PESTEL Analysis of Factors Influencing the Demand and Supply of Modular Construction: Perspectives from Hong Kong

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Abstract –

Modular construction (MC) shifts labour-intensive site-based activities to an off-site controlled environment through prefabrication, and is deemed an innovative approach for industry transformation. To maximise the benefits of MC, there is a need to predict the demand volume and supply capacity to inform proactive and strategic supply chain planning and development. This study aims to provide a holistic exploration of the factors influencing the MC market, based on a literature review and a study of the case of modular integrated construction (MiC) in Hong Kong. A systematic framework was proposed with 15 demand-related factors and 10 supply-related factors to explain the complex influential mechanism from the political, economic, social, technological, environmental, and legal (PESTEL) perspectives, which contribute to the understanding of the dynamic evolution of the MiC market. The findings revealed that the influencing factors are manifold, with the political factors influencing the MiC demand the most and the economic factors determining the development pattern of the MiC supply. The presented study lays a foundation for the establishment of a practical MC demand-and-supply model for better market planning. Attention should be devoted to rationalising the quantification of qualitative factors in future research.

Keywords –

Modular Construction; Demand and Supply; Market Dynamics; Influencing Factors; PESTEL Analysis

1 Introduction

Housing shortage has plagued many metropolitan areas. To meet the growing demand for housing and satisfy citizens' wishes towards better living standards, modular construction (MC) has gained increasing attention for its various benefits. Pan and Zhang [1] revealed that both concrete and steel modular systems outperform their conventional counterparts, reflected by heightened environmental sustainability (e.g. 46-87% reduction in waste disposal), improved social harmony (e.g. no records of accidents in modular works), and significantly improved economic efficiency (e.g. 32-50% increase in speed of superstructure construction). Owing to the enhanced sustainability of the modular approach, the governments of many countries and regions have actively advocated its adoption through various terms, such as modular integrated construction (MiC) in Hong Kong [2, 3], prefabricated prefinished volumetric construction (PPVC) in Singapore [4], and permanent modular construction (PMC) in the United States [5].

Nevertheless, due to the infancy nature of MC and its incomplete supply chain in many areas, the prospects of the MC market are full of uncertainties in the form of demand variability and supply capability [6]. The lack of anticipation of the MC market can be fatal to both the demand and supply sides. The imbalance of MC demand and supply can lead to the bankruptcy of factories due to insufficient orders, or unfulfilled MC demand and high prices due to the lack of supplier alternatives [7]. In reality, modular firms have witnessed some publicised failures, such as Urban Splash and Katerra [7, 8]. Despite the importance of MC market analysis, previous research solely focused on the demand side, such as exploring the drivers, constraints, and strategies for MC adoption [4, 9], while neglecting the upstream supply side. Few papers displayed a sense of supply chain management and provided a broad analysis of the evolving MC demand and supply. To optimise mass production, it is imperative to have a clear vision of the MC market to support the formulation of proactive government strategies and corporate plans for MC development. Therefore, there is an urgent need to understand the factors influencing MC market dynamics, which have not yet been fully explored.

To address the research gap, this study aims to explore the factors influencing MC demand and supply systematically through a literature review and a study of the case of MiC in Hong Kong. MiC encompasses all aspects of MC with the highest degree of integration of diverse construction activities [9]. Subsequently, Section 2 introduces the research methodology. Then, the influencing factors of the MiC demand and supply are structured into political, economic, social, technological, environmental and legal (PESTEL) aspects and delineated in Section 3. Section 4 discusses the findings of the study, followed by the conclusions in Section 5.

2 Methodology

The research was carried out in four main stages to analyse the factors influencing the MC demand and supply (see Figure 1).

The first stage was factor identification through a literature review. The reviewed literature covered construction demand prediction, housing supply modelling, diffusion of innovation, and MC adoption-related research. Factors were extracted through content analysis and those with similar meanings were merged.

The second stage was factor verification using a case study. As the relevant literature was limited and the influencing factors were context-sensitive, the case of MiC in Hong Kong and its supply chain in the Greater Bay Area (GBA) of China was used to supplement and adjust the factors [11]. The GBA is a mega-region that consists of nine major cities in Guangdong Province and two special administrative regions - Hong Kong and Macao. The case study was conducted using two interrelated methods: factory and site visits and interviews. Six group interviews were conducted during or after the visits with the managers and engineers in a semi-structured manner. All the respondents had over five years of working experience with MiC. Each interview lasted around 30 minutes to collect their basic and intuitive views on the topic. Table 1 presents the research activities conducted for the study. Data collected from the interviews were documented. Then, the factors were extracted from the records and synthesised.

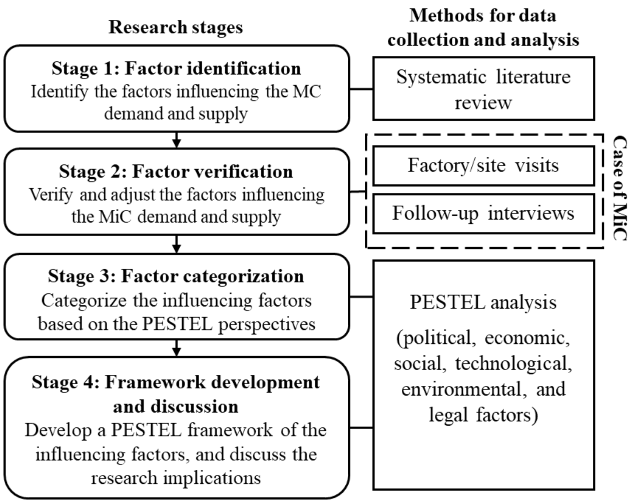
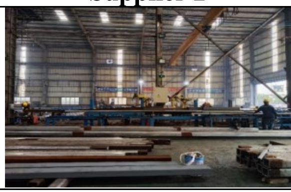


Figure 1 Research stages and methods

Table 1 Details of the case study

Factory visit	**Supplier 1**	**Supplier 2**	**Supplier 3**
MiC supplier			
Product type	Concrete MiC	Steel MiC	Concrete and steel MiC
Location	Guangzhou, Guangdong	Foshan, Guangdong	Zhuhai, Guangdong
Follow-up interview	3 suppliers	2 suppliers	3 suppliers
Site visit	**Project 1 (mockup)**	**Project 2 (mockup)**	**Project 3**
Construction sites			
Project type	Public housing	Private residential building	Affordable housing
Location	Hong Kong	Hong Kong	Shenzhen, Guangdong
Follow-up interview	1 client and 2 contractors	1 client and 1 contractor	1 contractor and 2 from the industry institution

The third stage employed the PESTEL analysis. PESTEL stands for political, economic, social, technological, environmental, and legal, offering a holistic guiding tool for scrutinising a wide spectrum of ‘climate’ elements for marketing planning [12]. Political factors refer to government intervention in the MiC market. Economic factors can significantly affect MiC market sentiment due to the cost-conscious culture in construction. Social factors mainly concern labour conditions, health consciousness and cultural aspects. Technological factors focus on MiC itself and the changes in the technological landscape. Environmental factors reflect the sustainable concerns and geographical constraints in practice. Legal factors focus on the regulatory environment for MiC, such as the approval process and design standards. The identified factors were divided into the demand and supply sides, and further grouped based on the PESTEL perspectives.

The fourth stage proposed a PESTEL framework of the factors influencing the MiC demand and supply, generating valuable theoretical and practical implications for market forecasting and supply chain configuration.

3 PESTEL analysis of factors influencing the demand and supply of MC

The influencing factors identified from the construction engineering and management literature and the case study are summarised from the six PESTEL aspects in Table 2 and elaborated below.

3.1 Political perspective

Political factors refer to government intervention in the MiC market, taking the forms of tax policy, financial incentives, and mandatory requirements [13]. The current MiC demand in Hong Kong is primarily driven by government policies. Since 2017 when MiC was first included in the Chief Executive’s Policy Address 2017 [2], a series of policies have been put in place to facilitate MiC development, reflecting a strong and pivotal push from the change agent. The most important political factor emphasised by the interviewees is the policy incentives for MiC implementation, such as the 10% gross floor area concession incentives and the Construction Innovation and Technology Fund (CITF) for MiC promotion. In addition to the financial incentives, the government has also formulated various policy initiatives to stimulate MiC adoption in the public sector. During the COVID-19 pandemic, MiC was promoted for the construction of modular quarantine camps due to its well-recognised advantages of fast delivery [14]. In 2020, the Development Bureau announced that government building projects with total construction floor area larger than 300m^2 under the Capital Works Programme are mandated to adopt MiC [15]. The Policy Address 2022 advocated for MiC adoption in public housing and set an ambitious adoption rate of no less than 50% from 2028/29 to 2032/33 [16]. These policies have sparked investments in MiC in the public sector, evidenced by the increasing number of modular buildings commenced, while MiC adoption in the private sector is still trailing.

As for the MiC supply in the GBA, the national and local governments have issued relevant policy measures to augment the supply of prefabricated buildings, of which MiC is a kind of product with the highest degree of prefabrication and integration but not the mainstream one. In 2017, Shenzhen was included in the first batch of national prefabricated building demonstration cities, and in 2020, Foshan earned selection in the second batch [17, 18]. As of 2022, 22 companies have been selected as the national prefabricated industrial bases and 83 companies (78 in the GBA and 5 in the other cities of Guangdong) have been selected as the provincial ones [17-19]. In addition, the government announced that prefabricated buildings would account for more than 50% of new buildings in Guangdong by 2030 [19]. Noticeably, the interviewee from the industry institution indicated that the boom in prefabricated buildings as well as the emergence of MiC in the GBA would increase factories’ supply capacity. This may be accompanied by a decrease in the proportion allocated to Hong Kong, but a high possibility for an increase in the absolute quantity of MiC supplied to Hong Kong. Overall, the government focused on leveraging the leading role of demonstration cities and industrial bases and the pull effects of the market demand to enhance the supply capability of prefabricated products including MiC, highlighting the whole supply chain synergy.

3.2 Economic perspective

Economic factors are the determining factors that affect the MiC market sentiment in the context of a cost-conscious culture in construction [9]. From the demand side, the perceived relative advantages of MiC in the economic aspect (e.g. reduced construction time and cost, improved quality, and enhanced productivity) are one of the most important driving forces for adopting this innovative approach [6, 9]. Besides, according to the law of supply and demand, the MiC demand will increase along with the improvement of MiC manufacturers’ supply capability and its resulting cost-effectiveness. Another important factor is the construction demand in the various building sectors and the favourable economic environment for construction. As construction demand increases, there is a likelihood of a concurrent increase in the MiC demand. Factors may influence the construction demand include population and household, gross domestic products, interest rate, labour employment, and housing stock and price [20-23, 31].

Table 2 PESTEL analysis of the key factors influencing MiC demand and supply

Category	Factors from the demand side	Factors from the supply side
Political perspective	• Economic incentives for MiC promotion (e.g. provision of innovation fund) [9, 13, 23, 29, 30, 33, 36, E] • Policy initiatives for MiC promotion (e.g. setting targets for MiC adoption rate) [9, 13, 26, 33, E]	• Policy support for MiC manufacturers [E]
Economic perspective	• Relative advantages in the economic aspect (e.g. time- and cost-efficiency, better quality performance) [6, 9, 25-28, 33, 34] • Supply capability of MiC manufacturers [6, 9, 23, 24, 28-30, 33, 36, E] • Construction demand [29, 32, E] • Economic environment (e.g. interest rate) [20-22, 31]	• MiC market demand [9, 22, E] • Profit earning [E] • Company strategic planning [E] • Market limitations (e.g. finance) [32]
Social perspective	• Relative advantages in the social aspect (e.g. improved health, safety, and welfare) [9, 25] • Labour conditions in Hong Kong (e.g. labour size, skill level) [9, 20-23, 29, 30, 31, 33, E] • End-user attitudes towards MiC [6, 9, 23, 26, 28, 30, E]	• Labour conditions in the other GBA cities (e.g. labour size, skill level) [9, 20-23, 29, 31, 33]
Technological perspective	• Complexities of MiC implementation [4, 6, 9, 23-25, 28, 30, 36] • Compatibility of MiC for different building sectors [25, 28, E] • Successful MiC demonstration projects [9, E]	• Adoption of innovative technologies in MiC [4, 9, 23, E] • Sufficient eligible MiC suppliers [6, 9, 23, 24, 28-30, 36, E]
Environment perspective	• Relative advantages in the environmental aspect (e.g. higher material utilisation) [9, 25, 27] • Geographical constraints on MiC implementation [4, 9, 23, 24]	• Achievement of sustainable goals [26]
Legal perspective	• Regulatory readiness for MiC implementation (e.g. improved approval procedures) [6, 9, 13, 23-26, 28-30, 36, E]	• Uniform standards and norms applicable to both Hong Kong and the other GBA cities [E]

Note: E represents empirical evidence obtained from the case study.
Hwang et al. [4], Feldmann et al. [6], Pan et al. [9], Jin et al. [13], Goh [20], Fan et al. [21], Jiang and Liu [22], Rahman [23], Choi et al. [24], Rogers [25], Jiang et al. [26], Choi et al. [27], Pan et al. [28], Mao et al. [29], Wuni and Shen [30], Kim et al. [31], MacAskill et al. [32], Pan et al. [33], Shin et al. [34], Katebi et al. [35], Bello et al. [36], Pan et al. [37]

The development pattern of the MiC supply is determined by economic considerations. The stable market demand for MiC and manufacturers' capability of profit earning positively influence the strategic planning of the MiC suppliers [6]. Since MiC places special emphasis on 'integration', more high-value construction activities were shifted from sites to upstream factories [3], attracting great interest in increasing MiC supply capacity to grab more profits. Besides, the MiC supply is expected to expand in response to the growing demand for MiC after seeing the burgeoning MiC market in Hong Kong, exemplified by several major MiC suppliers (e.g. Suppliers 1 and 3) who have new factories in planning. In contrast, market limitations (e.g. availability of finance, regional space, planning and construction capacities) may constrain the expansion of MiC factories [32].

3.3 Social perspective

Social factors mainly concern labour conditions, health consciousness and cultural aspects that affect the MiC market. With regard to the MiC demand, the severe labour ageing and shortage in Hong Kong have spurred the industry to find a way out, and MiC's advantages in saving site labour have made the industry explore this innovative approach [9]. However, as MiC involves many challenging works (e.g. heavy crane operations), the lack of skilled workers with MiC experience may hinder the widespread of MiC [35]. In addition to the better economic performance of MiC, the perceived relative advantages in terms of the social aspect (e.g. improved health, safety and welfare for workers) are also one of the driving forces for MiC promotion. Besides, the interviewees emphasised the importance of end-user attitudes towards MiC, because positive feedback from end-users can provide more confidence to developers and drive them to implement MiC in more projects. However, due to the current market preference for customized design, concrete structural systems, and conventional construction approaches, raising public awareness of MiC, such as through organising propagation campaigns, becomes a fundamental strategy for changing people's perspectives and thus increasing the take-ups of MiC.

Regarding the MiC supply, the major social barrier remains the labour issue. While the labour shortage in the other GBA cities may not be as acute as that in Hong Kong, the problem of ageing workers has become increasingly prominent [17]. Besides, the MiC suppliers argued that there is a shortage of mechanical, electrical and plumbing technicians with Hong Kong licenses to work in the factories in the Mainland, negatively influencing the supply capacity and production cycles. As such, the provision of regular training for the workers either in Hong Kong or in the other GBA cities is necessary for the rapid development of MiC.

3.4 Technological perspective

Technological factors focus on MiC itself and the impacts of changes in the technological landscape on the MiC market. As for the MiC demand, the complexity of MiC implementation (e.g. early design freeze, just-in-time delivery, heavy-duty machine operations) is the prominent technological consideration, since it may amplify the stakeholders' concerns about adopting MiC, thereby affecting the stakeholders' top management and investment in MiC [4, 30, 34]. Compatibility refers to the degree to which MiC is perceived to be consistent with the values, experiences, and needs of the potential adopters [17]. Normally, experiences in prefabricated construction should help MiC diffusion as these knowledge and skills are transferable to the MiC field. Whereas, since prefabricated construction has been extensively used in public housing construction and has demonstrated acceptable time and cost performance, part of the stakeholders display reluctance to embrace change and to invest in new equipment and worker training [29]. Besides, the compatibility of MiC in different building sectors varies. For example, as MiC benefits can be maximised through standardisation, public housing, elderly homes and staff quarters with repeated design were regarded as most suitable for MiC [28]. In contrast, as indicated by one of the manufacturers in the interview, the ongoing private residential building project in the factory is highly customised with no repeated module designs on a typical floor. This feature poses a challenge to the compression of production cost due to the need for more module moulds, leading to market hesitance to use MiC in the private sector. In addition, successful MiC demonstration projects allow potential adopters to observe the MiC benefits and see the innovative approach being used by their peers [17].

Technological factors that influence the MiC supply were related to the integration of MiC and other innovative technologies (e.g. building information model, artificial intelligence, robotics), which has the potential to enhance operational efficiency and significantly elevate supply capacity. As observed in the factories, Suppliers 2 and 3 have introduced robotic arms to improve production. The other factor that influences the MiC supply is the availability of eligible MiC suppliers [6, 9, 23]. The respondent from the industry institution indicated that many manufacturers have extensive experience in prefabricated construction and are capable of, or intend to, shifting to producing MiC. However, the contractors are concerned about the availability of concrete MiC suppliers, because some markets such as housing prefer concrete MiC systems that are more technically demanding and can be manufactured by fewer suppliers [29].

3.5 Environmental perspective

Environmental factors reflect the sustainable considerations and geographical constraints in MiC implementation. Regarding MiC demand, the perceived relative advantages in the environmental aspect (e.g. higher material utilisation, reduced impacts of noise, traffic and dust on the local community) can improve stakeholder and community satisfaction, thus increasing public acceptance of MiC adoption [1]. Whereas, the narrow streets and undulating terrain in Hong Kong impose restraints on module size, which may limit their utility and applicability across various scenarios and thus affect the widespread adoption of MiC.

The environmental motivation for increasing MiC supply is from the need for sustainable development. As the construction industry is often characterised by high investments, elevated levels of waste and pollution, and diminished productivity, moving labour-intensive site works to a controlled manufacturing environment is regarded as a lean practice for achieving carbon neutrality. Under sustainable-driven urbanisation, the advantages of MiC may gain more policy support [26].

3.6 Legal perspective

Legal factors refer to the laws and regulations, but this study focuses on a suitable regulatory framework for MiC practice. From the MiC demand side, both the extant literature and the interviews revealed that the over-stringent regulations and red tape in approval procedures pose a hindrance to the full realisation of MiC advantages, thereby impeding the formulation of market-driven MiC demand [9, 13]. According to an interviewee from a MiC manufacturer, the modules and connections are always over-designed given the current strict regulations and the conservative review approach adopted by the governments, leading to cost escalation and waste of materials. In addition, the approval procedures of various government departments are time-consuming, bringing great uncertainties to process control [24].

Regarding MiC supply, the absence of comprehensive standards and codes for MiC implementation leads to inefficient process operations and a lack of accountability structures [9]. Besides, due to the different regulations applied in Hong Kong and the other GBA cities (i.e. Hong Kong mainly follows the British standard system, but factories in Mainland China adopt the Chinese national standard), extra time and cost are spent on design, material sourcing and accreditation problems, hindering the efficient MiC supply.

4 Discussion

This study unveiled a variety of factors influencing MiC demand and supply from PESTEL perspectives, based on a comprehensive literature review and empirical evidence from Hong Kong. The identified influencing factors are manifold, which demonstrates the need for systems thinking in addressing the complicated MiC market issues. Therefore, a systematic framework is proposed for analysing the macro environment in terms of PESTEL aspects that influence MiC demand and supply in Hong Kong and the GBA of China (Figure 2).

The framework deconstructs the MiC market into the interacting demand and supply sides and elaborates on the PESTEL factors influencing these two sides. The demand-related factors mainly focus on the drivers that promote, and the constraints that inhibit, MiC adoption and the supply-related factors revolve around the supply capacity and the potential growth of MiC suppliers. The findings revealed the emphasis on political factors, especially in the early stage of MiC adoption. This is aligned with the findings by Pan et al. [9] and Mao et al. [29], which showed the current demand for MC as government-driven and the need for policy incentives to drive MC adoption. The rationale behind the emphasis on political factors is partly attributable to cost, as stakeholders expect more economic incentives to offset cost premiums [30]. The MiC supply evolves in tandem with the changes in MiC demand and is governed by technological and regulatory considerations. While Feldmann et al. [6] highlighted the significance of the availability of suitable suppliers, they did not regard regulation as a determinant of module supply in Germany. However, the pivotal role of regulatory factors has been recognized by many studies conducted within the Chinese context, e.g. [29]. In addition, the characteristics of different building sectors should be embedded in the analysis of the influencing factors, given the suitability of MiC for different building sectors. However, this study refrains from conducting an in-depth analysis of different building sectors due to page limits of the paper.

The proposed framework enhances the knowledge base of MiC market planning and its supporting supply chain design. Although some of the influencing factors were based on the context of MiC demand in Hong Kong and the supply in the GBA of China, they should provide valuable insights for other regions that rely on a cross-boundary supply chain. Furthermore, other regions could build upon the factors listed in Table 2 and incorporate region-specific considerations into the framework to enhance its applicability and effectiveness.

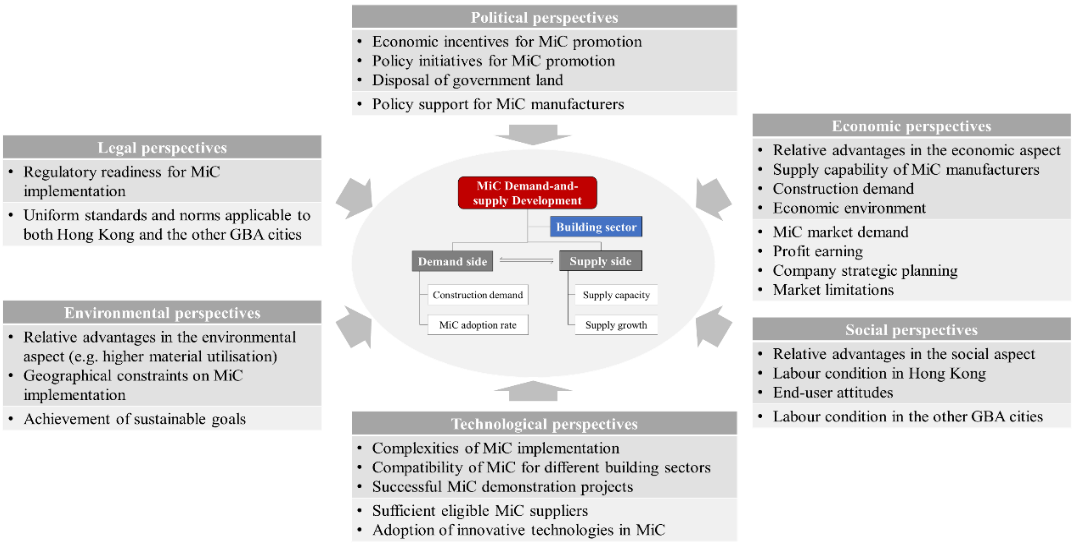


Figure 2 A systematic framework of factors influencing the demand and supply of MiC in Hong Kong and the GBA of China

Nevertheless, the presented work is a fundamental step to establishing a simulation model to understand the evolution of the MiC market. Several improvements for future research have been identified. First, it is meaningful to analyse the interrelationships between the critical factors and the pathways through which the factors influence MiC demand and supply. Second, the analysis of the factors should further incorporate the characteristics of different building sectors for a more accurate vision of the sector-level MiC market. Third, a sophisticated model employing advanced simulation techniques should be developed to accurately forecast future market trends and dynamics in the short and long terms. As some influencing factors were challenging to quantify, this might make future efforts to develop a practical simulation model difficult. Coupled with detailed scenarios that fit the societal movement, tailored policy recommendations should be generated to guide the sustainable development of MiC.

5 Conclusions

MC has been experiencing a global revival recently due to its various benefits, but how this momentum will develop further remains unclear. Building on the results of the literature review and a study of the case of Hong Kong, a holistic framework was proposed with a total of 15 demand-related factors and 10 supply-related factors to explain the complex influential mechanism from the PESTEL perspectives.

The findings revealed that the influencing factors of the MiC market are multifaceted, with the political factors most influencing the MiC demand and the economic factors determining the development pattern of the MiC supply. Also, there remains ample room for mitigating the constraints imposed by technological and legal factors on the MiC supply, e.g. increasing the availability of concrete MiC suppliers, and improving the standards and codes for MiC design and implementation. Noticeably, other influencing factors are not secondary. For example, social factors play an increasingly important role in the move towards a people-centred Industry 5.0 era. In addition, attention must be paid to rationalising the quantification of the qualitative factors.

The developed framework contributes to a better understanding of the dynamic evolution of the MiC market. The revealed factors help policymakers develop strategies to underpin the sustainable development of MiC and support corporates to proactively respond to market dynamics.

Being aware that the presented study is yet far from delivering a practical model to simulate future MiC demand and supply, future research is needed to explore the critical influencing factors, demonstrate the interrelationships and the evolution of these influencing factors, simulate the dynamic evolution of the MiC market, and conduct detailed scenario analysis to help formulate appropriate strategies for improvement.

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