, 0.43, 0.09)
CSF4	Standardization and mass production	0.322	(0.02, 0.07, 0.16, 0.55, 0.20)

4.5 Criticality indices of the PSFs

The criticality indices of the PSFs measured the relative significance of each PSF. It is an indicator for prioritizing and ranking the CSFs for MiC projects. Table 7 shows the criticality indices of the PSFs and their ranking. From Table 7, each PSF obtained a criticality index higher than the criticality threshold of 3.0 based on the 5-point grading scale adopted in the study.

Table 7. Critical indices of the PSFs for MiC Projects

Code	PSF	Index	Description	Ranking
PSF1	Adequate technical capability and infrastructure	3.691	Critical	1
PSF2	Effective stakeholder and supply chain management	3.595	Critical	3
PSF3	Early commitment	3.543	Critical	4
PSF4	Standardization and benchmarking	3.597	Critical	2

This outcome suggests that all the 4 PSFs have significant impact on the success of MiC projects. Based on the criticality indices, “adequate technical capability and infrastructure” was collectively evaluated by the experts as the most critical (3.691) and ranked 1st among the 4 PSFs. This was followed by “standardization and benchmarking” with a criticality index of 3.597, “effective stakeholder and supply chain management” with a criticality index of 3.595, and “early commitment” with the lowest but critical index of 3.543.

5. Discussions of research findings

5.1 Adequate technical capability and infrastructure (PSF1)

The successful use of MiC in a project requires specialists skills and capabilities of multidisciplinary players. Bertram et al. (2019) noted that the use of players with technical skills and capabilities in design, manufacturing operations, assembly and digital technologies are pre-requisite for success in MiC projects. *PSF1 – adequate technical capability and infrastructure* comprises CSFs intertwined with the skills and capability requirements of MiC projects. The five CSFs within PSF1 include CSF1 – fabricator experience and capabilities in modules design and production (3.91), CSF8 – experienced workforce and technical capability (3.71), CSF10 – availability of skilled workforce, management and supervising team (3.68), CSF12 – availability of sound local transport infrastructure and site equipment capabilities (3.63), and CSF16 – adequate experience and knowledge of key players (3.50). Throughout the life cycle of an MiC projects, very precise and specialized skills are required starting with designers to site labour through to the management teams. Designers, architects and engineers require adequate technical skills and specialization in the concepts of DfMA and should be able to reduce waste, improve sustainability & adaptability, achieve cost-effectiveness, reduce tolerance variability risk and generate higher quality from the final design of the project. The technical skills requirement of these players become severer in complex MiC projects, with often zero tolerance for errors. Increasingly, architects and designers are tasked to convert site-built designs into modular versions (Modular Building Institute 2017). The design team requires technical capabilities in 3D design and the ability to use building information modelling (BIM) to generate designs suitable for the planned location and design requirements. On completion and freezing of the project design, the fabricators must be able to produce modules which will directly reflect the design intent and specification of developers, owners and clients, once assembled on site. Meeting the functional and quality expectation of the clients depends largely on the technical capability of fabricators or manufacturers (Rentschler *et al.* 2016). The project management and supervising team require technical skills in DfMA, supply chain management, project integration, logistical and materials handling skills, production engineering, and process efficiency. Thus, adequacy of the technical capabilities and skills of the key players are required to deliver an MiC project which satisfies the planned objectives and expectations of the involved stakeholders. Modular transport restriction and challenges are recipes for schedule delays in MiC projects (Wuni *et al.* 2019). The effective and successful implementation of MiC projects require sound local transport infrastructure to facilitate timely delivery of the modules from the supplier or production plant to the construction site.

5.2 Effective stakeholder and supply chain management (PSF2)

MiC projects are a function of co-creation. The success of MiC projects requires the coordination and collaboration of systems, materials and people (Modular Building Institute 2017). It requires integration of the key players along the value and extensive coordination and management of the fragmented segments of the supply chain. Thus, *PSF2 – effective stakeholder and supply chain management* groups the CSFs associated with stakeholders and management of the MiC supply chain. The 9 CSFs within PSF2 include good working collaboration, effective communication and information sharing among project participants (3.86), effective coordination of the supply chain segments (3.79), availability and active involvement of key project participants at the earliest stages of the project (3.77), extensive project planning, scheduling and control (3.71), effective coordination of on-site and off-site trades (3.52), effective coordination and management of stakeholders (3.52), suitable procurement strategy and contracting (3.46), effective use of information and communication technology (3.38), and effective supply chain and execution risk management (3.34). The early stages of the MiC value chain is project conception and planning (Akagi *et al.* 2002, Song *et al.* 2005). Designers, engineers, architects, contractors and fabricators having skills, capabilities, and experience at modularization planning and execution constitute a CSF for MiC projects. Extensive planning allows for management to determine the staffing requirement, design planning, cost-benefit analysis, and early decisions. In MiC projects, upstream decisions have significant impact on the roles of downstream stakeholders (Wuni *et al.* 2019). For instance, the specifications and detailed drawing of the design team determines the work requirement of the modules' fabricator or manufacturer. Thus, the success of MiC projects hinges on extensive and excellent communication, information sharing, and coordination between stakeholders in all phases (Akagi *et al.* 2002, Tam *et al.* 2007, Wuni and Shen 2019a). This allows for key participants to be abreast of all major decisions and their implications on downstream segments of the MiC supply chain. Particularly, the involvement of the key players at the earliest stages of the MiC project life cycle allows for key decisions to be understood by all the relevant actors. The collaborative requirement of MiC projects imposes the need for an integrated project delivery method such as design-build procurement strategy. This procurement strategy is suitable because the design-build delivery method integrates the design and construction function of the MiC project into a single entity. The design-builders have experienced teams of designers, architects, engineers, fabricators, manufacturers, assembly contractors and project managers. Thus, it improves cooperation between project parties and integrates the key players in the MiC project decision-making process as early as a possible. Irrespective of the procurement method used, coordination and management of the involved stakeholders and the fragmented segments of the supply chain constitute CSFs for MiC projects. One effective mechanism for management the stakeholders and supply chain involve the use of digital construction technologies such as BIM. According to Choi (2014), BIM models uses digital tools and technologies to generate digital representation of the physical and functional characteristics of a project and provides a platform for information sharing and knowledge exchange. Li et al. (2017) developed a real-time BIM – Radio Frequency Identification (RFiD) platform for managing stakeholders and the supply chain of prefabricated housing projects in Hong Kong. Thus, the effective use of BIM will leverage the use of intelligent 3D model to facilitate real-time collaborative and coordinated planning, design, construction, and management of MiC projects. Effective coordination between on-site and off-site trades is critical to the success of MiC projects because it allows for significant reduction in the schedule and time performance of MiC projects (Pan *et al.* 2008, Li *et al.* 2018). The collaborative nature and fragmented segments of the MiC supply chain engenders significant risks and uncertainties. Thus, effective management of stakeholder, execution and supply chain risks has been found to be a CSF for MiC projects.

5.3 Early commitment (PSF3)

According to the Modular Building Institute (2017), the full benefits of MiC is often realized when modularization is considered and planned early in the design development process. Early commitment to modularization constitute one of the most cited CSFs for MiC projects in the literature (Wuni and Shen 2019a). *PSF3 – early commitment* comprises 8 CSFs including robust drawing specification and early design freeze (3.89), early involvement of modules suppliers and fabricators (3.70), early advice from experts and MiC consideration (3.66), realistic economic analysis, early decision and definition of project scope (3.55), appreciation of key early decisions and their implication between all parties involved (3.46), support and early involvement of top management in supply chain decision making (3.46), early completion and cost savings recognition (3.34), and module envelope limitations (3.25). According to Murtaza et al. (1993), not every project design and condition is suitable for modularization and the application of MiC. Thus, developers need to seek professional advice to ascertain the suitability of their design for modularization. This practice prevents failure of the project right from the earliest stages of the project life cycle because not every condition and circumstance renders MiC economical. Thus, detailed feasibility studies including realistic cost-benefit analysis is required to determine the economic viability of using MiC in a project. The economic benefits such as the early completion and cost savings inherent in the modularization should be incorporated in the modularization business case analysis model for the MiC project. Prior to design and fabrication of the modules, preliminary transportation study should be conducted to have a clear understanding of module envelope limitation such as the transport restrictions, shipping limitations, and trade-offs for larger modules. The Building and Construction Authority (2017) and Construction Industry Council

(2018) recommend the involvement of fabricators, suppliers and local contractors at the design stage of MiC projects. Fabricators with design experience and capabilities with modules often have the best ideas regarding module design ideas. Thus, it is a bad practice to have the design team supply set of drawings to the module fabricator who was not privy to the detailed module design specification. Integrating the design team, local contractor and fabricator allows for tolerance risks to be significantly minimized, resulting in improved constructability and reduced site-fit reworks. The integration results in robust engineering specification and early design freeze. Considering that the modules are often made-to-order, Wuni and Shen (2019a) explained that early design freeze allows for timely production of the modules which is crucial for meeting the schedules of the MiC project.

5.4 Standardization and benchmarking (PSF4)

Most countries are still at the early stages of the MiC learning curves. Thus, the inherent problems of higher cost, risks, and failures abound. According to Gibb (2001), standardization of design and modules for larger MiC projects constitute a driver for cost reduction through economies of scale. Benchmarking draws on the concept of continuous improvement using key performance indicators to identify best practices for a given business model. *PSF4 – standardization and benchmarking* comprise 3 CSFs including standardization and mass production (3.84), continuous improvement (3.48), and alignment on MiC project drivers and modules architecture (3.48). Gibb and Isack (2001) described standardization as "*the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability.*" The higher productivity of the manufacturing industry partly results from standardization and flow production of the standardized products on assembly lines. Consistent and repetitive design and fabrication of modular components have the advantages of reducing site errors and improving productivity in MiC projects. Existing research indicates that the significant impact of standardization and mass production to MiC project success could be realized when the decision is made early in the construction process (Gibb and Isack 2001). Incremental improvements in project delivery drawing on lessons from successful projects constitute a CSF for benchmarking best practices and improving the success of MiC projects. Choi (2014) found that alignment of the key players on the critical drivers of the MiC project results in effective realization of planned objectives and meeting the expectation of the associated stakeholders. Good working collaboration and coordination allows the key stakeholders to appreciate and align with the planning, objective and benefits of using MiC in a project. This alignment is a driver for collaborative working among the key players, which minimizes conflicts and delays in the MiC project delivery process.

6. Conclusions, contributions and limitations of the research

The quest to improve productivity and ill-performances in the construction sector is providing impetus for increasing adoption of OSM techniques. Although MiC has a long tradition and history in the construction industry, the prevailing momentum and interest indicates that the technology is sustainable and has a bright future. For many types of projects, MiC is increasingly becoming a preferred method of construction over the traditional construction approach. Where circumstances merit and favourable conditions prevail, the adoption of MiC with associated supply chain arrangement leverage significant gain in construction performance. However, not all implemented MiC projects have realized planned objectives and expectations of stakeholders. This research identified and assessed 25 factors which predicate success in MiC projects using FSE analysis. Reliability analysis of the dataset generated a high Cronbach's Alpha of 0.900, highlighting the excellent internal consistency of the responses and overall validity of the instrument used. Based on the mean scores, the top five CSFs for MiC projects include fabricator experience and capabilities in modules design and production; robust drawing specifications and early design freeze; good working collaboration, communication and information sharing among project participants; standardization and mass production; and effective coordination of the supply chain segments. These five CSFs highlight the profound importance of capabilities, design accuracy, collaboration, standardization and supply chain management to the success of MiC projects. A structure detection analysis transformed the CSFs into four PSFs, including adequate technical capability and infrastructure; effective stakeholder and supply chain management; early commitment; and standardization and benchmarking. The 4 PSFs obtained criticality indices exceeding the critical threshold, indicating that all the PSFs predicate success in MiC projects. The research outcomes constitute the first exclusive attempt at benchmarking the generic CSFs for MiC projects and have useful theoretical and practical implications. Theoretically, the results contribute to the checklists of CSFs for MiC projects which may form the basis for future studies on the success of MiC projects. Practically, the research has identified and prioritized the factors which predicate success and may help MiC project managers and stakeholders in the planning and appropriate allocation of limited resources. The results contribute to the practice of implementing and managing MiC projects in countries where bespoke studies cannot be conducted. The identified CSFs provide a useful framework for measuring and predicting the success of MiC projects. However, the study suffered some limitations. First, the general analysis overlooked the sensitivities of the CSFs to different project types and territories and thus, bespoke studies may have to be conducted to guide the implementation of a specific project. Second, although adequate, the sample size was small. Nonetheless, some reliable conclusions have been drawn in similar published studies with even fewer sample sizes. Future research aims at increasing the sample sizes and developing structural equation model and system dynamics model to explore the interrelationships of the CSFs for MiC projects.

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