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Critical Factors for Successful Implementation of Just-in-time Concept in Modular Integrated Construction: A Systematic Review and Meta-analysis

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ABSTRACT

Modular integrated construction (MiC) is a revolutionary construction method. However, the logistics management of MiC has always been a major barrier to the wider adoption of MiC. Nonetheless, this challenge can be tackled by the application of lean techniques, namely, just-in-time (JIT). Numerous studies have identified and evaluated the critical factors (CFs) required to implement JIT; however, there is no consensus among the previous studies on these CFs and their level of importance. Therefore, this research, for the first time, provides a systematic review and meta-analysis of these CFs. The systematic review identifies 42 CFs. To further provide a synthesis analysis of previous studies, a meta-analysis approach is used. This analysis is conducted on the identified CFs to evaluate their importance level and hence rank them. The results indicate that all the 42 CFs are important for applying JIT, of which seven are highly significant for successfully implementing JIT in MiC. Although the ranking obtained by meta-analysis is much more reliable than that provided in the individual studies, however, there is still a high heterogeneity in the results, which depicts the uncertain nature of the construction field. Therefore, sub-group analysis is conducted to investigate this heterogeneity and uncover the hidden patterns in the literature. This is achieved by studying the influence of predictive factors (moderators) on the importance level of CFs. This analysis shows that the economy of a country and the type of project executed are influential factors. The results further indicate that developing economies, in contrast to advanced economies, should pay more attention to three CFs. Also, the results show that seven CFs are much more important in MiC projects than the other project types. This research work is highly beneficial for theory development and for practitioners by identification of significant CFs that warrant management dedication to best apply JIT. Researchers, in particular, can consider the recommendations given here for implementing future meta-analysis studies.

Keywords: Critical success factors; Supply chain management; Lean; Logistics; Meta-analysis; Modular integrated construction.

1. INTRODUCTION

Modular integrated construction (MiC) brings radical changes to the traditional cast-in-situ construction method (Wuni and Shen, 2020a). In MiC, the whole building is divided into a number of full-volumetric modules produced off-site in a factory environment. Next, these modules are transported to the construction site for direct installation with minimal construction activities. MiC has many advantages over the traditional method, including reduction in construction duration (Zhang et al., 2018) and wastes (Wang et al., 2015), and improvement in quality (Tam et al., 2015) and safety (Xu et al., 2020). Moreover, some studies have demonstrated that MiC is cleaner and more sustainable than the traditional construction method (Wuni and Shen, 2020a). For example, Jaillon et al. (2009), through a qualitative study conducted in Hong Kong, have indicated that MiC implementation reduces construction waste by 52%. Recently, Hammad et al. (2019) have demonstrated, through a life cycle assessment, that MiC performs better than the traditional method by 60%, 52% and 21% in terms of economic, environmental and social indicators, respectively. However, logistics management of MiC supply chain is one of the primary barriers to adopting MiC (Ferdous et al., 2019). For example, the proper logistics planning and management contributed to the successful delivery of the Huoshenshan and Leishenshan hospital projects in Wuhan, China. Both hospitals have been constructed using modular construction in about ten days during the outbreak of the novel coronavirus COVID-19 (Luo et al., 2020).

The challenge of logistics management in MiC stems from its characteristic complex and multi-echelon supply chain. The complexity of the MiC supply chain is due to the fragmented nature of MiC (Wang et al., 2019) and the impact of multidisciplinary stakeholders (Xue et al., 2018). The MiC supply chain is a make-to-order type, where the MiC modules are customized according to project specifications. Therefore, MiC manufacturers typically do not keep stocks of these modules before receiving orders. Meanwhile, construction sites have limited storage areas and so, cannot hold stacks of such bulky modules (Hsu et al., 2018). Hence, MiC modules need to be delivered to the construction site on-time with the required quality and quantity. As a result, just-in-time (JIT), a lean construction technique, has been proposed to tackle the logistics challenges in MiC (Pheng and Chuan, 2001). Successful implementation of JIT results in reducing inventory, wastes and procurement costs (Akintoye, 1995). Besides these benefits, JIT can further improve the sustainability of MiC by reducing inventory levels. Hence, double handling and damages to stored materials are eliminated (Carvajal-Arango et al., 2019; Francis and Thomas, 2020). Also, Goh and Goh (2019) have utilized a discrete-event simulation model to evaluate the contribution of JIT in MiC in reducing the project's time, increasing labour productivity and enhancing process efficiency. Through a life cycle assessment, Heravi et al. (2020) have similarly demonstrated that successful application of lean techniques, including JIT, to MiC, can reduce energy consumption and CO_2 emissions by about 9.0% and 4.0%, respectively. Therefore, JIT has a sustainable potential to overcome the challenges of MiC logistics.

The merits of JIT have motivated many researchers to study the critical factors (CFs) required for successfully implementing it in MiC. For instance, Jaafar and Mahamad (2012) have identified CFs and challenges to apply JIT in MiC from the perspective of MiC manufacturers. Later, Rahimah Mohd Noor et al. (2018) have identified CFs and drivers to apply lean techniques, including JIT, in MiC from the perspective of project managers, contractors and engineers. Besides, other researchers have discussed CFs of JIT in different countries and for other project types. For building projects, Ayarkwa et al. (2012) have identified CFs of lean techniques, including JIT, in Ghana, while Olamilokun (2015) has determined CFs and barriers to apply these techniques from the Nigerian perspective. For infrastructure projects, Demirkesen and Bayhan (2019) have identified critical success factors for lean implementation in the USA, while Tezel et al. (2018) have identified these factors for British highway construction projects. These studies provide an evaluation of the importance level of the identified CFs. However, there is a little consensus among these studies. The disagreement between them is regarding the importance level of CFs, as shown in Table 1.

This table provides an example of three CFs where some studies consider them as significant factors to the successful implementation of JIT, while other studies find them as non-significant. Here, a factor is deemed to be significant if its mean value is higher than “4” on the five-point Likert scale (Lam et al., 2007; Chan et al., 2004). Therefore, there is little consensus among the previous studies on the ranking and evaluation of CFs based on their importance level.

Table 1

Many review papers have been published on MiC-related topics. Some of these topics include life cycle performance (Kamali and Hewage, 2016), sustainable design (Sonego et al., 2018), scientometric review analysis of MiC studies (Jin et al., 2018), critical risk factors (Wuni et al., 2019), critical success factors (Wuni and Shen, 2019), lean techniques (Innella et al., 2019), supply chain vulnerabilities (Ekanayake et al., 2020), and adoption barriers (Wuni and Shen, 2020a). However, the literature still lacks a systematic review of the CFs for implementing JIT in MiC. Moreover, prioritization of factors, risks or vulnerabilities, based solely on their frequency of occurrences in the literature is a common limitation of these review studies.

Although the lack of consensus among researchers may be attributed to the uncertain nature of the construction management research field, an international review of the CFs required for implementing JIT and a generalized understanding of the importance of these CFs are both warranted and imperative. Therefore, this study aims to achieve these two objectives. Firstly, the development of a checklist of CFs of JIT from an international perspective will help researchers in conducting further empirical studies. Secondly, a generalized understanding of the importance of these CFs will aid in theory building and practical adoption of JIT in MiC. These points can be achieved by addressing the following questions. What are the CFs required for implementing JIT in MiC? Do all CFs have the same level of importance? If not, what is the prioritization of these CFs? Are all CFs significant to the successful application of JIT? If not, then which CFs are significant? Are there any factors that may affect the importance level of these CFs? If yes, what are these factors? And how can they affect the evaluation of CFs? Thus, this study aims to address these questions, which are yet to be answered. Answering these questions will help MiC stakeholders to optimize their strategic resource allocation by investing in the significant CFs required for implementing JIT successfully.

Therefore, the novelty of this study can be summarized in two points. Firstly, it provides a systematic review of the CFs required for the successful implementation of JIT in MiC. Secondly, this study aims to meta-analytically synthesize the previous studies that have quantitatively evaluated the CFs of JIT. The meta-analysis approach adopted in this study provides a more reliable evaluation of the CFs than previously reported. Moreover, this study conducts a sub-group analysis to understand how different factors affect the evaluation of the identified CFs. Although few studies have used meta-analysis in the construction management research field (Alruqi and Hallowell, 2019), the approach is well-established in many research fields and considered as a key component for theory building (Hunter and Schmidt, 2004).

The rest of this paper is organized as follows; section 2 illustrates the importance of JIT in MiC and summarizes the main findings of the previous studies. Then, the methodology adopted to conduct the systematic review and meta-analysis is illustrated in section 3. The results of the systematic review and meta-analysis are presented in section 4. After that, a discussion of the results and research implications are provided in section 5. Finally, section 6 includes conclusions, while section 7 suggests some recommendations for studies to be valid for future meta-analysis studies.

2. BACKGROUND

2.1 Just-in-time (JIT) in Modular Integrated Construction (MiC)

JIT is a lean construction approach, which aims to deliver required materials on-time, at the right location, and with the required quality and quantity (Ballard and Howell, 2010). JIT is built on six fundamental principles. They are pull system, waste elimination, smooth workflow, total quality management, supplier relations, and top management commitment (Pheng and Chuan, 2001). The pull system requires that materials are sent only after receiving authorized orders from the demand side, which eliminates the need for high inventory levels. The waste elimination principle identifies and eliminates waste activities that do not add value to the final product. Hence the waste elimination principle emphasizes the pull system principle by considering the inventory as a waste activity. Since JIT targets zero inventory, the principle of smooth workflow tries to maintain an uninterrupted workflow through the different activities along the supply chain. The principle of smooth workflow cannot be implemented without ensuring good quality of the received materials through the principle of total quality management. To receive the required materials on-time, with the required quality and quantity, mutually beneficial and long-term customer-supplier relationships are of utmost importance. Finally, the benefits of JIT cannot be achieved without the commitment of top management and involvement of employees in the process. These benefits are inventory reduction, reduction of procurement costs, improvement of market competitiveness, building long-term supplier relationships, and enhancement of forecasting (Akintoye, 1995).

Due to the advantages of JIT, qualitative and quantitative studies have discussed the implementation of JIT in the MiC supply chain. As for quantitative models, Kong et al. (2017) have proposed an approach that optimizes the production sequence of prefabricated components for JIT delivery to construction sites. Similarly, Kim et al. (2020) have demonstrated an algorithm that considers multiple uncertainties to solve the sequencing problem of prefabricated components. Recently, Hammad et al. (2020) have developed a mixed-integer non-linear programming model that solves the job shop scheduling problem in MiC factories. Regarding logistics in MiC, Kong et al. (2018) have developed a mathematical model that optimizes the number of delivery batches of prefabricated components, the number of these components in each batch, and the delivery time of each batch. Hsu et al. (2018) have also developed a two-stage stochastic programming model that determines the optimal dispatch time, ordering quantities and transportation time of MiC modules. Likewise, Yusuf et al. (2019a) have utilized a stochastic simulation-based optimization model to find the near-optimum sequence of precast components, while Yusuf et al. (2019b) have considered supply chain risks in the developed simulation model. Recently, Li et al. (2020) have proposed an improved artificial bee colony algorithm, which finds the near-optimum route planning of prefabricated components within time windows.

As for qualitative studies, many researchers have discussed the CFs required for the successful implementation of different lean approaches, including JIT. For instance, Nasrollahzadeh et al. (2016) have used the fuzzy analytic hierarchy process and Delphi techniques to evaluate CFs required for implementing lean techniques in MiC. Asri et al. (2016b) have summarized these CFs by conducting a literature review. Also, Yunus et al. (2017) have identified CFs of lean thinking in MiC and evaluated them on a Likert scale. Besides identification and assessment of the importance of CFs, Rahimah Mohd Noor et al. (2018) have adopted the interpretive structural modeling and Matrice d'impacts croi-sés multiplication appliquée an classment (MICMAC) to identify the relationships between the CFs. Other studies identify and evaluate the CFs of JIT and lean techniques in the construction industry of different countries. These include South Africa (Aigbavboa et al., 2016), Ireland (Spillane and Oyedele, 2017), Nigeria (Amade et al., 2019), and USA (Demirkesen and Bayhan, 2019).

Overall, the above-mentioned studies show that academic attention towards studying CFs of JIT is increasing. Also, as MiC continues to draw more attention, many review studies have been published, as mentioned in section 1. However, a systematic review of CFs required for the successful implementation of JIT in MiC is missing. Moreover, the previous studies on CFs for implementing JIT have quantified the importance of each CF based on the opinions of its respondents. Therefore, a synthesis of the results presented in these studies is required to provide a more reliable evaluation of CFs. Consequently, meta-analysis is selected to achieve this objective in a transparent and replicable manner.

2.2 Meta-analysis

Meta-analysis provides a statistical synthesis of results collected from different studies to give a more reliable indication of the population mean than that provided by individual studies (Horman and Kenley, 2005). Meta-analysis is usually conducted with a systematic review to combine consistent results (Borenstein et al., 2009). The systematic review is required to find relevant studies. In meta-analysis, each individual study is assigned a weight based on the number of respondents (sample size) in it by using a standard statistical approach (Borenstein et al., 2009). In a narrative review, the researcher gives credence to each included study, and hence his/her conclusions are subjective. Accordingly, the obtained conclusions cannot be used without caution. Therefore, meta-analysis is deemed to be more reliable and transparent than a narrative review. However, the adoption of meta-analysis is not free of some challenges (Glass et al., 1981). Inconsistent studies that have used different measuring techniques or addressed different topics may be erroneously combined with each other. The risk of publication bias is another issue, where peer-review journals tend to publish only significant results. However, these issues can be tackled by a proper design of the systematic review and meta-analysis.

Some researchers have meta-analytically synthesized some previous studies on lean-related topics in the business management research field. For instance, Abreu-Ledón et al. (2018) have provided a meta-analysis study on the relationship between the application of lean production and the performance of firms. Recently, Liu et al. (2018) have meta-analysed the relationship between lean practices and enterprise performance. This relationship has been analysed by using the Bayesian network based on the meta-analysis results. In the construction management research field, few researchers have exploited the full-benefits of meta-analysis. Horman and Kenley (2005) have used meta-analysis to quantify the percentage of wasted time in construction activities from the different percentages reported in relevant studies. Sancini et al. (2012) have conducted meta-analysis to evaluate the trend of fatal and nonfatal injury in the construction industry. In the same manner, Umer et al. (2018) have educed the prevalence of different musculoskeletal symptoms among construction workers. Regarding using meta-analysis to evaluate the importance of CFs, Alruqi and Hallowell (2019) have assessed the correlation values of multiple safety leading indicators from results reported in previous studies. Despite that meta-analysis has been used frequently in the medicine, social, and business research fields (Hunter and Schmidt, 2004), its adoption in the construction management research field is still limited.

To the best of the authors' knowledge, this study is one of the first that conducts a systematic review of CFs for JIT implementation. Also, it performs a meta-analysis of results from multiple quantitative studies. Hence, it provides a more reliable assessment of the importance of the CFs required for implementing JIT in MiC.

3. RESEARCH METHODOLOGY

Fig. 1 shows the widely accepted steps to conduct a systematic review and meta-analysis, according to Cochrane guidelines (Higgins and Green, 2011). The figure shows seven sequential steps which are the specification of research question and objectives, validation of the research idea, determination of inclusion and exclusion criteria, selection of search databases and search strategy, evaluation of retrieved studies, data extraction and cleaning, and conducting meta-analysis. The procedures and methods applied in each step are discussed in detail in the following sections.

Fig. 1

3.1 Specification of Research Question and Objectives

Identification of a clear and feasible research question is the first step in any meta-analysis study (Tawfik et al., 2019). In this study, the main research question is as follows: what is the prioritization of CFs to implement JIT in MiC?. Answering this question requires firstly identification of CFs to apply JIT in MiC by conducting a systematic literature review methodology. Secondly, the importance of each identified CF needs to be quantified by using meta-analysis. Besides, secondary research questions are defined as follows: Are there any factors that might affect the importance level of these CFs? If yes, what are these factors? And how can they affect the evaluation of CFs?

3.2 Preliminary Research and Validation of the Research Idea

Conducting preliminary research is paramount to 1) ensure the novelty of the research idea; 2) assure that there are enough studies to perform systematic review and meta-analysis; 3) gain a deep understanding of the field of study; 4) collect a wide variety of keywords related to the study topic to help in retrieving relevant studies; and 5) help in defining the inclusion and exclusion criteria (Tawfik et al., 2019). The authors have conducted a preliminary search on Google Scholar and Scopus by using the following keywords: 'critical factors' AND 'just in time' AND 'modular construction' OR 'modular integrated construction'. This search has resulted in finding only two studies by Asri et al. (2016a) and Asri et al. (2016b). Through a literature review, the former has identified key success factors to integrate JIT in Malaysian MiC projects, while the latter has identified CFs for the successful application JIT to overcome transportation and delivery challenges of MiC. These results are justifiable due to the relatively new advent of MiC to the construction industry and the lack of awareness of JIT, as a lean tool, in the construction field (Innella et al., 2019). Also, this preliminary search indicates that the statistical meta-analysis approach has not been used before to prioritize CFs to apply JIT in either MiC or the traditional construction.

3.3 Definition of Inclusion and Exclusion Criteria

Specification of inclusion and exclusion criteria is a critical step in the meta-analysis study. This step aims to filter the retrieved studies and keep only the studies that answer the main research question (Wohlin, 2014). In this study, the inclusion criteria would include: 1) studies which contain critical success factors of JIT in the construction industry; 2) studies which include factors that affect on-time delivery of construction materials; 3) no restrictions regarding countries, publication year or publication type to avoid the risk of publication bias (Higgins and Green, 2011); and 4) quantitative studies which include sufficient statistical data to use it for conducting meta-analysis. The exclusion criteria are: 1) studies published in languages other than the English language; 2) studies without available full text; and 3) duplicated studies or overlapping data.

3.4 Determination of Search Databases and Search Strategy

At least two search databases are required to achieve accurate retrieval of relevant studies (Shea et al., 2017). The more the number of databases, the more comprehensive results are obtained. In this study, the authors have used Scopus, Web of Science, and Google Scholar to retrieve relevant studies. After the specification of search databases, the authors have adopted two search strategies to search for studies. The first strategy is the keywords-based search method. In this method, configurations of relevant keywords constituted by deploying Boolean operators such as (AND & OR) are used. With a full understanding of the critical role of keywords, representative keywords and their similar nomenclatures of “critical factors”, “just in time” and “modular construction” have been used to find relevant studies. Examples of alternative keywords of “modular construction” include “prefabricated/precast”, “industrialized construction”, “Prefabricated Prefinished Volumetric Construction” and “off-site construction”. These keywords have been used to search for relevant papers in multiple review papers on MiC such as critical risk factors (Wuni et al., 2019); critical success factors (Wuni and Shen, 2019); lean techniques (Innella et al., 2019); supply chain vulnerabilities (Ekanayake et al., 2020); and adoption barriers (Wuni and Shen, 2020a). The second strategy is a manual search method called snowballing search strategy (Wohlin, 2014). The first step of this strategy is to identify a start set of papers. These papers are identified after filtering the studies obtained from the keywords-based search method. Then, each study in the start set will be used to conduct backward and forward snowballing. In the backward snowballing, the researcher searches for relevant studies in the reference list of each study in the start set. In the forward snowballing, the researcher uses the list of papers that cited the article under investigation to find new articles. The newfound articles constitute a new start set which undergoes another cycle of backward and forward snowballing. This cyclic process is iterated until no new papers are found. As shown in Fig. 2, the adopted search strategies follow the steps of Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA), which is a widely accepted protocol adopted in systematic reviews and meta-analysis studies (Moher et al., 2009).

Fig. 2

3.5 Evaluation of Retrieved Studies

Screening the retrieved studies undergo three consecutive processes (Moher et al., 2009). Firstly, the title and abstract of each obtained study are evaluated according to the predefined eligibility criteria. The eligibility criteria are inclusive rather than exclusive because sometimes the title and abstract provide insufficient information. At this stage, the authors have included any study which addresses logistics issues in the construction field. Secondly, duplications are removed manually. In this step, duplications emerge only from using multiple databases. Then, eligible articles are downloaded for full-text evaluation. Thirdly, the evaluation of the full text is implemented according to the inclusion and exclusion criteria discussed in section 3.3. Then, the included studies are classified into qualitative and quantitative studies. The difference between them is that the former only discuss CFs to apply JIT without providing any statistical data to evaluate their importance. Forty-six out of 150 studies report statistical data to assess the CFs, as shown in Fig. 2. Only quantitative studies are applicable to meta-analysis.

3.6 Data Extraction and Cleaning

In this stage, the authors have collected data from the full-text articles in a structured Excel sheet. In this study, the extracted information is as follows: authors name, publication type (journal, conference, report, thesis, etc.), publication year, country of the conducted case study, type of project under study (buildings, infrastructure or MiC), CFs to apply JIT, the number of respondents (sample size), research method and the reported statistical data (mean and standard deviation (SD)). Only these data will be used to conduct meta-analysis.

Before the commencement of meta-analysis procedures, an examination of the extracted statistical data is essential to determine the dominant measuring technique among the retrieved studies. Determination of this dominant measuring technique allows us to include only studies that deploy this measuring technique. This step is necessary to prevent one of the limitations of meta-analysis, where a researcher mistakenly combines studies that use different measuring techniques or address different topics. In the meta-analysis jargon, this limitation is called mixing “apples and oranges” (Borenstein et al., 2009).

It is found that all of the 46 studies have used the Likert scale to evaluate the CFs except three studies. Hence, these three studies have been excluded. Then, the authors find that the remaining 43 studies have used different Likert scales. However, the five-point Likert scale has been adopted by 30 out of the 43 studies. In the five-point Likert scale, the scale is ranged from 1 to 5 where "1" indicates the least important and "5" represents the most important. It is worth mentioning that it is possible to convert the results obtained by other Likert scales into the five-point Likert scale (IBM Support, 2018). This conversion is possible only in the case that raw data are available and not only the statistical results such as the mean and SD. This case is applicable only for one study, which is the study by Kawish (2017), who has used the seven-point Likert scale. Regarding the statistical measures used in these studies, the authors find that 19 out of the 30 studies have used the mean and SD to prioritize the CFs, while only six out of the 30 studies have deployed other measures such as correlation coefficient and Cronbach's alpha. Hence, these six studies have been removed. The remaining five studies of the 30 studies report only the mean, which is not enough to perform meta-analysis, and thus these five studies have been excluded. Finally, 20 studies have been identified to undergo meta-analysis procedures. However, after rechecking the statistical results of the 20 studies, it is found that two of them have precisely the same results, which is not possible. After close examination, it is found that one of them is a journal paper, and the other is a conference paper, but both of them belong to the same researchers and the same case study. Therefore, the authors decide to exclude the conference paper. In summary, we have 19 studies applicable to perform meta-analysis. These studies will be mentioned in section 4.1.

Before starting meta-analysis, cleaning of the data extracted from the 19 studies is vital to enter these data to the meta-analysis software effortlessly (Tawfik et al., 2019). The data cleaning can be done by organizing an excel sheet for each factor containing the information mentioned above in a structured way.

3.7 Procedures of Meta-analysis

In this study, standard meta-analysis procedures are followed. These procedures are adapted from studies by Borenstein et al. (2009) and Higgins and Green (2011). These studies are deemed among the most widely accepted references to perform meta-analysis. Again, the objective of doing meta-analysis in this study is the prioritization of CFs to apply JIT in MiC. This objective is accomplished by the calculation of an aggregated mean and SD for each factor. Consequently, the meta-analysis is applied to each of the identified CFs. Each factor has to be reported in at least two studies to perform meta-analysis. The following sections explain how the aggregated mean and SD are calculated.

3.7.1 Effect size, summary effect, and the adopted statistical model

The first step in performing meta-analysis is to decide on the effect size based on the available type of data and the purpose of the analysis (Higgins and Green, 2011). In this study, the effect size represents the mean of the respondents' opinions reported for each factor in the included studies. In these studies, the respondents have evaluated the CFs on the five-point Likert scale. To make it clearer, for each factor, we have a number of studies that have evaluated this factor. Each study reports the mean, SD, and the number of respondents (sample size). The main idea of meta-analysis is to give each study a weight based on the precision of this study, as shown in Eqs. (1) and (4) (Borenstein et al., 2009). The precision is a function of the sample size. For simplicity, we can assume that the larger the sample size of a study, the higher the weight given to this study. In the meta-analysis, the summary effect is the weighted mean of the individual effects of each study, as shown in Eq. (5). The same idea can be used to calculate the weighted variance, as shown in Eq. (6). The weighted mean (summary effect) and the weighted variance of each factor can be used to rank the CFs. Hence, these statistics will answer the research questions mentioned in section 1. Specifically, research questions related to the significance level and prioritization of CFs. Again, these calculations are repeated for each CF. The mechanism used to distribute the weights among the studies depends on whether the fixed-effects model or the random-effects model is chosen to conduct the analysis. In this study, the random-effects model has been selected because of our conservative assumption of the heterogeneous nature of the included studies. Given that the sample sizes of all included studies are large (>30, (McClave and Sincich, 2013)), as will be illustrated in section 4.1, the parametric models are used in this meta-analysis (Adams et al., 1997). Although the sample size of the study by Jaafar and Mahamad (2012) is small (=15), its authors have assumed the normality of its data.

$$W_i = 1/V_i \quad (1)$$

Where W_i= weight assigned to study i in case of the fixed-effects model; and V_i = the variance of study i.

$$S = \sum_{i=1}^{n} W_i E_i^2 - \frac{(\sum_{i=1}^{n} W_i E_i)^2}{\sum_{i=1}^{n} W_i} \quad (2)$$

Where S= the weighted sum of squares over all studies; and E_i= effect size of study i.

$$V_t^2 = \frac{S-(n-1)}{\sum W_i - \frac{\sum W_i^2}{\sum W_i}} \quad (3)$$

Where V_t^2= the between-studies variance; and n= number of studies.

$$W_i^* = 1/(V_i + V_t^2) \quad (4)$$

Where W_i^*= weight assigned to study i in case of the random-effects model.

$$WM = \frac{\sum_{i=1}^{n} W_i^* E_i}{\sum_{i=1}^{n} W_i^*} \quad (5)$$

$$WV = \frac{1}{\sum_{i=1}^{k} W_i^*} \quad (6)$$

Where WM= weighted mean (summary effect); and WV= weighted variance.

3.7.2 Heterogeneity

Heterogeneity refers to variability in the effects of the different studies combined to perform the meta-analysis (Borenstein et al., 2009). This variability is due to true variation among studies rather than the random error (chance). Hence, it is crucial to check the presence of heterogeneity by using statistical tests such as chi-squared ($\chi 2$ or Chi^2) test and P-value, especially when confidence intervals of the individual studies do not overlap. A high P-value or a low chi-squared provides evidence of homogeneity or lack of heterogeneity. However, quantifying the heterogeneity is more important. The heterogeneity can be quantified by calculating the ratio of true heterogeneity to total observed variance (I^2), as shown in Eq. (7). As a rule of thumb, $I^2 < 25$ % implies low heterogeneity; I^2 between 25 % and 75 % indicates moderate heterogeneity; and $I^2 > 75$ % implies high heterogeneity (Higgins and Green, 2011). In case of finding high heterogeneity, investigation to explore the reasons behind such heterogeneity needs to be conducted. In this study, sub-group analysis and sensitivity analysis are deployed for investigating heterogeneity.

$$I^2 = \left(\frac{S-(n-1)}{S}\right) * 100\% \quad (7)$$

Where I^2= the percentage of variation between studies that is due to true heterogeneity rather than chance.

3.7.3 Sub-group analysis

The sub-group analysis aims at dividing respective studies of a CF into sub-groups based on a specific criterion. This criterion can be any factor that the researcher thinks that it might have an impact on the results (i.e. importance level of CFs in this study). For example, these criteria might be the project's type (e.g. MiC and traditional projects), project's budget (e.g. low, medium and high budget), project's country, etc. Hence, sub-group analysis can address our research questions related to the sensitivity of these CFs to specific factors. The sub-group analysis can be used to investigate the heterogeneity and to make a comparison between the sub-groups to answer specific questions (e.g. secondary research questions in section 3.1). If the sub-group analysis results indicate that there is a significant difference between the results of multiple sub-groups, it can be concluded that the dividing criterion might be the reason behind the heterogeneity. Hence, this dividing criterion (e.g. project's type) has an impact on the results, and consequently, insightful conclusions can be drawn for each sub-groub (e.g.

MiC and traditional projects). However, sub-group analysis is restricted by the data available in the studies under investigation (Higgins and Green, 2011).

In this study, the studies at each CF have been divided based on four criteria. The first criterion divides the studies based on the publication type. Studies published in journal papers are combined in a group, and studies published in other publication types are put in another group. The second criterion split the studies into two groups based on the publication year (i.e., old studies and recent studies). The third criterion combine studies conducted in the G20 countries in one group, while studies implemented in other countries are grouped in another group. In this study, the G20 membership is used to reflect the advancement of the country's economy. The last criterion divides the studies based on the project type into three groups. These groups are general building projects, infrastructure projects and MiC projects. The four criteria have been specified to answer the secondary research questions mentioned in section 3.1. It is worthy to note that each sub-group must contain at least two studies to perform the analysis.

3.7.4 Sensitivity analysis

The purpose of sensitivity analysis in meta-analysis is to study the effect of different sources of uncertainty in the participant studies to conclude robust findings (Higgins and Green, 2011). The sensitivity analysis is conducted by identifying studies whose effect sizes vary substantially from the other studies. Hopefully, by removing such studies, the overall heterogeneity would be reduced. Hence the findings become more reliable (tighter confidence interval). However, removing a study should be backed by a justification. This justification demonstrates why this study might be different from the others; otherwise, it should be included. The difference between studies is represented by the four criteria illustrated in section 3.7.3.

3.7.5 Numerical example

This section provides a numerical example on the statistical meta-analysis procedures. The results provided here are related to CF32 "*Contract and incentives*". Firstly, Table 2 shows statistical data (i.e. sample size, mean, SD and standard error (SE)) of CF32 obtained from studies which have addressed this CF. These data are identified to the meta-analysis software (RevMan 5.3). Table 3 summarizes the outputs of meta-analysis before and after conducting the sensitivity analysis. The outputs include the weight given to each study and different heterogeneity measures. It can be noticed that studies with less SE (larger sample sizes and/or less SDs) get higher weights. This can be achieved by setting the statistical analysis method to 'Generic inverse variance' in RevMan 5.3 (Higgins and Green, 2011). Here, the sensitivity analysis is conducted by removing the study by Yunus et al. (2017) because it is related to MiC while the other studies focus on general building projects. Excluding this study reduces the heterogeneity from $I^2 = 97\%$ to $I^2 = 79\%$. Table 4 summarizes the results of sub-group analysis based on the four criteria mentioned in section 3.7.3. The results indicate that the project type is the only influential criterion because there is a significant difference (P-value < 0.05) in the importance level of CF32 between general building projects and MiC. These procedures have been replicated for the remaining of 42 CFs.

Table 2

Table 3

Table 4

4. RESULTS

4.1 Data Extracted from the Included Studies

Table 5 shows the 19 studies which meet the inclusion criteria to conduct the meta-analysis. Also, Table 5 lists the information required to implement sub-group analysis such as publication type, publication year, country, and project type. Moreover, the table shows that the included studies have evaluated the importance of CFs by using questionnaires, interviews and case studies. As shown in Table 5, the publication year of the included studies ranges between 2009 and 2019. Therefore, the authors divided the included studies equally into two groups to conduct the sub-group analysis based on the publication year. The first group contains studies published from 2009 to 2015, while the second group includes studies published from 2016 to 2019.

Table 5

Table 6 summarizes 42 CFs to implement JIT identified from the included studies, concomitant with the definition and the frequency of occurrence of these CFs in the included studies. The seven most frequently reported CFs in the previous studies are CF27 "*Knowledge and awareness of JIT*" (17 times), CF1 "*Top management commitment*" (15 times), CF15 "*Quality assurance and quality control (QA/QC)*" (15 times), CF22 "*Culture and human attitude*" (15 times), CF34 "*Collaboration among supply chain members*" (14 times), CF35 "*Communication and information sharing*" (13 times) and CF28 "*Training*" (12 times). In addition, the 42 CFs are categorized into nine categories, which are managerial, technical, cultural and human, educational and knowledge, financial, communication-related, skills and expertise related, governmental, and logistics factors.

Table 6

4.2 Statistical Results of Meta-analysis

Table 7 and Fig. 3 summarize the results of the meta-analysis for each CF. Meta-analysis has been performed by using Review Manager (RevMan) 5.3, which is a standard meta-analysis software (RevMan Web, 2020). The second column of Table 7 shows the results of heterogeneity tests before and after conducting the sensitivity analysis. The third column shows whether there is a statistically significant difference between sub-groups in each of the four criteria mentioned in section 3.7.3. Fig. 3 shows the weighted mean (summary effect) and the weighted SD for each CF in an error bar.

Table 7

Fig. 3

The heterogeneity results are represented by three values, namely, $\chi 2$, P-value and I^2. Heterogeneity is detected in case of high values of $\chi 2$ and P-value < 0.05 based on a 95% level of confidence and quantified by the value of I^2. The heterogeneity results indicate widely dispersed data represented by high values of I^2 (I^2 > 75%) in the majority of CFs even after conducting the sensitivity analysis. However, the sensitivity analysis is applicable only when we find a justification for removing studies whose results vary substantially from the other studies. A justification here means a feature of a study, based on publication year, publication type, country's economy, or project type, which distinguishes it from the other studies. For instance, we have removed studies by Abdullah et al. (2009) and Yunus et al. (2017) in the sensitivity analysis of CF2 because the first one is the oldest study among the studies reported CF2, while the second one is unique by its project type which is MiC. The potential reasons behind these high levels of heterogeneity and how such heterogeneity has less impact on the findings of this study are discussed in section 5.

The results of the sub-group analysis for each CF are summarized in the third column of Table 7. Again, the sub-group analysis is applicable only if each group has at least two studies. For the publication type criterion, the results indicate that there is no statistically significant difference between the results published in journal papers and the results published elsewhere in all CFs except CF35 "*Communication and information sharing*". The results related to studies published in journals indicate that the summary effect (the importance level) of CF35 is 3.27 on the five-point Likert scale, while the studies published in other types of publications show that its summary effect is 4.05. However, these results of CF35 are characterized by high heterogeneity values. Similarly, there is no statistically significant difference between the results published in relatively old studies (between 2009 and 2015) and that published in recent studies (between 2016 and 2019) for all CFs.The sub-group analysis based on the project type is applicable only for 21 out of the 42 CFs. This means that the majority of studies focused mainly on building projects and ignored other project types. Interestingly, the sub-group analysis reveals that the importance levels of eight CFs vary significantly depending on the project type. These eight CFs are CF1 "*Top management commitment*", CF3 "*Extensive planning and scheduling*", CF15 "*QA/QC*", CF16 "*Agreed implementation methodology to implement JIT*", CF25 "*Employee morale and motivation*", CF27 "*Knowledge and awareness of JIT*", CF32 "*Contract and incentives*" and CF39 "*Supportive governmental regulations*". For the country's economy criterion, the sub-group analysis indicates that whether having the country an advanced or stable economy (within the G20) does not affect significantly the importance of the majority of CFs except three CFs. These CFs are CF6 "*Decentralization of decision making*", CF29 "*Education and research*" and CF39 "*Supportive governmental regulations*".

Finally, Fig. 3 shows the weighted mean and the weighted SD for each CF after conducting the sensitivity analysis. Apparently, all CFs have mean values higher than "3" on the five-point Likert scale. As a result, all of the 42 CFs deserve to be considered for successful JIT implementation. However, only seven CFs have weighted means higher than "4" which indicates that these factors have significant importance. This threshold has been adopted in previous studies by Lam et al. (2007) and Chan et al. (2004). These seven CFs are CF21 "*Production planning*", CF42 "*Route planning*", CF14 "*Willingness to invest in JIT practices*", CF16 "*Agreed implementation methodology to implement JIT*", CF40 "*Political and economic stability*", CF7 "*Market strategy to adopt JIT*" and CF27 "*Knowledge and awareness of JIT*".

4.3 Analysis of Studies on MiC

This section summarizes the CFs and their statistical results reported in studies on MiC. Only three out of the 19 included studies focused on MiC projects. Table 8 summarizes the CFs mentioned in these studies and the weighted mean and SD of each CF. As shown in Table 8, 30 out of the 42 CFs are mentioned in the three studies. As for the CFs mentioned in only one study, we have just put the mean and SD reported in the study. On the contrary, the weighted mean and weighted SD are calculated for CFs mentioned in multiple studies. All the 30 CFs have mean values higher than "4", as shown in Table 8. Hence these CFs are significant for JIT implementation in MiC, except six CFs. These CFs are CF5 "*Integrating risk management and supply chain management*", CF18 "*Site layout planning*", CF20 "*Standardization of activities*", CF34 "*Collaboration among supply chain members*", CF35 "*Communication and information sharing*" and CF41 "*Inventory management*".

Table 8

The high heterogeneity is observed despite the small number of studies and the fact that all the three studies were conducted in Malaysia. Interestingly, it is observed that the study by Jaafar and Mahamad (2012) is repeated in the vast majority of CFs characterized by heterogeneity. Also, this study is not found in any CF characterized by homogeneity. This observation indicates that the results reported in the study by Jaafar and Mahamad (2012) are heterogeneous from the results reported in the studies by Yunus et al. (2017) and Rahimah Mohd Noor et al. (2018). To validate this finding, removing the results of Jaafar and Mahamad (2012) from CF15 reduces the heterogeneity, from I^2 = 87% to I^2 = 69%.

4.4 Prioritization of Critical Factors to Implement JIT in MiC

In the previous section, the meta-analysis results indicate that seven CFs have mean values higher than "4" on the Likert scale and the other CFs have mean values between "3" and "4". Based on these results, it would be valuable for stakeholders of MiC projects to provide them with a prioritization of the most important factors to allocate their limited resources to these factors optimally. Prioritization of the CFs by using only their mean values, as mentioned in section 4.2, might be flawed because the variability of these values is ignored. Therefore, the authors adopted the signal to noise ratio (SNR) to prioritize the CFs. The SNR is frequently used within the context of the design of experiments to find the best parameter setting. The SNR is simply the reciprocal of the coefficient of variation, as shown in Eq. (8) (Holmes and Mergen, 1995; George and Kibria, 2012).

$$SNR = \bar{x}/s \qquad (8)$$

Where SNR = the signal to noise ratio; $\bar{x}$ and s = the sample mean and sample standard deviation, respectively.

Table 9 shows the ranking of CFs with considering all project types (global rank) and MiC only (MiC rank). The global rank is based on SNR values calculated from the values of the weighted mean and SD of each CF mentioned in section 4.2. On the other hand, the MiC rank depends on SNR values estimated from weighted means and SDs mentioned in section 4.3. The higher the SNR value, the more important the factor is on the Likert scale with considering variability. Consequently, Table 9 prioritizes the 42 CFs. Hence, the most seven critical factors with considering all project types are CF14 "*Willingness to invest in JIT practices*", CF11 "*Resources management*", CF10 "W*ell-established long-term supplier-client relationships*", CF26 "*Trust among supply chain members*", CF13 "*Adopt new management concepts*", CF12 "*Procurement management*" and CF21 "*Production planning*". Fig. 4 shows the forest plots of these seven CFs. In each forest plot, the size of the solid squares reflects the weight given to the respective study (W_i^*), while the diamond represents the summary effect (WM). The location of the diamond signifies whether the CF is significant (i.e., it's mean > 4 on the five-point Likert scale) to the successful implementation of JIT. However, the diamond width reflects the precision of the summary effect. Just for visualization purposes in RevMan 5.3, we have entered the means reported in each study subtracted by four, which is the adopted threshold, to judge the significance of CFs.

Table 9

Fig. 4

Despite that Table 9 provides a prioritization of the 42 CFs, it does not show whether there is a significant difference between the importance of these CFs. Also, if there are some CFs that are more important than the others significantly, it would be valuable to identify these factors. Therefore, a one-way analysis of variance (ANOVA)-F test has been performed to test if there is a significant difference between the importance of the 42 CFs. If there is a significant difference, then Tukey's method is used to identify which CFs are more important than the others. Tukey's method is a multiple-comparison method in ANOVA.

The first step to implement ANOVA is to collect the mean values of each CF from the studies which addressed this factor. Then, these data have been identified to Minitab®18 statistical software to conduct the one-way ANOVA and the Tukey's method. Fig. 5 shows the results of the ANOVA-F test and Tukey's method. Before the discussion of the ANOVA results, it is essential to check the conditions required for a valid ANOVA F-test. Fig. 5(a) shows that the normality assumption is verified by observing that the central points in the normal probability plot of residuals stick to the line (Montgomery, 2012). Also, Fig. 5(b) shows that there is no distinct pattern like an outward-opening funnel in the plot of residuals versus fitted values. Hence, the population variances do not differ significantly. Based on Figs. 5(a) and (b), the conditions to apply ANOVA are satisfied. As shown in Fig. 5(c), the *P*-value is less than 0.05, highlighting that there is a significant difference between the importance of the 42 CFs. However, the multiple pairwise comparisons test conducted by using Tukey's method suggests that there is no significant difference between the importance of the 42 CFs. This contradiction between the results of ANOVA and Tukey's method might be attributable to the high number of pairwise comparisons between the 42 CFs (Lee and Lee, 2018). Besides, some CFs have small sample sizes (a small number of studies).

Fig. 5

5. DISCUSSION

The results of the data extraction process indicate that 42 CFs to implement JIT are identified from 19 studies. In total, 1851 respondents in the 19 studies, working on different types of construction projects in twelve countries, participate in the evaluation of the 42 CFs. In this study, the meta-analysis is used to combine the information solicited from the 1851 respondents to provide a more reliable evaluation of these CFs than the evaluation provided in individual studies. The meta-analysis results indicate that these CFs have mean values higher than "3" on the five-point Likert scale, highlighting their importance to the successful implementation of JIT. However, seven of them have mean values higher than "4" indicating their significance to apply JIT.

However, considering only the mean values and ignoring the variability associated with these values may lead to flawed prioritization. Therefore, the *SNR* is used to tackle this issue. After that, a one-way ANOVA F-test is conducted to test if there is a statistically significant difference between the importance of the 42 CFs. With a P-value < 0.05, it is found that there is a significant difference between their levels of importance. However, Tukey's method could not cluster the 42 CFs. This failure may be attributable to the high number of pairwise comparisons and the few numbers of studies associated with some CFs. Some examples of these factors are CF14 "*willingness to invest in JIT practices*", CF21 "*production planning*" and CF42 "*route planning*", which are reported in only two studies.

The results summarized in Table 10 show that ranking CFs based on their frequency of occurrence is significantly different from the ranking obtained from weighted means and *SNR* values. This finding numerically demonstrates that the frequency of occurrence of any factor in the literature does not necessarily reflect its importance level. Consequently, the ranking of factors based solely on their frequency of occurrence may be misleading. The different ranking of CFs based on weighted means and *SNR* values may be attributable to the high heterogeneity associated with the majority of the 42 CFs.

Table 10

The high heterogeneity may be ascribed to multiple reasons. Firstly, the adoption of the random-effects model and the few numbers of studies in the case of some CFs increase the heterogeneity. Secondly, the sub-group analysis fails to investigate the heterogeneity of some CFs. This might be due to that studies which are combined in a sub-group based on a specific criterion may require further division based on another criterion to be more homogeneous. For instance, dividing the 15 studies, which evaluate CF22 based on a country's economy (seven studies related to G20 countries and eight studies from countries out of the G20), reduces the heterogeneity from I^2= 98% to I^2= 95.6% among studies in the G20 group. Dividing these seven studies in the G20 group based on the project type and country (additional criteria), further reduces the heterogeneity between studies, as shown in Fig. 6. This figure shows that the heterogeneity between studies on infrastructure projects in the USA, studies on general building projects in the UK, and studies on general building projects in other G20 countries have been reduced to 69%, 0%, and 0%, respectively.

Fig. 6

Another reason for the high heterogeneity is the difference between the characteristics of respondents who participated in the 19 studies. For example, the respondents may have different years of experience, different education levels, or work in different organizations. Unfortunately, the difference among the respondents could not be considered as a criterion in the sub-group analysis like publication type, publication year, project types, and countries. The inability to perform a sub-group analysis based on the respondents' characteristics is because the results from the 19 studies, are reported for all participated respondents, not for each type of them. The importance of this type of sub-group analysis is observed in the results provided in section 4.3. In this section, it is found that the results reported in the study by Jaafar and Mahamad (2012) are heterogeneous from the results of the studies by Yunus et al. (2017) and Rahimah Mohd Noor et al. (2018). This is despite that the three studies have been conducted on MiC projects in Malaysia. This heterogeneity may be ascribed to the fact that Jaafar and Mahamad (2012) have evaluated the CFs from the perspective of MiC manufacturers. On the other hand, Yunus et al. (2017) and Rahimah Mohd Noor et al. (2018) have solicited information from project managers, who may have different interests from MiC manufacturers. This conflict of interest between project managers and manufacturers in MiC projects has been argued by Pheng and Chuan (2001) and Ko (2010). The sub-group analysis, however, can uncover similar behaviours and validate such arguments by considering multiple sources of information. In short, the high heterogeneity of the data extracted from the included studies complicates the ranking of the 42 CFs.

However, the forest plots of the 42 CFs indicate that the high heterogeneity has less impact on the findings of this study. In the majority of these forest plots, there is a relative consistency among the studies of each CF. This consistency is related to the significance of a CF. For example, Fig. 7 shows the forest plots of some CFs whose respective studies agree that the importance of these factors is not significant. This consistency is despite the high heterogeneity reported in each CF.

Fig. 7

The sub-group analysis is conducted to achieve the secondary objectives of this study. The first one is to find if there is a statistically significant difference between the results obtained from journal studies and other publication types. A contradiction between the results obtained from the two types of publications is found only in CF35 "*communication and information sharing*". With high values of heterogeneity, the studies published in journals indicate that CF35 is not significant for successful JIT implementation. On the contrary, studies published in other publication types (i.e. conference proceedings and theses), conclude that CF35 is significant. Therefore, researchers may benefit from the data provided in different publication types besides journal papers. Considering these publications in their studies can reduce the risk of bias, which usually results from including studies published only in peer-review journals (Fanelli et al., 2017). Secondly, the sub-group analysis shows that there is no statistically significant difference between the results reported in relatively old studies (between 2009 and 2015) and the results obtained from recent studies (between 2016 and 2019) for all CFs. Consequently, there is no significant change in the importance level of these CFs during the last decade (between 2009 and 2019). Hence, the publication year or time is not an influential factor or moderator.

Regarding the third secondary objective, the sub-group analysis based on the project type is applicable only to half of the 42 CFs. This happens because the majority of the included studies focus solely on building construction projects. The results of this sub-group analysis show that the importance of eight CFs differs significantly between project types. Table 11 shows these eight CFs accompanied by their weighted mean values for each project type. Interestingly, all these CFs, except CF39 "*supportive governmental regulations*", are more important in MiC projects than in the other projects. As for MiC projects, only 12 CFs are evaluated by multiple studies, as discussed in section 4.3. These 12 CFs are CF1, CF3, CF5, CF15, CF16, CF18, CF21, CF25, CF27, CF34, CF35 and CF41. The meta-analysis results indicate that seven of them are significant for implementing JIT. These seven CFs are CF1 "*top management commitment*", CF3 "*extensive planning and scheduling*", CF15 "QA/QC", CF16 "*agreed implementation methodology to implement JIT*", CF21 "*production planning*", CF25 "*employee morale and motivation*" and CF27 "*knowledge and awareness of JIT*".

Table 11

The fourth secondary objective can be achieved by identifying if the importance of CFs differs significantly based on the country's economy. The sub-group analysis indicates that the importance of the majority of the 42 CFs does not differ significantly between countries with and without advanced economy except three CFs. These CFs are CF6 "*decentralization of decision making*", CF29 "*education and research*" and CF39 "*supportive governmental regulations*". The results of this sub-group analysis show that these CFs are more important to developing economies than advanced economies. Hence, developing economies may concentrate effort on these CFs to successfully implement JIT. Thus, the sub-group analysis can uncover and emphasize such pattern more reliably and transparently.

5.1 Theoretical Implications

This study provides a generalized assessment of the importance level of CFs required for successfully implementing JIT in MiC. Relying solely on the frequency of occurrence in previous studies to rank CFs may lead to flawed assessment (Wuni and Shen, 2019; Ekanayake et al., 2020). Therefore, using meta-analysis contributes to the theory development of JIT implementation by providing a more reliable assessment of these CFs that when thoroughly considered result in the successful application of JIT and, hence reaping its benefits. Moreover, sub-group analysis identifies the impact of some predictive criteria or moderators on the assessment of CFs.

In this study, the impact of four criteria is studied. These criteria are time, publication type, project type and country's economy. However, through extending the examination of literature, other criteria should be studied to further enrich the knowledge and help in the theory development of JIT in the construction industry. For instance, the sensitivity of the supply chain to disruptions and disturbances may affect the successful implementation of JIT in MiC (Wuni and Shen, 2020b). Also, order behaviour of the client is another potential factor that is likely to change how JIT is implemented in MiC (Mostafa and Chileshe, 2018). More importantly, understanding how JIT practices can enhance the performance of the MiC supply chain is critical to the theory development of JIT in MiC.

MacKelprang and Nair (2010) have meta-analytically studied the correlation between different JIT practices (e.g. schedule adherence, Kanban, pull system and preventive maintenance) and some performance measures, such as quality, cost, inventory levels and cycle time in different industries. However, as MiC is a cleaner construction alternative, assessment of the impact of JIT practices on different environmental metrics, such as embodied energy, global warming potential and acidification potential is imperative (Švajlenka et al., 2018). To complete the third triangular point of sustainability, Švajlenka and Kozlovská (2020) have included some social criteria to evaluate the efficiency of the off-site construction from the perspective of end-users. Using such sustainability criteria to evaluate the performance measures of JIT implementation calls for innovative methods for data collection and analysis. Hammad et al. (2019) have proposed a BIM-based approach to help in quantifying the sustainability impact of MiC through a life-cycle assessment. Others suggest using data analytics for monitoring sustainability (Eugene Wong et al., 2017). The above-mentioned criteria and their relationships with JIT practices have not been addressed yet.

Through a systematic review of previous studies, this meta-analysis research uncovers multiple gaps in the current theoretical knowledge of JIT application in MiC. This study could serve as a stepping stone for future studies to complete the theory development of lean implementation in MiC.

5.2 Managerial Implications

Given the challenges of MiC logistics and the potential of JIT to address them, the managerial implications of this study are invaluable. The lack of manuals to guide practitioners to implement lean techniques, including JIT, is one of the main barriers to adopt lean techniques in the construction industry (Demirkesen and Bayhan, 2019). Therefore, this study provides two important deliverables to convert JIT from mere theory to practice. Firstly, Table 6 provides checklists of CFs that when thoroughly considered, will aid in the successful application of JIT. Secondly, Table 9 provides a meta-analytical prioritization of these CFs. This ranking helps MiC stakeholders to optimize resource allocation strategies for a better implementation of JIT. Through a sub-group analysis, this study shows that the importance of these CFs is changing with different countries and project types. Moreover, the high heterogeneity between the included studies highlights that other factors might have an impact on the assessment of CFs. Therefore, stakeholders implementing JIT should note that ignoring the project characteristics (e.g. type, duration, budget, etc.) and the environment in which JIT is implemented may not end with obtaining the desired outcomes.

5.3 Implications for Lean Construction

Despite that this study examines CFs required for implementing JIT, many of these CFs are also associated with lean construction. JIT is a fundamental part of lean, and the concepts and techniques developed under lean are similar to that of JIT (Schonberger, 2007). Therefore, this study provides valuable theoretical and managerial implications for lean construction. In particular, this study shows that the importance of some CFs is sensitive to the type of project and the territory it is implemented. There is also the possibility that these CFs are also sensitive to additional criteria or moderators. Therefore, it would be valuable that researchers examine the sensitivity of CFs of other lean construction techniques (e.g. last planner system, six sigma, 5S, visual stream mapping, etc.) to potential moderators. Also, the study findings imply that lean construction practitioners should be aware that the importance of CFs to apply lean construction is dynamic with the project's characteristics and environment.

5.4 Impact of JIT Concept on the Sustainability of MiC

The successful implementation of JIT is directly and positively correlated with satisfying the triple bottom line of sustainability that concentrates on economic, environmental and social concerns (Green et al., 2019; Solaimani and Sedighi, 2020). From an economic perspective, the application of JIT can contribute to cost reductions and profit increase (Dehdasht et al., 2020). For instance, considering both CF42 "route planning" and CF21 "production planning" lead to the on-time delivery of MiC modules to the construction site (Kong et al., 2018). This would reduce the financial penalties associated with the early and late delivery of MiC modules and hence avoid project's cost overrun. Besides, JIT aims at reducing buffer inventory at the different MiC supply chain stages by considering CF41 “inventory management”. Storage of such heavy and bulky materials requires preparation of sheltered, secured and vast storage areas on the construction site to protect them from bad weather and vandalism. For congested construction sites, storage at consolidation centres is the solution (Magill et al., 2020). Both of these storage options imply a cost increase without adding value. Also, through CF11 “resources management”, JIT tries to maximize the resources utilization, which results in the reduction of the project’s direct costs (Kong et al., 2018). Moreover, JIT aims at delivering of MiC modules to the construction site in the required quality without any dimensional or geometric deficiencies through CF15 “QA/QC”. This would avoid additional costs associated with repairing of defective modules on-site or returning them to the factory (Enshassi et al., 2019). Other factors such as CF28 “training”, CF20 “standardization of activities” and CF25 “employee morale and motivation” also contribute to defect and cost reduction (Kumar et al., 2020). Last but not least, through CF7 “market strategy to adopt JIT”, successful JIT application could provide the organization with a sustainable competitive advantage and improve its market image which in turn increase its market share (Green et al., 2019). On the other hand, the successful implementation of JIT requires initial costs to consider factors such as CF28 “training”, CF31 “availability of resources”, CF33 “incentives and reward systems”, CF37 “existence of certified and qualified lean personnel” and CF38 “experienced and skilled workers”.

JIT implementation contributes significantly to environmental sustainability (Klassen, 2000). JIT aims at reducing inventory levels by maintaining more frequent deliveries (Min and Sui Pheng, 2007). Consequently, some researchers indicated that JIT might have negative impacts on environmental sustainability due to the inefficient utilization of the truck capacity and the increase in carbon emissions (Longoni and Cagliano, 2015). Conversely, in MiC, the truck can only transport one module at a time. Therefore, such environmental concerns of applying JIT are not applicable to MiC. However, Kong et al. (2018) have demonstrated that transportation of such heavy materials during peak hours increases the emissions. Through CF42 “route planning”, JIT can maintain environmental sustainability by delivering MiC modules during off-peak hours or by using uncrowded routes. Besides, carbon emissions and energy consumption associated with the double handling of MiC modules could be decreased by considering CF41 “inventory management” (Lu and Yuan, 2013). Also, CF41 “inventory management” and CF15 “QA/QC” ensure the reduction of construction wastes (Dehdasht et al., 2020). CF11 “resources management” contributes to the reduction of environmental pollution by maximizing resources utilization (Rothenberg et al., 2001). Finally, factors such as CF8 “human resources management”, CF28 “training”, CF34 “collaboration among supply chain members”, CF4 “stakeholder management” and CF22 “culture and human attitude” are necessary to engage respective stakeholders of MiC in the adoption of eco-friendly practices and techniques (Martínez-Jurado and Moyano-Fuentes, 2014).

The successful application of lean techniques, including JIT, contributes to the social sustainability of the built environment (Mellado and Lou, 2020). For instance, factors such as CF18 “site layout planning” and CF20 “standardization of activities” help in providing a safe working environment (Sanad et al., 2008). Also, consideration of CF42 “route planning” would reduce the social impacts (e.g., emissions and traffic accidents) associated with the transportation of such bulky materials in urban areas (Kong et al., 2018). Besides, reduction of inventory levels (through CF41 “inventory management”), especially for constriction sites in dense urban areas, contributes to the social welfare of their neighbours by reducing social impacts such as the noise and traffic congestion. CF35 “communication and information sharing” would help in avoiding disputes and claims among stakeholders and mitigating corruption risks (Faisal, 2010). In addition, paying attention to factors such as CF22 “culture and human attitude”, CF24 “knowledge sharing”, CF25 “employee morale and motivation”, CF26 “trust among supply chain members”, CF28 “training”, CF8 “human resources management", CF6 "decentralization of decision making", CF10 "well-established long-term supplier-client relationships" and CF4 "stakeholder management" would increase the engagement, motivation, communication, teamwork among respective stakeholders which in turn lead to a socially sustainable working environment (Martínez-Jurado and Moyano-Fuentes, 2014; Baliga et al., 2019). On the other hand, some researchers claimed that the successful application of lean techniques would add more workloads over employees (Hines et al., 2004). Such social concerns are applicable to factors such as CF3 "extensive planning and scheduling", CF13 "adopt new management concepts", CF20 "standardization of activities" and CF27 "knowledge and awareness of JIT". However, considering factors such as CF1 "top management commitment", CF6 "decentralization of decision making" and CF25 "employee morale and motivation" help in reducing the work stress (Conti et al., 2006).

Based on the previous discussion, considering CFs for successful application of JIT would contribute more to the economic, environmental and social sustainability of MiC. Fig. 8 shows a schematic system dynamics model to summarize how CFs of JIT contribute to the three sustainability aspects. This model can be extended in the future to estimate how each CF contributes to MiC sustainability and understand their dynamic behaviours over a time period.

Fig. 8

5.5 Study Limitations

Despite the obvious importance of this study, some limitations do exist. Firstly, combining and assessing CFs from several international studies overlook the sensitivity of these CFs to project characteristics such as the project's type, budget, territory, etc. However, these sensitivities may be overlooked for theoretical development or situations where bespoke research is not feasible or economical, but considering project characteristics is imperative in real-life projects (Wuni and Shen, 2019). The high heterogeneity that exists in this study is another limitation. Similarly, other meta-analysis studies in the construction management research field have reported high heterogeneity, such as studies by Horman and Kenley (2005) and Alruqi and Hallowell (2019). The high heterogeneity reflects the uncertainty embedded in the construction domain. Finally, although the number of MiC studies is limited in comparison with the number of studies on other project types, the results indicate a consistency between these studies in the evaluation of all CFs except for seven CFs which are more important in MiC projects. Therefore, including studies on other project types besides MiC has increased the reliability of the evaluation of the majority of CFs. However, the limited number of MiC studies shows the need for more empirical studies on CFs to apply lean techniques in MiC. Hence, it is worthy to replicate meta-analysis with more studies in the future.

6. CONCLUSIONS

This study contributes to the knowledge domain of application of lean techniques in the construction field, and its novelty is summarized as follows 1) CFs for implementing JIT in MiC have been identified by conducting a systematic review of quantitative studies; 2) the significance and importance of each CF are assessed by meta-analysis of relevant previous works; and 3) the impact of multiple criteria (i.e. publication year, publication type, project type, and country's economy) on the evaluation of CFs is investigated by conducting a sub-group analysis.

The systematic review identifies 42 CFs for implementing JIT from 19 studies. Then, meta-analysis is implemented to provide a weighted mean and SD for each CF. The weighted mean and SD represent the importance of these CFs on the five-point Likert scale. The results indicate that these CFs are not at the same importance level. Based on the obtained mean values, the most important and significant CFs are CF21 "*production planning*", CF42 "*route planning*", CF14 "*willingness to invest in JIT practices*", CF16 "*agreed implementation methodology to implement JIT*", CF40 "*political and economic stability*", CF7 "*market strategy to adopt JIT*", CF27 "*knowledge and awareness of JIT*". However, the ranking of CFs by frequency of occurrence in the literature yields a different outcome, demonstrating the risk associated with this approach. The obtained means of CFs are associated with high variability. This variability is originated from the high heterogeneity found among the included studies.

However, evaluation of CFs by means of meta-analysis is more reliable than that provided in the individual studies.

Sub-group analysis is conducted to explore whether publication type, publication year, project type, and country's economy influence the evaluation of the 42 CFs significantly. The results indicate that the importance level of the vast majority of CFs does not change significantly with the change of publication type or publication year. Consequently, researchers and practitioners could be benefited from conclusions and recommendations of JIT implementation available in old studies and other publication types besides journals. Similarly, the results of the sub-group analysis illustrate that the country's economy has not influenced significantly the importance level of the majority of CFs except three CFs. These CFs are CF6 "*decentralization of decision making*", CF29 "e*ducation and research*" and CF39 "*supportive governmental regulations*". The results highlight that these CFs are more important for developing economies than advanced economies. On the contrary, the results of the sub-group analysis based on project type reveal that the importance levels of eight CFs differ significantly between multiple project types. Seven of them are more important in MiC projects. These seven CFs are CF1 "*top management commitment*", CF3 "*extensive planning and scheduling*", CF15 "*QA/QC*", CF16 "*agreed implementation methodology to implement JIT*", CF25 "*employee morale and motivation*" and CF27 "*knowledge and awareness of JIT*" and CF32 "*contract and incentives*". Hence, the sub-group analysis can be used to uncover such hidden patterns in the literature. Overall, this study contributes to the theory development of JIT in the construction industry by identifying CFs to apply JIT from an international perspective. This would furnish researchers with the basis for further empirical studies. Also, the assessment of these CFs will help practitioners to optimize resource allocation strategies for better implementing JIT. The successful application of JIT contributes to the built environment by further improving the sustainability and cleaner production of MiC. Moreover, this study identifies some gaps in the current knowledge of JIT in the construction industry. More empirical studies on lean construction in MiC are required. Besides, future studies can address the correlation between the application of lean construction techniques and the sustainable performance improvement in MiC.

7. RECOMMENDATIONS FOR FUTURE META-ANALYSIS STUDIES

Despite that, the literature studying CFs to implement JIT is relatively mature (104 qualitative studies and 46 quantitative studies), only 19 studies are valid to conduct the meta-analysis. Therefore, the current authors provide the following recommendations for future works to be included in future meta-analysis studies.

1) Researchers should provide information on the variability of the obtained results, such as SD, standard error or confidence interval, etc.
2) It is advisable to use the most frequent measuring statistics (i.e., mean, correlation coefficient, Cronbach's alpha, etc.) used in the literature of the research topic under study.
3) Similarly, researchers should avoid using different psychometrics (i.e. Likert scale, slider scale, etc.) or different scales (five-point Likert scale, seven-point Likert scale, etc.) than those repeated in the literature of the research point under study.
4) It is preferable to provide not only the statistics of collected data but also data details. These include data that the researcher thinks that they may affect the obtained results, such as project type, project budget, project duration, characteristics of respondents, country, etc. Providing data details facilitates conducting sub-group analysis and meta-regression, which can uncover hidden patterns and provide meaningful information.

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Yusuf, M.M., Karam, A., Eltawil, A.B., 2019b. A simulation based optimization study for optimum sequencing of precast components considering supply chain risks. ICORES 2019 - Proc. 8th Int. Conf. Oper. Res. Enterp. Syst. 330–337. https://doi.org/10.5220/0007373303300337

Zhang, W., Lee, M.W., Jaillon, L., Poon, C.S., 2018. The hindrance to using prefabrication in Hong Kong's building industry. J. Clean. Prod. 204, 70–81. https://doi.org/10.1016/j.jclepro.2018.08.190

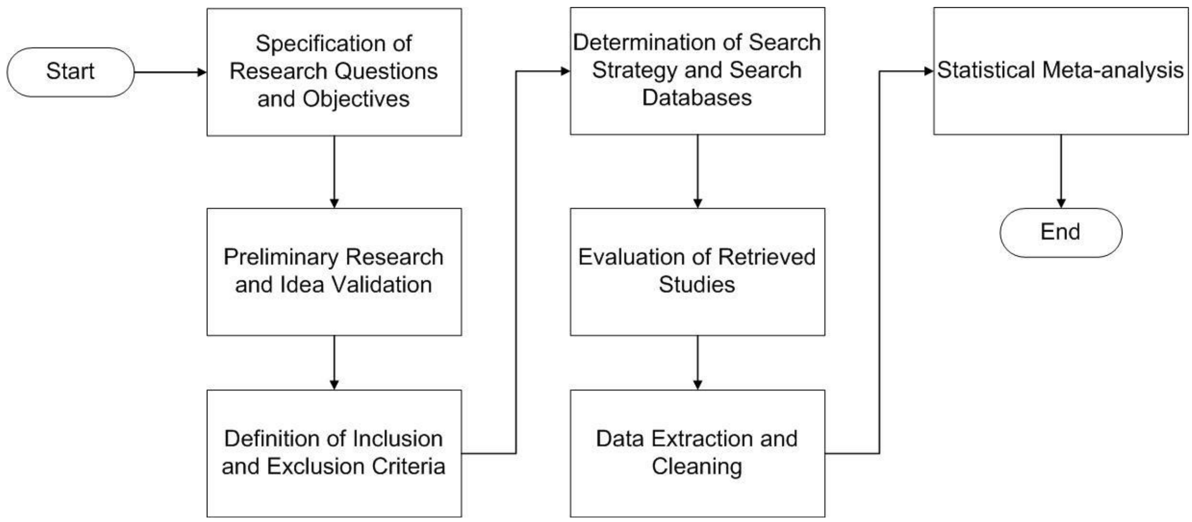


Fig. 1: Methodological flow diagram for the systematic review and meta-analysis.

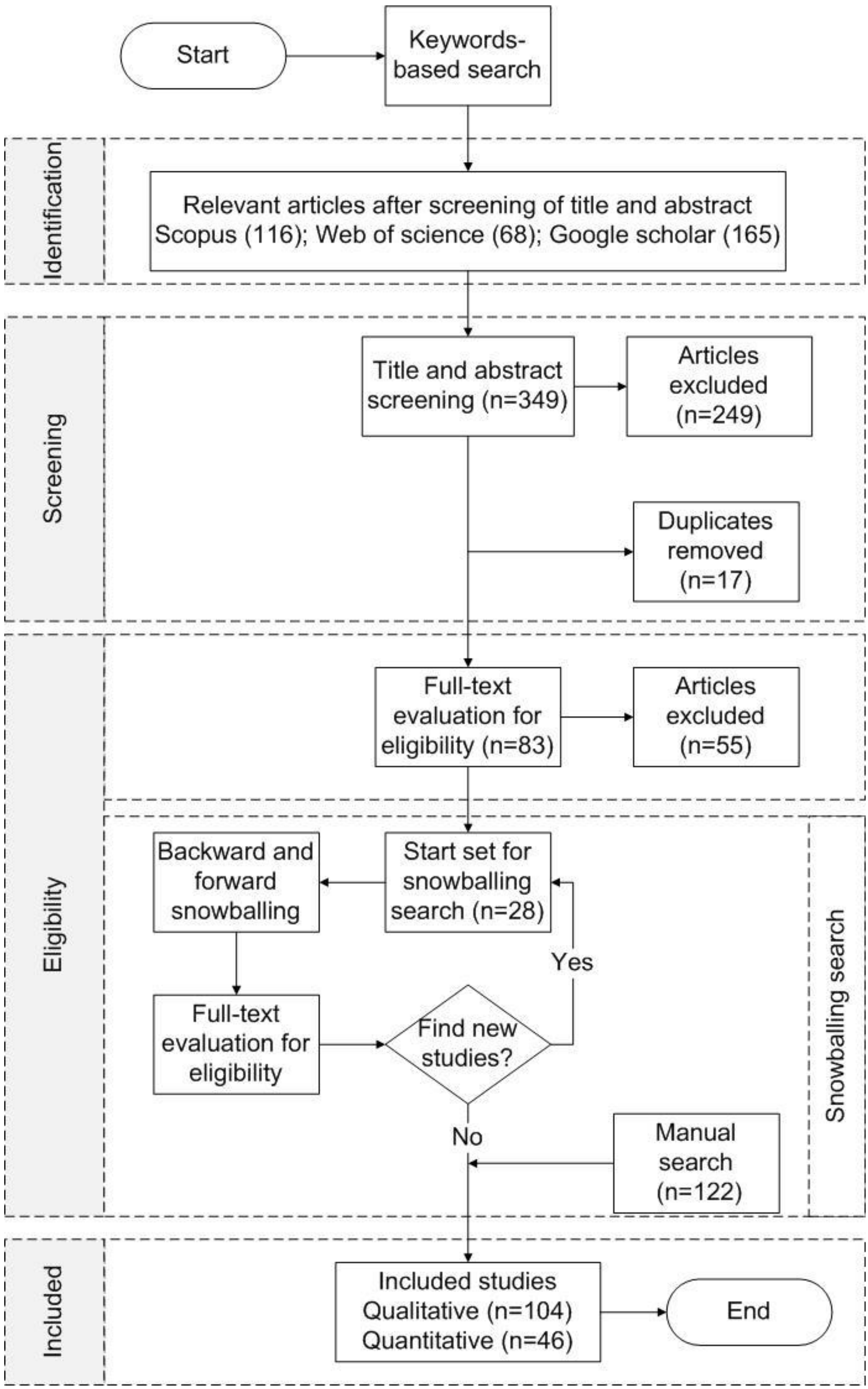


Fig. 2: PRISMA flow diagram for evaluating and selecting relevant studies.

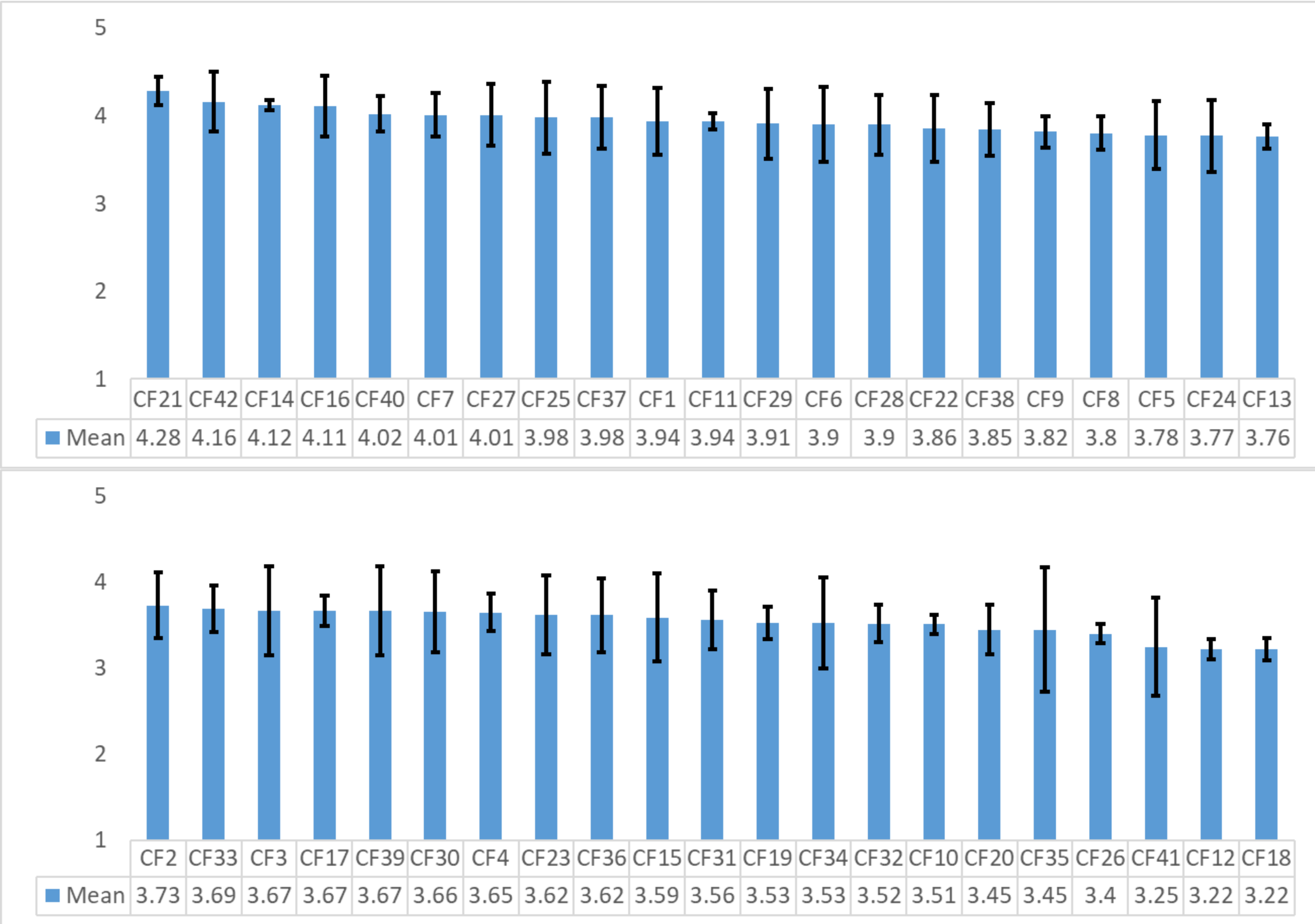


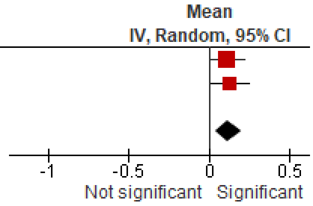
Fig. 3: Weighted mean ± weighted SD of each critical factor.

CFs	Forest plots

CF14 "*Willingness to invest in JIT practices*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Olamilokun 2015 (J) (NGA) (G)	0.11	0.055255	53.5%	0.11 [0.00, 0.22]	2015
Demirkesen 2019 (J) (USA) (Infra)	0.13	0.059248	46.5%	0.13 [0.01, 0.25]	2019
Total (95% CI)			**100.0%**	**0.12 [0.04, 0.20]**	

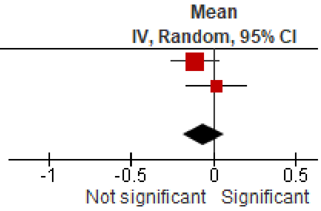
Heterogeneity: Tau² = 0.00; Chi² = 0.06, df = 1 (P = 0.81); I² = 0%
Test for overall effect: Z = 2.95 (P = 0.003)



CF11 "*Resources management*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Olamilokun 2015 (J) (NGA) (G)	-0.11	0.073673	59.5%	-0.11 [-0.25, 0.03]	2015
Enshassi 2018 (J) (PSE) (G)	0.02	0.093	40.5%	0.02 [-0.16, 0.20]	2018
Total (95% CI)			**100.0%**	**-0.06 [-0.18, 0.07]**	

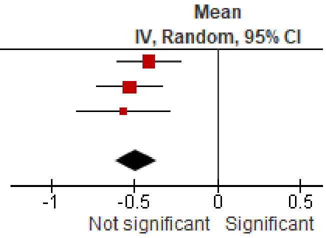
Heterogeneity: Tau² = 0.00; Chi² = 1.20, df = 1 (P = 0.27); I² = 17%
Test for overall effect: Z = 0.90 (P = 0.37)



CF10 "*Well-established long-term supplier-client relationships*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Shang 2014 (J) (CHN) (G)	-0.41	0.098853	40.8%	-0.41 [-0.60, -0.22]	2014
Kanafani 2015 (C) (UAE) (G)	-0.53	0.100215	39.7%	-0.53 [-0.73, -0.33]	2015
Aigbavboa 2016 (C) (ZAF) (G)	-0.57	0.142836	19.5%	-0.57 [-0.85, -0.29]	2016
Total (95% CI)			**100.0%**	**-0.49 [-0.61, -0.37]**	

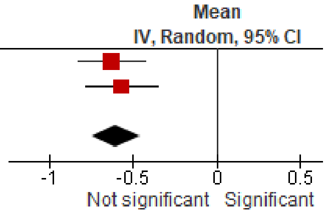
Heterogeneity: Tau² = 0.00; Chi² = 1.13, df = 2 (P = 0.57); I² = 0%
Test for overall effect: Z = 7.74 (P < 0.00001)



CF26 "*Trust among supply chain members*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Shang 2014 (J) (CHN) (G)	-0.63	0.103256	53.2%	-0.63 [-0.83, -0.43]	2014
Enshassi 2018 (J) (PSE) (G)	-0.57	0.11	46.8%	-0.57 [-0.79, -0.35]	2018
Total (95% CI)			**100.0%**	**-0.60 [-0.75, -0.45]**	

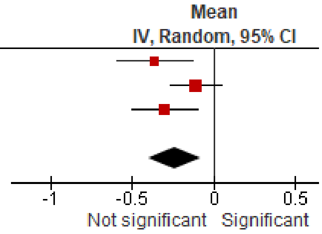
Heterogeneity: Tau² = 0.00; Chi² = 0.16, df = 1 (P = 0.69); I² = 0%
Test for overall effect: Z = 7.99 (P < 0.00001)



CF13 "*Adopt new management concepts*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Abdullah 2009 (J) (MYS) (G)	-0.36559	0.120177	27.1%	-0.37 [-0.60, -0.13]	2009
Sarhan 2013 (J) (UK) (G)	-0.11	0.08198	40.0%	-0.11 [-0.27, 0.05]	2013
Kanafani 2015 (C) (UAE) (G)	-0.3	0.101151	32.9%	-0.30 [-0.50, -0.10]	2015
Total (95% CI)			**100.0%**	**-0.24 [-0.40, -0.08]**	

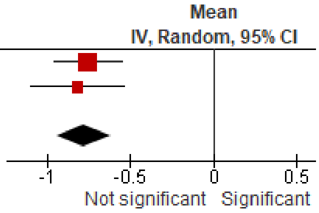
Heterogeneity: Tau² = 0.01; Chi² = 3.89, df = 2 (P = 0.14); I² = 49%
Test for overall effect: Z = 3.01 (P = 0.003)



CF12 "*Procurement management*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Kanafani 2015 (C) (UAE) (G)	-0.76	0.104898	65.0%	-0.76 [-0.97, -0.55]	2015
Aigbavboa 2016 (C) (ZAF) (G)	-0.82	0.142836	35.0%	-0.82 [-1.10, -0.54]	2016
Total (95% CI)			**100.0%**	**-0.78 [-0.95, -0.62]**	

Heterogeneity: Tau² = 0.00; Chi² = 0.11, df = 1 (P = 0.73); I² = 0%
Test for overall effect: Z = 9.24 (P < 0.00001)



CF21 "*Production planning*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Yunus 2017 (C) (MYS) (MiC)	0.38	0.052868	55.4%	0.38 [0.28, 0.48]	2017
Rahimah Mohd Noor 2018 (J) (MYS) (MiC)	0.16	0.089592	44.6%	0.16 [-0.02, 0.34]	2018
Total (95% CI)			**100.0%**	**0.28 [0.07, 0.50]**	

Heterogeneity: Tau² = 0.02; Chi² = 4.47, df = 1 (P = 0.03); I² = 78%
Test for overall effect: Z = 2.58 (P = 0.010)

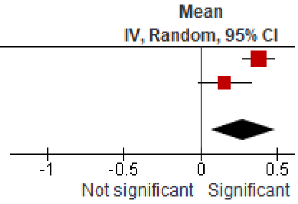
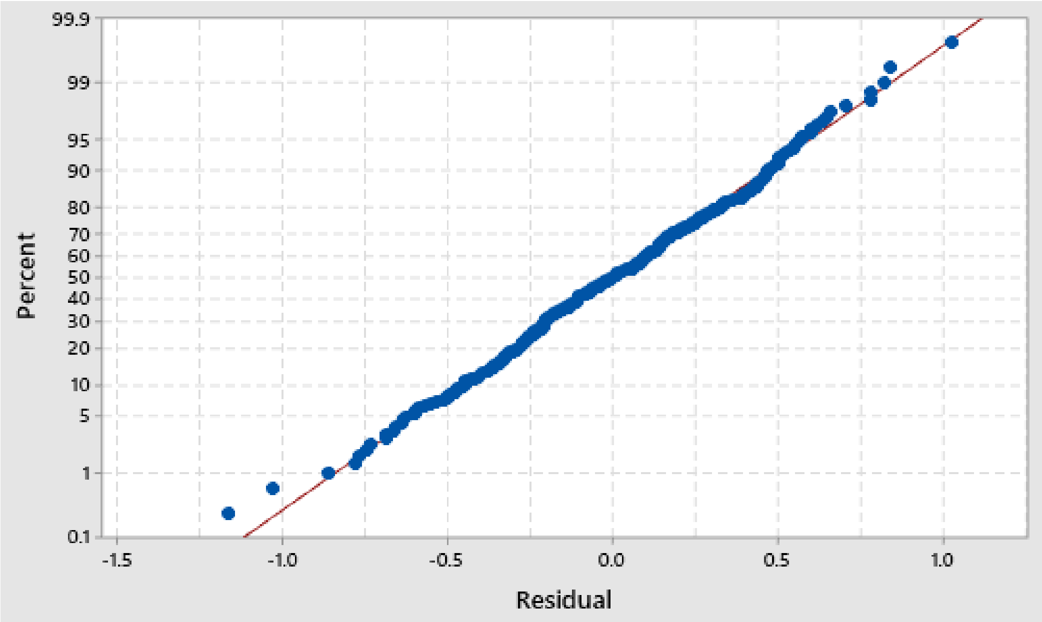
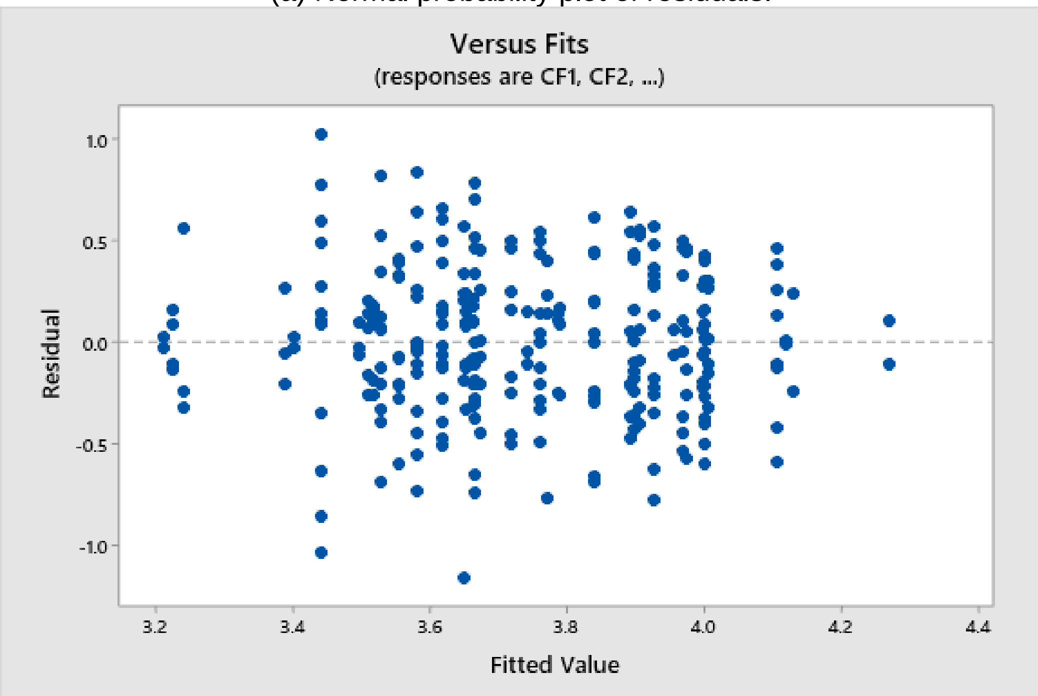


Fig. 4: Forest plots of the most influential CFs based on *SNR* values.



(a) Normal probability plot of residuals.



(b) Plot of residuals versus fitted values.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	41	12.96	0.3160	2.06	0.000
Error	240	36.82	0.1534		
Total	281	49.77			

(c) Results of the one-way ANOVA.

Fig. 5: Results of Tukey's method and checking of the model adequacy.

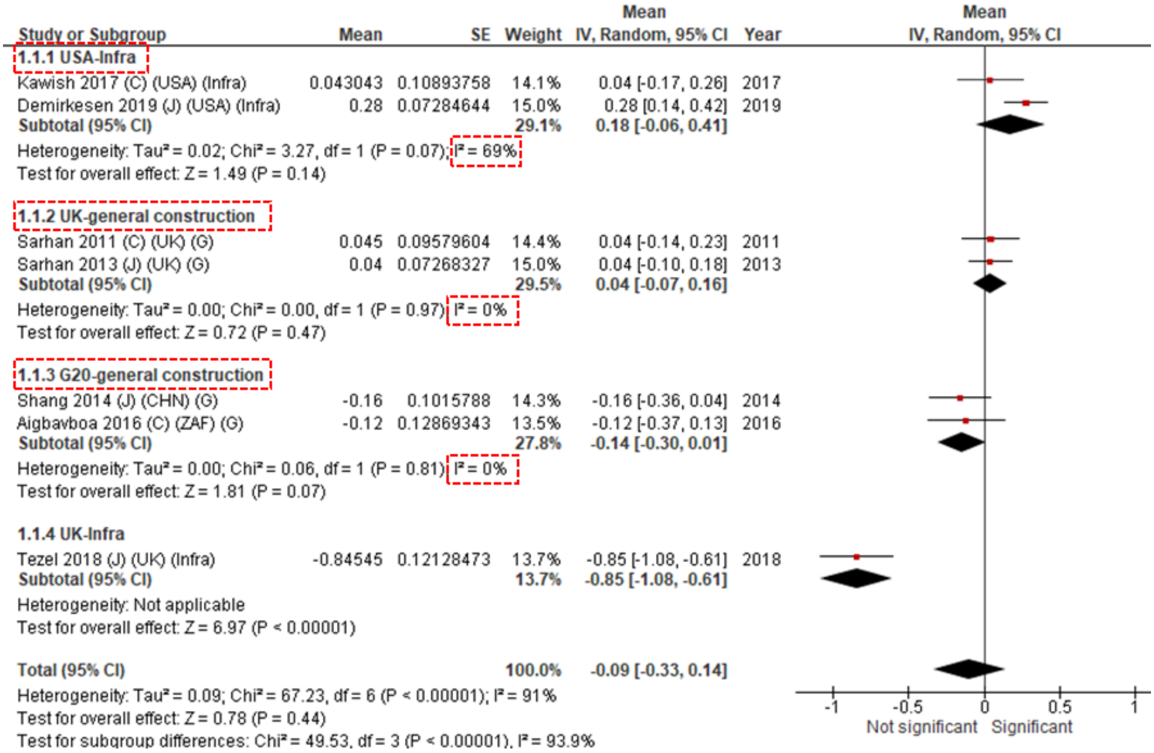


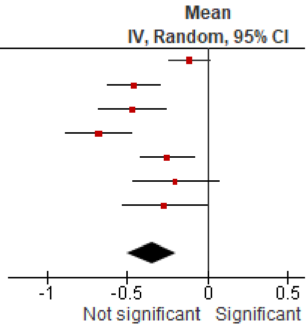
Fig. 6: The effect of further dividing the studies into smaller sub-groups on the heterogeneity.

CFs	Forest plots

CF4 "*Stakeholder management*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Ayarkwa 2012 (J) (GHA) (G)	-0.11	0.064035	16.7%	-0.11 [-0.24, 0.02]	2012
Sarhan 2013 (J) (UK) (G)	-0.46	0.082825	15.6%	-0.46 [-0.62, -0.30]	2013
Omran 2015 (J) (LBY) (G)	-0.47	0.107043	14.0%	-0.47 [-0.68, -0.26]	2015
Kanafani 2015 (C) (UAE) (G)	-0.68	0.106771	14.0%	-0.68 [-0.89, -0.47]	2015
Olamilokun 2015 (J) (NGA) (G)	-0.25	0.085075	15.4%	-0.25 [-0.42, -0.08]	2015
Aigbavboa 2016 (C) (ZAF) (G)	-0.2	0.137179	12.1%	-0.20 [-0.47, 0.07]	2016
Kawish 2017 (C) (USA) (Infra)	-0.26667	0.135974	12.1%	-0.27 [-0.53, -0.00]	2017
Total (95% CI)			**100.0%**	**-0.35 [-0.50, -0.19]**	

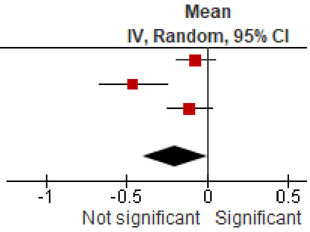
Heterogeneity: Tau² = 0.03; Chi² = 28.51, df = 6 (P < 0.0001); I² = 79%
Test for overall effect: Z = 4.34 (P < 0.0001)



CF8 "*Human resources management*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Ayarkwa 2012 (J) (GHA) (G)	-0.07	0.06439939	36.0%	-0.07 [-0.20, 0.06]	2012
Kanafani 2015 (C) (UAE) (G)	-0.46	0.1058342	29.1%	-0.46 [-0.67, -0.25]	2015
Olamilokun 2015 (J) (NGA) (G)	-0.11	0.0710417	34.9%	-0.11 [-0.25, 0.03]	2015
Total (95% CI)			**100.0%**	**-0.20 [-0.40, 0.01]**	

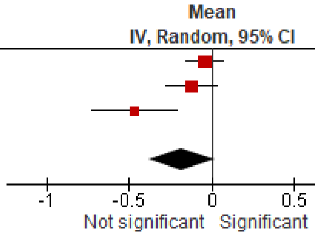
Heterogeneity: Tau² = 0.03; Chi² = 10.44, df = 2 (P = 0.005); I² = 81%
Test for overall effect: Z = 1.91 (P = 0.06)



CF9 "*Organisational structure*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Ayarkwa 2012 (J) (GHA) (G)	-0.04	0.057106	39.0%	-0.04 [-0.15, 0.07]	2012
Olamilokun 2015 (J) (NGA) (G)	-0.12	0.078058	35.3%	-0.12 [-0.27, 0.03]	2015
Aigbavboa 2016 (C) (ZAF) (G)	-0.47	0.131522	25.7%	-0.47 [-0.73, -0.21]	2016
Total (95% CI)			**100.0%**	**-0.18 [-0.38, 0.02]**	

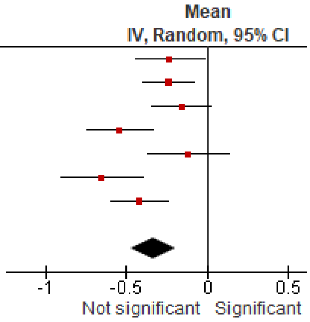
Heterogeneity: Tau² = 0.02; Chi² = 9.01, df = 2 (P = 0.01); I² = 78%
Test for overall effect: Z = 1.74 (P = 0.08)



CF17 "*Project complexities*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Sarhan 2011 (C) (UK) (G)	-0.2342	0.110386	13.9%	-0.23 [-0.45, -0.02]	2011
Sarhan 2013 (J) (UK) (G)	-0.24	0.08367	16.3%	-0.24 [-0.40, -0.08]	2013
Shang 2014 (J) (CHN) (G)	-0.16	0.094136	15.3%	-0.16 [-0.34, 0.02]	2014
Kanafani 2015 (C) (UAE) (G)	-0.54	0.106771	14.2%	-0.54 [-0.75, -0.33]	2015
Aigbavboa 2016 (C) (ZAF) (G)	-0.12	0.128693	12.3%	-0.12 [-0.37, 0.13]	2016
Kawish 2017 (C) (USA) (Infra)	-0.65136	0.128399	12.4%	-0.65 [-0.90, -0.40]	2017
Enshassi 2018 (J) (PSE) (G)	-0.42	0.09	15.7%	-0.42 [-0.60, -0.24]	2018
Total (95% CI)			**100.0%**	**-0.33 [-0.47, -0.20]**	

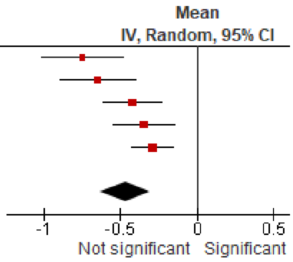
Heterogeneity: Tau² = 0.02; Chi² = 18.95, df = 6 (P = 0.004); I² = 68%
Test for overall effect: Z = 4.78 (P < 0.00001)



CF19 "*Apply appropriate lean tools*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Spillane 2017 (J) (IRL,USA) (G)	-0.75	0.136626	16.5%	-0.75 [-1.02, -0.48]	2017
Kawish 2017 (C) (USA) (Infra)	-0.65217391	0.127574	17.5%	-0.65 [-0.90, -0.40]	2017
Enshassi 2018 (J) (PSE) (G)	-0.42	0.098	21.0%	-0.42 [-0.61, -0.23]	2018
Tezel 2018 (J) (UK) (Infra)	-0.34545454	0.102867	20.4%	-0.35 [-0.55, -0.14]	2018
Demirkesen 2019 (J) (USA) (Infra)	-0.29	0.069933	24.5%	-0.29 [-0.43, -0.15]	2019
Total (95% CI)			**100.0%**	**-0.47 [-0.63, -0.30]**	

Heterogeneity: Tau² = 0.02; Chi² = 13.12, df = 4 (P = 0.01); I² = 70%
Test for overall effect: Z = 5.60 (P < 0.00001)



CF32 "*Contract and incentives*"

Study or Subgroup	Mean	SE	Weight	Mean IV, Random, 95% CI	Year
Sarhan 2011 (C) (UK) (G)	-0.3063	0.10507339	19.6%	-0.31 [-0.51, -0.10]	2011
Sarhan 2013 (J) (UK) (G)	-0.31	0.08028965	21.8%	-0.31 [-0.47, -0.15]	2013
Omran 2015 (J) (LBY) (G)	-0.67	0.14744196	15.9%	-0.67 [-0.96, -0.38]	2015
Kanafani 2015 (C) (UAE) (G)	-0.74	0.08429272	21.5%	-0.74 [-0.91, -0.57]	2015
Enshassi 2018 (J) (PSE) (G)	-0.39	0.087	21.2%	-0.39 [-0.56, -0.22]	2018
Total (95% CI)			**100.0%**	**-0.48 [-0.66, -0.29]**	

Heterogeneity: Tau² = 0.04; Chi² = 19.33, df = 4 (P = 0.0007); I² = 79%
Test for overall effect: Z = 5.01 (P < 0.00001)

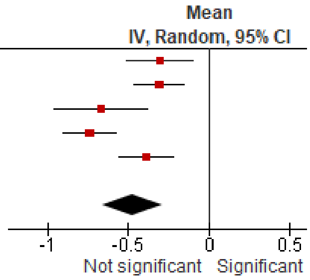


Fig. 7: Examples of some CFs whose studies agree on their significant level, albeit with high values of heterogeneity.

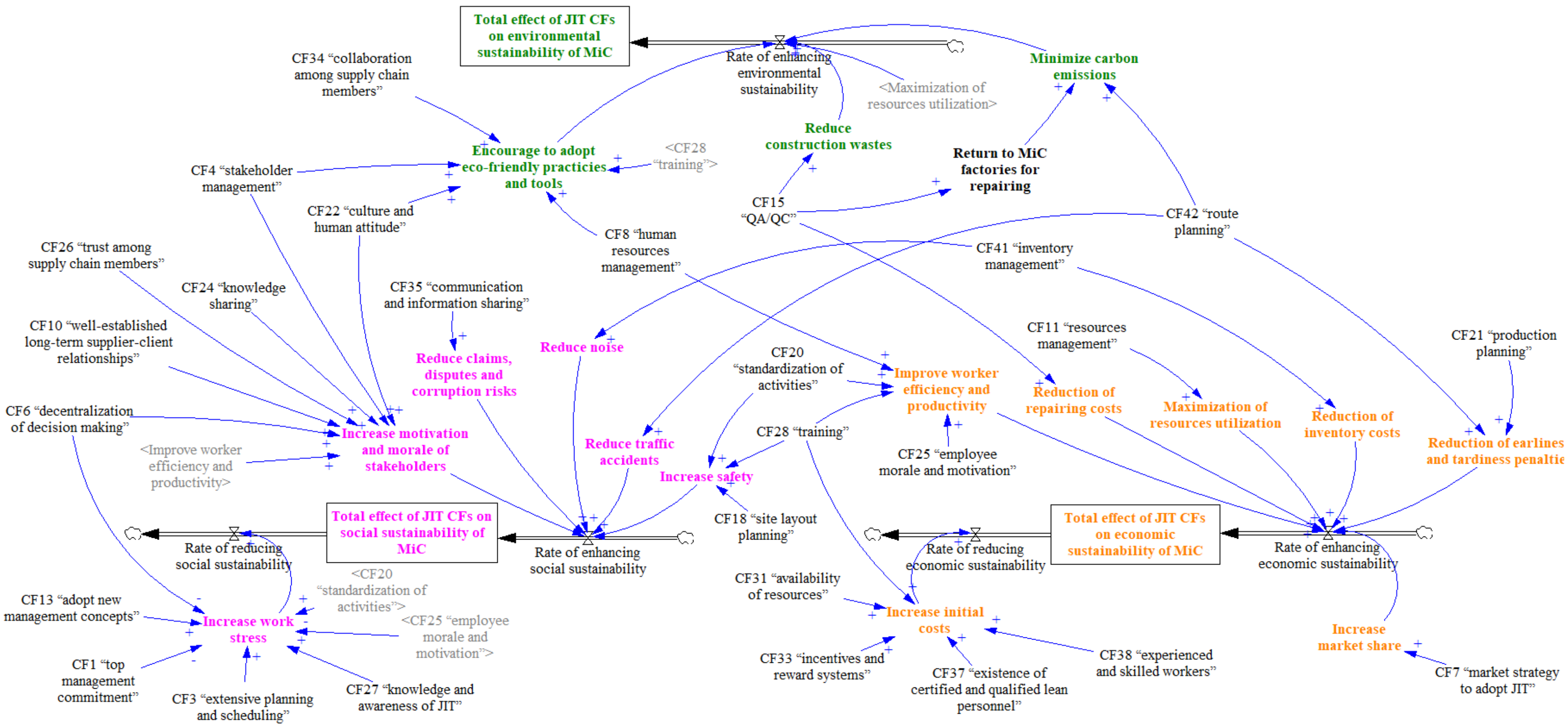


Fig. 8: A schematic system dynamics model of JIT CFs for a more sustainable MiC.

Table 1: Disagreement between previous studies on the importance level of some CFs to apply JIT.

Critical factor (CF)	Studies which agree on the significant importance of a CF	Studies which agree on the insignificant importance of a CF
"*Political and economic stability*"	(Ayarkwa et al., 2012); (Olamilokun, 2015) and ; (Enshassi et al., 2018)	(Alinaitwe, 2009); (Kanafani, 2015); (Aigbavboa et al., 2016); and (Demirkesen and Bayhan, 2019)
"*Market strategy to adopt JIT*"	(Olamilokun, 2015); (Tezel et al., 2018); and (Rahimah Mohd Noor et al., 2018)	(Aigbavboa et al., 2016); (Enshassi et al., 2018); and (Demirkesen and Bayhan, 2019)
"*Knowledge and awareness of JIT*"	(Abdullah et al., 2009); (Sarhan, 2011); (Ayarkwa et al., 2012); (Sarhan and Fox, 2013); and (Kawish, 2017)	(Shang and Sui Pheng, 2014); (Omran and Abdulrahim, 2015); (Amade et al., 2019); and (Enshassi et al., 2018)

Table 2: Statistical data obtained from studies of CF32 that are identified to meta-analysis software.

Study	Sample size	Mean	SD	SE*10^{-3}
Sarhan 2013 (J) (UK) (G)	140	3.69	0.95	80.29
Kanafani 2015 (C) (UAE) (G)	114	3.26	0.90	84.29
Sarhan 2011 (C) (UK) (G)	82	3.69	0.95	105.07
Omran 2015 (J) (LBY) (G)	46	3.33	1.00	147.44
Enshassi 2018 (J) (PSE) (G)	100	3.61	0.87	87.00
Yunus 2017 (C) (MYS) (MiC)	111	4.41	0.58	54.96

Table 3: Meta-analysis results of CF32 before and after conducting the sensitivity analysis.

Study	Study weight	
	Before	After
Sarhan 2011 (C) (UK) (G)	16.60%	19.60%
Sarhan 2013 (J) (UK) (G)	16.90%	21.80%
Kanafani 2015 (C) (UAE) (G)	16.80%	21.50%
Omran 2015 (J) (LBY) (G)	15.90%	15.90%
Yunus 2017 (C) (MYS) (MiC)	17.10%	0.00%
Enshassi 2018 (J) (PSE) (G)	16.70%	21.20%
Total	100.00%	100.00%
Summary effect (95% CI)	3.67 [3.26, 4.08]	3.52 [3.34, 3.71]
Heterogeneity	$Chi^2 = 178.99$, df = 5 ($P < 0.00001$); $I^2 = 97\%$	$Chi^2 = 19.33$, df = 4 ($P = 0.0007$); $I^2 = 79\%$

Table 4: Sub-group analysis results of CF32 based on the four criteria (i.e. publication type, publication year, country's economy and project type).

	Studies	Weight	Mean (95% CI)
1. Publication type			
1.1 Journals	Sarhan 2013 (J) (UK) (G)	16.90%	3.69 [3.53, 3.85]
	Omran 2015 (J) (LBY) (G)	15.90%	3.33 [3.04, 3.62]
	Enshassi 2018 (J) (PSE) (G)	16.80%	3.61 [3.44, 3.78]
	Subtotal (95% CI)	49.50%	3.58 [3.41, 3.75]
1.2 Other sources	Sarhan 2011 (C) (UK) (G)	16.60%	3.69 [3.49, 3.90]
	Kanafani 2015 (C) (UAE) (G)	16.80%	3.26 [3.09, 3.43]
	Yunus 2017 (C) (MYS) (MiC)	17.10%	4.41 [4.30, 4.52]
	Subtotal (95% CI)	50.50%	3.79 [3.04, 4.55]
Test for subgroup differences	Chi² = 0.28, df = 1 **(P = 0.59)**, I² = 0%		
2. Publication year			
2.1 2009-2015	Sarhan 2011 (C) (UK) (G)	16.60%	3.69 [3.49, 3.90]
	Sarhan 2013 (J) (UK) (G)	16.90%	3.69 [3.53, 3.85]
	Omran 2015 (J) (LBY) (G)	15.90%	3.33 [3.04, 3.62]
	Kanafani 2015 (C) (UAE) (G)	16.80%	3.26 [3.09, 3.43]
	Subtotal (95% CI)	66.10%	3.50 [3.26, 3.74]
2.2 2016-2019	Yunus 2017 (C) (MYS) (MiC)	17.10%	4.41 [4.30, 4.52]
	Enshassi 2018 (J) (PSE) (G)	16.80%	3.61 [3.44, 3.78]
	Subtotal (95% CI)	33.90%	4.01 [3.23, 4.80]
Test for subgroup differences	Chi² = 1.50, df = 1 (**P = 0.22**), I² = 33.5%		
3. Country's economy			
3.1 G20	Sarhan 2011 (C) (UK) (G)	16.60%	3.69 [3.49, 3.90]
	Sarhan 2013 (J) (UK) (G)	16.90%	3.69 [3.53, 3.85]
	Subtotal (95% CI)	33.40%	3.69 [3.57, 3.82]
3.2 Other countries	Kanafani 2015 (C) (UAE) (G)	16.80%	3.26 [3.09, 3.43]
	Omran 2015 (J) (LBY) (G)	15.90%	3.33 [3.04, 3.62]
	Yunus 2017 (C) (MYS) (MiC)	17.10%	4.41 [4.30, 4.52]
	Enshassi 2018 (J) (PSE) (G)	16.80%	3.61 [3.44, 3.78]
	Subtotal (95% CI)	66.60%	3.66 [3.03, 4.28]
Test for subgroup differences	Chi² = 0.01, df = 1 (**P = 0.92**), I² = 0%		
4. Project type			
4.1 General building	Sarhan 2011 (C) (UK) (G)	16.60%	3.69 [3.49, 3.90]
	Sarhan 2013 (J) (UK) (G)	16.90%	3.69 [3.53, 3.85]
	Omran 2015 (J) (LBY) (G)	15.90%	3.33 [3.04, 3.62]
	Kanafani 2015 (C) (UAE) (G)	16.80%	3.26 [3.09, 3.43]
	Enshassi 2018 (J) (PSE) (G)	16.80%	3.61 [3.44, 3.78]
	Subtotal (95% CI)	82.90%	3.52 [3.34, 3.71]
4.2 MiC	Yunus 2017 (C) (MYS) (MiC)	17.10%	4.41 [4.30, 4.52]
	Subtotal (95% CI)	17.10%	4.41 [4.30, 4.52]
Test for subgroup differences	Chi² = 65.08, df = 1 (**P < 0.00001**), I² = 98.5%		

Table 5: Data extracted from the included studies.

Study ID in meta-analysis*	Reference	Publication type	Publication year	Country	Project type	Sample size**	Research Method
Sarhan 2013 (J) (UK) (G)	(Sarhan and Fox, 2013)	Journal	2013	UK	General building	140	Questionnaire
Demirkesen 2019 (J) (USA) (Infra)	(Demirkesen and Bayhan, 2019)	Journal	2019	USA	Infrastructure	106	Questionnaire
Shang 2014 (J) (CHN) (G)	(Shang and Sui Pheng, 2014)	Journal	2014	China	General building	91	Questionnaire
Ayarkwa 2012 (J) (GHA) (G)	(Ayarkwa et al., 2012)	Journal	2012	Ghana	General building	188	Questionnaire & Interview
Kanafani 2015 (C) (UAE) (G)	(Kanafani, 2015)	Thesis	2015	UAE	General building	114	Questionnaire & Interview
Kawish 2017 (C) (USA) (Infra)	(Kawish, 2017)	Thesis	2017	USA	Infrastructure	47	Questionnaire
Tezel 2018 (J) (UK) (Infra)	(Tezel et al., 2018)	Journal	2018	UK	Infrastructure	110	Questionnaire & Interview
Alinaitwe 2009 (J) (UGA) (G)	(Alinaitwe, 2009)	Journal	2009	Uganda	General building	45	Questionnaire & Interview
Abdullah 2009 (J) (MYS) (G)	(Abdullah et al., 2009)	Journal	2009	Malaysia	General building	93	Questionnaire
Sarhan 2011 (C) (UK) (G)	(Sarhan, 2011)	Thesis	2011	UK	General building	82	Questionnaire & Interview
Amade 2019 (J) (NGA) (G)	(Amade et al., 2019)	Journal	2019	Nigeria	General building	233	Questionnaire & Case study
Omran 2015 (J) (LBY) (G)	(Omran and Abdulrahim, 2015)	Journal	2015	Libya	General building	46	Questionnaire
Enshassi 2018 (J) (PSE) (G)	(Enshassi et al., 2018)	Journal	2018	Palestine	General building	100	Questionnaire
Yunus 2017 (C) (MYS) (MiC)	(Yunus et al., 2017)	Conference	2017	Malaysia	MiC (IBS)	111	Questionnaire
Aigbavboa 2016 (C) (ZAF) (G)	(Aigbavboa et al., 2016)	Conference	2016	South Africa	General building	50	Questionnaire
Rahimah Mohd Noor 2018 (J) (MYS) (MiC)	(Rahimah Mohd Noor et al., 2018)	Journal	2018	Malaysia	MiC (IBS)	45	Questionnaire & Interview
Olamilokun 2015 (J) (NGA) (G)	(Olamilokun, 2015)	Journal	2015	Nigeria	General building	130	Questionnaire
Jaafar 2012 (J) (MYS) (MiC)	(Jaafar and Mahamad, 2012)	Journal	2012	Malaysia	MiC (IBS)	15	Questionnaire
Spillane 2017 (J) (IRL,USA) (G)	(Spillane and Oyedele, 2017)	Journal	2017	Ireland + USA***	General building	105	Questionnaire & Case study

* Study ID in meta-analysis is written as follows: last name of the first author + year + optional key information (publication type) (country) (project type).
** Sample size refers to the number of respondents.
*** This study discussed three case studies; two of them were in Ireland, and the third was in the USA.

Table 6: Critical factors (CFs) for JIT implementation.

Categories	ID	Critical factors (CFs)	Definition/Features	Studies	Frequency*
Managerial	CF1	Top management commitment	Top management commitment by providing sufficient resources is vital for successful JIT implementation in the long run.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Abdullah et al., 2009), (Sarhan, 2011), (Amade et al., 2019), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	15
	CF2	Business strategies	JIT needs to be a business strategy to increase the familiarity with JIT practices by setting the framework for the vision, main objectives, and strategies for the implementation.	(Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Abdullah et al., 2009), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Olamilokun, 2015).	10
	CF3	Extensive planning and scheduling	JIT implementation requires accurate planning and scheduling from all MiC supply chain members in a collaborative manner.	(Ayarkwa et al., 2012), (Kanafani, 2015), (Spillane and Oyedele, 2017), (Alinaitwe, 2009), (Amade et al., 2019), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	10
	CF4	Stakeholder management	Mapping the different stakeholders and understanding their impact on the project can help in reaping the full benefit of JIT.	(Sarhan and Fox, 2013), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Alinaitwe, 2009), (Omran and Abdulrahim, 2015), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	9
	CF5	Integrating risk management and supply chain management	MiC supply chain abounds with many risks along with its echelons. Identification, prioritization, assessment, mitigation, and control of these risks are crucial to ensure successful implementation.	(Ayarkwa et al., 2012), (Kanafani, 2015), (Spillane and Oyedele, 2017), (Jaafar and Mahamad, 2012), (Alinaitwe, 2009), (Enshassi et al., 2018), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	8
	CF6	Decentralization of decision making	Centralization of decision making resulted from complex organizational hierarchy leads to a slow decision-making process that does not fit with JIT implementation.	(Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Enshassi et al., 2018), (Yunus et al., 2017), (Olamilokun, 2015).	7
	CF7	Market strategy to adopt JIT	Benefits of JIT which satisfy the customers need to be promoted in a clear market strategy to adopt JIT.	(Demirkesen and Bayhan, 2019), (Tezel et al., 2018), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015), (Enshassi et al., 2018).	6
	CF8	Human resources management	Efficient human resources management leads to the selection of personnel whose skills fit with the job specification. Hence, it would foster waste elimination.	(Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Olamilokun, 2015).	4
	CF9	Organisational structure	Hierarchical and unstable organizational structure undermine the successful implementation of JIT.	(Ayarkwa et al., 2012), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	4
	CF10	Well-established long-term supplier-client relationships	Building strategic and long-term supplier-customer relations enhance JIT implementation by encouraging the supplier to invest more in automation and hence increase the quality and profit.	(Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Aigbavboa et al., 2016).	4

* = frequency of occurrences of each CF in the previous studies.

Table 6: Critical factors (CFs) for JIT implementation (Cont.).

Categories	ID	Critical factors (CFs)	Definition/Features	Studies	Frequency*
Managerial	CF11	Resources management	Improper planning of resources leads to wastes and an imbalanced workflow.	(Enshassi et al., 2018), (Yunus et al., 2017), (Olamilokun, 2015).	3
	CF12	Procurement management	Adopt different supplier selection criteria to select partners who are willing to adopt JIT rather than focusing only on the lowest price. Also, the selection of fewer and nearby suppliers support JIT success.	(Kanafani, 2015), (Aigbavboa et al., 2016), (Olamilokun, 2015).	3
	CF13	Adopt new management concepts	Adopt new management concepts that focus more on productivity and quality, not only on time and cost.	(Sarhan and Fox, 2013), (Kanafani, 2015), (Abdullah et al., 2009).	3
	CF14	Willingness to invest in JIT practices	Risk aversion by fear from invest in new strategies such as JIT is a critical barrier to adopt JIT.	(Demirkesen and Bayhan, 2019), (Olamilokun, 2015).	2
Technical	CF15	Quality assurance and quality control (QA/QC)	Rejection of defective materials will disrupt the MiC supply chain. Therefore, the QA/QC strategy and robust performance measurement system need to be applied through the whole MiC supply chain.	(Sarhan and Fox, 2013), (Ayarkwa et al., 2012), (Kanafani, 2015), (Spillane and Oyedele, 2017), (Kawish, 2017), (Jaafar and Mahamad, 2012), (Tezel et al., 2018), (Alinaitwe, 2009), (Sarhan, 2011), (Amade et al., 2019), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	15
	CF16	Agreed implementation methodology to implement JIT	The availability of agreed implementation methodology in the form of a manual to guide MiC supply chain members on how to implement JIT is valuable to convert JIT from theory to practice.	(Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Tezel et al., 2018), (Alinaitwe, 2009), (Enshassi et al., 2018), (Yunus et al., 2017), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	9
	CF17	Project complexities	The fragmented nature of MiC projects increases the adversarial relationships among supply chain partners. Also, the extensive use of sub-contractors impacts quality management.	(Sarhan and Fox, 2013), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Sarhan, 2011), (Enshassi et al., 2018), (Aigbavboa et al., 2016).	8
	CF18	Site layout planning	Site layout planning, preparation of site access, cleanliness of the site, preparation of storage space, and planning routes for materials movement are required to maintain the workflow.	(Shang and Sui Pheng, 2014), (Spillane and Oyedele, 2017), (Kawish, 2017), (Jaafar and Mahamad, 2012), (Alinaitwe, 2009), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	7
	CF19	Apply appropriate lean tools	Apply appropriate lean tools in an integrated manner to support JIT, such as value stream mapping, morning huddles, Last Planner System, 5S, six sigma, etc.	(Demirkesen and Bayhan, 2019), (Spillane and Oyedele, 2017), (Kawish, 2017), (Tezel et al., 2018), (Enshassi et al., 2018), (Yunus et al., 2017).	6
	CF20	Standardization of activities	Standardization of activities and planning of flows of workers, equipment, and materials can protect JIT implementation from any interruption.	(Spillane and Oyedele, 2017), (Jaafar and Mahamad, 2012), (Alinaitwe, 2009), (Olamilokun, 2015).	4
	CF21	Production planning	The production planning at MiC factories should satisfy the pull system, which is the main feature of JIT.	(Yunus et al., 2017), (Rahimah Mohd Noor et al., 2018).	2

Table 6: Critical factors (CFs) for JIT implementation (Cont.).

Categories	ID	Critical factors (CFs)	Definition/Features	Studies	Frequency*
Cultural and Human	CF22	Culture and human attitude	JIT as a lean tool requires the MiC supply chain members to have some soft and social skills to promote the communication and transparency between partners and overcome the fear of change and taking the risk.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Alinaitwe, 2009), (Abdullah et al., 2009), (Sarhan, 2011), (Amade et al., 2019), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	15
	CF23	Leadership and its managerial aspects	Like any other lean tools, JIT needs leadership capabilities to foster a lean culture and support lean activities in the organization.	(Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Kawish, 2017), (Tezel et al., 2018), (Alinaitwe, 2009), (Amade et al., 2019), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015), (Omran and Abdulrahim, 2015).	11
	CF24	Knowledge sharing	Knowledge sharing and documentation of lessons learned of JIT practices can improve JIT implementation.	(Kawish, 2017), (Alinaitwe, 2009), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	7
	CF25	Employee morale and motivation	To foster waste minimization culture, workers need to be motivated to accomplish their tasks right from the first time.	(Demirkesen and Bayhan, 2019), (Kanafani, 2015), (Kawish, 2017), (Enshassi et al., 2018), (Yunus et al., 2017), (Rahimah Mohd Noor et al., 2018).	6
	CF26	Trust among supply chain members	Trust among MiC supply chain members is critical for successful JIT. The trust can be built by transparency, honest information sharing, and appropriate contractual agreement.	(Shang and Sui Pheng, 2014), (Enshassi et al., 2018), (Yunus et al., 2017).	3
Educational and knowledge	CF27	Knowledge and awareness of JIT	Enhancing awareness and understanding of JIT philosophy is crucial to apply JIT in the whole MiC supply chain.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Alinaitwe, 2009), (Abdullah et al., 2009), (Sarhan, 2011), (Amade et al., 2019), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	17
	CF28	Training	Training through seminars and workshops is essential to develop communication and technical skills required to implement JIT.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Abdullah et al., 2009), (Enshassi et al., 2018), (Aigbavboa et al., 2016), (Rahimah Mohd Noor et al., 2018), (Olamilokun, 2015).	12
	CF29	Education and research	Introduction of JIT concepts to the curriculum of universities and colleges and the promotion of active and applied research on JIT would enhance the understanding of such new techniques in the construction field.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Sarhan, 2011), (Enshassi et al., 2018), (Yunus et al., 2017), (Olamilokun, 2015).	7
	CF30	Lean needs time	Application of JIT as an innovative strategy or new practice in the construction projects needs some time and patience from MiC supply chain members to adapt.	(Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Abdullah et al., 2009), (Sarhan, 2011), (Olamilokun, 2015).	6
Financial	CF31	Availability of resources	The successful implementation of JIT requires adequate funding to support training, employ lean consultants, increase fleet size and equipment needed to frequent deliveries of JIT and provide a sufficient workforce.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Tezel et al., 2018), (Sarhan, 2011), (Amade et al., 2019), (Enshassi et al., 2018), (Yunus et al., 2017), (Olamilokun, 2015).	11

Table 6: Critical factors (CFs) for JIT implementation (Cont.).

Categories	ID	Critical factors (CFs)	Definition/Features	Studies	Frequency
Financial	CF32	Contract and incentives	Traditional contracts undermine the JIT implementation because they do not guarantee a mutual benefit for MiC supply chain members. New contracts are needed to share JIT benefits and allocate JIT risks among the partners.	(Sarhan and Fox, 2013), (Kanafani, 2015), (Sarhan, 2011), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017).	6
	CF33	Incentives and reward systems	incentives and reward systems are required to convince each member of the MiC supply chain to adopt JIT.	(Sarhan and Fox, 2013), (Demirkesen and Bayhan, 2019), (Kanafani, 2015), (Alinaitwe, 2009), (Enshassi et al., 2018), (Olamilokun, 2015).	6
Communication-related	CF34	Collaboration among supply chain members	Successful implementation of JIT across echelons of MiC supply chain requires collaboration between suppliers of raw materials, the manufacturer, the logistics manager, and the project manager.	(Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Spillane and Oyedele, 2017), (Kawish, 2017), (Jaafar and Mahamad, 2012), (Tezel et al., 2018), (Alinaitwe, 2009), (Amade et al., 2019), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	14
	CF35	Communication and information sharing	Lack of communication and information sharing between MiC supply chain members leads to adverse relationships where each partner tends to increase his/her inventory as a hedging strategy, and hence JIT fails.	(Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Spillane and Oyedele, 2017), (Jaafar and Mahamad, 2012), (Alinaitwe, 2009), (Abdullah et al., 2009), (Amade et al., 2019), (Omran and Abdulrahim, 2015), (Enshassi et al., 2018), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	13
	CF36	Collaboration between the design and construction stages	JIT implementation is hampered by the dichotomy between design and construction stages, which leads to rework in both of them and deterioration of quality and productivity, and hence JIT is missed.	(Sarhan and Fox, 2013), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Alinaitwe, 2009), (Sarhan, 2011), (Enshassi et al., 2018), (Aigbavboa et al., 2016), (Olamilokun, 2015).	10
skills and expertise related	CF37	Existence of certified and qualified lean personnel	Hiring a certified and qualified logistics manager who has the know-how of JIT implementation would tackle the issue of lack of skills and technical experience.	(Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Tezel et al., 2018), (Amade et al., 2019), (Yunus et al., 2017), (Aigbavboa et al., 2016), (Olamilokun, 2015).	8
	CF38	Experienced and skilled workers	Extensive use of poorly skilled migrant workers increases wastes and disrupts the workflow.	(Ayarkwa et al., 2012), (Kawish, 2017), (Alinaitwe, 2009), (Aigbavboa et al., 2016), (Olamilokun, 2015).	5
Governmental	CF39	Supportive governmental regulations	government support through consistent policies and incentives such as tax exemptions and rewards mechanisms is vital for the adoption of any new strategy such as JIT.	(Demirkesen and Bayhan, 2019), (Shang and Sui Pheng, 2014), (Ayarkwa et al., 2012), (Kanafani, 2015), (Kawish, 2017), (Amade et al., 2019), (Enshassi et al., 2018), (Olamilokun, 2015).	8
	CF40	Political and economic stability	JIT is not suitable in unstable political and economic environments characterized by corruption, high inflation, and unsteady prices of commodities.	(Demirkesen and Bayhan, 2019), (Ayarkwa et al., 2012), (Kanafani, 2015), (Alinaitwe, 2009), (Enshassi et al., 2018), (Aigbavboa et al., 2016), (Olamilokun, 2015).	7
Logistics	CF41	Inventory management	Frequent deliveries and smaller lot sizes are required to achieve JIT. Therefore, robust optimization of MiC modules ordering while considering uncertainties is vital.	(Spillane and Oyedele, 2017), (Jaafar and Mahamad, 2012), (Alinaitwe, 2009), (Yunus et al., 2017).	4
	CF42	Route planning	Route planning to deliver MiC modules JIT is required. The route planning should consider traffic	(Alinaitwe, 2009), (Yunus et al., 2017).	2

regulations, traffic congestions and bad weather conditions.

Table 7: Summary of heterogeneity and sub-group analysis results for each critical factor.

CFs	Heterogeneity						Sub-group analysis			
	Before sensitivity analysis			After sensitivity analysis			Publication type	Publication year	Project type	Country's economy
	$\chi 2$	P-value	I^2	$\chi 2$	P-value	I^2				
CF1	278.27	< 0.00001	95%	NA*	NA*	NA*	Insignificant	Insignificant	**Significant**	Insignificant
CF2	321.69	< 0.00001	97%	114.74	< 0.00001	94%	Insignificant	Insignificant	Insignificant	Insignificant
CF3	318.40	< 0.00001	97%	187.14	< 0.00001	96%	Insignificant	Insignificant	**Significant**	Insignificant
CF4	256.94	< 0.00001	97%	28.51	P < 0.0001	79%	Insignificant	Insignificant	NA**	Insignificant
CF5	129.43	< 0.00001	95%	108.77	< 0.00001	94%	NA**	Insignificant	Insignificant	NA**
CF6	220.32	< 0.00001	97%	NA*	NA*	NA*	Insignificant	Insignificant	NA**	**Significant**
CF7	42.92	< 0.00001	88%	NA*	NA*	NA*	NA**	NA**	Insignificant	Insignificant
CF8	19.07	P = 0.0003	84%	10.44	0.005	81%	NA**	NA**	NA**	NA**
CF9	22.90	< 0.0001	87%	9.01	0.01	78%	NA**	Insignificant	NA**	NA**
CF10	159.56	< 0.00001	98%	1.13	**0.57**	0%	Insignificant	NA**	NA**	Insignificant
CF11	41.49	< 0.00001	95%	1.20	**0.27**	17%	NA**	NA**	NA**	NA**
CF12	48.96	< 0.00001	96%	0.11	**0.73**	0%	NA**	NA**	NA**	NA**
CF13	3.89	**0.14**	49%	NA*	NA*	NA*	NA**	NA**	NA**	NA**
CF14	0.06	**0.81**	0%	NA*	NA*	NA*	NA**	NA**	NA**	NA**
CF15	419.84	< 0.00001	97%	NA*	NA*	NA*	Insignificant	Insignificant	**Significant**	Insignificant
CF16	233.72	< 0.00001	97%	152.26	< 0.00001	95%	Insignificant	Insignificant	**Significant**	Insignificant
CF17	234.21	< 0.00001	97%	18.95	0.004	68%	Insignificant	Insignificant	NA**	Insignificant
CF18	112.68	< 0.00001	95%	5.36	**0.15**	44%	NA**	Insignificant	Insignificant	Insignificant
CF19	187.15	< 0.00001	97%	13.12	0.01	70%	Insignificant	NA**	Insignificant	Insignificant
CF20	38.30	< 0.00001	92%	5.15	**0.08**	61%	NA**	NA**	NA**	NA**
CF21	4.47	0.03	78%	NA*	NA*	NA*	NA**	NA**	NA**	NA**
CF22	754.08	< 0.00001	98%	243.12	< 0.00001	95%	Insignificant	Insignificant	Insignificant	Insignificant
CF23	431.59	< 0.00001	98%	144.50	< 0.00001	94%	Insignificant	Insignificant	Insignificant	Insignificant
CF24	145.86	< 0.00001	96%	71.08	< 0.00001	94%	Insignificant	Insignificant	NA**	Insignificant
CF25	103.96	< 0.00001	95%	NA*	NA*	NA*	Insignificant	NA**	**Significant**	Insignificant
CF26	144.60	< 0.00001	99%	0.16	**0.69**	0%	NA**	NA**	NA**	NA**
CF27	306.96	< 0.00001	95%	259.31	< 0.00001	94%	Insignificant	Insignificant	**Significant**	Insignificant
CF28	205.61	< 0.00001	95%	115.68	< 0.00001	91%	Insignificant	Insignificant	Insignificant	Insignificant
CF29	208.52	< 0.00001	97%	NA*	NA*	NA*	Insignificant	Not significant	NA**	**Significant**
CF30	145.48	< 0.00001	97%	NA*	NA*	NA*	Insignificant	NA**	NA**	Insignificant
CF31	349.24	< 0.00001	97%	123.59	< 0.00001	93%	Insignificant	Insignificant	Insignificant	Insignificant
CF32	178.99	< 0.00001	97%	19.33	0.0007	79%	Insignificant	Insignificant	**Significant**	Insignificant
CF33	53.77	< 0.00001	91%	NA*	NA*	NA*	NA**	Insignificant	NA**	Insignificant
CF34	523.63	< 0.00001	98%	326.29	< 0.00001	97%	Insignificant	Insignificant	Insignificant	Insignificant
CF35	759.08	< 0.00001	98%	NA*	NA*	NA*	**Significant**	Insignificant	Insignificant	Insignificant
CF36	240.69	< 0.00001	96%	138.71	< 0.00001	94%	Insignificant	Insignificant	NA**	Insignificant
CF37	190.99	< 0.00001	96%	NA*	NA*	NA*	Insignificant	Insignificant	Not significant	Insignificant
CF38	62.58	< 0.00001	94%	23.42	< 0.0001	87%	Insignificant	Insignificant	NA**	Insignificant
CF39	236.70	< 0.00001	97%	NA*	NA*	NA*	Insignificant	Insignificant	**Significant**	**Significant**

CF40	114.94	< 0.00001	95%	18.64	0.002	73%	Insignificant	Insignificant	NA**	Insignificant
CF41	140.62	< 0.00001	98%	21.37	< 0.0001	91%	NA**	Insignificant	Insignificant	NA**
CF42	7.24	0.007	86%	NA*	NA*	NA*	NA**	NA**	NA**	NA**

* = sensitivity analysis is not applicable; ** = sub-group analysis is not applicable due to insufficient number of studies; $\chi 2$ = chi-squared test statistic; and I^2 = percentage of variation.

Table 8: Statistical results of studies on MiC.

CFs	Studies	Weighted mean	Weighted SD	Heterogeneity (P-value)
CF1	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.32	0.14	0.06
CF2	Yunus 2017 (C) (MYS)	4.51	0.54	NA*
CF3	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.50	0.06	0.92
CF4	Yunus 2017 (C) (MYS)	4.49	0.52	NA*
CF5	Rahimah Mohd Noor 2018 (J) (MYS) Jaafar 2012 (J) (MYS)	3.88	0.51	0.01
CF6	Yunus 2017 (C) (MYS)	4.44	0.55	NA*
CF7	Rahimah Mohd Noor 2018 (J) (MYS)	4.31	0.79	NA*
CF9	Rahimah Mohd Noor 2018 (J) (MYS)	4.31	0.70	NA*
CF11	Yunus 2017 (C) (MYS)	4.42	0.51	NA*
CF15	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS) Jaafar 2012 (J) (MYS)	4.13	0.3	0.0004
CF16	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.38	0.17	0.03
CF18	Rahimah Mohd Noor 2018 (J) (MYS) Jaafar 2012 (J) (MYS)	3.74	0.89	0.0003
CF19	Yunus 2017 (C) (MYS)	4.47	0.54	NA*
CF20	Jaafar 2012 (J) (MYS)	3.33	1.11	NA*

CFs	Studies	Weighted mean	Weighted SD	Heterogeneity (P-value)
CF21	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.28	0.15	0.03
CF22	Yunus 2017 (C) (MYS)	4.46	0.52	NA*
CF23	Yunus 2017 (C) (MYS)	4.64	0.48	NA*
CF24	Yunus 2017 (C) (MYS)	4.41	0.61	NA*
CF25	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.44	0.07	0.87
CF26	Yunus 2017 (C) (MYS)	4.48	0.52	NA*
CF27	Yunus 2017 (C) (MYS) Rahimah Mohd Noor 2018 (J) (MYS)	4.40	0.06	0.36
CF28	Rahimah Mohd Noor 2018 (J) (MYS)	4.31	0.70	NA*
CF29	Yunus 2017 (C) (MYS)	4.43	0.50	NA*
CF31	Yunus 2017 (C) (MYS)	4.51	0.52	NA*
CF32	Yunus 2017 (C) (MYS)	4.41	0.58	NA*
CF34	Yunus 2017 (C) (MYS) Jaafar 2012 (J) (MYS)	3.72	1.18	< 0.00001
CF35	Yunus 2017 (C) (MYS) Jaafar 2012 (J) (MYS)	3.65	1.18	< 0.00001
CF37	Yunus 2017 (C) (MYS)	4.43	0.52	NA*
CF41	Yunus 2017 (C) (MYS) Jaafar 2012 (J) (MYS)	3.74	1	< 0.00001
CF42	Yunus 2017 (C) (MYS)	4.37	0.56	NA*

* = heterogeneity calculation is not applicable for CFs reported in only one study.

Table 9: Prioritization of CFs to implement JIT for all project types (Global rank) and for MiC only (MiC rank).

CFs	Global rank	MiC rank	CFs	Global rank	MiC rank	CFs	Global rank	MiC rank
CF14	1	NA	CF7	15	25	CF29	29	9
CF11	2	11	CF32	16	21	CF25	30	3
CF10	3	NA	CF33	17	NA	CF5	31	20
CF26	4	13	CF38	18	NA	CF24	32	22
CF13	5	NA	CF42	19	19	CF6	33	18
CF12	6	NA	CF20	20	30	CF36	34	NA
CF21	7	5	CF16	21	6	CF23	35	8
CF18	8	26	CF28	22	24	CF30	36	NA
CF9	9	23	CF27	23	2	CF3	37	1
CF17	10	NA	CF37	24	15	CF39	38	NA
CF40	11	NA	CF31	25	10	CF15	39	7
CF8	12	NA	CF1	26	4	CF34	40	28
CF19	13	17	CF22	27	14	CF41	41	27
CF4	14	12	CF2	28	16	CF35	42	29

NA = means that this factor has not been mentioned in MiC studies.

Table 10: Ranking of CFs based on no. of frequencies, mean and SNR values.

Rank	Ranking method		
	Frequency	Mean	*SNR*
1	CF27	CF21	CF14
2	CF1	CF42	CF11
3	CF15	CF14	CF10
4	CF22	CF16	CF26
5	CF34	CF40	CF13
6	CF35	CF7	CF12
7	CF28	CF27	CF21

Frequency = refers to ranking of CFs based on their frequency of occurrences in the previous studies; Mean = refers to ranking of CFs based on their weighted means; and *SNR* = refers to ranking of CFs based on their values of signal to noise ratio *(SNR)*

Table 11: Values of weighted means of the eight CFs whose importance differs significantly between the different project types.

CFs	General building projects	Infrastructure projects	MiC projects
CF1	3.90	3.78	4.32
CF3	3.67	NA	4.50
CF15	3.45	3.65	4.13
CF16	3.68	4.18	4.38
CF25	3.72	3.80	4.44
CF27	3.83	4.07	4.40
CF32	3.52	NA	4.41
CF39	3.84	3.15	NA

NA = No studies have discussed the respective CF for this project type.