Evaluating the Critical Failure Factors for Implementing Residential Modular Integrated Construction Projects

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ABSTRACT

Residential modular integrated construction (RMiC) offers the benefits of speed, economy quality, and mass production in housing delivery. Evidence in some countries have established the feasibility of using RMiC to address the housing shortfalls, but not all initiated RMiC projects have achieved the desired level of success. However, there is limited knowledge of the shared factors contributing to the failure of RMiC projects. This research identified and prioritized the critical failure factors (CFFs) for RMiC projects. Analysis of international survey-based data showed that the top 4 CFFs for RMiC projects include inaccurate engineering specifications and late design freeze; limited fabricator experience and capabilities in modules design and production; poor working collaboration and infrequent communication among project participants; and supply chain disruptions and disturbances. This research constitutes the first exclusive quantitative evaluation and prioritization of the CFFs for RMiC projects and makes a useful contribution to the knowledge of RMiC project management. It may provide decision support to practitioners and form a useful basis for future research.

INTRODUCTION

There is an increasing tendency to accept the global housing crisis as a problem that cannot wholly be addressed (Wuni and Shen, 2019a). The housing crisis has both physical and economic dimensions because, amid the deficit, houses are regularly being advertised for sale. Thus, the greatest challenge for the construction industry is to deliver quality mass housing at affordable prices (Terner and Turner, 1972). However, the traditional construction approach (TCA) has consistently and historically demonstrated its inability to provide the economy and speed required to address the housing deficit (Lu and Liska, 2008). This long-standing drawback of the TCA imposed a need to identify an innovative solution for responding to the increasing housing shortfall.

Off-side production (OSP) of buildings is proposed as an innovative solution to the economic and physical aspects of the housing crisis (Blismas and Wakefield, 2009; Pan and Goodier, 2012). OSP is a construction approach that transfers significant components of building construction to an offsite factory where components are mass-produced and transported to a job site for installation (Pan and

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Goodier, 2012). Following the Egan Report on "Rethinking Construction" (Egan, 1998), OSP has become a significant disruption to the housing construction business model (Wuni and Shen, 2019b and 2019c). Modular integrated construction (MiC) is an innovative OSP technique proposed by the Hong Kong Government to address the increasing housing shortfall. MiC is considered the highest end of prefabrication and the most complete form of OSP, where over 80-90% of a building can be manufactured in an offsite factory (Smith, 2016).

For several types of construction projects, MiC is increasingly becoming a preferred construction method over the traditional site-based construction approach. Residential MiC (RMiC) projects are housing projects generated using the MiC approach (Wuni et al., 2019; Wuni and Shen, 2019d and 2019e). RMiC shares many similarities with OSP techniques such as industrialized building systems (IBS), modular construction, industrialized housing construction (IHS), prefabricated housing production (PHP), and prefabricated prefinished volumetric construction (PPVC) (Wuni and Shen, 2019b and 2019a). The RMiC technology is widely used in Japan, Germany, Canada, UK, Sweden, Finland, Hong Kong, Australia, and Malaysia to respond to the increasing demand for quality affordable housing. An effectively implemented RMiC project reduces construction time, improves project quality control, reduces life cycle cost, improves environmental performance, the safety of workers, efficiency, and productivity of construction projects (Blismas et al., 2006; Wuni and Shen, 2019c). However, several factors and conditions converge to determine the success or failure of RMiC projects (Sanvido et al., 1992; Wuni and Shen, 2019c).

Although some implemented RMiC projects have realized planned objectives and met the expectations of stakeholders, others failed and are considered unsuccessful (Wuni and Shen, 2019b and 2019c). The failure of RMiC is of critical importance because it acts both as a barrier and disincentive to the adoption of MiC in the construction industry. However, existing studies have focused mainly on identifying the critical success factors for OSP techniques. As a result, there is very limited knowledge of the factors and conditions which predicate and determines the failure of RMiC projects. This research seeks to identify and prioritize the critical failure factors (CFFs) for RMiC projects, drawing on international experiences and lessons. The study forms part of an ongoing Ph.D. research project which seeks to develop a best practice framework for implementing MiC projects. The outcome of the current research will provide a useful framework for managing RMiC projects towards the realization of more calculated project outcomes and may serve as a solid foundation for future studies.

RESEARCH BACKGROUND AND THEORETICAL FRAMEWORK

The concept of critical failure factors. A failed construction project is one that does not realize planned objectives and meets the expectations of stakeholders (Belassi and Tukel, 1996). Several factors and conditions converge to trigger construction project failure (Sanvido et al., 1992). The concept of CFFs emerged in the same decade, during which critical success factors (CSFs) was officially codified (Rockart, 1982). CFFs was first used to explain the failure of enterprise resource

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planning in business process reengineering and information management (Lyytinen and Hirschheim, 1987). The concept of CFFs describes the conditions and management areas that must go wrong for an ERP project to fail (Yeo, 2002). As a result, this research defines CFFs as the key few management areas that must go wrong for an RMiC project to fail to realize planned objectives and meet the expectations of stakeholders. This conceptualization of the CFFs is crucial because RMiC project failures have technical and managerial aspects (Wuni et al., 2019), but the latter forms the crust of the current research. Drawing on the works of Lyytinen and Hirschheim (1987), this research classifies RMiC project failures into five categories: (i) correspondence failure occurs when an RMiC project does not meet its specific design objectives; (ii) process failure occurs when the RMiC project significantly exceeds the schedule or budget; (iii) interaction failure occurs when the completed RMiC projects face negative occupancy attitude to the project; (iv) expectation failure occurs when the RMiC project does not meet the requirements, expectations, and values of the involved stakeholders; and (v) termination failure occurs when the RMiC project terminated before completion or abandoned during operation.

Overview of residential modular integrated construction. RMiC is an innovative construction method involving offsite manufacturing of value-added volumetric building components (usually completed with finishes, fixtures and fittings), which are trucked to a construction site in sections, set in place with powerful cranes and systematically installed to generate a building project (Construction Industry Council, 2018; Wuni and Shen, 2019c). Although wood is commonly used in North America and Europe, the three types of RMiC based on construction material include reinforced concrete modules, steel frame modules, and a hybrid module (Construction Industry Council, 2018). The construction process of RMiC projects involves engineering design of modular components, statutory approval of design and permitting, manufacturing of the modules in the factory, transportation of the modules to a construction site, and on-site installation of the modules.

There are several reasons why RMiC is a panacea to the housing crisis. First, the nature of the RMiC project delivery project allows for both on-site and off-site trades (usually the factory production stage) to run concurrently. This accounts for the significant savings in the schedule of RMiC projects (Modular Building Institute, 2017). The speedy construction has significant positive implications for housing delivery. The reduced construction time translates into cost-effectiveness for housing authorities and faster solvency for developers. Second, RMiC supports mass housing production. When coupled with the speedy construction, it leverages higher elasticity and responsiveness to mass housing demand (Wuni and Shen, 2019a). Third, mock-up testing, and trial assemblies are often conducted before mass production. Thus, RMiC can generate high-quality housing units. Fourth, RMiC projects are industrialized housing systems and products rather than projects (Bertram et al., 2019), where the same engineering and design specification could generate highly individualized, diversified, flexible, demountable, and adaptable housing systems. Fifth, the mass production of housing provides an economy of scale, which generates lower design costs and optimal housing construction costs.

However, several key considerations must be made during the implementation of RMiC. First, the suitability of the design for modularization must be verified because not every project design lends itself to modularization. RMiC is most suitable for projects with repetitive design such as residential houses, hotels, schools, and prisons (Wuni and Shen, 2019e). Second, the implementation of RMiC requires an early commitment to the approach. It requires early engineering design specifications and timely design freeze to facilitate factory production of the modules. The Construction Industry Council (2018) recommends early involvement of suppliers, fabricators, and a local contractor to the design stage of the project, considering that early decisions have significant implications on their roles. Third, systemic risks such as dimensional and geometric variabilities must be carefully managed because a single design error will be replicated in all the produced modules, which might generate complications during the on-site assembly process. The Construction Industry Council (2018) also recommends good working collaboration, frequent communication, and adequate information sharing among project participants along the RMiC supply chain. Indeed, effective stakeholder and supply chain management constitute CSFs for MiC projects (Wuni and Shen, 2019c).

RESEARCH METHOD AND APPROACH

The research adopted a quantitative research design and expert approach where the opinions and experiences of international experts constituted the primary basis for evaluating the significance of the CFFs. A multistage methodological framework was adopted, including a comprehensive review of literature, pilot survey, questionnaire design and administration, data collection, pretesting of the dataset, and the use of mean scores and significance indices to rank the CFFs. Figure 1 shows the methodological approach for the study.

A comprehensive review of OSP and MiC literature. There are currently limited published research studies on MiC and thus, the CFFs for RMiC could hardly be directly extracted from the literature. However, there are some studies on other OSP techniques that provided a useful basis for identifying potential CFFs for RMiC projects. Structured queries in Scopus and Web of Science generated some useful articles addressing the management of OSP. Following a thorough review of the literature, a list of 17 CFFs relevant to RMiC projects was developed. However, due to the limited space requirement, documentation of the literature synthesis was not considered prudent.

Survey design and data collection. The 17 potential CFFs were sent to three experts in Hong Kong, Canada, and Australia to ascertain their relevance to RMiC projects. The piloting outcome resulted in a merger of two CFFs, rewording of others, and elimination of 1 CFF. The final list comprised 15 CFFs and formed the basis for the questionnaire design. A structured questionnaire was designed for study. A questionnaire was used because the research aimed to generate quantitative data from the opinions and views of the experts, which is effectively achieved using questionnaires. Questionnaire is also a time and cost-effective survey instrument for generating reliable data and is widely used in construction management research (Wuni and Shen, 2019e and 2019c). The questionnaire consisted of two sections. Section 1 collected the background information of the experts to verify their suitability as respondents, and section 2 requested the experts the rate the 15 CFFs on a 5-point grading scale comprising 1=Not critical, 2=Slightly critical, 3=Critical, 4=Very critical; and 5=Extremely critical.

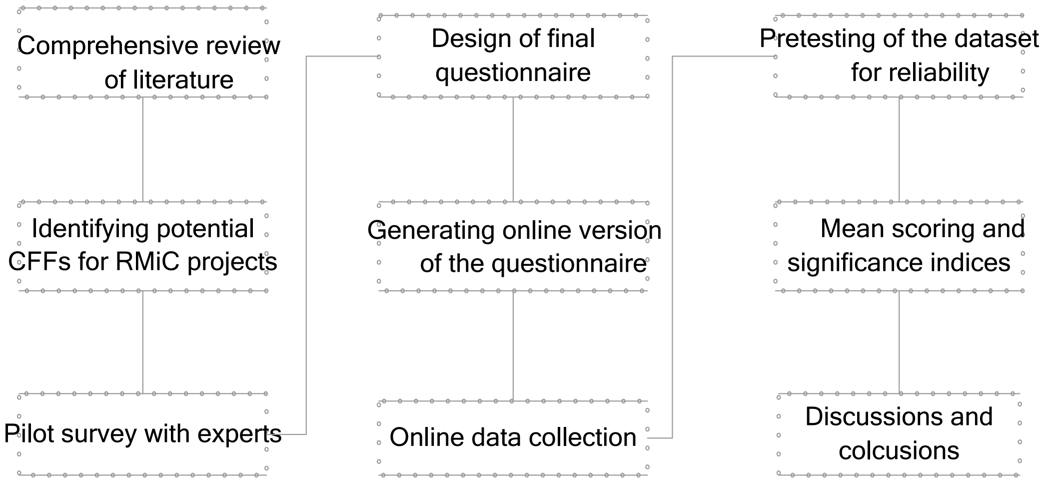

Figure 1.Methodological approach for the research.

Considering that an expert approach was adopted, international experts formed the respondents of the study. The international survey approach was adopted because the study sought to draw on international lessons and hands-on experiences to establish a comprehensive framework of the CFFs, which may be relevant to several countries. This approach has been adopted in previous studies (Ameyaw and Chan, 2015). A purposive sampling technique was adopted because there is no central global database for OSP experts, which rendered random sampling impractical. Ameyaw and Chan (2015) used this approach to select experts in their study. OSP and MiC practitioners and academics formed the sampling frame for the study. Drawing on best practices of international expert surveys (Ameyaw and Chan, 2015), the academic experts were easily located from relevant OSP articles published in top-rated construction management journals whereas the industry practitioners were extracted from OSP councils, associations, and bodies.

Considering that data quality problem constitutes a significant drawback of international survey studies, the experts were carefully selected based on the following predefined criteria: (i) the experts should have substantial theoretical and practical understanding of the management and implementation of an OSP technique; and (ii) the expert should have some years of hands-on experience and has been involved in the implementation of an OSP project. Based on these criteria, a total of 400 experts from academia and industry were identified during a period of 11months of literature review as part of an ongoing Ph.D. research project.

The questionnaire was then transformed into an online version with the aid of 'Survey Monkey.' A link to the survey was generated from the 'Survey Monkey' platform. The researchers wrote personalized emails (with the survey link attached) to the 400 experts, inviting them to participate in the survey. After two rounds of reminders, a total of 56 valid responses were generated. Considering that the research was time-bound, the survey was terminated, and the data was extracted from 'Survey Monkey.' Although small, the sample size was considered adequate due to the following reasons: (i) the sample exceeds the minimum of 30 responses required by the central limit theorem for valid conclusions to be made; (ii) smaller sample sizes are characteristic of online international surveys. The sample is higher than some similar studies such as 27 (Sachs et al., 2007); and (iii) the sample size was distributed across 18 countries and six countries. Thus, it constituted a useful international knowledge-base for evaluating the CFFs for RMiC projects.

Method of data analysis. The dataset was analyzed using the Statistical Package for the Social Science (IBM SPSS v.25). First, the reliability of the grading scale and survey instrument was measured using Cronbach's Alpha. The reliability analysis generated a Cronbach's Alpha of 0.849, which indicates high and acceptable internal consistency in the responses and validity of the survey instrument (Tavakol and Dennick, 2011). The normality of the dataset was analyzed using the Shapiro-Wilk test (Chou et al., 1998). The test was significant ($p<0.000$) for all CFFs at a 95% confidence level, indicating that the dataset is not normally distributed (see Table 1). This instructed the use of the nonparametric test to further analyze the dataset (Wuni and Shen, 2019d). Based on the recommendation of Chou et al. (1998), the Kruskal – Wallis test was used to test the null hypothesis that there are no significant variations between the responses of experts from academia and industry. The test was not statistically significant ($p>0.05$) for all CFFs at a 95% confidence level (see Table 1), the responses can be treated holistically.

The mean scores of the CFFs were computed as standard measures of their central tendency. Mean scores are widely used to rank factors measured using a grading scale. The mean scores of the CFFs were computed using the Formula 1.

$$MS = \frac{\sum(f*s)}{N}, 1 \leq \mu \leq 5 \quad (1)$$

Where MS = mean index of a CFF; f = the number of ratings (i.e., 1-5) for a CFF; s = scores assigned to a CFF by the experts ranging from 1 to 5; and N = total number of responses obtained by a CFF. Table 3 shows the mean scores of all the CFFs. The research further computed the significance indices of the CFFs. In computing the significance indices, the 5-point scale was converted to a linear scale where 1, 2, 3, 4, and 5 had significance indices of 20, 40, 60, 80, and 100, respectively. Significance index of each CFF was computed as follows: Significance index:

$$(S_i) = \frac{1*R_{i1} + 2*R_{i2} + 3*R_{i3} + 4*R_{i4} + 5*R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} = \frac{20R_{i1} + 40R_{i2} + 60R_{i3} + 80R_{i4} + 100R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} \quad (2)$$

Where: S_i = significance index a CFF; R_{i1} = number of responses for the grading alternative "1" for a CFF; and R_{i5} = number of responses for the grading alternative "5" for a CFF. The significance indices, together with the mean scores, formed the basis for raking and prioritizing the CFFs for RMiC projects.

RESULTS OF DATA ANALYSIS

Background information of the survey experts. The experts were requested to indicate the sector (academia or industry) they were actively working, the country where they were involved in the RMiC project, and the years of relevant hands-on experience in OSP projects. Figure 2 shows the results for section one of the questionnaires. The analysis showed that a majority of experts who responded to the survey were working in academia. A similar distribution has been reported in previous studies (Ameyaw and Chan, 2015). This pattern was expected because most academics understand the questionnaire survey approach and constitute citizens of the scientific community. So, they may be keen on advancing knowledge in the field. These academics (78.6%) worked mainly in academia but collaborate actively with industry practitioners and thus, deployed both research and practical experience in assessing the CFFs. Most of the experts (71.4%) had less than 10 years of working experience with RMiC or OSP projects. This was also expected because the OSP renaissance, disruption and diffusion in the construction industry took place during the last three decades.

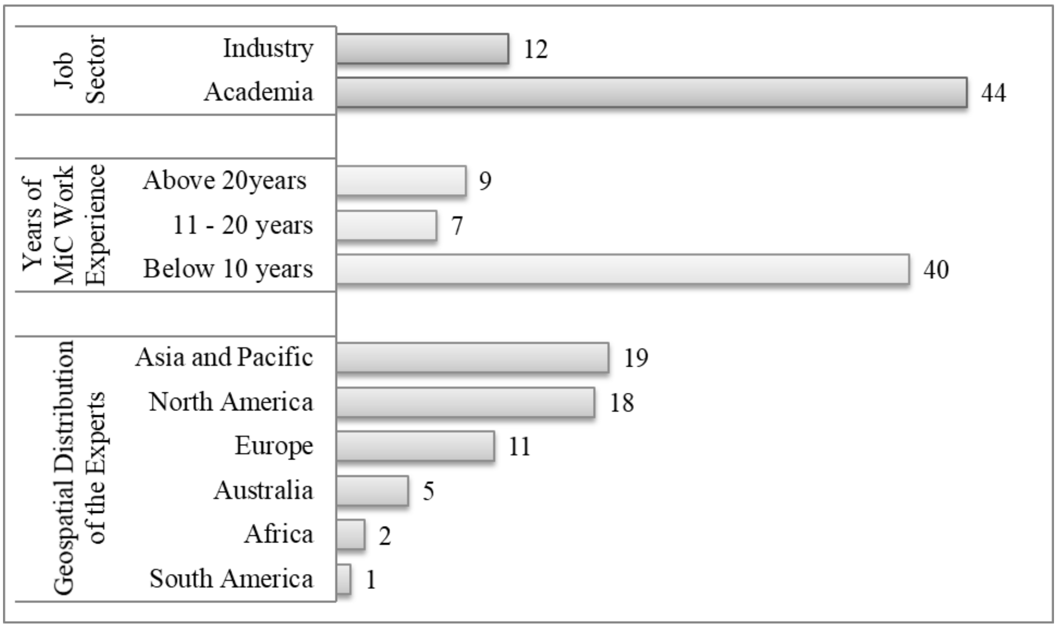

Figure 2.Background information of the experts.

Thus, some countries are still experimenting with the techniques while others are operating some completed projects. About 28.6% of the experts had at least 11 years of working with OSP or RMiC projects. This suggests that the surveyed experts had adequate experience to comment on the CFFs for RMiC projects. The majority of the experts were working in North America (e.g., Canada, United States) and Asia (e.g., China, Hong Kong, Singapore, Malaysia). A good number of experts were working in Europe (e.g., Germany, Sweden, UK). These countries and economies have some of the most advanced forms of OSP and RMiC. Thus, diverse experiences and lessons formed the basis for evaluating the CFFs.

Analysis and ranking of the CFFs for RMiC projects. The mean scores and significance indices of the CFFs for RMiC projects were computed using equation 1 and 2, respectively. Table 1 shows the mean scores and significance indices of the CFFs. Results of the Shapiro – Wilk test and the Kruskal – Wallis test are shown in Table 1. Based on linguistic terminologies assigned to the grading scale adopted, a mean score of at least 3.0 and a significance index of at least 60 indicated that a CFF is at least "critical" to RMiC projects. The analysis generated mean scores and significance indices above 3.5 and 60, respectively, for all CFFs. This outcome suggests that the 15 CFFs predicate and determine failure in RMiC projects and should be considered carefully when implementing RMiC projects. . Based on the mean scores and significance indices, the top 6 CFFs for RMiC projects include: inaccurate engineering specifications and late design freeze (3.96); limited fabricator experience and capabilities in modules design and production (3.91); poor working collaboration and infrequent communication among project participants (3.86); supply chain disruptions and disturbances (3.80); poor coordination of the fragmented supply chain segments (3.79); and unsuitability of design for RMiC (3.79). Due to the limited space, only the 6 CFFs are briefly discussed in the next section.

DISCUSSIONS AND IMPLICATIONS OF KEY FINDINGS

Inaccurate engineering specifications and late design freeze. The engineering design of the modules constitutes one of the early stages of the RMiC value and supply chain (Wuni et al., 2019). The modular components are the key drivers of the RMiC projects. Inaccurate engineering specifications and design freeze are CFFs for RMiC projects. Early freezing of the modular design is required for factory production of the modules. Considering that the design stage is part of the entire schedule of the RMiC project, late design freeze results in untimely production of the modules, translating into expensive schedule delays. Errors in the design also translate into repeated errors in the produced modules. The errors generate significant dimensional and geometric variabilities in the modules. Such variabilities will generate connection problems during on-site assembly. Where the variabilities are too wide beyond the allowable tolerance, re-engineering, reproduction, and re-assembly of the modules may be required. This ultimately increases costs and overruns the schedule.

Limited fabricator experience and capabilities in modules design and production. The quality of the final RMiC project depends on the quality of modules used in the construction of the project. The quality of the modules also depends on the experience and capability of the fabricator (Blismas and Wakefield, 2009). The modules fabricators constitute important RMiC project participants because they translate the design expectations of the developer within the modules into reality.

Table 1.Mean Scores and Significance Indices of the CFFs for RMiC Projects.

Code	Critical Failure Factors	MS	SD	S_i	Rank	S-W test (P-value)	K-W test (p-value)
CFF1	Inaccurate engineering specifications and late design freeze	3.96	0.81	79.29	1	0.000	0.931
CFF2	Limited fabricator experience and capabilities in modules design and production	3.91	0.79	78.21	2	0.000	0.291
CFF3	Poor working collaboration and infrequent communication among project participants	3.86	0.80	77.14	3	0.000	0.534
CFF4	Supply chain disruptions and disturbances	3.80	0.90	76.07	4	0.000	0.627
CFF5	Poor coordination of the fragmented supply chain segments	3.79	0.76	75.71	5	0.000	0.736
CFF6	Unsuitability of design for RMiC	3.79	0.97	75.71	5	0.000	0.834
CFF7	Unavailability of consistent key participants throughout major stages of the project lifecycle	3.77	0.85	75.36	7	0.000	0.605
CFF8	Poor client understanding, receptivity, and acceptance of RMiC	3.77	1.03	75.36	7	0.000	0.900
CFF9	Incomprehensive project planning, scheduling, and control	3.71	0.91	74.29	9	0.000	0.958
CFF10	Inexperienced workforce and inadequate technical capability	3.71	0.87	74.29	9	0.000	0.874
CFF11	Late involvement of modules suppliers and fabricators in the project lifecycle	3.70	0.89	73.93	11	0.000	0.816
CFF12	Significant dimensional variabilities and site-fit-reworks	3.68	0.99	73.57	12	0.000	0.393
CFF13	Limited skilled workforce, management, and supervising team	3.68	0.96	73.57	12	0.000	0.697
CFF14	Late advice and consideration of RMiC in the project	3.66	1.00	73.21	14	0.000	0.453
CFF15	Unavailability of sound local transport infrastructure and site	3.63	0.96	72.50	15	0.000	0.504

	equipment capabilities	

Note: S – W = Shapiro -Wilk; K – W = Kruskal-Wallis; MS = Mean Score; and SD = Standard Deviation

Fabricators with limited experience in modules design and production may have an inaccurate interpretation of the design. They may produce components with significant dimensional variabilities and poor quality (Wuni et al., 2019). These translate into a poor quality of the final RMiC projects which may require expensive site-fit-reworks to improve its quality and functionality (Wuni and Shen, 2019d).

Poor working collaboration and infrequent communication among project participants. Multidisciplinary stakeholders and project participants dominate the various stages of the RMiC project life cycles. The roles of the different project participants are interdependent (Wuni and Shen, 2019e and 2019d). For this reason, RMiC projects are a function of co-creation, requiring the collaboration of all involved stakeholders. Thus, poor collaboration and infrequent communication among project participants are recipes for conflicts and non-realization of their expectations on the project (Belassi and Tukel, 1996). For instance, poor communication and information sharing between the design team and the factory production team means that the latter will produce modules based on the specification to which they were not privy.

Supply chain disruptions and disturbances. The distinct stages of the RMiC supply chain are complex and linked. As a result, disruptions and disturbances in upstream segments have negative implications on downstream segments (Wuni et al., 2019). For instance, inaccurate modular design results in the production of inaccurate modular components. The faulty modules eventually generate a poor quality final RMiC project after the final assembly. Supply chain disruptions and disturbances constitute CFFs because several unplanned events could trigger their occurrence, and yet, they are obscure to identify proactively. The effects of supply chain disruptions and disturbances are schedule delays and an increase in construction costs (Li et al., 2016).

Poor coordination of the fragmented supply chain segments. Closely related to the above CFF is poor coordination of the fragmented supply chain segments. Successful implementation of RMiC requires extensive coordination of the RMiC supply chain segments before and during the construction process (Hwang et al., 2018). Thus, poor coordination of the fragmented but linked segments constitute recipes for cost increase and expensive schedule delays (Li et al., 2016).

Unsuitability of design for RMiC. The failure of RMiC projects could often be traced to decisions made at the early stages of the project life cycle (Wuni and Shen, 2019e). Not every project design is suitable for MiC. Thus, if the suitability of the design for modularization is not ascertained before implementing RMiC, the project might fail even before the modules are produced. The effect of using an unsuitable design for RMiC projects is that the full benefits associated with the technology will not be realized. Blismas and Wakefield (2009) recommended that developers and housing authorities seek professional advice on the suitability of their design for modularization before implementing RMiC projects.

CONCLUSION

RMiC offers the benefits of economy, quality, mass, and speed in housing production. These promises are crucial for responding to the rapidly increasing housing shortfalls across the globe. However, several factors and conditions converge to predicate the success or failure of RMiC projects. Existing studies have continuously explored the CSFs for implementing RMiC projects and neglected the failure factors. This research identified and examined 15 CFFs for RMiC projects drawing on an international survey of experts. The analysis revealed that all the factors are critical factors causing RMiC project failures because each of 15 CFFs obtained a mean above 3.50 on the 5-point grading scale adopted and significance index above 60. The results are instructive and highlights the significance of these CFFs in generating RMiC project failure. Of these, the top 6 CFFs included: inaccurate engineering specifications and late design freeze; limited fabricator experience and capabilities in modules design and production; poor working collaboration and infrequent communication among project participants; supply chain disruptions and disturbances; poor coordination of the fragmented supply chain segments; and the unsuitability of design for RMiC. The study recommends that these management areas should be given critical attention to improve the success of RMiC projects. The results of the study make a unique contribution to the knowledge of managing RMiC projects by identifying and prioritizing the key few areas that predicate failure in RMiC projects. A potential impact of the study is that it will guide the implementation of RMiC projects towards achieving more measurable outcomes and may form a useful basis for future studies. However, the study suffered some limitations: (i) although adequate, the sample size was small and may compromise the generalizability of the findings, and (ii) the generic analysis of the CFFs overlooked their sensitivities to different project stages and territories. Thus, future research will increase the sample and explore the interactions among the CFFs in a specific context and validate the findings with real-world case project.

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