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Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies

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Abstract

The benefits of modular integrated construction (MiC) is extensively documented. Rapid and effective implementation of MiC will leverage significant gains in construction project performance. However, its widespread diffusion and uptake have been hindered. Although manifold empirical studies have identified the barriers to the adoption of MiC in different countries, a holistic international review and integrated conceptual framework for the barriers are not well-established. This research analysed studies on the barriers conducted in 15 countries across five continents. Based on a meta-synthesis framework, the research identified 120 barriers to the adoption of MiC. The analysis revealed a co-existence of both perceived and real barriers, for which the authors argued that some existing studies engaged inexperienced participants during their surveys. An extended classification framework is proposed to group the 120 constraints into knowledge, attitudinal, financial, technical, aesthetic, industry, process, and policy clusters of barriers. The paper proposed an integrated conceptual framework mapping the interactions among the barriers. The framework revealed that the 5 most problematic clusters include industry, knowledge, process, financial and technical barriers which have at least 4 interactions with other groups. The paper further proposed strategies to address the identified groups of barriers. Thus, this research has established the ecosystem of the barriers, and how they hinder the wider diffusion of MiC. As such, it provides a holistic perspective of the barriers to the wider diffusion of MiC and initiated a debate towards developing integrated strategies to promote uptake of the technique.

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1. Introduction

Although the construction industry is fragmented, conservative and sluggish in adopting change and innovation (Ruparathna and Hewage, 2015), one overt change and trend is the move towards offsite construction (OSC) approaches (Tsompanidis, 2018). Modular integrated construction (MiC) is a distinctive OSC technique which embraces the theories of modularity, modularization, design for manufacture and assembly (DfMA), and lean production in providing value-for-money in the construction process. According to Pan and Hon (2018), MiC is a disruptive construction technique which changes the fragmented site-based construction process into an integrated value-driven production and assembly of factory-made prefinished modules. MiC adopts an offsite-based construction approach where components of a building are manufactured in a factory environment and then transported to a site entirely (or largely) completed for final assembly and installation (Gibb, 1999; Wuni and Shen, 2019a). Similar models of MiC include modular construction, industrialized building systems, offsite manufacturing, offsite production, modern methods of construction, and prefabricated prefinished volumetric construction (Wuni et al., 2019a; Wuni and Shen, 2019b). Based on the experiences with these OSC models in countries such as UK, Australia, Singapore, US, China, Canada, Sweden and Malaysia, the effective implementation of MiC leverages significant gains such as improved productivity, speedy construction, reduced life cycle cost, and improved construction quality control (Pan and Hon, 2018; Wuni and Shen, 2019c) in construction project performance

Research studies have confirmed that MiC improves the environmental sustainability of building construction. Mao et al. (2013) found that the effective implementation of MiC reduces construction greenhouse gas emission by 32kg/m^2. Tam et al. (2007) reported that the implementation of MiC reduces construction waste by 100%, with a significant cost savings of 84.7% in wastage reduction. Similarly, Jaillon et al. (2009) found that MiC significantly reduces construction waste. Blismas et al. (2006) reported that the effective implementation of MiC reduces construction pollution, neighbourhood nuisance, and less business disruptions. McGraw Hill Construction (2013) reported that MiC improves the safety and health of construction workers due to the reduced need to work from height and the fewer workers required on site.

Thus, the multiple benefits of MiC are no longer esoteric but overt. Considering the significant benefits of the technology, several countries have recognized and initiated policies and incentives to improve the uptake of MiC. Rapid adoption and wider uptake of MiC is crucial to reap the full benefits of the technology such as improving productivity and addressing the ill-performances of the conventional construction approach (Blismas et al., 2006; Wuni and Shen, 2019c).

Despite the widely reported benefits of the technology and the effort by governments to promote the uptake of MiC, its adoption in many countries is very low (Nadim and Goulding, 2011). Research studies have attempted to identify the barriers to the adoption of MiC in many countries. A number of these studies succeeded in identifying and ranking some constraints to the adoption of the approach. However, the global progress of MiC is measured as a function of the adoption rates in the individual countries. As a result, this research argues that a more holistic review and framework of the barriers is imperative. Additionally, many of the existing empirical studies examined the barriers in isolation and ignored their significant interlinkages (Blismas et al., 2005; Gan et al., 2018b). However, some studies have attempted to explore the interlinkages of the barriers to the adoption of MiC. For instance, Blismas et al. (2005) used a simple model to demonstrate the interrelationship among the value, process, supply chain and knowledge-related barriers to the adoption of MiC in Australia but at a project-level. Gan et al. (2018) examined the interlinkages of thirteen (13) barriers to the adoption of MiC in China using an interpretive structural modelling approach.

While of merit, these studies suffered a limitation of not providing a broader perspective of the barriers and their interlinkages. Thus, an international review and conceptual framework of the barriers to the adoption of MiC is not well-established. This paper addresses the existing research gap through a holistic review of the barriers, development of an integrated conceptual framework and proposition of strategies to promote MiC diffusion. Drawing on the relevant international literature, this paper contributes to the existing knowledge and offers new insight into the nature of barriers to the adoption of MiC. The international perspective and integrated conceptual framework of the barriers established in the paper have a wide appeal and significance to the global OSC researchers, practitioners, stakeholders and policymakers who are at the nucleus of the MiC diffusion.

2. Overview of modular integrated construction

The Construction Industry Council (2018) defined MiC as an innovative construction method and technology whereby “free-standing integrated modules (completed with finishes, fixtures, and fittings) are manufactured in a prefabrication factory and then transported to site for installation in a building”. Pan and Hon (2018) described MiC as the highest order of prefabrication involving the greatest integration of value-added factory-made prefinished modules. MiC constitutes the most complete form of OSC where 80-95% of a building can be completed in an off-site factory (Hwang et al., 2018a; Wuni et al., 2019a). Depending on the degree of modularization, Gibb (2001) identified the four levels of MiC as components manufacture and subassembly (e.g. doors, light fittings), non-volumetric preassembly (e.g. panel systems, cladding panels), volumetric preassembly (e.g. plant rooms, bathroom pods) and complete modular buildings (e.g. modular restaurant, multi-residence housing). The three common types of MiC include reinforced concrete modules, steel frame modules, and hybrid modules.

Although MiC and the conventional construction approach have commonalities in the planning, design, statutory approval, site preparation, and development stages, significant differences between the two methods emerge beyond these phases. Wuni et al. (2019a) described MiC as an innovation because it engenders significant changes to the way traditional projects are planned, procured, delivered, and managed. MiC have several disruptive effects on the construction industry. Unlike traditional projects where overlapping among construction phases can be tolerated, MiC lends itself to a fixed and unique supply chain involving a distinct sequence of modular design, procurement, engineering, manufacturing, transportation, storage, buffer, and on-site assembly (Wuni et al., 2019a; Wuni and Shen, 2019d). Multidisciplinary stakeholders dominate these distinct stages with their unique goals and value systems (Luo et al., 2019), which increases the complexity of stakeholder management in MiC projects. Often, the modular components are made-to-order and designed to be used exclusively in a specific MiC project (Hsu et al., 2018). Thus, scheduling requires that the quantity of each module produced precisely matches its optimum requirement for completion of the project and the inventory returns to zero on completion of the project (Hsu et al., 2018; Wuni et al., 2019a). Overall, the unique business model of MiC has disruptive effect on construction cost engineering and quantification, defects rectification and treatments, and valuations of works (Wuni et al., 2019a). The concomitant uncertainties associated with these changes are sources of scepticism and cynicism in the diffusion of MiC.

3. Research methods and approach

This research is situated within a constructivist epistemology where a systematic review methodology is adopted to evaluate research studies on the barriers to the adoption of MiC. Consistent with the research paradigm, the study adopted a qualitative research design where the authors draw on empirical studies to identify, summarize and consolidate the barriers to the adoption of MiC. Systematic literature review (SLR) constitute a powerful methodological tool for delineating the boundaries of existing studies on a subject (Wuni et al., 2019b). It strengthens the methodological rigor of research, ensures analytical objectivity and replicability. Considering the rapid growth of research publications and the organic attribute of literature, SLR constitutes a useful tool for keeping up-to-date with developments on a subject.

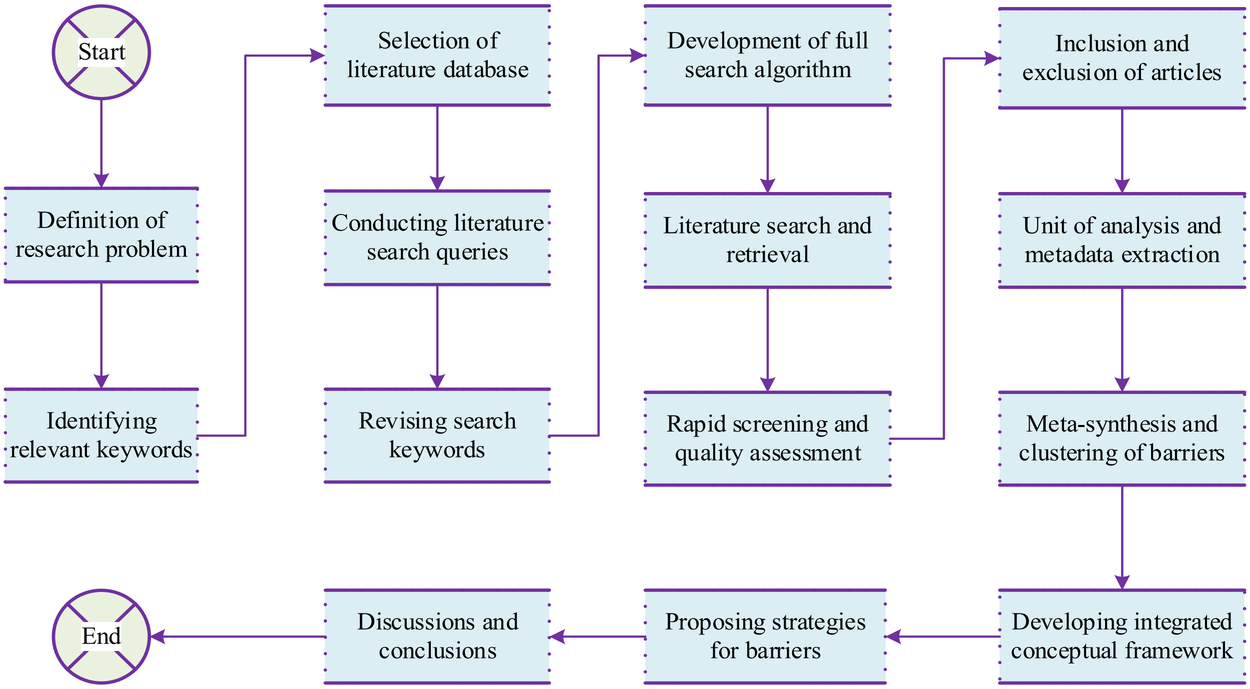


Figure 1. Methodological framework for the study

The paper adopted the SLR based on a comprehensive methodological framework (Figure 1). After stating the research problem, the review progressed with a selection of academic database and literature search. Although it is recommended that multiple databases be used in an SLR to improve coverage of the included studies (Wuni et al., 2019b), this research adopted only Elsevier's Scopus as the search engine because it is found to have wider coverage, accuracy, and ease of retrieving articles compared to similar literature databases such as Web of Science, Google Scholar, and ASCE library (Wuni et al., 2019b; Wuni and Shen, 2019c). Keywords were identified to facilitate the structured query in Scopus. Using the *TITLE* functionality of Scopus, the authors searched for keywords comprising "barriers, challenges, factors, hindrances, problems, obstacles, constraints and bottlenecks" AND "offsite construction, offsite production, off-site production, off-site manufacturing, prefabrication, prefabricated, pre-fabricated, off-site fabrication, industrialized building, industrialized systems, modular construction, modular integrated construction, modern methods of construction, prefabricated prefinished volumetric construction, industrialized construction, and industrialized housing".

The first set of keywords targeted articles with the term "barrier or its synonyms" and the second set of keywords targeted articles with the term "MiC or similar business models". The Boolean concatenator "*AND*" allowed for multiple keywords to be searched within each article. The use of "AND" targeted articles which contained at least one of each of the two sets of keywords. The search was restricted to articles in the *English* language and the document type was restricted to *articles* only. This generated 574 Scopus records (As of November 2018). Following a rapid screening of titles and abstracts of the Scopus records, 43 articles were deemed valid for inclusion. However, prior to submission (April 2019), the search was repeated, and 3 additional articles were identified resulting in the inclusion of 46 articles covering the period 2000 – 2019. The authors then extracted metadata from the included studies. Prior to the extraction, the authors defined the unit of analysis which denotes the major entity to be analysed in the articles. The primary unit of analysis in this research was "barriers" to the adoption of MiC. However, for each study, the authors recorded the year of publication, journal of publication, the context of the study, data collection method employed, and the reported barriers. The authors then adopted meta-synthesis as the organizing framework to summarize and integrate the findings. According to Lachal et al. (2017), meta-synthesis refers to the systematic review and integration of findings from both qualitative and quantitative studies The meta-synthesis was adopted because it provides legitimacy for the inclusion of both quantitative and qualitative studies in a single review(Wuni et al., 2019b). Meta-synthesis is an intentional and coherent approach to analysing data across studies with different research designs.

According to Lachal et al. (2017), meta-synthesis provides a coherent framework for researcher(s) to identify a specific research question and then search for, select, evaluate, summarize, and integrated both qualitative and quantitative evidences to address the research question. Some recent review studies adopted meta-synthesis as the organizing framework. For instance, Wuni et al. (2019a) adopted meta-synthesis in their review of critical risk factors in the application of MiC. Wuni and Shen (2019b) used meta-synthesis in their review of decision-making factors for implementing MiC whereas Wuni and Shen (2019a) adopted same in their review of critical success factors for implementing MiC projects. The meta-synthesis was also adopted because it provides a framework for resolving variations (in terms of wording) in the way the same barriers were reported disparately in different studies (Wuni and Shen, 2019a, 2019b). Through the meta-synthesis, the authors extracted the barriers and their clusters from the 46 articles verbatim. The authors then collated and integrated all the extracted barriers. Barriers with similar meanings were merged and reworded. Disagreement between the coders were resolved by referring to specific articles and in some cases, discussed between the researchers. Following several reconciliations, the paper identified 120 barriers prevailing in 15 different countries. These were considered excessive and overwhelming for the conceptual framework and thus, the authors proposed an extended classification framework to cluster the barriers. Drawing on precedents (Blismas et al., 2005; Han and Wang, 2018), the barriers were grouped into the attitudinal, industry, process, financial, aesthetic, knowledge, technical, and policy clusters of barriers. These formed the integrated conceptual framework and provided the basis for proposition of the mitigation strategies to improve uptake of MiC.

4. Findings and discussions

4.1 Characteristics of the studies included in the analysis

It is imperative to offer the summary and characteristics of studies used in an SLR as part of the methodologic rigor and quality. At least 46 research articles have been published on the barriers to the adoption of MiC. This significant number highlights the importance attached to barriers and the keenness of researchers in understanding their nature and form. It reinforces the need for the current study which seeks to integrate the findings of all these studies to generate a holistic perspective of the barriers. The studies covered a period of about two decades, spanning between 2000 and 2019 (Figure 2). Although a sinusoidal trend is observed in the annual publications pattern, some periods witnessed consistently higher number of publications.

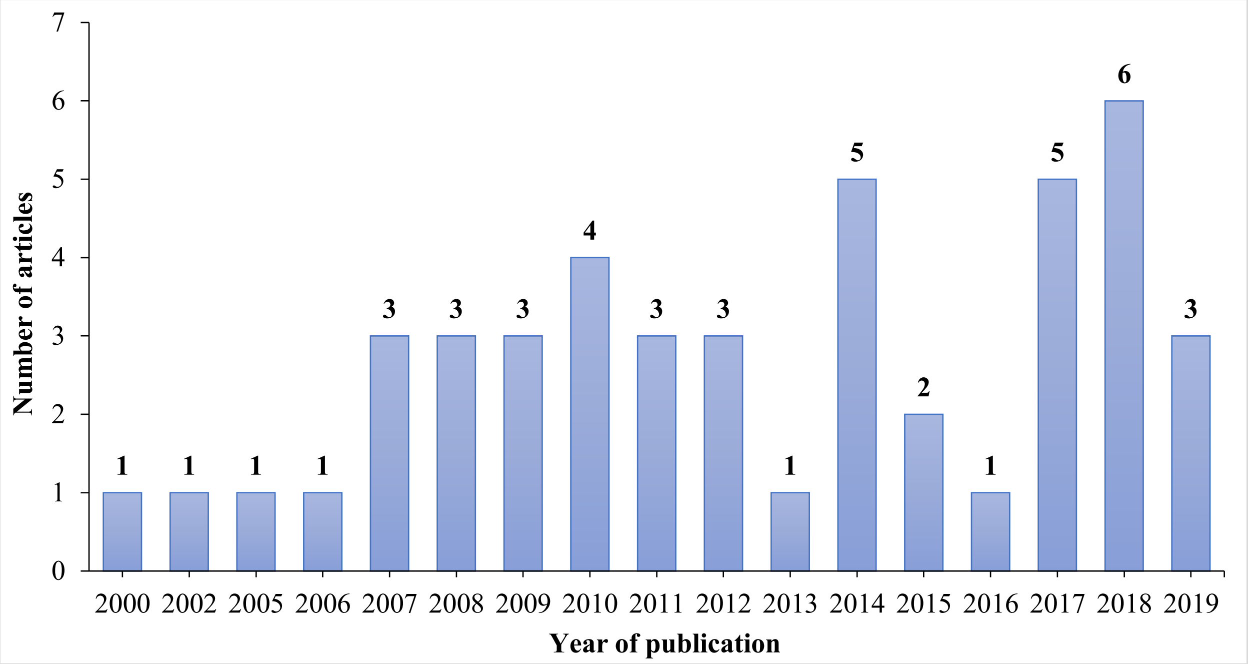


Figure 2. Annual publications trend on the barriers to the adoption of MiC.

During the first decade (2000-2010), the period between 2007 and 2010 witnessed an average of 3 per annum and marked the early years of the MiC renaissance (Gibb, 1999; Wuni and Shen, 2019c). The last decade witnessed a substantial research commitment towards understanding the barriers and recorded significant rise in the number of publications. Particularly, at least 6 publications were recorded in the year 2018. This highlights the rising commitment to addressing the barriers towards promoting uptake of MiC in the coming decades. Furthermore, the included articles were published in high impact construction management journals (Table 1). Analysis showed that the 46 articles were published in 20 different journals, indicating that the barriers constitute a part of the research scope of nearly all construction management journals. This further reinforces the dire need to closely examine them and propose a holistic conceptual framework. At least three articles on the barriers were published in Journal of Cleaner Production (7), Construction Management and Economics (6), Engineering, Construction and Architectural Management (5), Journal of Architectural Engineering (4), and Architectural

Engineering and Design Management (3). This information provides a useful submission reference for future studies on the barriers because it highlights the journals in which researchers can make their scholarly submissions.

Table 1. Journal distribution of the included studies

Name of journal	**Number of articles**
Journal of Cleaner Production	7
Construction Management and Economics	6
Engineering, Construction and Architectural Management	5
Journal of Architectural Engineering	4
Architectural Engineering and Design Management	3
Habitat International	2
International Journal of Construction Education and Research	2
Construction Innovation	2
Journal of Civil Engineering and Management	2
Journal of Management in Engineering	2
Sustainability (Switzerland)	2
Building and Environment	1
Journal of Construction Engineering and Management	1
Building Research and Information	1
Waste Management	1
International Journal of Strategic Property Management	1
Journal of Physics Conference Series	1
Jurnal Teknologi (Sciences & Engineering)	1
Procedia Engineering	1
International Journal of Construction Management	1
Total	46

A geospatial analysis of the included studies revealed that the 46 studies were conducted in the context of 15 countries (Figure 3), of which majority of the studies were conducted in China (15), United Kingdom (11), Hong Kong SAR (5), United States (5), Australia (2), Malaysia (2) and Sweden (2). Figure 3 is a geospatial distribution of the included studies. These countries constitute some of the major front liners in the industrialized construction movement (Hwang et al., 2018a). The countries consist of both developing (e.g. China, Malaysia) and developed economies (e.g. the United Kingdom, United States). The 15 countries are distributed across 5 continents comprising Asia (e.g. Singapore, China), Europe (e.g. Germany, The Netherlands, Sweden), North America (e.g. United States), Australia (e.g. Australia), and Africa (e.g.

Lebanon, Nigeria). Thus, the conceptual framework will reflect the global perspective of the barriers to the adoption of MiC. The absence of studies from South American countries could be due to the language restriction during the Scopus search. The 46 studies adopted several methods in collecting data on the barriers to the adoption of MiC (Figure 4). The data collection instruments used included questionnaires (19, 43.1%), interviews (6, 13.0%), workshop discussions (2, 4.3%), and mixed methods (20, 43.5%).

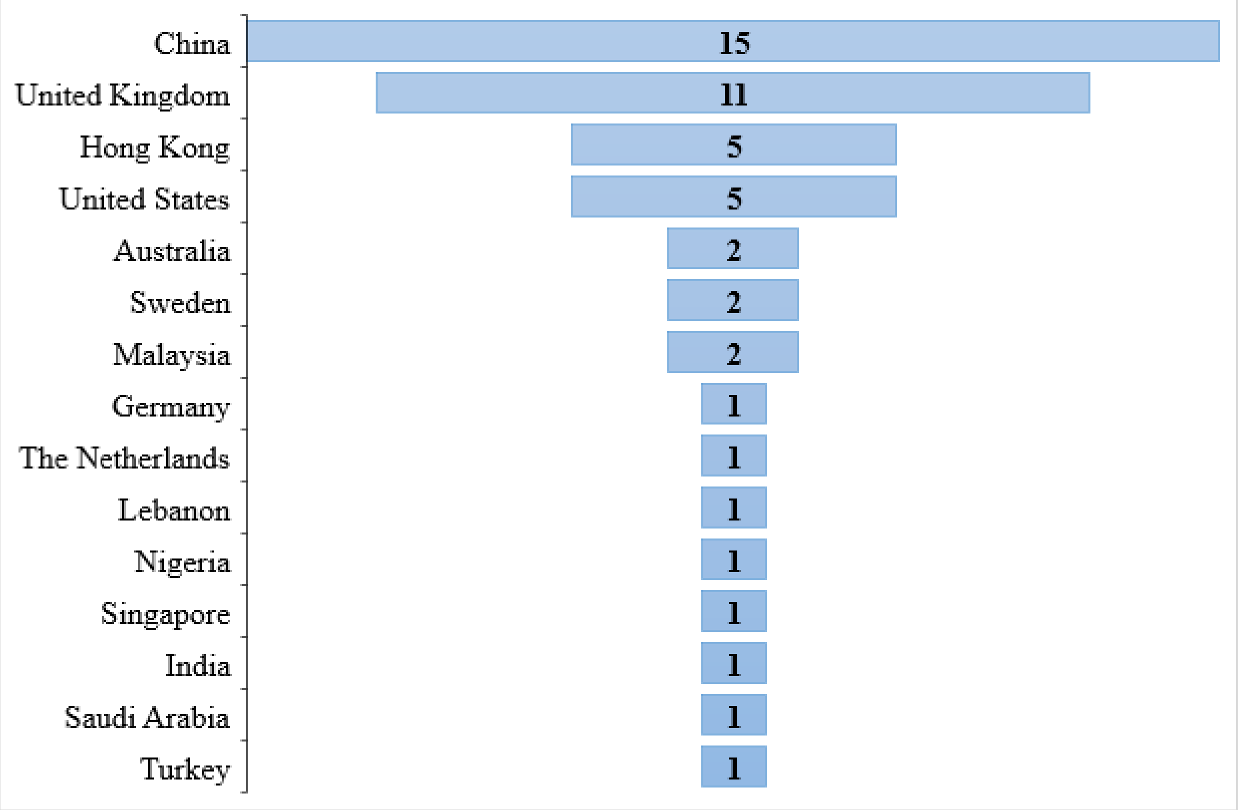


Figure 3. Geospatial distribution of the included studies

These instruments are appropriated because data on the significance and impact of the barriers can only be collected from the opinions of practitioners and stakeholders (Wuni et al., 2019a). The superior adoption of questionnaires is justifiable data collection is quicker, quantitative can easily collected, and it constitutes the most commonly used survey instrument in construction management studies (Wuni and Shen, 2019a, 2019c).

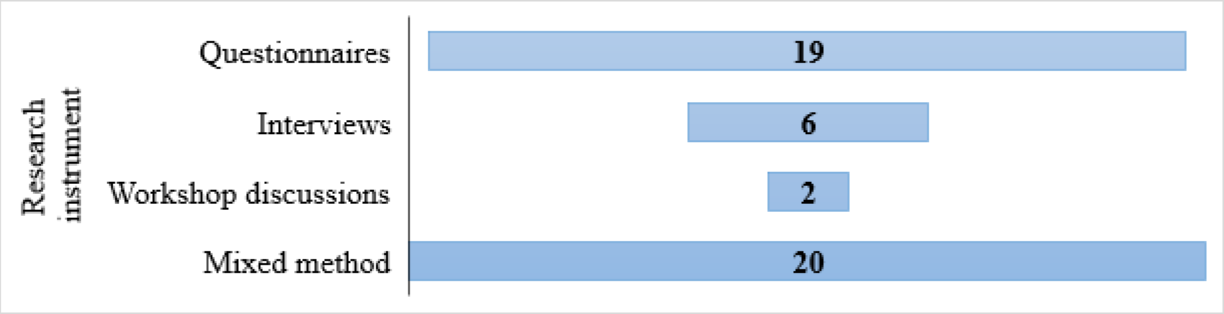


Figure 4. Distribution of data collection instruments used in previous studies.

Most of the studies adopted mixed methods in exploring the barriers (Figure 4). 15 of them used both questionnaires and interviews, 2 used both interviews and case studies (Hamzeh et al., 2017; Pan and Sidwell, 2011), 1 used both questionnaire and workshop discussions (Goulding et al., 2015), and 1 used both questionnaire and case studies (Hwang et al., 2018a). Thus, the included studies used suitable and rigorous approaches in evaluating the barriers to the adoption of MiC and provide sound basis for developing a conceptual framework.

4.2 Analysis of the barriers to the adoption of MiC

The adoption of MiC in the construction industry is a classic example of innovation diffusion in the sector (Rogers, 1983; Slaughter, 1998). According to Bass (1969), the adoption of innovation is influenced by the perception of whether or not the innovation offers improved utility as against existing technologies and as such, a social process is required to reduce the uncertainties associated with the perceived utilities from the innovation. The diffusion of MiC into the construction sector is disruptive and demands significant changes to some entrenched practices. Given that the construction industry is slow to adopt innovative solutions (Ruparathna and Hewage, 2015), the diffusion of MiC is battling a hostile welcome amid complex host of barriers. This research identified 120 barriers (*actual* and *perceived)* because as noted by Sepasgozar et al. (2001), the respondents in some studies did not have enough experience with MiC to comment on the actual barriers. However, the holistic argument in the current study provides legitimacy for the integration of all the barriers into a single conceptual framework. Based on an extended classification framework, the authors grouped the 120 barriers into attitudinal (10), industry (10), process (30), financial (15), technical (25), aesthetic (5), knowledge (15), and policy (10) barriers. The authors immediately acknowledge and recognize that clustering the barriers into typologies is highly subjective and that there might be overlaps among the groupings. However, the grouping were informed by the previous clustering in empirical studies (Blismas et al., 2005; Hamzeh et al., 2017; Rahman, 2014). The clusters of barriers in discussed below.

4.2.1 Attitudinal barriers

Attitude constitutes a behavioural pattern which makes a significant difference in innovation diffusion (Rogers, 1983). The settled way of thinking about the operations, relevance and business model of MiC has an influence on its diffusion into the construction sector (Luo et al., 2015). The wider adoption of MiC is partly hindered by some uninformed perceptions of stakeholders. Pan et al. (2007) noted that some of the negative perceptions towards MiC are grounded on the historical failures of offsite construction techniques such as the post-war prefabricated construction strategies. Although there is improved perceptions towards MiC in the recent decade (Pan and Hon, 2018), the approach still suffers from the poor attitude of the construction industry towards innovation (Ku and Taiebat, 2011). Figure 5 shows 10 attitudinal barriers to the adoption of MiC.

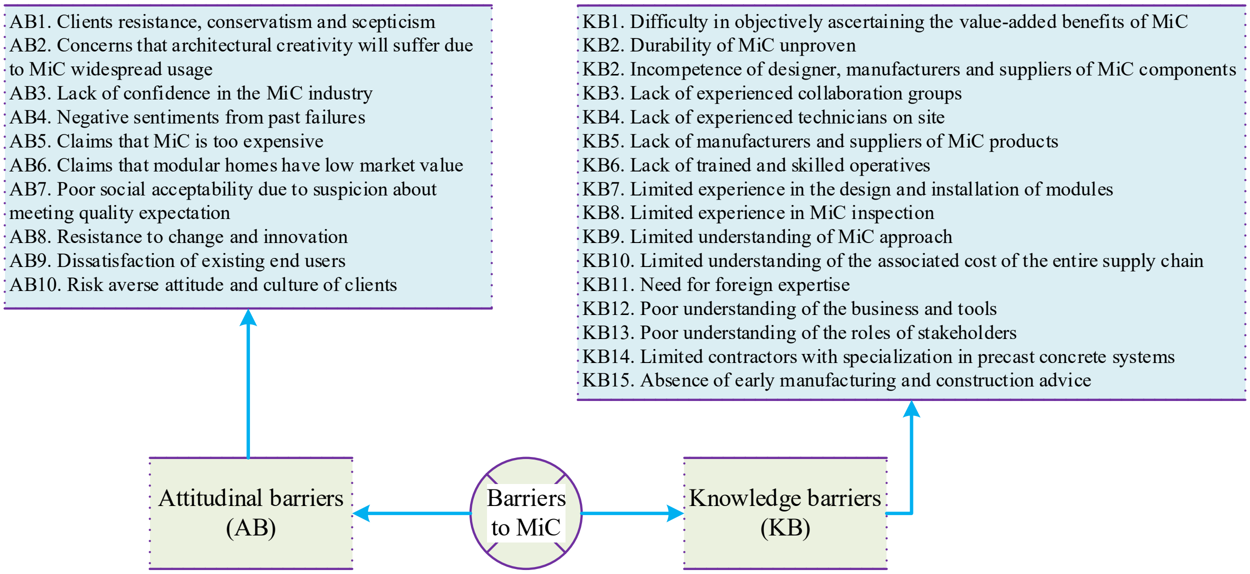


Figure 5. Attitudinal and knowledge barriers to the adoption of MiC

Particularly, some stakeholders still express scepticism about the actual benefits of MiC over the traditional construction approach (Lovell and Smith, 2010). The negative mindset and low confidence in MiC highlight the impact of the post-war prefabricated stigma on the wider acceptance and diffusion of MiC in the construction sector. The prevailing negative perceptions are driven by the limited MiC experience and knowledge of the respondents (Sepasgozar et al., 2001). This is evident because some studies identified that stakeholders are reluctant to adopt MiC because they believe rapid adoption will destroy architectural creativity (Rahman, 2014) and some claim modular homes have lower market values (Steinhardt and Manley, 2016). The former is based on shear inexperience with MiC because offsite architecture makes it possible for several designs to be created with same modules (Richard, 2006). Additionally, MiC offers more opportunity for architectural innovation since the same design details could generate highly diversified aesthetic options. The latter is also not justifiable because there is a growing market for modular homes in major cities around the world (Hwang et al., 2018a; Lee and Kim, 2017). However, some of the attitudinal barriers (Figure 5) are persistent and hard to address. Some stakeholders in the construction industry are risk averse and will not invest into any technology with some amount of uncertainties. This risk averse attitude is worsened by the fact that investment in MiC takes a long time to break-even, in its current form. Dissatisfaction of some existing end-users with modular homes (Havinga and Schellen, 2018) further increases the negative attitude towards MiC. However, improvement in modular design and engineering during the last decades has delivered highly advanced and state-of-the-art buildings in Singapore, Australia, and Canada (Blismas, 2007; Hwang et al., 2018a). Thus, some of these attitudinal barriers may have improved and require new investigations. Nonetheless, the attitudinal barriers are prevalent due to the limited understanding of the technology (Gan et al., 2018b). Meanwhile, attitudinal and behavioural barriers are staggeringly difficult to correct (Simon, 1962) since they are intrinsic recipes for ill-informed entrenched negative perceptions. This highlights the need for improvement in the ongoing industry-wide education and training of the actual promises and problems of MiC.

4.2.2 Knowledge barriers

Although the principles of MiC dates to the 12th century in line with the construction of Great Egyptian Pyramids in 2600 BC, its current form is yet to be well-understood by many stakeholders and practitioners. Knowledge of MiC is and would be gained through education, training, and experience in its implementation (Sepasgozar et al., 2001). The knowledge barriers reported in the literature are associated with the limited experience, skills, and understanding of MiC among the research participants, rendering some of the reported barriers speculative and "spurious". The limited understanding directly influences some of the attitudinal barriers

(Blismas et al., 2005) highlighted above. Figure 5 shows 15 knowledge barriers to the adoption of MiC. The most critical knowledge barrier is the limited understanding of MiC business model (Aburas, 2011; Cheng et al., 2017; Zhang and Skitmore, 2012). The effective implementation of MiC requires high skilled manpower and powerful lifting equipment. Whiles these two are readily available in developed economies, they constitute significant inertia to the adoption of MiC in developing countries. Contractors, labourers and key players of the traditional construction approach require additional manufacturing skills to remain relevant in MiC projects (Wuni and Shen, 2019b). Considering that MiC is still fledgling in some economies following its renaissance in the last 3 decades, previous generation of construction engineering and management graduates did not have the privilege of obtaining knowledge in MiC. For this reason, there are fewer trained and skilled operatives, contractors, and technicians with specialization in MiC. These further corroborate the role of education and training in creating well-informed attitudes towards the approach and its increased adoption. Studies have further reported that existing designers, manufacturers and suppliers do not have sufficient experience in the design, production and delivery of modular components (Zhang et al., 2014; Zhang and Skitmore, 2012). The limited knowledge further manifest into limited experience in design and installation of modular components (Luo et al., 2015) and limited experience in MiC project inspection. Two other prominent knowledge barriers are difficulty in objectively ascertaining the value-added benefits of MiC (Blismas et al., 2005; Blismas and Wakefield, 2009) and limited knowledge of the associated cost in the entire supply chain of MiC. Whiles the latter is less of a realistic barrier in recent times, the former remains a significant constraint to the adoption of MiC. Although studies have confirmed that MiC improves productivity, reduces waste, improves health and safety, reduces carbon emissions and reduces neighbourhood nuisance (Building and Construction Authority, 2019a; Construction Industry Council, 2018), the monetary values of these are not often quantified and included in cost-benefit analysis. Thus, comparison between MiC and the traditional construction approach still draws on direct cost and benefits (Blismas et al., 2006). This accounts for the difficulty in ascertaining the value-added benefits of MiC. However, most of these barriers were reported in developing countries such as Malaysia, China, Nigeria, and Lebanon where the technology is not well-established. Nonetheless, improvement of these barriers is necessary for the wider uptake of MiC.

4.2.3 Technical barriers

The design and engineering of MiC projects are different from those of conventional construction projects. Particularly, MiC requires complex interfacing between modules, longer lead-in time (Pan et al., 2007) and highly restrictive tolerances (Gibb and Neale, 1997). MiC is less tolerant to dimensional and geometric variabilities which are recipes for modular assembly errors, problematic rectification procedure and prohibitive costs of reworks (Shahtaheri et al., 2017). As a result, stakeholders have expressed some level of resistance owing to the specialized tasks and technological requirements of MiC. Figure 6 shows 25 technical barriers to the adoption of MiC. Based on a frequency of occurrences in the literature, the most significant technical barriers include inflexible for design changes (TB7), insufficient capacity to fabricate enough modules (TB9), and unable to freeze design specification early to suit preassembly(TB23) (Gibb and Isack, 2003; Zhang et al., 2018). These barriers prevail in both developing and developed economies, suggesting that they (are perceived to) hinder the adoption of MiC. The technical barriers are associated with technical problems, risks and challenges inherent in MiC.

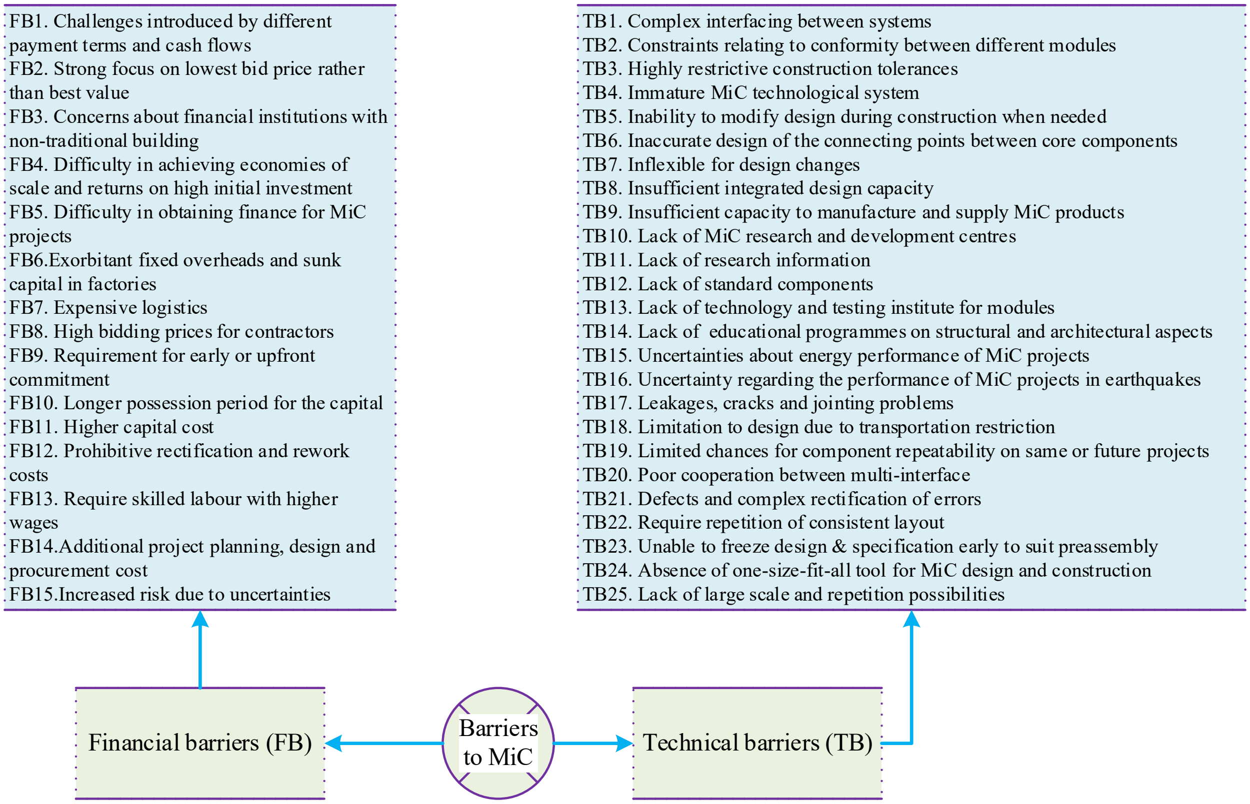


Figure 6. Financial and technical barriers to the adoption of MiC

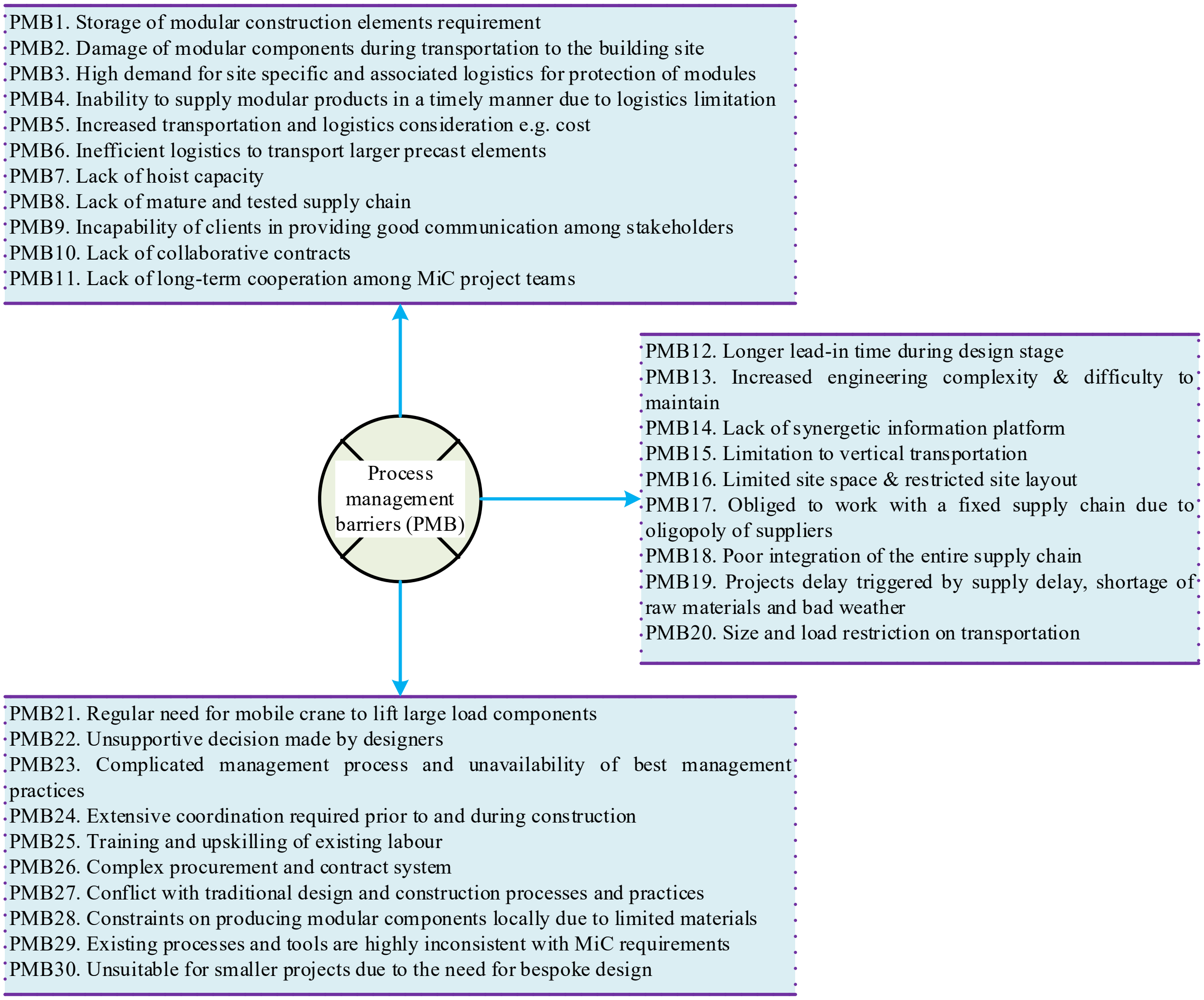
Some other critical technical barriers are poor cooperation between multiple, inability to modify design during construction and constraints relating to conformity between different modules (Lu and Liska, 2008; Luo et al., 2015). However, some of the technical barriers captured in Figure 6 are either outdated or reported in developing countries where most of the respondents have little or no experience with MiC (Sepasgozar et al., 2001). Given the progress of MiC in the last decade, (perceived) barriers such as lack of training and educational programmes on structural and architectural aspects (TB14), lack of technology and testing institute for modules (TB13), lack of standard components (TB12), lack of MiC research and development centres (TB10), and immature MiC technological system (TB4) are hardly verifiable and justifiable in developed economies such as the United States, United Kingdom, Hong Kong SAR, Canada, Singapore and Australia who have made significant advances in the technology. Particularly, MiC project engineering, operations, and management are now incorporated in many Universities CEM programme modules. Several MiC research laboratories are currently operations as MiC R & D centres. Furthermore, the last decade witnessed improvement to some of the wicked technical challenges in the implementation of MiC. For instance, precise modular production technologies such as 3D fixturing and jig systems, laser cutting and robotic assembly are currently used to manage geometric variabilities in the modules (Shahtaheri et al., 2017). There is also increasing use of laser scanning for inspecting and testing manufactured modules. This suggests that there are both *perceived* and *actual* technical barriers to the adoption of MiC in the literature. However, some barriers and problems such as inability to modify design during construction when needed (TB5), inflexibility for design changes (TB7), insufficient integrated design capacity (TB8) and complexity of error rectification (TB21) during on-site installation remain significant and pervasive. Improvement in structural design and engineering have produced in new generation of MiC projects which can accommodate strong wind loads and turbulence from earthquakes (Hong et al., 2017). Thus, claims about the poor performance of MiC projects in times of earthquake can hardly be justified. Most of these perceived barriers are influenced by the limited knowledge of MiC and its progress (Gan et al., 2019; Wu et al., 2019).

4.2.4 Financial barriers

Construction projects delivery is capital intensive and resources demanding. As such, the research clustered barriers associated with MiC project costs, risks, cash flows, and financial decisions into financial barriers. Figure 6 shows 15 financial barriers to the adoption to the adoption of MiC. The most cited financial barrier is the higher (initial) capital cost associated with MiC. This paper recognizes that MiC requires huge capital (FB11) to establish modular factories, purchase moulds, secure yards and to hire specialized workforce. However, there are some ambiguities associated with how the cost barrier has been stated in the literature. For instance, it is stated as higher capital cost (Pan et al., 2007), increased initial cost (Nadim and Goulding, 2011) or high initial cost (Goodier and Gibb, 2007). These varying citations contribute to the poor understanding of the cost performance of MiC. Nonetheless, the exorbitant fixed overheads and sunk capital in factories (FB6) account for both the higher initial capital cost and the higher capital outlay for MiC (Luo et al., 2015). The higher cost translates into high bidding prices for contractors (FB8). In most countries, contractors are required to make early or upfront commitment in MiC projects (Hwang et al., 2018a), resulting in a significant disadvantage to small and medium scale enterprises who dominate the industries and yet, cannot afford such huge commitments. Furthermore, prevailing practices which favour lowest bid price rather than best values (FB2) render MiC less competitive (Blismas and Wakefield, 2009). This is because the value-added benefits are hard to objectively ascertain and be incorporated into cost-benefit analysis (Blismas et al., 2005). Another significant financial barrier is the difficulty in achieving economies of scale and quicker commensurate returns on the higher initial capital investment (FB4). The demand for MiC projects is cloudy and, in some cases, modular homes could take some time to be purchased. In such conditions, active capital of contractors and stakeholders are tied to MiC project for a very long time and act as disincentive to the wider implementation of MiC. There is also the difficulty in obtaining financing for MiC projects (Blismas et al., 2005; Blismas and Wakefield, 2009). In New Zealand, banks provide significant advance payment to contractors throughout the building process using the traditional approach but in the case of MiC projects, banks provide funding only when the modules are assembled on site (Mills, 2018). In some countries, there are no innovative financing vehicles and sources for MiC. This inertia in obtaining finance for MiC projects act as a disincentive to the wider adoption of the technology. The disruptive nature of MiC introduces significant changes to the payment terms and cash flows (FB1). Although the speedy construction associated with MiC translates into faster solvency and cash flow generation, it is still unclear regarding the contractual payment terms for MiC projects since the supply chain is fragmented and involves a complex web of stakeholders (Luo et al., 2019; Wuni et al., 2019a). In countries with limited capacity to manufacture and supply the modules, cross-border transportation results in expensive logistics (FB7) for MiC projects (Pan and Hon, 2018). Even though MiC requires fewer workers on site (McGraw Hill Construction, 2011), the use of skilled and specialized labour force results in payment of higher wages. Thus, the cost savings associated with the reduced labour sometimes becomes insignificant. According to Wuni et al. (2019a), MiC is associated with numerous risks and uncertainties (FB15) which could increase the cost of MiC projects (Lee and Kim, 2017) if not carefully identified, planned and managed. For instance, there is often the need to seek early professional advice on the suitable of the project design for MiC (Blismas et al., 2005; Wuni and Shen, 2019a). This generates additional project planning, design and procurement cost (FB14). Shahtaheri et al. (2017) reported that defects in MiC projects are expensive to rectify and reworks sometimes involves a repetition of the entire supply chain ranging from redesign through to remanufacturing and reassembly of modules on site. These constitute challenges with financial implications and serve as significant constraints to the adoption of MiC.

4.2.5 Process barriers

Compared to the conventional cast-in-situ construction approach, MiC is associated with a longer value and supply chain involving a complex network of stakeholders and processes. The supply chain of MiC involves planning, modular design, statutory approval, site preparation, and development, modular manufacturing, transportation, storage, buffer, and on-site assembly and installation.



PMB1. Storage of modular construction elements requirement
PMB2. Damage of modular components during transportation to the building site
PMB3. High demand for site specific and associated logistics for protection of modules
PMB4. Inability to supply modular products in a timely manner due to logistics limitation
PMB5. Increased transportation and logistics consideration e.g. cost
PMB6. Inefficient logistics to transport larger precast elements
PMB7. Lack of hoist capacity
PMB8. Lack of mature and tested supply chain
PMB9. Incapability of clients in providing good communication among stakeholders
PMB10. Lack of collaborative contracts
PMB11. Lack of long-term cooperation among MiC project teams

PMB12. Longer lead-in time during design stage
PMB13. Increased engineering complexity & difficulty to maintain
PMB14. Lack of synergetic information platform
PMB15. Limitation to vertical transportation
PMB16. Limited site space & restricted site layout
PMB17. Obliged to work with a fixed supply chain due to oligopoly of suppliers
PMB18. Poor integration of the entire supply chain
PMB19. Projects delay triggered by supply delay, shortage of raw materials and bad weather
PMB20. Size and load restriction on transportation

PMB21. Regular need for mobile crane to lift large load components
PMB22. Unsupportive decision made by designers
PMB23. Complicated management process and unavailability of best management practices
PMB24. Extensive coordination required prior to and during construction
PMB25. Training and upskilling of existing labour
PMB26. Complex procurement and contract system
PMB27. Conflict with traditional design and construction processes and practices
PMB28. Constraints on producing modular components locally due to limited materials
PMB29. Existing processes and tools are highly inconsistent with MiC requirements
PMB30. Unsuitable for smaller projects due to the need for bespoke design

Figure 7. Process management barriers to the adoption of MiC

Thus, successful MiC implementation requires system integrators such as architects, designers, engineers, material suppliers, modular fabricators, developers, and contractors to be actively involved from initiation of the project through to the implementation of workflows in the design, construction, operations and maintenance stages (Zhai et al., 2014). Figure 7 shows 30 process management barriers to the adoption of MiC. Majority of the process management barriers are intertwined with the supply chain and nature of the MiC business model. At a simplified level, the construction of MiC projects involves design, engineering, production of modules, temporary factory storage, transportation to site, temporary site storage, and final assembly and installation (Wuni et al., 2019a). One significant process barrier is limited capacity of logistics to transport larger modules to job-site (PMB6). In most developing countries, the sizes and weights of the modules cannot be supported by the available trucks or nature of roads (Jiang et al., 2017). The poor nature of transport systems in some countries result in significant damages to the modules during transportation to site (PMB2). The poor logistics services are recipes for significant delays in the supply of modular components, which affects the schedule and cost of MiC (Wuni et al., 2019a; Wuni and Shen, 2019d). In cases where cross-border logistics services are sourced to supply modules, it results in increased transportation and logistical cost (PMB5). Transport regulations such as limitations to vertical heights of modules (PMB15) as well as size and load restrictions during transportation (PMB20) complicates the implementation of MiC. Additionally, given that modular plants in some countries are located in remote areas, transport restrictions on the size and load of modules generate logistics challenges in the implementation of MiC (Gibb, 2001). When the modules are eventually transported to the job-site, some complications are still encountered which makes MiC unattractive in some circumstances. For instance, there is the requirement of modular storage (PMB1) and demand for site specific logistics for protection of the modules (PMB3). In densely populated cities with scare developable lands, there will be serious problems with getting space for storage of the modules (Li et al., 2017a). In some developing countries, there are problems regarding hoisting capacity (PMB7) to support the on-site installation of the modules. This is because powerful cranes are not readily available or accessible to many contractors. Pan and Hon (2018) argued that the prevailing incomplete MiC supply chain (PMB8) in some countries constitutes the greatest threat to the wider adoption of MiC. In most cases, developers and clients are coerced to work with a fixed supply chain due to oligopoly of suppliers (Blismas et al., 2005; Blismas and Wakefield, 2009). Furthermore, the complex management process of MiC results from the requirement for increased communication among the complex web of stakeholders (Gan et al., 2018a) who have their unique goals and value systems within the MiC supply chain (Luo et al., 2019). MiC also requires extensive coordination of workflow, trades, resources, and stakeholders prior to and during the construction process (Hwang et al., 2018a). This unique requirement complicates the process of managing stakeholders in MiC projects. The prevailing lack of synergistic information platform (PMB14) constitute a significant challenge to collaborative working relationship and information sharing in MiC projects (Wuni et al., 2019a). However, the increasing use of real-time integrated building information modelling and radio frequency identification platforms allows for information sharing among project participants and real-time monitoring of the MiC supply chain progress (Li et al., 2017b). Moreover, supply chain disturbances and uncertainties such as weather disruptions, mechanical malfunction of cranes, and modular production plants operational inefficiencies may generate additional costs to the baseline budgets.

4.2.6 Policy barriers

Policies are the systems and machinery required to guide the implementation of an initiative towards achieving rational and measurable outcomes. The research identified barriers which are associated with the absence of policies, regulations, design codes and standards. Figure 8 shows 10 policy-related barriers to the adoption of MiC. The most cited policy barriers to the adoption of MiC were identified as absence of government incentives and subsidies (PB1), inadequate policies and regulations (PB2), lack of technical guidance and information (PB4), lack of modular design codes and standards (PB5)(Luo et al., 2015; Mao et al., 2014; Zhang et al., 2018). However, the common use of the phrase *"lack of"* highlights their dominance in developing countries because developed economies such as Singapore, Japan, United States, United Kingdom, and Sweden have made substantial policy advancement in the implementation of MiC. For instance, the Construction Industry Council (2018) developed and published a comprehensive guideline for implementing MiC projects in Hong Kong and the Building and Construction Authority (2019b) developed a similar policy document for implementing prefabricated prefinished volumetric construction projects in Singapore. Thus, citations of these policy barriers in developed countries corroborate the argument that some of the research participants who were engaged in some of the existing studies were ill-informed of the MiC progress in their countries (Sepasgozar et al., 2001) or some of the barriers are simply outdated.

Government policies and incentive schemes have already been implemented in Malaysia, Singapore, Hong Kong, and elsewhere to encourage the adoption of MiC by private developers. Nonetheless, the policy barriers in Figure 8 highlights the critical role of government in the MiC implementation discourse. Notably, the government is at the forefront of the MiC revolution in China (including Hong Kong SAR), Malaysia, Singapore, Sweden, and elsewhere. Thus, policy interventions drawing on the participation of small, medium and large-scale construction firms along with all relevant stakeholders is pivotal to improved MiC diffusion in the construction sector.

4.2.7 Industry barriers

Historically, the construction industry is slow to adopt innovative business models and solutions (Blismas et al., 2006). The thinking and ideological orientation of the fragmented construction sector generate some barriers to the adoption of MiC. The paper immediately recognizes the many overlaps and interrelationships between the attitudinal, knowledge and the industry barriers. Figure 8 shows 10 industry barriers to the adoption of MiC. One of the most cited industry barriers is the fragmentation of the construction sector (IB4) (Blismas and Wakefield, 2009). The sector is fragmented at both the industry and project level. For the latter, the prevailing lack of integration project processes or entities is inconsistent with the co-creation business model of MiC. At the industry level, there are so many firms or enterprises of varying sizes and several project types. Thus, it is obscure to diffuse the MiC technology into the fragmented environment. Two other most cited industry barriers to the adoption of MiC include conservative mind-set of the industry towards conventional construction (IB1) and dominance of entrenched traditional construction practices (IB2). Change is difficult and unpleasant. It becomes more difficult if threatens the survival of companies and the jobs of people. Industry practitioners and stakeholders have stronger attachment to the traditional construction approach and will not adopt an innovative solution unless they are convinced that there is significant additional value or utility associated with the innovation. The conservative attitude is further strengthened because of the disruptive nature of MiC. The wider adoption of MiC will change many entrenched practices and will require new set of skills and techniques to remain relevant and competitive (Wuni and Shen, 2019b). There is also fear of lost identity and role descriptors (IB3) (Blismas and Wakefield, 2009; Gan et al., 2018a; Luo et al., 2015). This reality is critical because of the introduction of new project participants such as designers, manufacturers and assembly contractors.

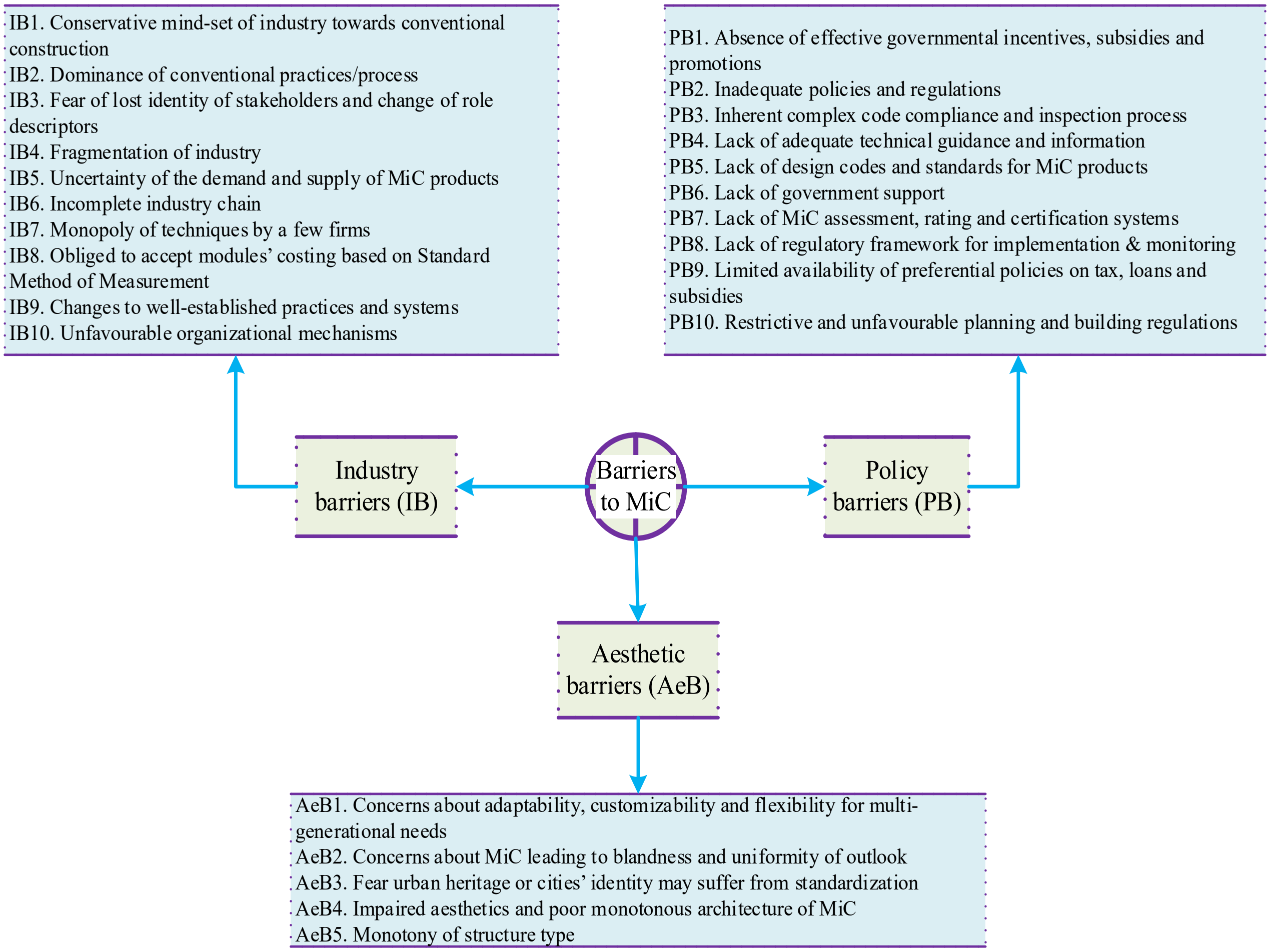


Figure 8. Aesthetic, industry and policy barriers to the adoption of MiC

The traditional roles of several key project actors will be altered and taken over by other players if their skills are not upgraded. For instance, contractors may have to acquire manufacturing skills or fabricators will become the new contractors. Particularly, the implementation of MiC presents a threat to the traditional role of contractors who may become assemblers or "just concrete contractors". In addition, the implementation of MiC means the current culture of late design changes and modifications are slightly compromised. Thus, more rhetoric strategies are required to balance these conflicting issues in the implementation of MiC. It should be reiterated that the industry barriers are quite obscure to address as redress may take the form of significant structural changes in the industry. As such, the diffusion of MiC into the industry must be gradual but steady to reap the full benefits of the approach in the coming decades.

4.2.8 Aesthetic barriers

The heterogeneity of the built environment is a product of the different construction projects types from the disparate design and architectural specifications of clients. However, some less experienced stakeholders indicated that MiC is a recipe for monotonous design and structures (Zhai et al., 2014; Zhang et al., 2014). Figure 8 shows 5 aesthetic barriers to the adoption of MiC. The research identified the most cited (perceived) aesthetic barriers as possible monotony of structure (AeB5), poor monotonous architecture and impaired outlook (AeB4), and concerns about the adaptability of MiC projects (AeB1). These perceptions are critical because clients enjoy multiple design options in the traditional construction approach. Thus, the perceived absence of these design options in MiC constitute a source of scepticism towards the approach. However, analysis of all the aesthetic barriers corroborates the argument (Sepasgozar et al., 2001) that some of the studies engaged respondents with very little or no experience (and/or knowledge) of MiC. The reason been that during the last 3 decades, the renaissance and commitment to the implementation of MiC give birth to offsite architecture to cater for heterogeneous design requirement of MiC clients (Richard, 2006). From Figure 8, the concerns that MiC is not adaptable, flexible and customizable indicates that some of the aesthetic barriers are outdated and reflects the inexperience and inadequate knowledge of some respondents. This is because MiC does not simply generate construction products but rather industrialized building system where same details generate highly individualized, diversified, adaptable, flexible and demountable houses (Richard, 2006). The whole MiC philosophy is grounded on the concept of modularity and modularization which increases adaptability and flexibility by allowing system integrators to mix, match and reconfigure modules obtained from various suppliers (Baldwin and Clark, 1997). Thus, citations of MiC as not flexible and adaptable actually reflects the inexperience of the respondents with MiC and does not truly represent any actual inflexibility (Sepasgozar et al., 2001).

4.3 Integrated conceptual framework of the barriers to the adoption of MiC

The research developed integrated conceptual framework of barriers to the adoption of MiC based on a systems-thinking philosophy. The integrated conceptual framework combined and consolidated all the barriers to illustrate the overall nature of their interactions. Figure 9 shows a conceptual total interpretive structural model (TISM) of the barriers to the adoption of MiC. The framework draws on two previous studies on the interactions between the barriers. Blismas et al. (2005) used a simple model to demonstrate the interrelationships between the clusters of barriers and Gan et al. (2018b) used developed an interpretive structural model to explore the interlinkages among the individual barriers to the adoption of MiC. The current research makes a unique extension of the existing literature through a combination of the works of Blismas et al. (2005) and Gan et al. (2018b) in developing an integrated conceptual framework for the barriers. Wuni and Shen (2019c) adopted a similar approach to develop a conceptual framework for the drivers of OSC. The current framework constitutes a useful contribution to knowledge of the barriers because it modelled the macro and micro interactions of the barriers. The study immediately recognizes that the developing a conceptual framework using systems-thinking involves initial scoping, consensus building, and quantitative modelling (Costanza and Ruth, 1998). These stages involve identification of the problem, its intrinsic structure and subsystems, their interactions and interdependences, development of the conceptual model, quantitative modelling, implementation and model verification, calibration, validation, and approbation. However, this information is already available in the literature but are scattered and not organized. The study further recognized that the barriers and their interactions are geospatially sensitive but argues that such consolidation is required towards an integrated intervention mechanism (s).

In Figure 9, three key observations can be made. First, the barriers are hierarchical and divided into three different levels. Second, double arrows are used to show the two-way or counteractions among the barriers. Third, two types of lines are used to illustrate the interrelationships among the barriers. The normal lines are used to show interactions between two close levels and the dotted lines are used to show interactions between extended levels of the barriers. From Figure 9, it can be deduced that the five (5) most problematic clusters include the industry, knowledge, process, financial and technical barriers which have at least 4 interactions with other clusters. Although important, the least interactive clusters include the attitudinal, aesthetic, and policy barriers (Figure 9). Blismas et al. (2005) argued that addressing the less interactive barriers will have a significant positive influence on the more prominent groups of barriers and thus, each cluster is considered important in the current study. Figure 9 shows that the industry barriers (IB) counteract directly with attitudinal (AB), policy (PB), knowledge (KB), process management (PMB), and aesthetic barriers (AeB). For instance, the conservative mindset of the industry towards the conventional method of construction reinforces the resistance to change and innovation in the industry. The counteractive closed-loop structure of IB, AB, and KB highlights the extent to which the entrenched construction culture, poor innovative attitudes of practitioners, and their limited knowledge of MiC hinder the wider diffusion of MiC (Blismas et al., 2005). Similar closed-loop structures can be observed among other clusters of barriers (Figure 9).

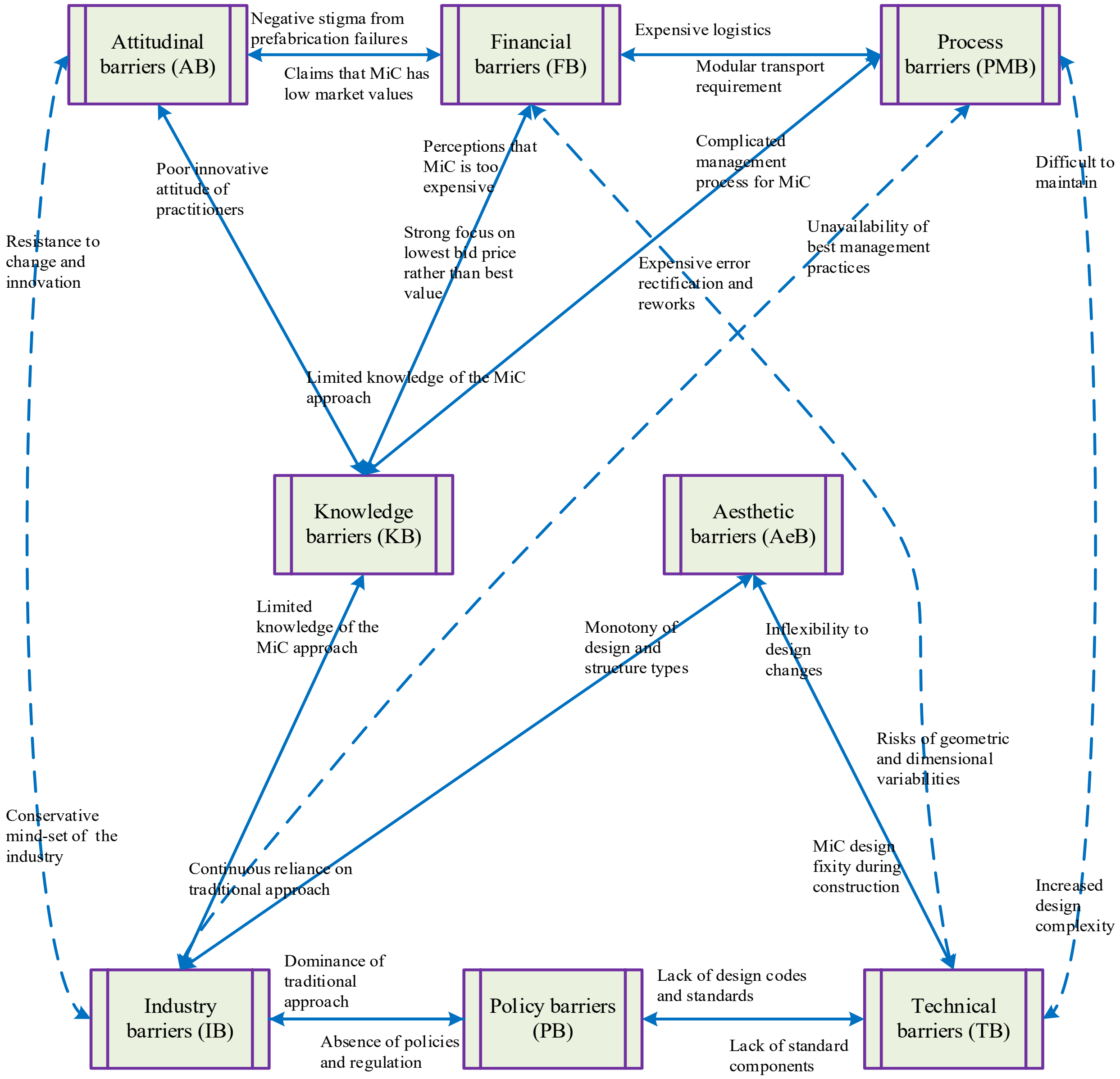


Figure 9. Conceptual total interpretive structural model of the barriers to the adoption of MiC

Consistent with the prominence of KB in Figure 9, Blismas et al. (2005) explained that the successful completion of every construction (including MiC) project is grounded on a clear appreciation of the critical success factors, risk factors, and management strategies. However, the limited knowledge and experience with MiC influence the perception that MiC is associated with a complicated management process and further claims that MiC is far expensive to justify its adoption. Clients' perception of the value of a project often dictates the construction option to adopt (Blismas et al., 2005) but due to the limited understanding of the added value in MiC and its measurement, less experienced industry practitioners continue to perceive MiC as having lower market value. This perception is more pronounced given the strong focus on lowest bid price rather than best value (Blismas and Wakefield, 2009). According to Gan et al. (2018b), the absence of policies and regulations supporting the requirement to incorporate MiC into private projects in some countries is a driver of the continued dominance of the conventional construction approach. It should be reiterated that not every project design lends itself to modularization and suitable for MiC (Murtaza et al., 1993; Wuni and Shen, 2019b) and so, MiC can be made mandatory. Several key factors need to converge to make MiC feasible and economical (Wuni and Shen, 2019b). For instance, the implementation of MiC may depend upon availability of modules' supplier or manufacturer, availability skilled labour and management team, good transport network, and tight project schedules (Hwang et al., 2018b; Wuni and Shen, 2019b).

From Figure 9, several profound interactions among the barriers can be observed. For instance, the negative stigma of the post-war prefabricated construction failures (AB) and the concomitant lower confidence in the MiC industry are partly responsible for poor social climate and limited market demand (FB) for MiC (Gan et al., 2018b). The risk-averse attitude of some construction clients partly contributes to the higher perception that MiC is risky. The risk perceptions are exacerbated by the prevailing manifold uncertainties and absence of best practices. Moreover, the perception that MiC is associated with the monotony of design and structure types provides a greater impetus for the continuous reliance on the traditional construction approach where diversity and variety of design options abound. The ill-informed perception that MiC is inflexible is a product of the MiC design fixity during construction. Furthermore, the limited availability of MiC design codes, standards and technical guidance in some countries contributes to the low level of standardization of modular components (Gan et al., 2018b). Additionally, complex interfacing between systems and the problematic dimensional variabilities associated with MiC are partly responsible for the complicated rectification process and higher costs of reworks (Shahtaheri et al., 2017). More of the interactions are self-explanatory in Figure 9.

4.4 Proposed strategies to promote the uptake of MiC

Most existing studies often identified and evaluated the barriers to the adoption of MiC but have seldom proposed strategies to promote uptake of the technology (e.g. Gan et al., 2018b; Zhang et al., 2018). Those that manage to propose the strategies have often focused on few critical barriers (e.g. Hwang et al., 2018a; Luo et al., 2015). However, as demonstrated using the conceptual framework, the barriers are manifold, complex, dynamic and interconnected. Blismas et al. (2005) argued that the full promises and benefits of MiC could be realized if an integrated approach is adopted to address the barriers and promote wider uptake. Blismas and Wakefield (2009) further argued that at every point a conglomerate of barriers hinders the adoption of MiC and as such, it is practically uneconomical to tackle the barriers individually. Thus, the current research argues that integrated set of strategies are required to contemporaneously tackle the complex web of barriers. Figure 10 shows the strategies which may be pursued to address the different barriers and the associated stakeholders which can champion the excellence of the strategies. The strategies and associated stakeholders were extracted from the 46 articles and some policy documents. Thus, it constitutes the first attempt at delineating the barriers and matching each against a set of strategies and stakeholders. In Figure 10, the key stakeholders who can address the attitudinal barriers include academics, industry practitioners, government, and media partners. Considering that government is the biggest construction clients, exemplar MiC projects should be initiated by the government to demonstrate the feasibility of implementing MiC. This approach has been adopted in Hong Kong (Pan and Hon, 2018), Singapore (Hwang et al., 2018a), UK (Pan et al., 2012), Malaysia (Yunus and Yang, 2016), China (Jiang et al., 2017), New Zealand (Mills, 2018), Sweden (Larsson et al., 2014), among others. MiC researchers would have to develop rhetoric strategies such as the Aristotelean pathos, logos, and ethos to diffuse the technology into the industry. Effort should be made to reverse the negative stigma associated with failures of post-war prefabricated housing projects such as the collapse of the 22-storey Ronan Point Tower in East London in 1968. Regarding the knowledge barriers, Luo et al. (2015) suggested that more training programs and short courses should be organized to improve the knowledge and skills sets of developers, contractors, designers, and other key players. The role of academic institutions is critical to improve knowledge of MiC.

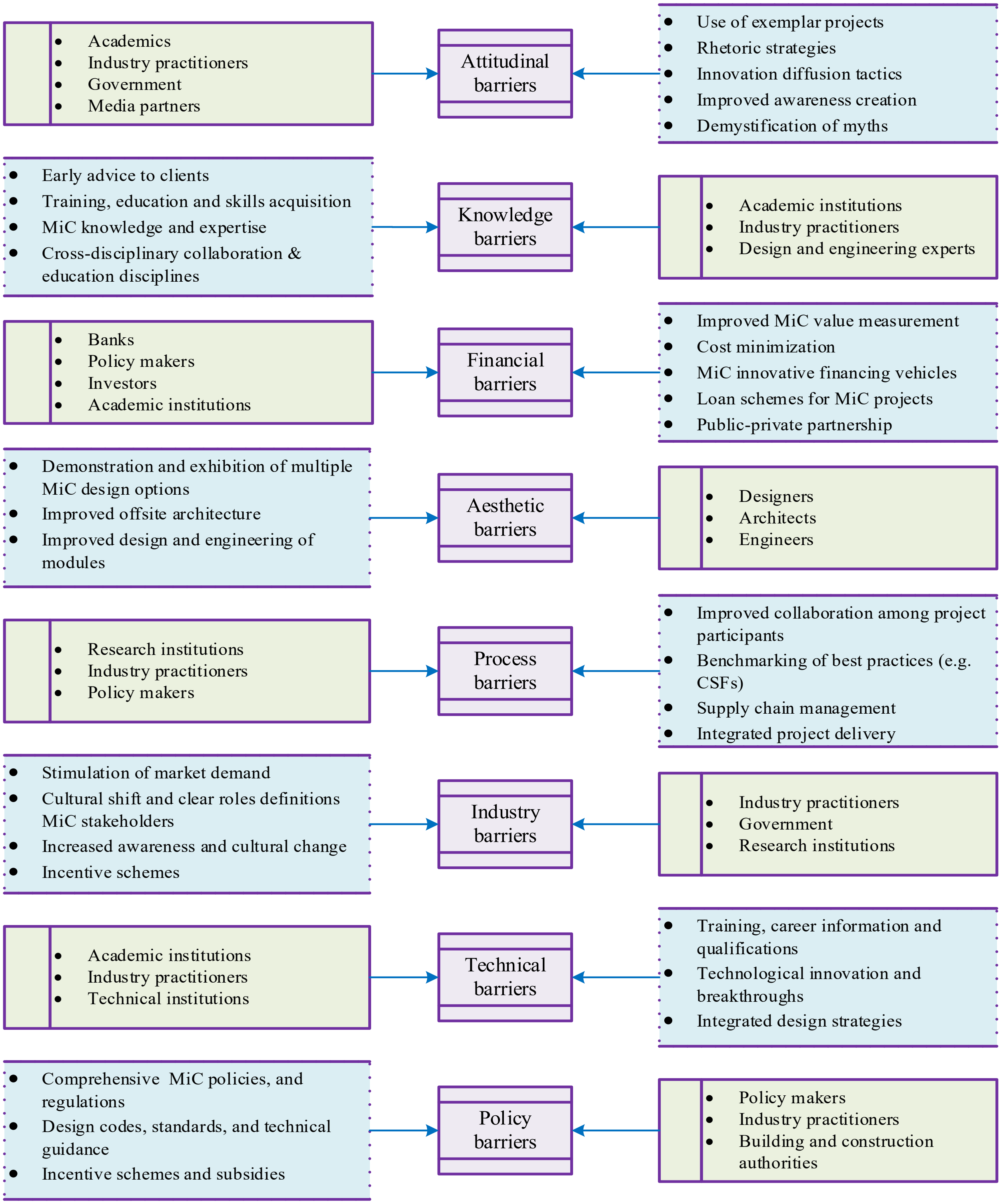


Figure 10. Integrated strategies to promote the adoption of MiC

The knowledge barriers can be addressed through the commitment of academic institutions, industry practitioners, and MiC design and engineering experts. For instance, Blismas and

Wakefield (2009) proposed that early advice should be made available to clients and developers to ascertain the suitability of their project designs to modularization and MiC. Researchers should provide feasibility assessment frameworks for MiC. Hwang et al. (2018a) proposed the use of computerized decision-support systems to perform detailed economic analysis for the options of using both MiC and the conventional approach in a project. Industry leaders and practitioners should collaborate with academic institutions to offer training courses for project teams and workers to enhance their knowledge and skills (Hwang et al., 2018a; Luo et al., 2015).

The financial barriers may addressed using a combination of strategies. Wuni et al. (2019a) suggested that researchers should model, analyse and optimize the supply chain of MiC to determine optimal configuration with an objective of cost minimization. Wuni and Shen (2019b) also proposed that researchers should identify, quantify and monetize the intangible benefits of MiC to develop a more comprehensive cost-benefit analysis framework. This would objectively demonstrate the value-added benefits and the competitiveness of MiC. Mills (2018) proposed development of innovative financing schemes for MiC projects. Long term loan schemes which can be provided in advance to contractors or developers will encourage the adoption of MiC. The possibility of using public-private partnership as a financing vehicle for MiC projects is high and should be considered.

The roles of designers, architects, and engineers in addressing the aesthetic barriers to the adoption of MiC cannot be over-emphasized (Luo et al., 2019; Wuni et al., 2019a). There should be innovation in offsite architecture aimed at improving the architectural design options for MiC projects. This should be augmented by improved design and engineering of the modules to be consistent with the innovative architectural design options. The multiple design options for MiC projects should be demonstrated and exhibited at the industry level to eliminate the perception that MiC is recipe for monotony of project outlook and constitutes a threat to architectural creativity.

The process barriers to the adoption of MiC can be mitigated through the commitment of research institutions, industry practitioners, and policy makers. Hwang et al. (2018a) identified five strategies to improve the process management of MiC projects: (i) encouraging collaboration between project stakeholders during early phase of the project; (ii) use of building information modelling tools to improve coordination and facilitate communication among project participants; (iii) fabricating and assembly modules as close as possible to the construction site reduce transportation effort; (iv) use of information technology (e.g. electronic file transfer) to overcome the extra requirement of planning, coordination and communication; and (v) applying Temporary Occupation License (TOL) to set up temporary worksite in the vicinity of the construction. These strategies aim at minimizing the complexity of the MiC project management process and the associated costs. Li et al. (2017a) proposed the use of Just-in-Time (JiT) delivery arrangement to avoid delays in the supplying modular components to a construction site. The smart digital construction technologies should be leveraged to improve collaboration among MiC project participants. The use of integrated project delivery models will improve the collaboration of project participants (Wuni and Shen, 2019a). Commitment should be made to benchmark best practices towards promoting knowledge transfer. This will minimize risks and improve project performance. A key challenge with MiC is the extensive coordination and management of the supply chain (Hwang et al., 2018a).Thus, research institutions should collaborate with industry practitioners to develop effective MiC supply chain management strategies.

The industry barriers may be addressed through the committed collaboration of industry practitioners, government, and researcher institutions. Researchers need to develop frameworks and strategies for promoting the cultural shift in the industry. This should be preceded by a clear definition of the roles of the traditional key players in MiC projects. This will help project participants to understand that the disruptive nature of MiC is associated with role descriptors but does not significantly alter the importance of the key actors. Government should collaborate with industry leaders to also initiate some MiC projects to stimulate demand and raise awareness. Like the practice in Malaysia, Hong Kong, Singapore and many other countries, government should establish incentive schemes and subsidies to encourage the adoption of the technology by industry actors.

Technical institutions, research institutions and industry practitioners have significant roles to play in addressing the technical barriers to the adoption of MiC. Industry practitioners should be equipped with MiC planning, design and management skills to deal with the complexities associated with the technology. Short technical courses should be made available to upgrade the technical and manufacturing skills required by practitioners to remain relevant in MiC projects.

Technical and research institutions have the most significant roles to play. These institutions should be financed to innovate technologies and breakthroughs which can address the technical challenges associated with the technology. For instance, improvement in structural design for MiC projects is required to accommodate strong wind load such as Typhoons for high-rise buildings in Hong Kong (Pan and Hon, 2018). As such, the technical and research institutions should innovate advanced structural design to meet this and similar compelling requirements.

The building and construction authorities, policymakers, and industry practitioners have a lot to provide in addressing the policy barriers to the adoption of MiC. Like the case of Hong Kong and Singapore, policy makers should develop comprehensive guidelines, polices and regulations on the use of MiC in projects. Luo et al. (2015) argued that an effective legal framework for guiding practitioners constitutes a risk reduction vehicle and a recipe for successful implementation of MiC. Technical support should be made available to developers and clients who are interested in using MiC. The building authorities and policymakers should develop comprehensive design codes, standards, and technical guidance on the use of MiC. This should be accompanied by incentive schemes to encourage adoption of MiC in projects.

5. Conclusions, limitations and future research

MiC is an innovative and disruptively offsite construction technique which changes the way in which construction projects are planned, designed, scheduled, delivered and managed in the architecture, engineering and construction industries. As the construction sector is historically known for its slow adoption of innovative solutions, the implementation of MiC is thwarted by several barriers, challenges and problems. This research conducted an international review research on the barriers to the adoption of MiC. A total of 46 articles were recruited and analysed to provide a holistic perspective of the barriers. These research studies were conducted in 15 countries distributed across Asia, Africa, North America, Europe, and Australia. The analysis showed that previous studies mainly used questionnaires, interviews, workshops discussions, and mixed methods as data collection instruments. These were considered appropriate because the barriers are best identified through the engagement and solicitation of views from MiC stakeholders. The literature analysis revealed 120 barriers to the adoption of MiC. However, a substantial number of these barriers were classified as perceived or spurious because they were speculative and obscure to justify. As such, this study argued that some existing studies engaged respondents who had very little knowledge of and experience with MiC. The research found an extensive co-existence of both actual and perceived barriers in the literature. However, since the study sought to establish a holistic perspective of the barriers, the researchers clustered the 120 constraints into knowledge, attitudinal, industry, financial, aesthetic, technical, process, and policy-related barriers. Drawing a systems-thinking philosophy, the study proposed a conceptual TISM framework of the barriers, highlighting their interrelationships. The framework revealed that the five (5) most problematic groups include the industry, knowledge, process, financial and technical barriers which have at least 4 interactions with other groups. The paper further proposed set of strategies to address each barrier and to promote the adoption of MiC. As such, the paper makes useful contributions to the existing body of knowledge of MiC diffusion.

Theoretically, this paper established the complex nature of the barriers hindering the wider diffusion of MiC in the construction industry. The research makes a useful contribution to the literature through analysing and mapping the holistic interactions among the barriers. Practically, the paper offered and reinforced the need to adopt integrated strategies to address the barriers and proposed some strategies for the various groups of barriers. Thus, the paper provides a holistic perspective of the barriers hindering the wider uptake of MiC which was missing prior to this study. However, the study suffers some limitations. First, the study immediately recognizes that the sweeping generalization of the barriers overlooks their geospatial sensitivity. However, it is theoretically useful to overlook these sensitivities and differences as they become critical when such generalized analysis is tailored towards a specific country as the basis for policy recommendations. Second, the rigorous holistic analysis of the barriers was beset by the absence of empirical data. Nonetheless, this study has initiated a debate towards developing more practical and realistic integrated strategies to promote the adoption of MiC. Future studies will examine and compare the holistic interaction of the barriers in different countries using empirical data.

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