MODELLING POLICY-DRIVING FORCES FOR THE UPTAKE OF MODULAR INTEGRATED CONSTRUCTION IN HONG KONG

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Modelling Policy-Driving Forces for the Uptake of Modular Integrated Construction in Hong Kong

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CERTIFICATE OF ORIGINALITY

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Abstract

Modular integrated Construction (MiC) is an innovative and effective manufacturing-based method of construction that draws significant attention from the industry stakeholders to enhance construction practices in Hong Kong. By adopting the concept of on-site installation after factory manufacturing, MiC has been proven to be beneficial to the construction industry, given the advantages of enhanced quality and site safety, improved efficiency and productivity, minimal disturbance and nuisance to neighbourhoods, and savings in construction time, cost and labour. The past few years have witnessed an increasing interest in policy-related research on the adoption and advancement of MiC. Recently, the Hong Kong government has implemented relevant policies and incentive schemes to encourage the wide adoption of MiC. However, the construction industry continues to observe policy-related issues in adopting MiC that retard the industry performance to a greater extent. Therefore, it is essential to conduct research for the improvement of relevant policies targeting MiC uptake in Hong Kong. Further, existing policies for promoting the uptake of MiC invariably focus on incentive schemes and compulsory requirements. These interventions disregard the real-life dynamic impacts of the Policy-Driving Forces (PDFs) on MiC processes and their interactions with related stakeholders, both of which significantly affect the large-scale adoption of MiC. Thus, the construction industry seeks strong support from promotional policy implementations for the mass adoption of MiC. Given this background, an in-depth study on PDFs in MiC practice is essential, particularly in Hong Kong, where MiC is gaining significant prominence in application.

The aim of this research is to understand the complexity of policy-driving forces and their

impacts on MiC uptake and to formulate appropriate measures for improving MiC policy-making in Hong Kong. To realise this aim, this study progressively pursues three research objectives:

(1) Identify and examine critical PDFs across major MiC project phases: initiation, planning and design, and construction;

(2) Investigate the interactions between critical PDFs and stakeholders at different MiC project phases in Hong Kong;

(3) Propose measures to improve policy-making for the overall MiC uptake via developing a System Dynamics (SD) model to simulate and assess the potential impacts of critical PDFs.

To fully understand the industry development situation of MiC, a comprehensive review of the existing literature was conducted. Accordingly, seven key issues of MiC existing in Hong Kong were identified, seven common research themes on construction industrialisation policies were summarised, and 26 PDFs identified from the literature were explained.

To achieve Objective 1, data were first collected from literature review, questionnaire survey and expert interviews. Then, relevant significance and factor analysis was conducted to identify critical PDFs of MiC and their appropriate groupings from the perspective of industry professionals. Accordingly, a total of seven critical PDF components consisting of 7, 6, and 10 critical PDFs were proposed in Stage I (Initiation Stage), Stage II (Planning and Design Stage), and Stage III (Construction Stage), respectively. In Stage I, two components were included: Promotional and Sustainable PDFs, and Regulative PDFs. In Stage II, Sustainable PDFs and Regulative PDFs were included, while in Stage III, the three components included were Greater Bay Area development PDFs, Technical and Regulative PDFs, and Promotional PDFs.

To achieve Objective 2, expert interviews and case studies were adopted to collect research data. A total of 10, 14, and 31 stakeholders were recognised in Stages I, II, and III, respectively. Three PDF-stakeholder networks at different stages were established using the Social Network Analysis (SNA) based on the collected data. Further, six indicators were measured using a two-mode network quantitative analysis to determine the critical stakeholders and PDFs associated with the implementation of MiC. Environmental protection policy (Stage I), COVID-19 pandemic and construction waste disposal charging scheme (Stage II), and quality acceptance standard for project completion (Stage III) were considered to be the most important PDFs in each stage. The Hong Kong government and developers were highlighted as prominent stakeholders at all three stages. The dynamic interactions between stakeholders and critical PDFs at different stages of MiC were discussed. Recommendations were accordingly proposed to improve the application of MiC from the perspective of various stakeholders.

To achieve Objective 3, a system dynamics model was developed to simulate the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong. Results were generated from the SD model simulation and policy scenarios analysis, which indicated that PDFs in the initiation phase have the greatest impact on the overall uptake of MiC in Hong Kong, followed by the construction phase, and the planning and design phase. Moreover, Regulative PDFs have the highest tendency to enhance MiC uptake at each phase. Six strategies were then proposed based on the outcomes of case simulation and experts' opinions to improve the uptake of MiC practices in Hong Kong: (1) boost MiC adoption in buildings under emergencies (e.g. COVID-19 pandemic), (2) expand MiC adoption in public housing and encourage its application in private buildings, (3) provide additional Gross Floor Area (GFA) exemption for MiC projects,

(4) enhance information technology support across the supply chain, (5) formulate explicit standards and guidelines for MiC and (6) promote further implementation of relevant policies in the Greater Bay Area.

This study explored PDFs for MiC uptake through three project phases of initiation, planning and design, and construction, which made significant contributions to promoting the overall uptake of MiC in Hong Kong from both theoretical and practical perspectives. In theory, this study (1) filled the gap of lacking quantitative research on PDFs in the construction industry, specifically in the emerging modular construction field; (2) facilitated an in-depth understanding of the interactions between critical PDFs and associated stakeholders across the MiC project phases and (3) extended the body of knowledge in recognising the dynamic impacts of critical PDFs for the overall MiC uptake in Hong Kong. In practice, this research provides implications for the government to anticipate the impact of different policy revisions and adjustments towards MiC uptake, by applying a developed dynamic model for policy scenario simulations. With these supportive policy design, revision and implementation, MiC practices in Hong Kong will be beneficial. The construction industry performance could be further enhanced by overcoming the existing policy-related issues regarding MiC. Ultimately, the Hong Kong economy would be boosted through MiC uptake while contributing to sustainable development.

Publications arising from the thesis

Journal Papers

1. **Jin, X**., Shen, G. Q. P., Wang. Qian-Cheng, Ekanayake, E. M. A. C., & Fan, Siqi* (2021). Promoting Construction Industrialisation with Policy Interventions: A Holistic Review of Published Policy Literature. *International Journal of Environmental Research and Public Health*, 18(23), 12619. https://doi.org/10.3390/ijerph182312619

2. **Jin, X.**, Ekanayake, E. M. A. C., & Shen, G. Q. P.* (2021). Critical Policy Drivers for Modular integrated Construction Projects in Hong Kong. *Building Research and Information*, Accepted. https://doi.org/10.1080/09613218.2021.2010030

3. **Jin, X**., Shen, G. Q. P., & Ekanayake, E. M. A. C.* (2021). Improving Construction Industrialization Practices from a Socio-Technical System Perspective: A Hong Kong Case. *International Journal of Environmental Research and Public Health*, 18(17), 9017. https://doi.org/10.3390/ijerph18179017

4. Luo, L., **Jin, X.**, Shen, G. Q.*, Wang, Y., Liang, X., Li, X., & Li, C. Z. (2020). Supply Chain Management for Prefabricated Building Projects in Hong Kong. *Journal of Management in Engineering*, 36(2), 05020001. https://doi.org/10.1061/(asce)me.1943-5479.0000739

5. Zhou, J. X., Shen, G. Q.*, Yoon, S. H., & **Jin, X.** (2021). Customization of on-site assembly services by integrating the internet of things and BIM technologies in modular integrated construction. *Automation in Construction*, 126(June 2020), 103663. https://doi.org/10.1016/j.autcon.2021.103663

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8. Xiang, L., Tan, Y., **Jin, X.**, & Shen, G.* (2020). Understanding stakeholders' concerns of age-friendly communities at the briefing stage: a preliminary study in urban China. *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-01-2020-0070

9. Zhai, Y.*, Chen, K., Zhou, J. X., Cao, J., Lyu, Z., **Jin, X.**, … Huang, G. Q. (2019). An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong. *Advanced Engineering Informatics*, 42(July), 100997. https://doi.org/10.1016/j.aei.2019.100997

Conference Papers:

1. Xiang, L., **Jin X.**, Shen, G., and Tan, Y.*, 2020. Applications of multi-agent systems in the construction management area: A literature review. In: *The 25th International Symposium on Advancement of Construction Management and Real Estate 2020*, 27-28 November 2020, Wuhan, China. (Merit Paper Award)

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G.Q.P. Shen, eds. *Intelligent Construction and Sustainable Buildings: Proceedings of the International Conference on Construction and Real Estate Management 2020*, 24-25 August 2020, Stockholm. Reston: American Society of Civil Engineers, pp.639-650. (Best Paper Award)

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Chapter 1 Introduction

1.1 Research Background

1.1.1 Why focusing on the Modular integrated Construction?

The construction industry has consistently been an engine of economic growth and a driving force for social development in Hong Kong (Wilding, 1997). Industry 4.0, which signifies the promise of a new industrial revolution, provides new opportunities for economic growth, particularly in the field of construction (Dallasega et al., 2018). The possibilities of Industry 4.0 include convertible factory: production lines can be built in modules and assembled for tasks (HKIE, 2021). Oztemel and Gursev (2020) and Lu (2017) summarised six principles that should be noted in the implementation and promotion of Industry 4.0: service orientation, virtualisation, interoperability, real-time capability, modularity and decentralisation. Smart manufacturing is a key driver of Industry 4.0, and Modular integrated Construction (MiC) is one of its main features worthy of attention.

MiC enables the majority of the work to be substantially completed off-site, starting from the manufacturing process, generally in a controlled factory environment, in which a variety of building materials are combined to shape free-standing three-dimensional volumetric modules (prefabricated and completed with fixtures, fittings and finishes). Thereafter, completed modules are transported to the construction site for assembly as part of the construction process (CIC, 2021; Tatum et al., 1986). By adopting the concept of on-site installation after factory manufacturing, MiC helps alleviate some of the challenges currently faced by the local construction industry (CIC, 2021). These challenges include an increasingly ageing construction workforce, limited land availability, a lagging tendency of innovation and adoption of advanced technologies and high construction costs (e.g. materials, labour and transportation) (Han & Wang, 2018; HKIE, 2021). The superior performance of MiC in the following aspects makes it an appropriate solution for the entire construction industry to promote green sustainable development: (1) savings construction time, cost and labour (Kamali & Hewage, 2016); (2) better quality control of buildings (Mao et al., 2015); (3) enhancing productivity, efficiency and durability (Wuni & Shen, 2019); (4) reducing the pressure of construction site waste (Lu & Yuan, 2012); (5) minimally requiring skilled on-site workforce (Ferdous et al., 2019); (6) improving occupational health and site safety (Jankovic, 2019) and (7) lessening disturbance and nuisance to neighbourhoods (HKIE, 2021). Kamali and Hewage (2016) made a relatively detailed summary of the key benefits of modular off-site construction (see Table 1.1).

Table 1.1 Summary of Major Advantages for MiC (Kamali & Hewage, 2016)

Parameters	Description
Time	Simultaneous construction work and site preparation
	No work disruption due to weather extremes
	Less vandalism and site theft due to a shorter schedule
Cost	Labour transportation reduction
	Machinery transportation reduction
	Ordering bulk materials and receiving volume discounts
	Saving due to on-site labour reduction
	Less site overhead and congestion
	Reduced interest charges due to fast construction
	Avoidance of costly delays due to weather or site severe conditions
	Distribution of overheads, admins, and technician costs over quantity production
On-site safety	Reduction in elevated work and dangerous activities
	Reduction in on-site workforce congestion
	Less workforce exposure to neighbouring construction operations
	Less workforce exposure to severe weather

	Less working time on-site
Product quality	Controlled manufacturing facilities
	Highly engineered fabrication
	Repetitive processes and operations
	Automated machinery
	Specialized skilled workforce
	Using high-quality materials to withstand transportation
	Less material exposure to harsh weather on-site
Workmanship and productivity	Less skilled workforce requirement
	Highly organized operations
	Better supervision
	Less time intervals
	Workforce stability
Environmental Performance	Waste generation reduction
	Potential for waste management
	Less disturbance on-site such as noise and dust
	Efficient land resources use
	Reduction in greenhouse gas emissions

Given the overwhelming demand for high-quality, affordable housing in Hong Kong in recent years, the government has implemented compulsory policies and incentive schemes for the wide adoption of MiC. Particularly, MiC was introduced in the Policy Address 2017 of Hong Kong as an initiative to promote innovative construction methods with the view of enhancing productivity and cost-effectiveness (HKSAR, 2017). Through the years, the Buildings Department (BD) has been assisting the industry in adopting prefabrication from two-dimensional prefabricated construction to three-dimensional MiC. To support innovative construction technologies, including MiC, the Financial Secretary announced a HK$1billion Construction Innovation and Technology Fund from the government budget. Additionally, the Development Bureau and Construction Industry Council (CIC) actively organise related activities and launch-related construction projects to promote and support the further development of MiC. These projects include the Kong Ha Wai Transitional Housing Project, CIC–Zero Carbon Park in Kowloon Bay (officially renamed MiC Resources Centre on 26 July 2021) and Student Residence at Wong Chuk Hang Site for the University of Hong Kong (currently under construction). Moreover, the management and uptake of MiC have received extensive attention and risen to the height of administrative region policy in Hong Kong. For example, the BD has established a pre-acceptance mechanism under PNAP ADV-36 (2019) for granting in-principle acceptance of individual MiC systems for local projects. In March 2020, the Technical Circular (Works) No. 2/2020 stipulated the policy of adopting MiC for new government buildings and government-funded construction projects to be tendered on or after 1 April 2020. Moreover, the MiC method has become mandatory for new building works of suitable building types with a total construction floor area larger than 300m^2 under the Captical Works Programme (Development Bureau, 2020).

1.1.2 Why policy-driving forces are essential in MiC?

Driving forces are all forces that promote change, and these change drivers promote and encourage the change process (Bürgi et al., 2004). Various driving forces form a complex system of dependencies, interactions and feedback loops (Blaikie, 1985). Brandt et al. (1999) identified driving forces from five aspects: technology, policy, socioeconomic environment, natural environment and culture. Recent years have witnessed an increasing interest in driving forces research on the adoption and development of green building technologies (Darko et al., 2017). MiC is an innovative method of construction dedicated to green buildings. Under this background, the current study refers to Policy-Driving Forces (PDFs) in MiC as the driving forces to promote MiC adoption in terms of public policies.

MiC is attracting fresh interest and investment boom following improvements of technology and changes in the global economy (Bertram et al., 2019). Given the increasing acceptance of the importance of MiC in improving construction quality and efficiency and its strong environmental performance, numerous countries and regions have attempted to promote MiC uptake by formulating relevant policies and regulations (Mao et al., 2015). Government policies with substantial supportive MiC measures can encourage the widespread use of advanced industrialised methods in the construction industry (Abdelmageed & Zayed, 2020). Although different regions involve different construction contexts and social backgrounds, policy implications for promoting the adoption of MiC invariably focus on incentive schemes and compulsory requirements (Jin et al., 2021). However, the real-life impact of PDFs on MiC processes is disregarded, thereby significantly impeding the efficient management of MiC.

Studies have shown that policy support is significant and effective for the smooth promotion of the innovative construction technology of MiC (Gao & Tian, 2020). Although government policy change is listed as a risk embedded across the supply chain of MiC in Hong Kong (Luo et al., 2019), Ekanayake et al. (2021) highlighted that policy drivers and enablers emerging from promotional, regulative, standardised, managerial and sustainable policies are expected to promote and boost the supply chain resilience uptake of MiC. This development influences the widespread application of MiC in Hong Kong. Wuni and Shen (2020) identified ten policy-related barriers that hinder the uptake of MiC, thereby providing clues for the further exploration of PDFs. Gan et al. (2018) emphasised that special attention should be given to policies and regulations to find the corresponding driving forces to facilitate the adoption of MiC. Implications obtained from policy enablers can clarify the effective development measures for policymakers to promote MiC uptake (Jiang et al., 2018). Therefore, a systematic exploration of PDF research and analysis can considerably contribute to the government's comprehensive understanding of the impact of different policies on the implementation of MiC, and inspire policy makers to examine the realisation of policy targets.

The following key issues existing in Hong Kong regarding the application of MiC were identified (Jin et al., 2021): complex cross-border transportation process, low innovation in prefabrication techniques, high initial costs, lack of preferential policy, low standardisation, lack of management practices and experiences and absence of timely communication between parties. These key issues reflect the limitations of temporary organisations, which are the features of construction projects, particularly network associations amongst different policies and stakeholders (Nguyen et al., 2021). Such relationships reveal the uptake of MiC over time in the complex systems of the construction industry. Additionally, MiC drivers (typically government, clients and industrialisation technology suppliers) in the construction industry are pressured to develop suitable measures to effectively solve the aforementioned problems (Wuni & Shen, 2020). Given that policies are adopted in complex social contexts, in which multiple interactions amongst stakeholders influence their performance (Luo et al., 2020), the social environment should be fully understood, and the impact of MiC policies on its uptake must be examined.

The adjustment of policies or regulations is neither entirely a function of market demand nor a simple government operation. Instead, such an adjustment is mediated by a range of stakeholders and influenced by the socioeconomic environment and dynamic interactions amongst PDFs. To establish a foundation to identify the dynamics of PDFs, critical PDFs associated with MiC that are currently absent in the literature should be identified. However, a Hong Kong-specific study should be conducted because MiC policies are jurisdiction-specific, and MiC supply chain configurations differ across countries (Ekanayake et al., 2020). Therefore, there is an essential need to identify and examine critical PDFs associated with MiC projects in Hong Kong from the perspective of industry experts, and to dynamically explore the impact of PDFs on MiC uptake.

1.2 Research Problem

In the past decades, the construction industry in Hong Kong has continued to upgrade to make the building process faster and safer as technology advances (Chan & Chan, 2002). Amongst the numerous new technologies available, MiC has been proactively adopted by the government in various public works (Wuni & Shen, 2019). The government has implemented several policies, such as Technical Circular (Works) No. 2/2020, PNAP ADV-36 & APP-161 & APP-151, Green and Innovative Buildings Policy and Code of Practice for Precast Concrete Construction 2003 & 2006 (2003 Code & 2006 Code) (HKIE, 2021), to harness innovative construction technologies, including MiC; the construction industry is also actively responding to these policies to meet demand and pursue sustainable competitiveness (Mao et al., 2018). However, the industry continues to observe policy-related issues in adopting MiC (Mao et al., 2015; Seaden & Manseau, 2001), such as legal framework issues, lack of design codes and standards for prefabricated components and lack of government incentives (Mao et al., 2015), all of which provide opportunities and space for the further improvement of policies. Moreover, policy interventions for promoting the uptake of MiC invariably focus on incentive schemes and compulsory requirements. However, these interventions disregard the real-life dynamic impacts of PDFs on MiC processes and their interactions with related stakeholders, both of which significantly influence the effectual large-scale adoption of MiC. Thus, the construction industry seeks strong support from promotional policy implementations to uptake MiC more effectively.

Although existing studies have demonstrated that challenges continue in the building process of MiC, three problems have been found in previous research. Firstly, the majority of the published studies have conducted a comprehensive analysis of the barriers and risks to modular construction. By contrast, only a few in-depth explorations have been conducted from the detailed perspective of policy-driving forces. Secondly, studies relevant to MiC management have consistently started from an isolated and static orientation without systematically considering the interconnections between different influential PDFs and relevant stakeholders. Thirdly, existing studies have generally focused on qualitative analysis on the basis of surveys, failing to quantify the impacts of PDFs on the successful uptake of MiC projects in three phases (initiation, planning and design, and construction). Moreover, the methods established in previous studies have neither resulted in a comprehensive understanding of the policy management of modular construction nor can they better promote the development of public modular housing in Hong Kong from the perspective of policymakers. The possible reason is that previous studies have failed to fully understand key PDFs of prefabricated modular house construction during the life cycle when conducting project management research in MiC practice. Thus, the current study investigates the interrelationships between critical PDFs and relevant stakeholders in MiC, as well as their impact on the successful uptake of MiC buildings from a dynamic perspective. The objective is to achieve sustainable development of the construction industry goals in the context of policy management considerations. The specific research questions are as follows:

(1) What are the specific PDFs of the MiC industry in Hong Kong?

(2) How can the interrelationships between critical PDFs and relevant stakeholders be examined in the context of MiC in Hong Kong?

(3) How can the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong be assessed?

1.3 Research Aim and Objectives

This study aims to understand the complexity of policy-driving forces and their impacts on MiC uptake and to formulate appropriate measures for improving the MiC policy-making in Hong Kong.

Three specific objectives of this research are listed below:

(1) To identify and examine critical PDFs across major MiC project phases: initiation, planning and design, and construction;

(2) To investigate the interactions between critical PDFs and stakeholders at different MiC project phases in Hong Kong and

(3) To propose appropriate measures to improve policy-making for the overall MiC uptake via developing a system dynamics model to simulate and assess the potential impact of critical PDFs.

1.4 Research Design

To achieve the specific objectives, a research path diagram is designed, as illustrated in Figure 1.1, to facilitate the process management of this study. The corresponding methodologies and research steps used to realise the objectives and expected outcomes are explained.

Firstly, through a comprehensive review of existing literature and a thorough examination of relevant documents, the status quo of current MiC policy research is fully understood, research problems and gaps are identified, research objectives are clarified, and research methods are selected. This process is explained in Chapters 1 to 3 of the thesis (i.e. Introduction, Literature Review and Methodology, respectively).

Secondly, an associated PDF checklist in the three phases of MiC projects is formulated according to the description of PDFs and MiC processes in Hong Kong. After drawing on the extensive relevant literature and conducting a pilot study, an expert opinion survey is conducted to gather the necessary data for this study. An investigation is conducted on the occurrence possibility and degree of impact of various PDFs across three stages of the MiC process. Statistical techniques are applied to aid in the quantitative analysis (relevant significance and factor analyses). Consequently, critical PDFs are presented from a comprehensive impact degree based on the analysis outcomes of the combination of two dimensions: occurrence possibility and impact degree. Appropriate groupings of critical PDFs are also identified. This process is detailed in Chapter 4 of the thesis, critical PDFs for MiC projects in Hong Kong.

Thirdly, relevant stakeholders in MiC are refined and confirmed through literature review, real case studies and expert interviews. PDF-stakeholder relationship matrixes are presented after the expert interviews. Thereafter, the social network analysis (SNA) method is applied to examine the interrelationships between critical PDFs and relevant stakeholders during the initiation, planning and design and construction phases of MiC. A series of network indicators are utilised to present the critical PDFs and stakeholders and their interaction links. The most prominent PDFs and stakeholders are determined, and the impact dynamics of stakeholders at each phase, core stakeholders in the construction phase and the implications of promoting MiC, are discussed. This process is described in Chapter 5 of the thesis, SNA of stakeholders associated with critical PDFs in MiC.

Fourthly, a dynamic model is developed on the basis of system dynamics theory and data collected from previous steps. This dynamic model is used to assess the impact of critical PDFs on the overall uptake of MiC in Hong Kong for policy-making optimisation. Model description, establishment and validation are represented, along with the various policy scenarios displayed. This process is depicted in Chapter 6 of the thesis, an SD model for simulating PDFs for MiC uptake in Hong Kong. A summary of all research findings will be presented after this stage.

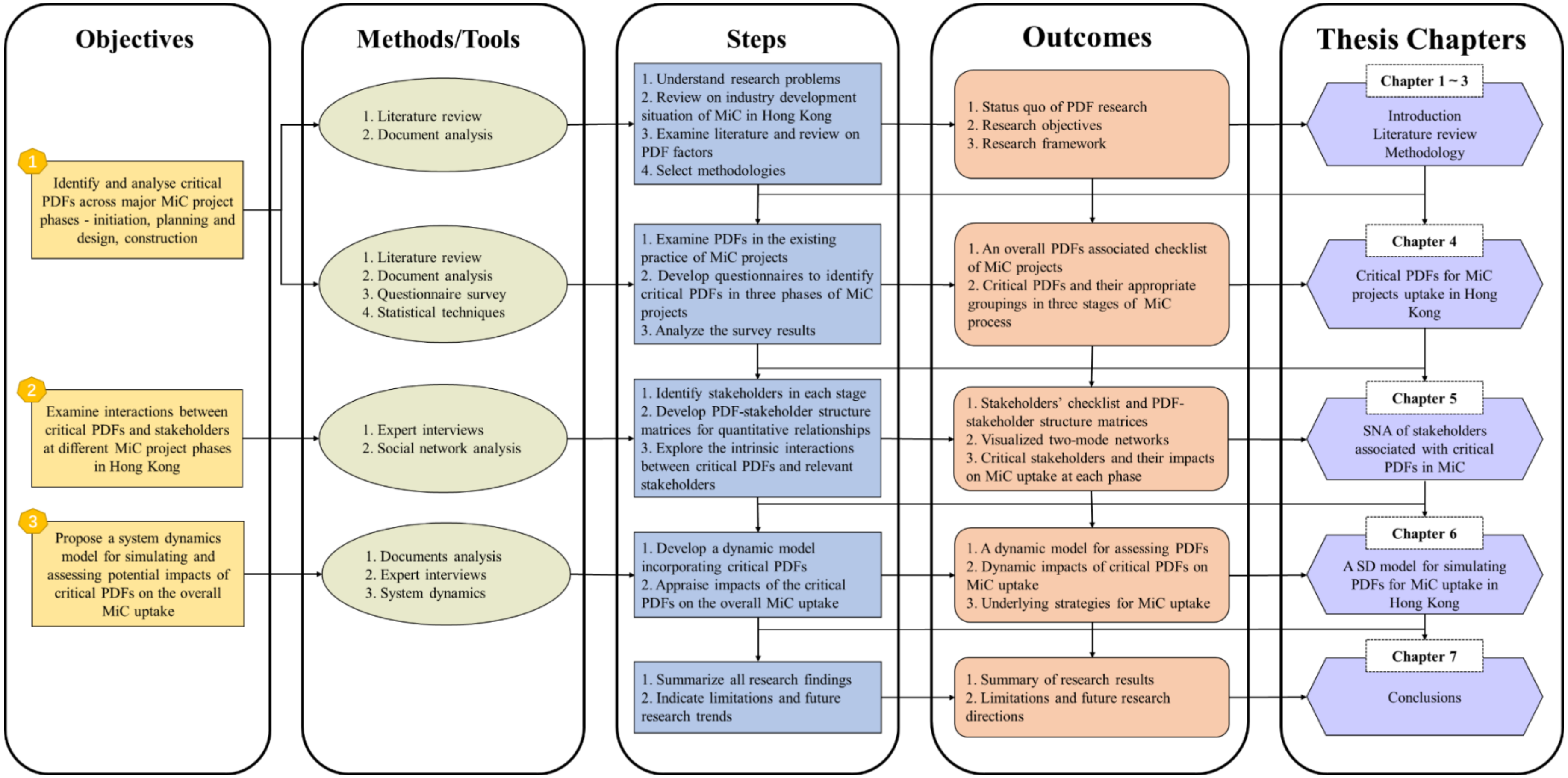

Figure 1.1 Overall Research Roadmap of the Thesis

1.5 Significance of the Research

The theoretical and practical significance of this research is reflected in the following four aspects.

From an academic perspective, this research contributes to the current body of knowledge on policy-oriented management in the construction industry, particularly in the emerging modular construction field. This study recognises a series of PDFs associated with MiC projects, owing to some policy revisions and adjustments, during the three major project phases (initiation, planning and design, construction) in Hong Kong from the perceptions of industry experts, which is subject to diversified changes and uncertainties in the market. The possibility of occurrence and degree of impact of different PDFs in the three phases of MiC projects are further examined and analysed respectively, such that the comprehensive pattern of impact of PDFs throughout all project phases can be established. This research fills in the current research gap that lacks a systematic quantitative analysis method for investigating PDFs at different stages of MiC.

From a theoretical point of view, a profound understanding of the interactions between critical PDFs and their associated stakeholders across the three phases of MiC projects is considered an important contribution to this research. Moreover, this study proposes an SNA model to identify the most prominent PDFs and stakeholders in each phase, and explore the dynamic fluctuations of underlying interrelationships between stakeholders and detailed PDFs in the three different stages of MiC projects in Hong Kong. Thus, critical interactions and impacts that play significant roles in building the entire network of policy-oriented management throughout three phases of MiC projects can be investigated and analysed. The SNA model can assist in filling in the knowledge gap by providing a scientific tool to understand and analyse critical PDFs, related stakeholders and their interconnections from a network perspective.

In terms of theoretical contribution, this research is meaningful in recognition of the dynamic impacts of critical PDFs during the process of the overall MiC uptake in Hong Kong. PDFs are not static during MiC adoption, and their impact may vary across different stages over time, thereby forming a large and complicated system. The stages of diverse PDFs in the MiC uptake system are interrelated, generating various positive feedback. Developing an SD model to portray the relationships amongst various PDFs under different stages, and to assess the dynamic impacts of these critical PDFs on the overall uptake of MiC, which have been rarely investigated before, can be substantially comprehended.

The outcomes of this study have significant practical contributions to the entire construction industry and involved policymakers. From the industry perspective, existing PDFs on business operations in the modular construction industry are recognised and considerably understood, further promotion and wide-scale application of building prefabrication technologies are improved and significant progress in the performance of MiC projects is achieved. From the perspective of relevant policymakers, this study can help them considerably focus on PDFs with low occurrence frequency but high impact degree, before making decisions and implementing updated strategies and substantially informing policymakers on how to initiate, design and implement MiC-related policies to boost MiC practice in Hong Kong.

The result of this research provides valuable implications for the government to anticipate the impact of different revisions and adjustments in policy on driving MiC uptake. Additionally, this study is of value in offering project managers with an effective and comprehensive tool, through which to identify, analyse and assess the possible impact of PDFs on the delivery of modular building projects in Hong Kong, such that critical PDFs can be maximised to ensure the successful completion of modular housing projects. Consequently, outcomes serve as a scientific foundation to provide practitioners with beneficial guidance to boost productivity in the construction industry and overcome the industry's performance shortfalls whilst enhancing sustainability through MiC uptake.

1.6 Structure of the Thesis

This thesis comprises seven chapters, the contents of which are summarised as follows.

Chapter 1 provides an overview of this research, highlighting essential information on the entire study, including research background, statement of the research problem, research aim and objectives, structure design with methods, research significance and contribution in theory and practice and the detailed structure of this thesis.

Chapter 2 conducts comprehensive reviews of the existing literature and documentation on prefabrication and MiC research in the field of construction project management. The content analysis includes three aspects: the industry development situation of MiC in Hong Kong, common research themes on construction industrialisation policies and knowledge of PDFs in MiC projects. Three research gaps in this area and practical needs from the industry are summarised to justify the significance of this research.

Chapter 3 illustrates a detailed depiction of the research methodologies to realise the research objectives. Starting from an outline of the research design and process, this chapter describes different research methods used for data collection, namely, document analysis, questionnaire survey and expert interviews; followed by the interpretation of data analytical techniques adopted, which include descriptive statistics, mean score ranking, Cronbach's alpha, factor analysis, partial least squares structural equation modelling, SNA and system dynamics modelling.

Chapter 4 shows the process of identifying and examining critical PDFs associated with MiC projects in Hong Kong from the perspective of industry experts. After drawing on the extensive relevant literature and conducting a pilot study, an expert opinion survey is conducted to gather the necessary data for this study. The collected data are analysed using relevant significance and factor analyses to identify critical PDFs and appropriate groupings, providing an in-depth understanding of MiC from a policy perspective.

Chapter 5 demonstrates the PDF-stakeholder networks of MiC using SNA. The interrelationships between the relevant stakeholders and critical PDFs at each of the three stages in MiC are investigated. Visualisation and quantitative analysis of PDF-stakeholder networks are carried out. On the basis of the findings, valuable recommendations are proposed to improve the application and practicality of modular buildings in Hong Kong in terms of policies from the perspectives of different stakeholders.

Chapter 6 develops an SD model to simulate the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong. Specific model description, establishment and testing are explained in detail. After analysing the results of the base run simulation and discussing the outcomes of various policy scenarios, six underlying strategies are suggested to improve the uptake of MiC practices.

Chapter 7 summarises the entire research process and main findings of this study. The achievement of the research aim and objectives are re-examined, whilst emphasising the implications of the research and its theoretical and practical contributions towards the existing body of knowledge and the construction industry. Lastly, the research limitations and further research directions are revealed and discussed.

1.7 Summary of the Chapter

This chapter aims to provide a comprehensive description of the research composed of six essential information parts: research background of the current topic, statement of the research problem, research aim and objectives, structure design with methods, research significance and theoretical and practical contributions and detailed structure of this thesis.

Chapter 2 Literature Review

2.1 Introduction

This chapter comprehensively reviews the existing literature and documentation on prefabrication and MiC research in the field of construction project management over the past few decades. Firstly, the current chapter portrays the development situation of the MiC industry in Hong Kong. Secondly, this chapter outlines and explains a broad scope of common research themes in this discipline from around the world. Thirdly, PDFs associated with MiC projects are identified and investigated from a plethora of relevant studies. Lastly, three research gaps are evident based on the analysis of scientific articles, and practical needs from the industry are summarised. This chapter serves as a solid foundation for justifying the significance of this research.

2.2 Industry Development Situation of MiC in Hong Kong

2.2.1 Concepts of MiC

Modular integrated Construction (MiC) is an innovative and effective manufactory-based method of construction. As an alternative to the traditional onsite construction method, it has been progressively adopted throughout the world over the past few decades (Xu et al., 2020). To be more specific, most of the work in MiC buildings can substantially be completed off-site, starting from a manufacturing process, generally at a controlled factory environment, in which a variety of building materials are combined to shape free-standing integrated modules (equipped with fixtures, fittings and finishes), and then completed modules are transported to the construction site for installation as part of the construction process (CIC, 2021; Tatum et al., 1986). Since CI has attracted more attention not only from the construction industry but also from academia, various related terminologies and acronyms have sprung up, including off-site prefabrication (Mao et al., 2013), prefabricated construction (Li et al., 2014), prefabricated building (Jaillon & Poon, 2009), precast concrete building (Priestley et al., 1999), industrialised building (Luo et al., 2015; Richard, 2005; Yunus & Yang, 2011), modular building/construction (Kamali & Hewage, 2016), modular integrated construction (Shan et al., 2019; Wuni & Shen, 2019), and modern construction methods (Gong et al., 2015; Liu et al., 2018), just to name a few. Based on some practical experience, social scientific survey and confirmatory studies conducted amongst the three major construction industry sectors - suppliers/manufacturers, contractors and designers/clienteles, Gibb (1999) and Goodier (2007) conclusively analysed and inductively classified the four progressive levels associated with work off the construction sites undertaken on the product, as shown in Figure 2.1. With the increasing level of off-site construction, the degree of integration of buildings is gradually improving. This study focuses on Level 3 and Level 4 on the basis of considering all off-site buildings.

Increasing level of offsite

Level	Category	Definition
1	Component manufacture & sub-assembly	Items always made in a factory and never considered for on-site production
2	Non-volumetric pre-assembly	Pre-assembled units which do not enclose usable space (e.g. timber roof trusses)
3	Volumetric pre-assembly	Pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the buildings structure (e.g. toilet and bathroom pods)
4	Whole buildings	Pre-assembled volumetric units which also form the actual structure and fabric of the building (e.g. prison cell units or hotel/motel rooms)

Figure 2.1 Four Progressive Levels Associated with Offsite Construction (Gibb, 1999)

Although MiC evolved from prefabrication, there are still some differences between them. For prefabrication components, they comprise simply small parts of a building, and beyond that, structural components still have to be constructed using traditional construction methods, which involve a substantial amount of steel, formwork fixing and reinforcement and concreting works (CIC, 2021). In addition, the laying of pipes and interior decoration of the building can only be carried out later. For the innovative MiC, the majority of the building's structure is basically completed off-site. By using this technology, on-site construction procedures can be significantly reduced, and on-site safety can be enhanced, thereby achieving higher productivity (Mok, 2021). The process of MiC consists of manufacturing the free-standing integrated modules (equipped with fixtures, fittings and finishes) in the factory, after which the modules are transported to the construction site and eventually installed to form a general building (CIC, 2021). Common prefabricated components in construction projects mainly include prefabricated facades, prefabricated walls, prefabricated slabs, prefabricated staircases, semi-prefabricated panels, prefabricated bathrooms, and so on (Chiang et al., 2006). In comparison, various types of MiC include reinforced concrete modules, steel frame modules, and hybrid modules.

2.2.2 A retrospective look at MiC practices in Hong Kong

With the increasing acceptance of the significance of the MiC for construction quality and efficiency improvement, as well as strong environmental performance, many countries and regions have realized to positively promote MiC uptake by means of releasing various relevant policies and regulations (Chen et al., 2017). Although they are under different construction surroundings and social backgrounds, their promotional policies of MiC universally focus on mandatory requirements and incentive schemes. In particular, the significant impact and progress of MiC are shown in developed regions, such as Hong Kong.

Off-site construction has been applied in public housing projects for many years in Hong Kong, contributing significantly to dealing with the severe shortage of housing (Li et al., 2016). Since the 1960s, when public housing blocks with 16 stories were constructed with prefabricated concrete panels, MiC, together with standardized modular designs, was first introduced and been used in public housing developments by the Hong Kong Housing Authority (HKHA) (HKHA, 2019), established in 1973, as one of the main providers of public accommodation in Hong Kong. Since then, HKHA has put more effort into the encouragement and investment of the MiC technology adoption and has been committed to increasing the precast rate through the greater use of prefabricated concrete components (Li et al., 2016).

From the increasing proportion of prefabricated elements volume and the gradually diversified types of precast components, it is obvious to see the promotion of MiC in Hong Kong. Off-site prefabrication generally comprises the off-site construction of precast concrete components (PCCs) and ‘cut & bent’ steel reinforcement bars (HKHA, 2019). By the 1990s, the average volume of precast concrete applied in HA buildings was around 18% of the total concrete used (HKHA, 2019). According to Chiang et al. (2006), up to 2002, among the public housing project, prefabricated components accounted for an approximate proportion of 17% in the total used concrete volume. A rise to around 20% of the volume of precast concrete in the basic PCCs occurred after the release of Modular Flat Design in 2008. Based on the newest statement in the Annual Report of the HKHA 2018/2019, an amount would increase to 35% (or 70% on plan, i.e. as a percentage of a flat's floor plan) after volumetric precast bathrooms and kitchens were adopted (HKHA, 2019). Other ways of incorporating enhanced versions of PCCs into the prospectively public housing development construction are also currently explored. For instance, adopting semi-precast slabs with pre-installed service conduits, precast lift shafts with pre-installed lift guide rails, and precast structural walls with concealed conduits. Once introduced successfully, these adoptions will increase the precast rate from 70% to approximately 90% on plan.

Commonly used PCCs by HA involves precast façades, precast concrete panels, semi-precast slabs, panel wall partitions, and precast staircases, which would be going on to incorporate into subsequent public housing development projects together with precast concrete technology. A study has even sorted out the overall proportion of the most frequently used precast components based on the database of 179 prefabricated residential projects in Hong Kong, including precast façade (51%), precast staircase (22%), semi-precast slab (9%), and semi-precast balcony (7%) (Jaillon & Poon, 2009). On the website of HKHA, the widely used prefabricated components included precast panel walls and volumetric precast bathrooms. Since 2011, aiming to satisfy different project requirements, HKHA also attempted to adopt precast ground floor water tanks, precast roof water tanks, and precast roof parapets into the applicable buildings and review and refine their designs for further development adoption future projects. Precast acoustic balconies were also introduced to a pilot project in 2013. Earlier in the Annual Report (2013) issued by HKHA, roof parapets, manholes and drainage channels, precast lift machine rooms, as well as prefabricated electrical trunking were also being explored for possibly extendable use. In summary, the Hong Kong government is committed to ensuring the durability of whole housing stock through extensive use of prefabricated components and precast elements, which is reflected by the percentage of precasting volumn and the different kinds of precasting assembly units.

The Buildings Department (BD) has been facilitating the construction industry to adopt prefabrication throughout the years, from two-dimensional prefabricated construction to three-dimensional MiC. MiC was introduced in the Policy Address 2017 as an initiative, which aims to promote innovative construction methods with a view to enhancing cost-effectiveness and productivity (HKSAR, 2017). Immediately afterwards, the Financial Secretary announced in the 2018-19 Budget that the Government would be the first to pilot MiC in public projects. In addition, the Government has set up a HK$1 billion Construction Innovation and Technology Fund to boost the capabilities of practitioners and enterprises to adopt new technologies, including MiC, and to support the industry in leveraging innovative construction technologies (HKIE, 2021). The Technical Circular (Works) No. 2/2020 promulgated in March 2020 stipulates the policy of adopting MiC for new government buildings and government-funded construction projects to be tendered on or after 1 April 2020. Under this policy, MiC should be adopted for appropriate building types, including hostels, staff quarters, office buildings, school buildings, residential and nursing homes, and medical facilities, unless exemptions are granted based on exceptional grounds.

BD has established a pre-acceptance mechanism under PNAP ADV-36 (2019) for granting in-principle acceptance of individual MiC systems for local projects. By 1 March 2021, BD has pre-accepted a total of 31 MiC systems, including 21 steel and ten concrete MiC systems. In terms of practice, two pilot projects, namely the transitional housing project at No. 202-220

Nam Cheong Street and the InnoCell at Hong Kong Science Park, have been completed in the third and fourth quarters of 2020, respectively. Besides, at Pak Shing Kok, the installation of MiC for the disciplined services quarters of the Fire Services Department by the Architectural Services Department was also completed in the third quarter of 2020. Furthermore, remarkable success was also achieved by adopting MiC in the temporary quarantine facilities with a total of 4,000 quarantine units as well as the North Lautau Hospital Hong Kong Infection Control Centre, both of which worked under very tight schedules (HKIE, 2021). In April 2020, LWK + PARTNERS, a leading architecture and design practice rooted in Hong Kong, completed the temporary quarantine facilities in Sai Kung Outdoor Recreation Centre in collaboration with Paul Y. Construction and Paul Y. – iMax to assist the government in responding to COVID-19 (Ng, 2020). It is one of Hong Kong's pilot cases for MiC, and it took only 77 days to design and build three blocks of three-storey facilities from scratch, setting a record for the city. All of these pilot projects have achieved positive results in terms of the shorter construction period and reduced manpower.

Other MiC projects in the pipeline are also expected to bring good benefits, including the Wong Chuk Hang Student Residence project for the University of Hong Kong, the Transitional Housing project at the Junction of To Kwa Wan Road and Sung Wong Toi Road for the Lok Sin Tong Benevolent Society Kowloon, the Composite Development at Ash Street, Tai Kok Tsui by the Urban Renewal Authority, and the Elderly's Home at Jat Min Chuen, Sha Tin and Subsidised Sale Flats project at Hung Shui Kiu by the Hong Kong Housing Society.

2.2.3 Current issues and opportunities of MiC

In view of the diversified benefits of MiC, as mentioned, many countries and regions are promoting MiC along with relevant policies, including mandatory requirements and incentive programs (Zakaria et al., 2018). However, at the same time, some challenges and barriers in the application of MiC cannot be ignored. Mao et al. (2015) pointed out the top three obstacles that led to the failure of MiC as lack of government regulations and incentives, high initial costs and reliance on traditional construction methods. Through an SNA analysis, Gan et al. (2018) indicated that the government and developers, as the principal stakeholders, have played the most important role in establishing intensive cooperation with other core stakeholders to overcome barriers and promote the development of MiC. This viewpoint is also supported by Luo et al. (2019), who revealed that governmental policy change is a considerable risk for prefabricated building projects. For companies engaged in prefab business, offsite facilities issues, shortage of skilled workers, financing issues, and capital investment were critical factors, and they were their particular concerns (Masood et al., 2020). For industrialized buildings, market risk, onsite management risk, economic risk, and technical risk were identified as the significant barriers that inhibit MiC implementation (Luo et al., 2015). On the other hand, for the public, the negative sentiment towards MiC adoption is mainly due to the simple design, advanced technical level, safety issues, relatively high prices, and unemployment caused by insufficient skills (Wang et al., 2019). The above-identified obstacles indicate that MiC's building performance, supportive policies, and the availability of the latest information of long-term significance are far from sufficient.

Based on literature review and field observations of typical cases in Hong Kong during the construction period, the following key issues existing in Hong Kong regarding the application of MiC were identified:

A. Complex cross-border transportation process
B. Low innovations in prefabrication techniques
C. High initial cost
D. Lack of preferential policy
E. Low standardization
F. Lack of management practices and experiences
G. Non-timely communication between the parties

A detailed explanation about each point is as follows.

A. Complex cross-border transportation process

A complex cross-border transportation process and related issues are reflected in transportation constraints, which is a unique feature of Hong Kong that is different from other places. Land resources available in Hong Kong are limited, and the suppliers have established their fabrication yards around the Pearl River Delta area as it is economical due to the lower cost of labour and land (Luo et al., 2019). Prefabricated elements, such as precast concrete panels, precast façades, precast staircases, panel wall partitions, and semi-precast slabs, are relatively large and typically very heavy. Hence, based on a pilot project considered in this study, commonly, only a very small number of prefabricated façades (5-7) can be delivered by a heavy truck at a time. During the transportation of prefabricated components, not only additional costs will be incurred, but also time consumption will be required (Chiang et al., 2006). The automated data collection techniques are popular nowadays during the cross-border transportation process (Li et al., 2016). In order to further reduce the implementation cost of data collection, ensure that real-time information in the transportation process is adequate and share information effectively among all the involved stakeholders (Xu et al., 2019), some relationship-based data exchange platforms have been proposed (such as RFID-enabled BIM platform) (Li et al., 2017), along with some of the latest information tracking technology applications (such as IoT, RFID, QR code, and NFC) (Zhou et al., 2021). For modular construction in Hong Kong, logistics usually consist of two procedures: cross-border transportation from the factory in Mainland China to the staging zone in Hong Kong (Logistics A), and local transportation from the staging zone to the construction site (Logistics B) (Luo et al., 2020). To a large extent, the cost, timing and progress of construction rely on the logistics of prefabricated module delivery. In general, it took nearly two days to transfer the prefabricated façades from the factory to the laydown yard, and it took half a day to complete Logistics A, including the customs clearance time. Complex cross-border transportation processes mainly affected the modules transportation and onsite assembly stages. In these two stages, the critical stakeholders related to this issue are the fleet manager, logistic company, truck driver, the main contractor. A lot of efforts have been made from both theoretical and technical aspects to promote the operation and management of fleet and logistics management in various fields (Xu et al., 2019), such as Internet of Things (IoT)-enabled smart BIM platform (Zhou et al., 2021).

B. Low innovations of prefabrication techniques

The core of improving the construction industry's productivity lies in technological innovations (Slaughter, 2000). The government has permanently attached great importance to promoting innovative building technologies (Zhou et al., 2021). The effectiveness of promoting MiC adoption largely depends on addressing the technical issues. Additionally, several essential factors deserve attention, including poor manufacturing capability and insufficient maturity of techniques used at the detailed design stage (Li et al., 2018). The intricate design is a multi-disciplinary process that includes assembly design and analysis, mould design, and piece and connection design (La Rocca & Tooren, 2007). The role of detailed design is to transform construction drawings into assembly drawings. This process is time-consuming as it is based on two-dimensional computer-aided design (CAD) drawings. With the development of three-dimensional (3D) modelling software and BIM technology, the way building information is represented and managed has the potential to be revolutionized (Perkins & Skitmore, 2015). However, the data interoperability between the software (e.g., Autodesk Revit, Tekla Structures, ArchiCAD, and GraphiSoft) (Steel et al., 2012) has not yet been achieved. Applicability of Just-In-Time (JIT) tools also requires technological innovations, which save construction time and enhance productivity (Bamana et al., 2019); however, there are many obstacles for JIT application that construction organizations need to pay much more attention to. Innovations in prefabrication techniques affect the modules production, transportation, and onsite assembly stages. In all these three stages, the critical stakeholders related to this issue are the chief executive officer (CEO) of the prefabrication manufacturer, production project director, production managers, production workers, main contractor, project manager, agency (HA/HS), foreman, fleet manager, truck driver, but especially the decision-makers.

C. High initial cost

A critical obstacle to the adoption of prefabricated construction is the high initial cost associated with it (Jiang et al., 2019; Mao et al., 2015), which includes the initial investment (e.g. the costs of transportation and setting up prefabrication yards), the rent of high-quality hoist equipment for vertical transportation onsite, extra expenses on labour training, and higher wages for skilled labour (Gao & Tian, 2020). While tradesmen engaged in the construction industry always expected financial support from the government to balance the high initial cost (Lee & Baldwin, 2008). High initial cost mainly affects the production and onsite assembly stages. At these two stages, the critical stakeholders related to this issue are the prefabrication manufacturer, production workers, main contractor, project manager, agency (HA/HS), and foreman.

D. Lack of preferential policy

Inadequate government incentives is a key issue that hinders the large-scale application of MiC (Wuni & Shen, 2020). The main challenge identified in this respect is the lack of preferential policy (Jiang et al., 2019). From the aspect of incentives, multiple monetary incentive schemes like Joint Practice Note 1 confines GFA exemption to an 8% cap for projects using prefabricated external walls (HKBD, 2001). However, this measure should probably be improved as time goes by, such as increasing the proportion of exemptions or expanding the scope of adoption of precast components. While the MiC practitioners always expect more preferential policies to support the development of the construction industry (Jiang et al., 2019), the government's positive response could stimulate an increasing number of contractors to invest in prefabrication housing production. According to Luo et al. (2015), preferential policies, including improving income tax incentives and subsidy provisions for MiC, would generate a high positive impact on MiC promotion. Preferential policies within Hong Kong mainly affect the onsite assembly stage. At this stage, the critical stakeholders related to this issue are the prefabrication manufacturer, main contractor, project manager, agency (HA/HS), and foreman.

E. Low standardization

Low standardization significantly affects the adoption of offsite construction (Gan et al., 2018). It causes severe compatibility problems, especially when multiple manufacturers are involved in a MiC project. Moreover, incompatibility has been a serious issue in implementing integrated, prefabricated façade development (Jiang et al., 2020a). This is mainly attributed to lacking peremptory industry norms for MiC, which has been treated as a cornerstone of the overall success of adopting MiC (Gan et al., 2019). Without a national standard, most construction components are not standardized, making it hard to design a prefabricated building. Inappropriate design codes and standards for industrialized buildings is another reason leading to low standardization (Luo et al., 2015). Although the government issued a code of practice for precast concrete construction in 2003 and updated it in 2016 (Building Department, 2016), more universal mandatory standards on MiC should be promoted. It also emphasizes the government's leading role in promoting MiC by issuing and enforcing adequate policies and regulations. Low standardization mainly affects the production and onsite assembly stages. In these two stages, the critical stakeholders related to this issue are the prefabrication manufacturer, production workers, main contractor, project manager, agency (HA/HS), and foreman.

F. Lack of management practice and experience

When following up on some representative projects in Hong Kong, it was found that prefabrication was still technologically unfamiliar to some local contractors. Most of them might have experienced projects using a few types of prefabricated components such as precast slabs, façades, and staircases, but have less experience in more complex MiC systems that could be more complicated in arrangement and installation (Li et al., 2021). With the experience gained, these contractors could be able to arrange the installation and handle the collaboration between prefabrication and onsite concreting components more effectively (Lu et al., 2018). Some project professionals mentioned that for newcomers to the construction industry or ordinary workers, lacking knowledge and expertise of MiC is a common phenomenon. The manufacturer's experience of MiC would be invaluable for achieving JIT while enhancing the overall building efficiency (Si et al., 2020). The project manager's ability to solve problems and cope with onsite management risks can be further improved through training. Lacking management practice and experience affects the production, transportation and onsite assembly stages (Jiang et al., 2018; Luo et al., 2015). In all these three stages, the critical stakeholders related to this issue are the CEO of prefabricated components manufacturer, production project director, production managers, production workers, main contractor, project manager, agency (HA/HS), foreman, fleet manager, and the truck driver, especially those involved in decision making.

G. Non-timely communication between the parties

Severe inconsistency between production, transportation, and onsite assembly shows poor communication among stakeholders, which is revealed as one of the root causes of poor supply chain management and low adoption of MiC (Luo et al., 2019). Poor interactions between stakeholders may be due to ineffective communication (Luo et al., 2020). Progress updates and changes were exchanged mainly by email, WhatsApp, and hard copies of project documents, resulting in weak coordination between the upstream production of precast components and their downstream demand (Li et al., 2016). Poor communication between stakeholders affects the production, transportation and onsite assembly stages (Xu et al., 2021). At these three stages, the critical stakeholders related to this issue are the CEO of the manufacturer, production project director, production managers, production workers, main contractor, project manager, agency (HA/HS), foreman, fleet manager, and the truck driver, especially those involved with decision-making.

The key issues reflect the limitations of temporary organizations, which are the features of construction projects, particularly the network associations among different policies and stakeholders. Such relationships reveal the uptake of MiC over time in the complex systems of the construction industry. In addition, the construction sector's CI drivers (usually government, clients, and industrialization technology suppliers) are pressured to develop suitable measures to tackle these problems effectively. Since policies are adopted in complex social contexts where multiple interactions among stakeholders influence their performance, it is vital to fully understand the social environment and examine the impact of MiC policies on its uptake. The systematic literature review approach provides comprehensive insights into the realistic social backdrop of MiC uptake and the dynamic interactions among stakeholders. From the previous research findings, legitimacy is the most important attribute of stakeholders, indicating that support from the government is necessary to promote different MiC policies on its uptake. Thus, these above-mentioned issues existing in the current context of Hong Kong also provide opportunities for the whole construction industry to promote MiC through policy-driving forces vigorously. In response to the above key issues, the following chapters will discuss in detail the policy implications and recommendations that can promote the MiC uptake in Hong Kong from different perspectives (PDFs and stakeholders).

2.3 Common Research Themes on CI Policies

MiC is an important advanced stage in the construction industrialization (CI), while it is still in its early stage of development. In order to comprehensively understand its development themes, this section broadens the scope of the review, analyzing and summarizing all existing works of literature related to construction industrialization policies (CIP).

2.3.1 Selection of reviewed papers

A systematic literature review (SLR) methodology, which is followed in this study, is explained in detail in this section. The review methods adopted in the related CI research (Kamali & Hewage, 2016; Li et al., 2014; Wang et al., 2019) have provided beneficial guidance when picking out the target academic articles that fit the topic in the CI research area. Accordingly, systematic analysis of published papers is often used for reviewing and exploring various knowledge domains in research (Corbin & Strauss, 2008). Given its obvious advantages such as efficiency, availability, stability and cost-effectiveness (Bowen, 2009), a systematic review of literature is applied in this study.

The current study selected the Web of Science (WoS) core collection and Scopus as the database to search for articles that are applicable since they are the most frequently used international databases for conducting literature reviews. Considering that this study is focusing on the CIP research domain, combinations of the keywords are set, namely, 'construction industrialization', 'industrialized building/housing', 'modular construction/building', 'prefabrication', 'prefabricated construction/building', 'precast concrete', 'off-site construction' and 'policy*' (where * means policy or policies in searching) as the basic searching criterion. Documents consisting of these phrases in their title or abstract or keywords were examined during the study. The purpose was set to acquire just the original and review papers on CIP, making the results more accurate and convincing. The rest, such as proceedings articles were excluded, for the reason that they contribute very little to the outcomes and yet, would not be beneficial to the analytical practice (Butler & Visser, 2006). Therefore, the search results were further purified by refining the document types as article or review, and based on the science categories of environmental sciences, engineering environmental, green sustainable science technology, engineering civil, construction building technology, engineering industrial and urban studies. Nonetheless, some irrelevant papers still appeared in the search results under the rigorous selection criteria. After a thorough scanning of the abstracts of these articles, the unrelated papers were excepted. Eventually, 105 CIP-related papers were filtered and retrieved for further review.

2.3.2 Characteristics of the target papers

2.3.2.1 Annual publications trend

Based on the systematic and comprehensive search in the Web of Science and Scopus database and following the publications selection criteria given above, 105 publications related to CIP over the period to 2021 were extracted and analysed further in this study. The development of the knowledge domain spanning between 1992 and 2021 is illustrated in Figure 2.2, which indicates the annual publications trend of CIP. Among these selected publications, there are 99 journal papers, which accounted for 94%, and the other six publications are review papers whose proportion is 6%.

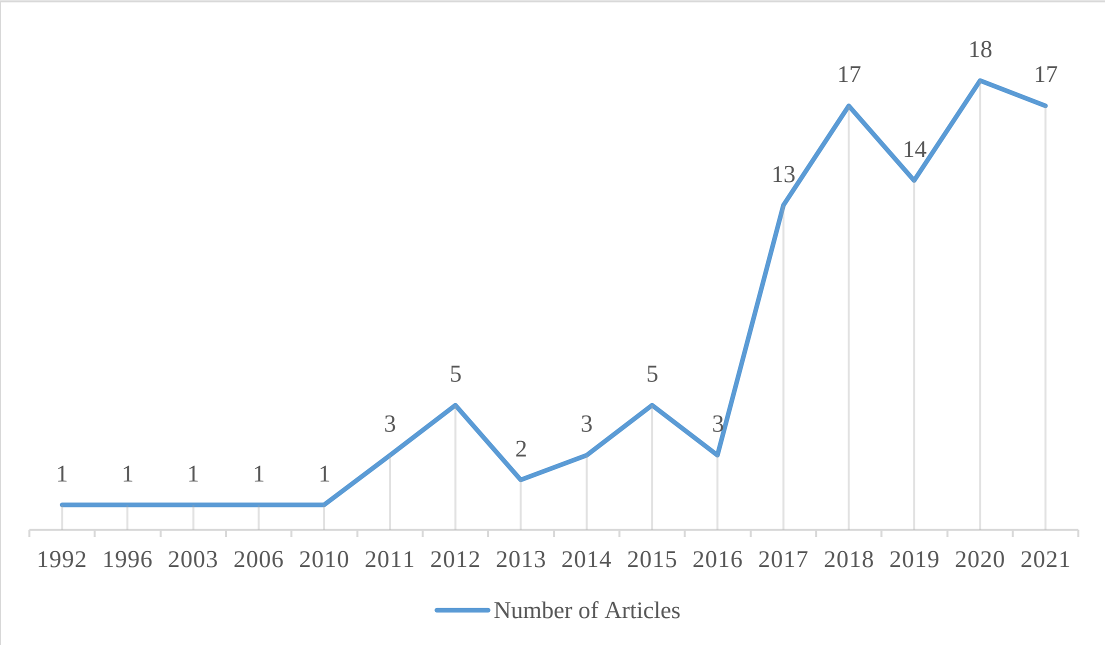

Figure 2.2 Annual Publications Trend on CIP from 1992 to 2021

Figure 2.2 shows the variations in the quantity of the selected yearly journal publications on CIP during the 30-year research period (1992-2021). As can be seen, a general and gradual rate of increasing trend is there from 1992 onwards. The previous 30 years can be further subdivided into three stages: 1) 1992-2010, when the emergence of CIP maintained a relatively slow pace of development with the number of annual journal articles issued no more than 1 in the databases, and there were only five papers recorded in total during this 9-year period; 2) 2011-2016 when the emergence of this topic had been on the rise, varying between 2 to 5 yearly; and 3) since 2017 the annual academic journal papers has risen steeply to 13 or more, with the highest number of 18 in the year 2020. Specifically, the publications in the last five years (2017-2021) contributed the largest percentage (79, 75%) of the total included articles. It is worth noting that the number of journal publications in 2021 is incomplete as the chosen research papers in 2021 were up to July of 2021. Figure 2.2 also highlights that the CIP research area gained a rising interest among researchers over the last decade (2011-2021). This is validated by the findings of Li et al. (2014) that CI is becoming progressively valuable to the whole construction manufacturing, along with the research topic named guideline and policy in CI had been identified as principal research direction of industrialized building studies following the development of some innovative technologies and approaches. Therefore, under this current increasing trend, it is expected that the CIP implementation would keep enriching over the intervening years, and this research is of value in contributing to the CIP development.

2.3.2.2 Geospatial distribution of the involved papers

Academic and public research plays a vital role in industrial research and development (R&D) (Cohen et al., 2002), particularly in the construction industry. Moreover, existing studies in different regions are more targeted and give significant guidance to the formulation of local policies in corresponding industries. Wuni et al. (2019) also illustrated that the construction field in one country, where previous research practise is not available, could learn some experiences based on published verification from other nations to design policies in line with their own circumstances. Thus, it is of some significance to emphasize the geographical distribution of the involved publications on CIP for promoting CI application. The basis of the distribution figure is the idiographic regions studied in each included article instead of the country where the authors belong. The included literatures are categorized by their geographical context, as indicated in Figure 2.3, showing geospatial distribution.

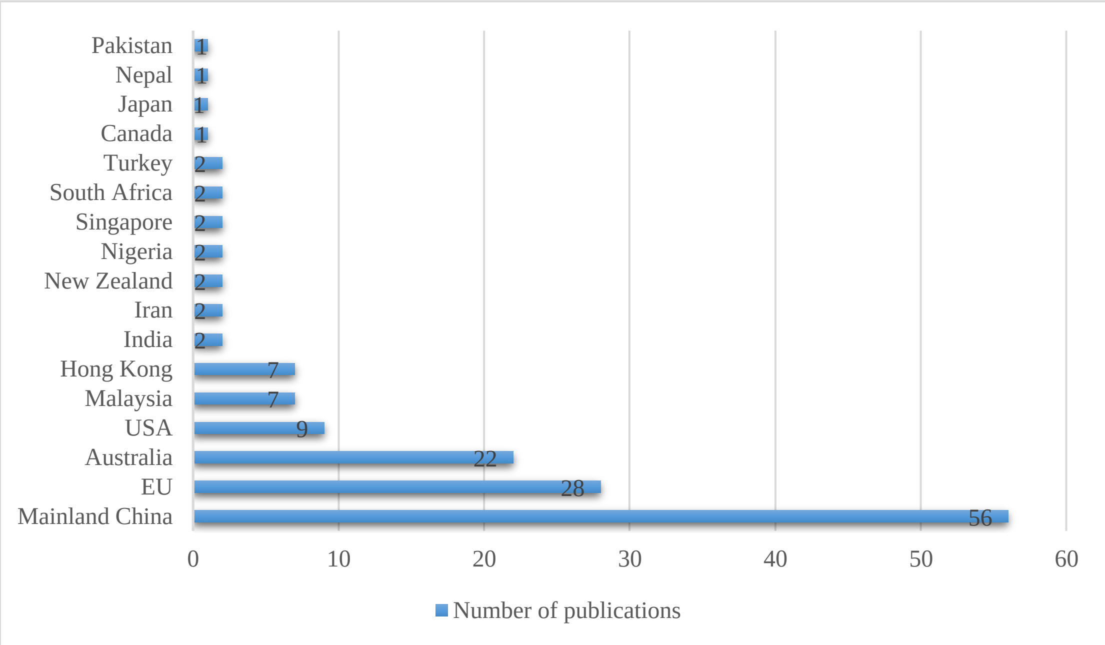

Figure 2.3 Geospatial Distribution of the included CIP Publications

The statistical records in Figure 2.3 reveal that 17 different regions have contributed at least one CI-related paper independently to the CI policy implementation research. The sample provides a typically broad perspective on CI policy promotion within the globe, for developing, transition and developed economies are all included in these nations. Some countries have more leverage than others in the CIP research discourse. The slightest territorial contributors contain Canada, Japan, Nepal, and Pakistan with only one publication respectively, whereas the six leading contributing countries or regions to the development of CIP research include the Mainland China (56), (European Union) EU (28), Australia (22), USA (9), Malaysia (7) and Hong Kong (7). These states, the biggest contributors, account for a substantial proportion of cutting-edge research to spearhead the improvement, promotion and application of CI. Among all the 17 regions, China is the dominant contributor, with 56 articles in the mainland and seven publications from Hong Kong over the study period. This finding is consistent with the current situation because China is the top market for construction around the world (Han & Wang,

2018) and continuously devotes many efforts to the effective promotion and implementation of industrialized residential building (IRB) policies (Li et al., 2018). Thus, sorting and generalizing policies in CI from these selected countries could suggest the advanced international experience, which could be valuable to the guidance of CI policies' promotion.

2.3.2.3 Citation analysis toward CIP related research

The authors of the targeted papers are recommended to indicate their reference foundation when a fresh derivative conception is proposed; in support of the findings, some convincing citations should be presented to be the evidence (Li et al., 2014). Therefore, a detailed citation index analysis, normally applied as one of the effective methods for the assessment of the impact of a specific journal or article, is carried out in this study. In general, a larger quantity of citations a paper records usually illustrates that this article is regarded as a pioneering publication, albeit not suitable for all situations (Wuni et al., 2019). Citation statistics of the involved 105 documents were examined to extract the landmark publications in the domain of CIP.

Table 2.1 presents the most frequently cited journals. By setting the lowest number of citations of a periodical to 40, this study found that 11 of 50 research journals crossed the threshold. The influence of a journal in the field of CIP is assessed by its total cited counts, number of related papers published and citations per paper. Among the 11 high-referred journals, the *Journal of Cleaner Production (JCR)* was the most frequently cited journal, with a maximum number of citations up to 534 times, followed by *Energy and Buildings* (*EB*) with 219 referrals and *Habitat International (HI)* with 193 referrals. In terms of average per item, papers in *HI* were most cited (96.50 times per article), while those in the *Journal of Management in Engineering*

(JME) and *EB* had been cited 92 and 73 times, respectively.

Table 2.1 Most Frequently Cited Journals

Journal	Total times	Number of papers	Times per paper
Journal of Cleaner Production	534	18	29.67
Energy and Buildings	219	3	73.00
Habitat International	193	2	96.50
Journal of Management in Engineering	184	2	92.00
Resources Conservation and Recycling	110	4	27.50
Journal of Construction Engineering and Management	81	5	16.20
Engineering Construction and Architectural Management	77	3	25.67
Sustainability	70	10	7.00
Journal of Construction Engineering and Management ASCE	69	2	34.50
Sustainable Cities and Society	61	4	15.25
Land Use Policy	40	3	13.33

In Table 2.2, the top 15 most-cited influential research papers in CIP based on citations and the sum of frequencies each article was cited is recorded. These papers spanned from 2006 to 2018. The article by Mao et al. (2013) from Chongqing University was identified as the most frequently referred literature, reaching a maximum of 186 times citations totally, followed by Mao et al. (2015), Chiang et al. (2006), Cao et al. (2015) and Zhang et al. (2014) of 151, 113, 104 and 80 times, respectively. The 15 pieces of literature listed in Table 2.2 represent the most referenced publications related to CIP research. This exercise exposes an emphasis on the obstacles and challenges of CIP-related research in the context of government policy on CI, as well as comparative studies of sustainable buildings or environment-based residential projects between off-site prefabrication and traditional construction methods. By implication, the successful implementation of CI policies can be linked to overcoming barriers, sustainable consumption, and zero waste in CI development.

Table 2.2 Most Frequently Cited Papers

Document Title	Times
Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects. (Mao, C., Shen, Q. et al., 2013)	186
Major Barriers to Off-Site Construction: The Developer's Perspective in China. (Mao, C., Shen, Q.et al., 2015)	151
Prefabrication and barriers to entry-a case study of public housing and institutional buildings in Hong Kong. (Chiang, Y. H., Hon-Wan Chan et al., 2006)	113
A comparative study of environmental performance between prefabricated and traditional residential buildings in China. (Cao, X., Li, X. et al., 2015)	104
Exploring the challenges to industrialized residential building in China. (Zhang, X. et al., 2014)	80
A holistic review of off-site construction literature published between 2008 and 2018. (Jin, R., Gao, S. et al., 2018)	79
Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. (Li, Z., Shen, G. Q. et al., 2014)	77
A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. (Jiang, R., Mao, C. et al., 2018)	64
Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction. (Pan, W. et al., 2012)	64
Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. (Gan, X., Chang, R.et al., 2018)	60
Evaluating the transition towards cleaner production in the construction and demolition sector of China: A review. (Ghisellini, P., Ji, X. et al., 2018)	52
Adoption of prefabricated housing-the role of country context. (Steinhardt, D., & Manley, K., 2016)	50
Risk factors affecting practitioners' attitudes toward the implementation of an industrialized building system a case study from China. (Luo et al., 2015)	50
Optimizing urban material flows and waste streams in urban development through principles of zero waste and sustainable consumption. (Lehmann, S., 2011)	45
BIM Investment, Returns, and Risks in China's AEC Industries. (Jin, R., Hancock, C. et al., 2017)	41

2.3.3 Classification and Correlations among existing studies on CIP

To enhance the comprehensive understanding of CIP, the selected scientific papers were explored and categorized by conducting two steps. First, the objective policies and specific strategies in relation to CI mentioned in the journal papers were thoroughly and carefully extracted based on their statement. Second, the categories of the CIP within the studied period were established upon analysing and sorting the data collated in the previous step. Further, exploratory research was carried out on the discovery of internal correlations among the classified policies. The findings from this classification and interrelationships among CIP can reveal the focus of current policy for this discourse, as well as better promote the implementation of CI policy step by step.

CIP-related research has witnessed continuous growth throughout the last few decades. The CIP research field is characterized by its different policy preferences and directions, from promoting the technological development of the industry to achieving overall green and sustainable industrialization. This study extracted all the related details about policy from a set of published papers through systematic and comprehensive exploration analysis and repetitive assessment. Accordingly, this study classified the CIP into seven categories according to their underlying common themes: (1) regulative policies, (2) standardized policies, (3) promotional policies, (4) urbanized policies, (5) technical policies, (6) managerial and educational policies, and (7) sustainable policies.

Among these seven CI policy types, regulative policies refer to the regulations and policies formulated by local governments to impose controls and restrictions on the implementation of CI; standardized policies aim to normalize the practices of CI and help codify the best practices and technical requirements; promotional policies are the ones carried out by governments to stimulate the markets, usually pursued by various stimulus initiatives and incentive measures; urban design and planning policies tackle the issues while bringing the CI into urban design and urban development; technological policies focus on the application of emerging CI technologies and innovations which can be better reflected in CI practice; managerial and educational policies provide guidance on workforce management and effective educational programs to the relevant stakeholders in CI; and sustainability policies aim to help achieve sustainability around the use of CI from economic, social and environmental aspects. The classification of this study is established from the perspective of instrument purpose and mandatory degree. As defined by Mao et al. (2015), several clusters associated with critical factors in CI practice included regulations, technological innovations, and economic incentives. Luo et al. (2015) emphasized the governments' leading role in promoting the standards for CI buildings and enhancing management and education practices. When analysing prefabrication policies, Gao et al. (2020) revealed urbanization and sustainable development could encourage the widespread use of CI. In line with the existing groupings related to CI research, this study classified the seven policy types by relating CI to the regulative system, economic development and sustainable conditions.

However, there is still a limitation: as is well known, the nature, purpose and impacts of policies are pluralistic and not absolute. Moreover, the criteria for this categorization are not absolute. Therefore, the categories are not utterly separate from each other. Such as the 'housing policy' pertains to 'regulative policies', while it is also slightly related to 'urban design and planning policies'. Because when considering the degree of strictness by government, 'housing policy' is an obligatory instrument and be treated as the cornerstone of other policies. The following sections describe the structured framework of these specific topics in detail.

(1) Regulative policies

- Public Procurement Law
- Governmental mandatory policies and regulations
- Intervention strategies

- Buildability score regulation
- Requisition–Compensation Balance policy
- EU construction policy
- Industrialized Residential Building (IRB) policy
- Advance industrialization of the construction industry policy
- Improved real estate policies
- Housing policy
- Land Development Plan & Control & Supply & Restructure Regulation

Literature on the first category of the CI policies mainly focuses on the policies and regulations formulated by the governments to impose controls and restrictions on CI. The Public Procurement Law (PPL) in Turkey, which has been modified extensively in recent years (2002-2014), has limited the powers of the Public Procurement Authority (PPA) to adjust the public land sales and other building-based government procurements after the revisions. At the same time, these reforms impeded the transparency of the procurement in the real estate development sector (Demiralp et al., 2016), hindering the development of CI. The absence of governmental mandatory policies and regulations is identified as one of the top three barriers in China for CI development in the construction industry (Mao et al., 2015). Han and Wang (2018) also considered governmental regulations as one of the six important aspects that limit CI improvement by using grey DEMATEL analysis. Jiang et al. (2018) emphasized the importance of governmental mandatory policies and regulations in CI development on the basis of a thorough review of 85 governmental documents and by conducting a SWOT analysis.

On the other hand, governmental mandatory policies and regulations are listed as the most critical driving force to transfer the model of traditional construction to CI (Liu et al., 2017; Mao et al., 2018) and promote CI-related technology such as building information modelling (BIM) (Jin et al., 2017). Based on fuzzy cognitive maps, Gan et al. (2019) concluded that strengthening intervention strategies yields the strongest whole effect in promoting CI. The construction industry grew rapidly in Turkey between 2002 to 2006, and the growth was mainly supported by state interventions (Demiralp et al., 2016). The Singaporean government started to enforce the buildability score regulation from 2001, in which a minimum buildability score in building designs is required, aiming to accelerate the diffusion of CI into the private sector (Park et al., 2011a). Requisition–Compensation balance policy is also helpful to narrow the spatial discrepancies between obtainable construction land and existing development requirements (Dang et al., 2015), which is fundamental to the CI process. In China, the government shall play a leading role in promoting perfricated construction, and among the policy factors, the regulatory mechanism is revealed to be the most influential factor (Jiang et al., 2020b).

Regarding the policies which are directed towards any specific country, the EU construction policy has been established to standardize functional building codes (Tykkä et al., 2009), and China introduced the IRB policy for construction enterprises that still need to improve (Li et al., 2018; Zhang et al., 2014). Dou et al. (Dou et al., 2019) suggested that the government should issue advisable policies with higher priority for leading provinces to achieve the differentiated promotion of prefabricated construction. The development of advanced industrialization of construction industry policy and improved real estate policies have proved to be the applicable way to manage the housing bubble (Huang et al., 2018). Housing policy, such as ‘measures of Beijing on the reward for IH residential Projects’ which was issued in 2010 (Zhang & Skitmore, 2012) and some measures for introducing CI into the current construction system in Romania (Mare, 2018) and the USA (Goodman, 2017), as well as adjusted rents and the focus rearrangement from hiring to ownership in the Czech Republic

(Zarecor, 2012), are dedicated to encouraging the popularization of CI proactively. The law on land development and control in Turkey simplified the procedures for acquiring building permits, thus promoting property development (Demiralp et al., 2016). Land supply regulation is an intermediate step, which serves to improve real estate policy (Huang et al., 2018). Land-restructuring regulations in China indicate an 'increasing versus decreasing balance', which plays a significant role in rural construction industrial development (Zhao & Zhang, 2017). In developing countries such as Libya, the development of prefabricated buildings is considered to be at a starting point, as most of the industrial practitioners were unable to receive plentiful knowledge of regulative policy guidelines (El-Abidi et al., 2019). To the developed context such as the U.S., regulatory barriers are essentially recognized in the built environment to implement circular economy principles, especially the inconsistency in environmental regulations at city, state and federal levels (Guerra & Leite, 2021). From the foregoing, it concluded that regulative policies enforced by the government are a critical and indispensable cornerstone for promoting CI in the construction industry.

(2) Standardized policies

- Regional precast construction standards
- Building prefabricated components design codes standards
- Design level standards
- Construction quality acceptance criteria
- Prefabrication technical and construction method standards
- Housing technology standards
- Site selection criteria

Articles about the second category of CIP concentrate on standardized policies, which help codify best practices and technical requirements to ensure structures are safe and proper. According to Wang et al. (Y. Wang et al., 2019), low standardization was listed as a major barrier for CI promotion in China, indicating the relevant standard specification system should be continuously improved over time. In Mainland China, regional level policies associated with CI standards are biased. Research conducted by Zhu et al. (2018) revealed that particular emphasis was placed on precast construction standards for central rapid-developing areas such as Yangtze River Delta (8 standards) and Bohai Economic Rim (5 standards), while the specific and targeted standards relevant to the CI were still rare in the 'backwater' regions such as northwest and southwest China (1 standard). Therefore, refining and enhancing the regional precast construction standards, especially in some less developed areas, is not only necessary but urgent in order to achieve an overall highly evolved CI in China. There have been numerous studies showing that inappropriate or non-existent design codes and standards for prefabricated components in industrialized buildings are a critical political factor related to inefficient adoption and poor performance of CI (Han & Wang, 2018; Lu et al., 2018; Luo et al., 2015; Mao et al., 2015; Zhang et al., 2014). Both developed and developing regions have issued regulations associated with building design codes, such as the 'Code of Practice for Precast Concrete Construction 2016' produced by HKBD (2016); the 'Precast Concrete Construction Handbook' prepared by the HKIE (2003, 2015); the China State Council Announcement (2016); 76 local codes for assembly building design issued by 24 provinces and autonomous regions (Jiang et al., 2018) in Mainland China; EU policies relating to the creation and harmony of building codes (Tykkä et al., 2009); and improvement of design guide and new codes and standards in New Zealand (Masood et al., 2020) and Australia (Evison et al., 2018). The relatively low level of standardization in designing was recognized as one of the major barriers and challenges by Li et al. (2017) in the piping prefabrication areas.

After a comprehensive literature review and in-depth interviews with many CI industry professionals, Han and Wang (2018) found that the lack of acceptable construction quality criteria is an obstacle to CI adoption. The reality is that reliance on conventional construction methods is still one of the three foremost barriers to CI adoption (Mao et al., 2015) and that the enhancement of prefabrication technical standards and optimization of construction methods (Evison et al., 2018) is urgently needed in the emerging CI market (Jin et al., 2017). A range of housing technology standards, listed as 'Technical Assessment for Residential Projects' and 'Standards for Modular Combination of Residential Houses', and so on, have been supported by Chinese authorities for CI development (Zhang & Skitmore, 2012). A study was conducted by Azman et al. (2012) on the site selection criteria after the endorsement of a CI application for domestic buildings in Malaysia, in which 15 site selection criteria were analysed through a literature review, questionnaires, and ANOVA statistical test. The aforementioned standardized policies emphasize the leading role of the government in promoting CI to the construction manufacturing industry.

(3) Promotional policies

- Industrialized housing and off-site construction (OSC) adoption policies
- Design-build contracts encouraging policy
- CI market acceptance encouraging policy
- IH residential projects rewarding policy
- Governmental economic incentive push or supportive policies
- Governmental preferential policies
- Interest-free finance policies
- Government subsidies and fines policies
- Welfare measures
- Insurance policy terms

The third category of the CI policies explores what stimulus initiatives and incentive measures have been introduced to vitalize the market and increase the share globally. Findings by Zhang and Skitmore (2012) and Gan et al. (2018) indicate that formulating policies and strategies are required to encourage industrialized housing and to effectively facilitate the adoption of offsite construction in China. Lu et al. (2018) developed a systematic framework to determine the optimal prefabrication adoption level under different political backgrounds. The Singaporean government has made a great effort to encourage the application of CI in the private sector, and one way was by encouraging private projects to employ design-build contracts (Park et al., 2011a). By taking a mixed system approach, Zhang et al. (2017) took inspiring market acceptance of CI as a countermeasure in policy management from a Chinese firm perspective. China has also announced many policies at the regional level. The Chinese government issued a housing policy named 'Measures of Beijing on the Reward for IH Residential Projects' in 2010, in which three per cent of all construction work should be assigned to industrialized housing (Zhang & Skitmore, 2012), to encourage the rapid development of CI. Both developed and developing countries have issued corresponding administrative and economic incentives, such as Turkey (Demiralp et al., 2016), EU (D'Oca et al., 2018), China (Mao et al., 2015; Wuni & Shen, 2019), Iran (Nikmehr et al., 2017) and Singapore (Park et al., 2011a). However, from investigation and analysis, it can be concluded that imperfect or non-existent government economic incentives or support are one of the foremost barriers to adopting CI (Zakaria et al., 2018; Han & Wang, 2018; Mao et al., 2015; Wuni & Shen, 2019; Zhang et al., 2014).

Persistent policies and incentives have been revealed as the critical success factors influencing the successful implementation of CI (Li et al., 2018; Lu et al., 2018). A hybrid model of prefabricated construction has indicated that the government, the developers, and buyers can share the external benefits of the prefabrication implementation by 38%, 35% and 27%, respectively (Zhou & Ren, 2020), which could motivate their enthusiasm in future CI practices. Interestingly, reputational and financial incentive policies are found to behave the most effective for real estate enterprises to adopt industrialization. However, they do not apply to consumers (Zhou et al., 2019). The latest research has pointed out that incentive policies shall focus not only on real estate enterprises, but also give emphasis to consumers, manufacturers and contractors (Wang et al., 2021). In order to further accelerate the promotion of CI for public and private building construction, a series of incentive schemes have been proposed. For example, the GFA compensation for modular integrated construction was mentioned in Joint Practice Notes No. 1 and No. 2 of the HKBD (Jiang et al., 2018; Lu et al., 2018; Mao et al., 2018), and more floor areas are permitted to be built through the planning gains mechanism driven by the statutory authorities (Chiang et al., 2006). The Chinese government also released a series of incentive policies, from central to the provincial level, to promote CI (Li et al., 2018; Liu et al., 2017) by providing a 'green channel' for CI projects (Chen et al., 2017), and increasing supportive efforts to small and medium-sized enterprises (Du et al., 2021). CI, as a low-carbon construction method, incentive policies should be formulated accordingly, such as financial subsidies or tax relief (Zhang et al., 2021).

Particularly, with regarding economic incentives, fund support, tax privileges and floor area rewards are the three ways that work excellently for promoting prefabrication in the Chinese context (Jiang et al., 2019). Other financial support, such as tax deductions (Jiang et al., 2018; Lu et al., 2018), also applies if a project has reached several requirements in applying CI. On account of the state interventions, in the form of administrative and economic incentives, the construction industry in Turkey flourished rapidly in 5 years, starting from 2002 (Demiralp et al., 2016). Financial support schemes in the EU are essential to speed up deep reformation in the CI market (D'Oca et al., 2018). Iran also offered incentives to sites that produce less construction waste (Nikmehr et al., 2017), which can be achieved by adopting CI.

Governmental preferential policies in China stimulated an increasing number of contractors to invest in prefabrication housing production (PHP) (Li et al., 2018). Singaporean prefabrication policy included interest-free finance provided to PHP contractors, plants and purchasers, leading to the successful application of CI in public housing (Park et al., 2011a). Based on simulation results, Li et al. (2014) claimed that when compared with income tax incentives, subsidy provisions for CI adoption in the construction industry generates a higher positive impact on CI promotion and construction waste reduction, which is the practice in Singapore (Park et al., 2011a) and China (Liu et al., 2017). Tesla (2018) suggested that Indian construction policies should pay more attention to improving the welfare of building workers for CI development. Insurance policy terms were discussed by Demartino et al. (2017) when considering the seismic economic losses of CI buildings. As mentioned above, promotional policies involve a variety of forms and measures, which could be used as means or paths to further promote the CI application in the field of construction.

(4) Urbanized policies

- Urban design and reform policy
- Distinct urban policy
- Socialist urban policies

The selected academic papers regarding the fourth category of CIP are namely urbanized policies, which tackle how cities grow and expand. Lehmann (2011b, 2011a) indicated that it was time to bring CI into urban design systems, which would benefit from reduced waste. Monclús and Medina (2016) investigated the role of urban design in the process of CI growth in Europe. At the same time, urban reform policy came up as a solution to improve the matter of slow growth of CI in Turkey (Demiralp et al., 2016). Different urban policy in eastern and western cities of China explain their unbalanced development of CI. In eastern towns, socialist urban policy leads housing estates towards both traditional and CI buildings (Monclús & Díez Medina, 2016). Notably, the capacity of construction land stays large as highly developed Chinese cities are still in rapid industrialization (Jin et al., 2020), so corresponding policies have emerged. For example, the 'National New Urbanization Plan (2014–2020)' (NNUP) in China is a ground-breaking urbanization scheme that has been stated to help reach national urbanization targets as well as improve the competency of the construction industry. In addition, CI promotion is a strategy involved in NNUP. These urbanization policies are indirectly promoting CI development. On the other hand, it is precisely what is needed for urbanization to drive CI-relevant policy. Moreover, the urbanized policy is a way to expand CI adhibition, and the wide range of CI applications is a manifestation of urbanization.

(5) Technical policies

- CI technology research and development promotional policy
- CI application level improvement policy
- Technology-to-productivity enhancement policy
- Technological Innovation (TI) policy
- BIM practical authority policy
- Industrialised Building Systems (IBS) technology promotion tailored policy
- Efficient government supervision systems and regulatory enhancement policy
- Technical guidelines and instructions

The selected articles in the fifth category generally focus on the applications of emergent CI technologies and innovations which can be better incubated in future practice. In China, given the fact that CI technology development is still in its early stage, when compared to other regions or countries where CI is highly developed, Cao et al. (2015) suggested that government should take targeted measures to encourage CI technology-related research and development in the Chinese prefabricated residential building (PRB) industry. Apart from CI technology research and development promotional policy, emphasis should be placed on inspiring policies to enhance the CI technology application level (Liu et al., 2017). Based on the entropy method and average score method, Zhang et al. (2017) identified the challenges of CI and policy management and put forward some measures to encourage the transfer of CI technology into productivity. Jean-Louis Cohen asserted that TI would bring about the supremacy of modernism in architecture (Mare, 2018). Guo et al. (Guo et al., 2021) showed that technological progress contributes to curbing the increase of industrial pollution emissions, indicating the government should support technological innovation. According to a thorough investigation conducted by Mao et al. (2015), TI was listed as one of the critical factors among the five categories inhibiting the adoption of CI in the Chinese construction industry. Mao et al. (2018) further identified TI as an essential driving force to promote CI development. Thus, devoting more effort to systematic TI in the PRB industry is strongly suggested (Han & Wang, 2018; Lehmann, 2011b).

TI policies formulated by the government also encourage CI builders to carry out TI research and development to improve construction efficiency (Chen et al., 2017). However, when adopting TI in the PRB industry, the attitudes of labour unions should be taken into account since they play a vital role in the diffusion of TI, especially in western countries (Gan et al., 2018). BIM is one of the most beneficial advancements in the architectural, engineering, and construction (AEC) field (Eastman et al., 2011). When accurate virtual models are constructed digitally with BIM technology, the precise geometry information contained could be used to support the CI activities required to realize prefabricated buildings. An empirical study conducted by Jin et al. (2017) suggested the relevant public authorities formulate policies on BIM practice and applications in the AEC industries. However, the industrialization of building in BIM is highly capital-dependent. Companies are suggested to organize experts to effectively evaluate the risks in BIM uptake at all stages of an industrialized building construction project (Wu et al., 2020). Moreover, there are other technologies, such as virtual construction management platforms, that enable automated functions throughout the life cycle of a building (Hajdukiewicz et al., 2019). IBS is considered to be a vital construction system with obvious advantages in terms of cost, schedule, quality, labour demand, and environmentally friendly (Luo et al., 2015; Mydin et al., 2014).

In Malaysia, IBS is a recognized term used to describe the CI concept (Azman et al., 2013; Lu et al., 2018). IBS technology is a prevalent and flourishing building technology in many western and eastern countries, which concentrates on offsite prefabrication and modularization. Its adoption is relatively sluggish, so tailored policy approaches should provide adequate support to promote the IBS technology implementation (Zakaria et al., 2018). Based on fuzzy set theory and through a questionnaire survey conducted in China, Zhang et al. (2014) found that well-organized government supervision systems and regulatory mechanisms are insufficient at the current stage to generate enthusiasm for the CI development. To improve the operability of CIP, an exploratory study carried out by Li et al. (2018) suggested that supportive technical guidelines and instructions are essential. Science and technology are the primary productive forces, and technical policies actually better promote CI development through technology as an implementation approach; in turn, the wider range of CI applications promotes advances in technology. Technological advancements can help the construction industry evolve (Zhang et al., 2019), which also necessitate the proliferation of technical policies.

(6) Managerial and educational policies

- Human resource management policies
- Effective cooperation between research institutions and enterprise policies
- Proper training programs supportive policies
- Stricter safety policies
- Risk management decisions
- Preventive maintenance policies
- Company supply-chain policies
- Performance management policies

Academic articles about the sixth category policies mainly concentrate on effective management and educational training programs among stakeholders. Human resource management has been identified to be an important factor that could affect industrialization policies based on current literature (Becker et al., 2014; Collins & Perret, 2015; Solnosky et al., 2015; Zhang et al., 2017). Specifically, by applying STRO- BOSCOPE simulation techniques, Wang et al. (2012) found that a reliable work scheme was more useful than just keeping employees busy when comparing different policies. However, it takes time for a corporation to change its labour policy to adapt to CI processes, so much more effort should be put to stimulate prefabrication adoption by the private sector (Park et al., 2011a). Resource planning has an essential impact on project performance after comparing multiple change-management policies (Ansari, 2019). Nasirian et al. (Nasirian et al., 2019) also investigated different resource management policies, such as hiring multiskilled crew to optimize the prefabrication projects. Research conducted by Zhang et al. (2017) found that substantial policy management is needed in the local construction industry to improve its sustainable CI levels and that enhancement policies on practical cooperation among research institutions, universities and companies should be a priority.

In the legal dimension, adequate OSC skills and qualifications highlight that CI development has reached a certain level (Han & Wang, 2018). During the design stage, it is found that increasing investment in designers' professional training and strengthening policies are two efficient strategies to make full use of the potential prefabrication methods (Yuan et al., 2021). Luo et al. (L. Luo, Liang, et al., 2020) also implied that organizing educational and training programs for manufacturers, contractors, and clients is an effective way to enhance their expertise, thus reducing supply chain risks. On the other hand, educating the public can improve people's knowledge level and awareness level and further reduce the investment from stakeholders in labour education (Jankovic, 2019; Wu et al., 2021). CI requires practitioners to be equipped with a higher skill set for operating the IBS, so the government needs to provide suitable training programs effectively (Luo et al., 2015). For example, the Singaporean government offered consciousness forming and skill up-gradation programs to several private sector organizations to encourage them to increase prefabrication adoption (Park et al., 2011a). Australian researchers also claimed that skills embedded with industrialization- and digitalization-driven technological advancements are urgently needed (Ginigaddara et al., 2020). The attitudinal change towards CI is considered to be significant, so raising awareness with efficient education programs and policies is necessary (Lehmann, 2011b, 2011a). Zakaria et al. (2018) suggested that stricter safety policies, such as mandatory safety awareness-building programs, should be in place to better protect the life security of project staff when they are moving large prefabricated components. Risk awareness is particularly important, especially in the construction industry. Adopting suitable risk management policies and methods (Luo et al., 2015) is undoubtedly necessary to promote CI application in China, and Demartino et al. (2017) has proposed a probabilistic estimation model to help stakeholders make risk management decisions in relation to the risks associated with CI buildings.

Company policy on preventive maintenance is also promising. Although machinery maintenance costs are high, this policy is helpful for JIT implementation during CI application (Oral et al., 2003), as well as for reducing inventory levels. The supply-chain policy of a company is especially important (Oral et al., 2003) to avoid prefabricated component production deferrals, and the related manufacturers should be in reasonable control of the production line and the supply chain to manage inventories. Globally, stakeholder relationships management featured by collaboration, supply chain management, housing and social network analysis is frequently mentioned in off-site construction (Nguyen et al., 2021). Wong et al. (2017) suggested that construction project organizations (CPOs) should pay more attention to performance management strategies when they commit to institutionalizing an organizational change in the face of CI promotion. These managerial and educational policies indirectly promote CI application from the perspective of organizational management and ideological education.

(7) Sustainable policies

- Sustainable buildings supportive policies
- Environmental impacts of consumption and production reduction policies
- National environmental legislation and policy
- Green construction evaluation standards
- Construction waste reduction policies
- Extended producer responsibility (EPR) policy
- ‘polluter pays principle’ guideline
- Construction and demolition wastes management (C&DWM) & recycling policies

- Carbon emissions mitigation policies
- Energy-saving policies

Literature related to the seventh category of the CI policies put an emphasis on sustainability, which integrates economic, social, and environmental concerns. In today's society, developing a circular economy to fundamentally make full use of resources and step on the road to industrialization is a frontier topic related to many industries (Sun, 2021). Big data, supply chains, industry 4.0, carbon emission, and policy are essential indicators of future trends in world regions (Shrestha, 2020; Tsai et al., 2021). These supportive policies of sustainable construction recommend beneficial measures to enhance the construction process through C&DWM of the construction enterprise (Ghisellini et al., 2018). Xie et al. (Xie et al., 2020) also emphasized that the policy support of sustainability is indispensable. Lehmann (2011b) suggested that the government should formulate operational policies to reduce the environmental impact of consumption and production and that CI application would be a good choice. Cleaner production, together with a circular economy, plays a very important part in national environmental legislation and policy, which deals with the challenges caused by environmental pollution, as well as promoting the industry's transition towards a sustainable future (Ghisellini et al., 2018). For instance, the EU has set a target to achieve EU climate change policies for 2050 (D'Oca et al., 2018). Compared to traditional construction methods, CI is recognized as a cleaner building method as it significantly reduces on-site construction waste.

Extended producer responsibilities principles can be implemented by adopting green design, using recyclable materials and developing low-waste technologies (Xu et al., 2020). The concept of a green tax suggested by Cao et al. (2015) is used to decrease carbon emissions and conserve natural resources. There are several systems or models, such as Green Construction Assessment (GCA), the Evaluation Standard for Green Construction of Buildings (ESGCB) and the Evaluation Standards for Green Building (ESGB), which was developed in China during the last decade to evaluate the Environmental impacts (EIs) of construction projects (Cao et al., 2015). Owing to these green construction evaluation standards, CI has developed more quickly since PRB construction has been found to be a more efficient use of energy. CI has been commonly regarded as a sustainable construction method for its outstanding performance on environmental protection, which is reflected in the construction waste reduction (Chen et al., 2017; Nikmehr et al., 2017) and subsequent waste processing activities, namely waste sorting, reuse, recycle, and disposal (Li et al., 2014). Therefore, construction waste reduction policies are beneficial to CI application to some extent, which needs continuous support from the government (Bao et al., 2020). Some countries, such as Iran, set incentives for construction sites that produce less waste (Nikmehr et al., 2017), and in the Iranian context, the 'polluter pays principle' is treated as a practical guideline in formulating effective regulations and policies. In the UK, mass customization has been adopted as one of the main paths to providing a sustainable housing context (Jimenez-Moreno, 2021). In HK, more strategies have been proposed, mainly on public policies to promote waste sorting, research on the minimization and management of construction waste, development of a more mature recycling market, and government supports for a green building industry (Yu et al., 2021). Moreover, the concept of 'zero-waste', which was put forward by Lehmann (2011b, 2011a), often requires a higher level of industrialization. To achieve the 'zero-waste' economy, the EU introduced a policy called EPR (Lehmann, 2011b), which deepened the public's impression of ‘zero-waste’. The adoption of lean thinking is another principle to ensure waste elimination in construction (Lekan et al., 2020).

The construction sector has indirect impacts on the C&DWM (Ghisellini et al., 2018), so in order to improve its environmental performance, many countries or regions have developed their own regulations, laws and policies, including current C&DWM regulations in China (Ghisellini et al., 2018; Huang et al., 2018), the offsite construction waste sorting (CWS) program in Hong Kong (Lu & Yuan, 2012), construction and demolition (C&D) waste management regulations in Iran (Nikmehr et al., 2017), and National Waste Strategy Policy and recycling policies in Australia (Lehmann, 2011a).

A CI approach produces fewer carbon emissions when compared with traditional construction. Adopting prefabricated construction methods are regarded as a helpful carbon emissions mitigation approach in China (Mao et al., 2013; Tian et al., 2017; Zhang et al., 2017), encouraging a less CO_2-intensive lifestyle (Zhu et al., 2017). Further, CI is also used as a way for carbon emissions reduction in many countries such as the UK (Jankovic, 2019), Malaysia (Bin Marsono & Balasbaneh, 2015), Australia (Olanrewaju & Ogunmakinde, 2020) and New Zealand (Evison et al., 2018). Energy-saving policies have also been adopted in China, targeting sustainable development with the promotion of CI (Mao et al., 2013). In addition, the various stakeholders involved in the construction industry attach considerable importance to sustainable policies. Xue et al. (H. Xue et al., 2021) pointed out that environmental policies have significant direct effects on developers to implement off-site construction, suggesting the necessity of taking the impact of policies into consideration. Jiang et al. (Y. Jiang et al., 2019) found that prefabricated manufacturers gave the highest ratings to sustainability. Liang et al.

(2021) and Zhang et al. (M. Zhang et al., 2021) suggested that government decision-makers should take the actual carbon emission efficiency of the construction industry as the main basis for policy formulation, and put forward effective strategies on regional sustainable development. Among all the policies, sustainable policies are the most important policies for the sustainable development of mankind. The AEC industry shall work closely with the government to further achieve sustainable construction. No matter which construction methods are adopted, the ultimate goal shall be achieved in sustainable, green and healthy manners.

Correlations among Policies

This review sheds light on how these policies can assist and facilitate the development of CI under different contexts, comprising developing and developed countries. Strengthening policies yield the strongest overall effect in invigorating construction industrialization (Gan et al., 2019; Jiang et al., 2019). As shown in Figure 2.4, the interconnections and mutual influence among these aforementioned policies are explored and discussed in detail.

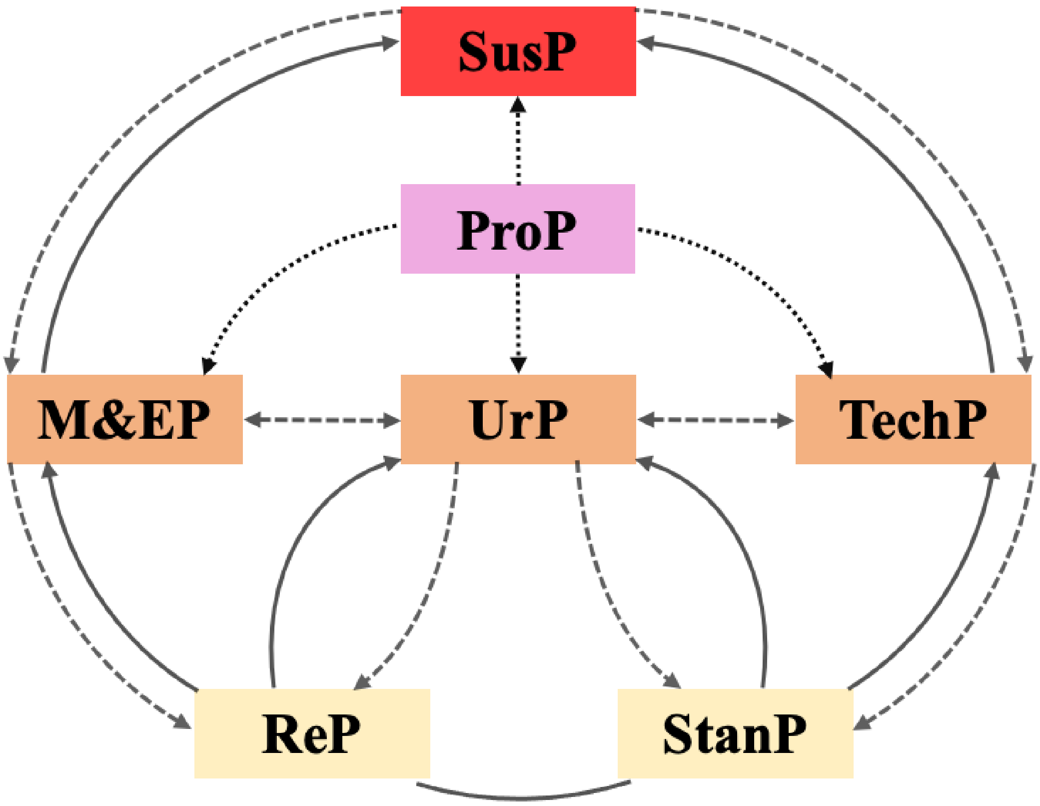

Figure 2.4 Interconnection and Mutual Influence among CI Policies

ReP: Regulative Policies
StanP: Standardized Policies
ProP: Promotional Policies
UrP: Urbanized Policies
TechP: Technical Policies
M&EP: Managerial and Educational Policies
SusP: Sustainable Policies

Firstly, the seven categories of CI policies are divided into four levels with different colours. Regulative policies and standardized policies are the two fundamental ones enforced by the government as the critical and indispensable cornerstone for the CI promotion to the construction industry (Luo et al., 2015; Mao et al., 2018). These two policies reflect the highest degree of mandatory governance in the CI area, which have a strong implementation effect and can fundamentally affect the construction area. They serve as the foundations of CI development and provide a basis for upper knowledge of policies, which provide guidance to all stakeholders and clarify the industrial standards. Upon these, at the middle level, the application scope of CI is further expanded through the promotional policies and three implementation practices, namely urban design and planning policies, technological policies, managerial and educational policies. Remarkably, promotional policies have been introduced into the CI development process as they play a crucial role in connecting the middle level and upper level of sustainability policies. Only with the presence of promotional incentives, the flourish of CI could be pursued comprehensively, such as fresh technological innovations, rational urban planning, and effective management and educational mechanisms. Sustainability policies at the top level represent the highest pursuit of construction worldwide.

Secondly, the seven categories are connected with solid lines and dotted lines accordingly, to illustrate the information extracted from 105 CI-related papers. Solid lines represent direct relationships. Namely, regulative policies focus on the restrictions and regulations on the CI implementation, which inevitably involves the standardized policies which define the standards in CI. On the one hand, many regulative policies mention the CI with urban design systems and design strategies as CI can be seen as a solution to fit future urban areas. The regulative policies, on the other hand, provide the basis for managerial and education policies. For instance, mandatory regulations and intervention strategies direct the risk management and performance management policies among enterprises. Furthermore, managerial and educational policies could lead to the progress of sustainable industrialization. An important part of the lower level of standardized policies is to formulate the technical operations and enhance the technology and innovations of CI. Meanwhile, better-standardized policies can promote industrialization in future urbanization. Technological policies such as efficient government supervision systems and technological innovations can help the pursuit of sustainability policies. Dotted lines represent the potential relationships of policies. For instance, promotional policies play an essential role in stimulating M&EP, UrP, TechP and SusP, as they are developed by governments worldwide to guide and assist markets and serve as the mainstay for other policies.

Overall, the successful implementation of higher-level policies will vitalize the further maturing of lower-level policies in virtuous cycles and vice versa. CI policies are categorized by their features, but they accelerate the CI development cooperatively in essence. Shifting from traditional construction to sustainable construction has gained increasing attention in both academia and industry (Jin et al., 2018; Xie et al., 2020). Practitioners and governments have been looking for sustainable ways to design, build, construct, and operate in the AEC industry. No matter which construction methods are adopted, the ultimate goal should be obtaining sustainable, green, and robust development. Therefore, sustainability policies have been given the sustainable blossoming of humanity. The development tendency of CI policy should unswervingly adhere to sustainable development and rely on regulative policies and standardized policies as the essential cornerstone.

2.4 Policy-Driving Forces in MiC Projects

Several previous studies have focused on identifying the success factors of MiC. Therefore, this study conducted a comprehensive systematic literature search to identify the PDFs associated with the MiC projects. As identified from the literature search, Han and Wang (2018) conducted a study on offsite construction issues. They suggested specific managerial implications for policymakers to uptake industrial practice using grey DEMATEL analysis from six main perspectives: policy, publicity, technology, supply chain coordination, training and education, and market demand. The authors further indicated government regulations and incentives as essential aspects to uptake MiC adoption. A study conducted by Lu et al. (2018) developed an analytical framework to seek the optimal level of prefabrication adoption in a certain political, economic, social and technological (PEST) context, highlighting political factors. Luo et al. (2015) analysed 24 risk factors associated with industrialized buildings and emphasized the government's leading role in its enforcement of adequate policies and regulations in MiC promotion. Further research has highlighted the importance of government policy changes to manage better supply chain risks in prefabricated building projects (Luo et al., 2019). Mao et al. (2015) grouped the 18 critical factors that influence the use of off-site construction into five categories, government regulations and policies, technological innovation, industry supply chain, cost, and market demand, with government regulations and policies as the most dominant grouping.

In previous attempts, Han and Wang (2018) indicated that the economic factors were closely related to the development of industry, society, technology, and regulations, which should be regarded as one of the top important factors for the implementation of MiC. Through the strengths, weaknesses, opportunities and threats (SWOT) analysis, Jiang et al. (2018) advocated that financial incentive should be considered as a primary driver for 'S' empirically, while the financial policies and tax reduction policies were listed as key policy measures to underpin the strategic purpose of promoting MiC. Liu et al. (2017) also emphasized that financial incentives and taxation could stimulate construction companies to enlist the modularization market. Chen et al. (2017) mentioned that enterprises were very expected for the government's preferential policies due to the high extra costs of adopting MiC. Since the high initial investment was listed by Luo et al. (2015) as one of the top five risks for implementing MiC, the PDF in terms of investment becomes even more important. Similarly, the uncertainty of property market demand was believed to be an obstacle factor for MiC development (Mao et al., 2015). Housing programmes were highlighted by Mare (2018) as a strong impetus to innovation and a catalyst for a comprehensive reform of traditional building techniques. Han and Wang (2018) suggested that at the land transaction or planning stage for new buildings, mandatory requirements for MiC could be considered to scale up its practices, which is closely linked to land supply policies and national urbanization plan (Jiang et al., 2018; Jin et al., 2020). Jiang et al. (2018) deemed that the hidden value of MiC will eventually be reflected and recognized by the public and industry if publicity, social awareness and public opinion are guided and strengthened. As Lu and Yuan (2012) pointed out, Government policy has been playing an important role in promoting current construction waste management, with MiC being a primary measure that will ultimately have an impact on the environment and contribute to environmental protection. Lu et al. (2018) noted that the demand and supply of prefabricated modules and related materials influenced the adoption of MiC, as they were necessary to keep production and on-site installation running smoothly. Pan et al. (2012) provided further evidence that the decision to adopt traditional or MiC technology solutions is usually based primarily on material, labour and transportation cost considerations. Thus, policies related to the labour and import of materials should be concerned. Many scholars have proved through various methods that the popularity of MiC cannot be achieved without technological support and advancement (Jiang et al., 2018; Wu et al., 2020). In 2002, the proportion of prefabricated components in the concrete consumption of public housing projects reached 17% (Chiang et al., 2006). This proportion has been continuously increased in the past 20 years due to the adoption of MiC (Jiang et al., 2018), with the continuous expansion of the scope and type of module design (Wuni & Shen, 2020). While Luo et al. (2015) and Mao et al. (2015) indicated that the lack of authoritatively designed standards, codes and guidelines for MiC is a major hindrance to MiC practices. Azman et al. (2012) denoted that political and regulatory criteria for the selection of new precast manufacturing sites will influence the initiation stage of MiC project approval because it takes time and will affect the cost of miscellaneous projects. Although government officials acknowledged that a four to five-day cycle is achievable, due to the availability of resources, the HKHA's public housing projects followed a six-day cycle (Lu et al., 2018). To a certain extent, construction schedule constraints will facilitate the application of MiC. Zhang et al. (2017) believed that multisectoral governance could encourage financial institutions to provide loans to construction companies during the preparation phase of MiC projects, contributing to the sustainable MiC. An appropriate MiC project qualification supervision mechanism is very necessary and critical, which helps the government and construction enterprises to manage the quality and safety of prefabricated modules during the construction phase, so as to further evaluate whether the project meets the completion acceptance standard of project quality (Luo et al., 2015; Zhang et al., 2017). The findings of Park et al. (2011a) showed that encouraging design-build contracts for private projects seems to have little effect on the private sector to increase the MiC adoption, but further increasing the proportion of design-build contracts for current public projects is considered to bring beneficial outcomes. On the other hand, the construction industry is improving its adaptability of MiC in terms of business processes, such as the adoption of engineering, procurement and construction (EPC) contracts (Zhang et al., 2017). In order to overcome the typical barrier of lacking integration among relevant stakeholders during project delivery process of MiC, a new type of collaborative procurement, integrated Project Delivery (IPD), was proposed (Osman et al., 2017). Furthermore, Guerzoni and Raiteri (2015) demonstrated that innovative public procurement seems to be more applicable than other tools. All 26 PDFs identified from literatures have been explained in detail above. Combined with the actual situation and practical interviews, the author added additional seven PDFs (Table 4.1), which will be covered in Chapter 4.

2.5 Research Gaps and Industry Needs

Adopting hybrid bibliography and bibliometrics, this study carefully reviews the major outputs of prefabrication and MiC research in the field of construction project management published in peer-reviewed journals over the past several decades, from which it investigated and summarised a broad range of research themes in this discipline from around the world. The research findings of these literatures have made significant contributions to the knowledge system of MiC and provided valuable, constructive information for the scholars, managers and practitioners in CI, especially MiC. Despite their acknowledged contributions, one crucial research gap in the previous literature should be resolved: a lack of study on how to devise an operative approach to effectively utilize critical PDFs in MiC from a dynamic perspective, considering the stakeholders involved. Based on the analysis of these scientific articles, research gaps are evidenced as follows:

(1) Policy implications for promoting the adoption of MiC invariably focus on incentive schemes and compulsory requirements while ignoring the real-life impact of PDFs on MiC project processes- initiation, planning and design, and construction, which significantly impedes the efficient management of MiC. The adjustment of policies or regulations is neither entirely a function of market demand nor a simple operation of government but rather is mediated by a range of stakeholders and influenced by the socioeconomic environment and dynamic interactions among PDFs. To establish a foundation to identify the dynamics of PDFs, it is essential to identify critical PDFs associated with MiC that are currently absent in the literature. Since MiC policies are jurisdiction-specific and MiC supply chain configurations differ across countries (Ekanayake et al., 2020), a Hong Kong-specific study is needed.

(2) Previous studies mostly adopted the direct ranking method to analyze the priority of stakeholders and critical factors or directly link stakeholders with risks and key success factors, but few researchers identify and further analyze the underlying relationships between stakeholders and detailed PDFs, especially in MiC projects. Traditional studies only explore the problem 'what', which factors/barriers/driving forces significantly affect the success of MiC projects, rather than how they affect the success and the internal relationships between them. Since the influence of the driving force on the success of MiC projects is reflected and supported by various stakeholders, it is necessary to consider the relevant stakeholders as intermediate variables to better understand the policy development

trend of MiC projects from a holistic perspective.

(3) Although most of the studies have gained some valuable enlightenment to promote the development of MiC through traditional methods such as factor analysis, there are still some limitations worth noting, including a. relevant research were carried out from a static point of view; b. the processes of MiC included are usually the whole supply chain (design, production, transportation and installation) or one of its processes, rather than a complete three phases of MiC projects (initiation, planning and design, and construction); c. the key success factors are broad and in-depth research on policy factors is still lacking. How to identify the key policy drivers throughout the three phases of MiC projects and measure their impact on MiC uptake from a dynamic manner has always been a central focus of the MiC research field, which can also assist a better understanding and timely adjustment of policies contributing to the success MiC projects in practice.

(4) In addition to the above research gaps, industry needs are also highlighted. The relevant findings of this research would be beneficial to boost the productivity of the construction industry in Hong Kong and to overcome the performance shortfalls faced by the industry while enhancing sustainability through MiC uptake. Also, industry practitioners will be well informed on policy design and implementation in the construction industry, specifically in the emerging MiC field.

2.6 Summary of the Chapter

This chapter provides a thorough review of the main findings of prefabrication and MiC research in the context of construction project management by adopting hybrid bibliography and bibliometrics. A retrospective assessment of MiC practices in Hong Kong is depicted to show its industry development situation. Thereafter, seven key issues existing in Hong Kong regarding the application of MiC are discussed: (1) complex cross-border transportation process, (2) low innovations in prefabrication techniques, (3) high initial cost, (4) lack of preferential policy, (5) low standardisation, (6) lack of management practices and experiences and (7) lack of timely communication between the parties. From these issues, opportunities to explore the PDFs in MiC are illustrated. Moreover, there are seven policy categories according to the underlying common research themes in the CI domain: (1) regulative, (2) standardised, (3) promotional, (4) urbanised, (5) technical, (6) managerial and educational and (7) sustainable policies. The interconnection and mutual influence amongst the seven policies are revealed. Additionally, 26 PDFs associated with MiC projects are identified, laying a solid foundation for subsequent in-depth analysis. Lastly, three main knowledge gaps are highlighted, whilst the practical needs of the MiC industry are also emphasised.

Chapter 3 Research Methodology

3.1 Introduction

This chapter captures in detail the entire research framework, design, scientific methods and data analytical tools applied to this study. To accomplish the research objectives, this study adopts qualitative and quantitative research methodologies. Section 3.2 presents an overview of the research design and process. Section 3.3 illustrates different research methods used for data collection, namely, document analysis, questionnaire survey and expert interviews. Section 3.4 presents the analysis techniques used in the current study, including statistical techniques, SNA and system dynamics modelling.

3.2 Research Framework

To effectively conduct this research, a range of actions and procedures are required. Based on the research objectives, questions and settings, the applicable research methodologies and data analytical tools are determined, which are summarised in Table 3.1 to describe the entire framework of this study in detail. Adopting widely used and illustrious research methods helps to obtain meaningful and valuable outcomes. In addition to the systematic literature review mentioned in Chapter 2, empirical methods such as document analysis, questionnaire survey, expert interviews and case study are applied to this study principally for data collection, whereas statistical techniques, social network analysis and system dynamics are utilised as tools for qualitative and quantitative analysis of data.

Table 3.1 Corresponding Research Methods for Research Objectives

Research objectives	Data collection methods	Data analysis techniques
(1) To identify and analyse critical PDFs along the MiC project phases: initiation, planning and design and construction.	1. Document analysis 2. Questionnaire survey 3. Expert interviews	1. Mean score ranking 2. Statistical techniques 3. Factor analysis
(2) To explore the interrelationships between critical PDFs and stakeholders involved in different phases in the MiC context in Hong Kong.	1. Document analysis 2. Expert interviews	1. Statistical techniques 2. Social network analysis
(3) To develop a system dynamics model for simulating and assessing the potential impact of critical PDFs on the overall MiC uptake.	1. Document analysis 2. Questionnaire survey 3. Expert interviews 4. Case study	1. PLS-SEM 2. System dynamics

3.3 Research Methods

To achieve the mentioned three research objectives, the following research methods are employed. The flowchart shown in Figure 3.1 depicts the connection between the methodologies and various contributions. The analysis results of factor analysis in Chapter 4 could be the basis of SNA and SD analysis, which aims to identify the critical PDFs in the three stages. In Chapter 5, the main concern is the stakeholders in MiC, and the relationships between the relevant stakeholders and critical PDFs were explored; In Chapter 6, the main concern is the PDFs in MiC, and the quantitative relationships among PDFs to put forward some useful strategies for policy-making were investigated. Therefore, focus of SNA and SD application is different, and the analysis results of SNA were not applied in the SD analysis. Both SNA and SD are practical tools to reveal internal relationships among MiC policy factors.

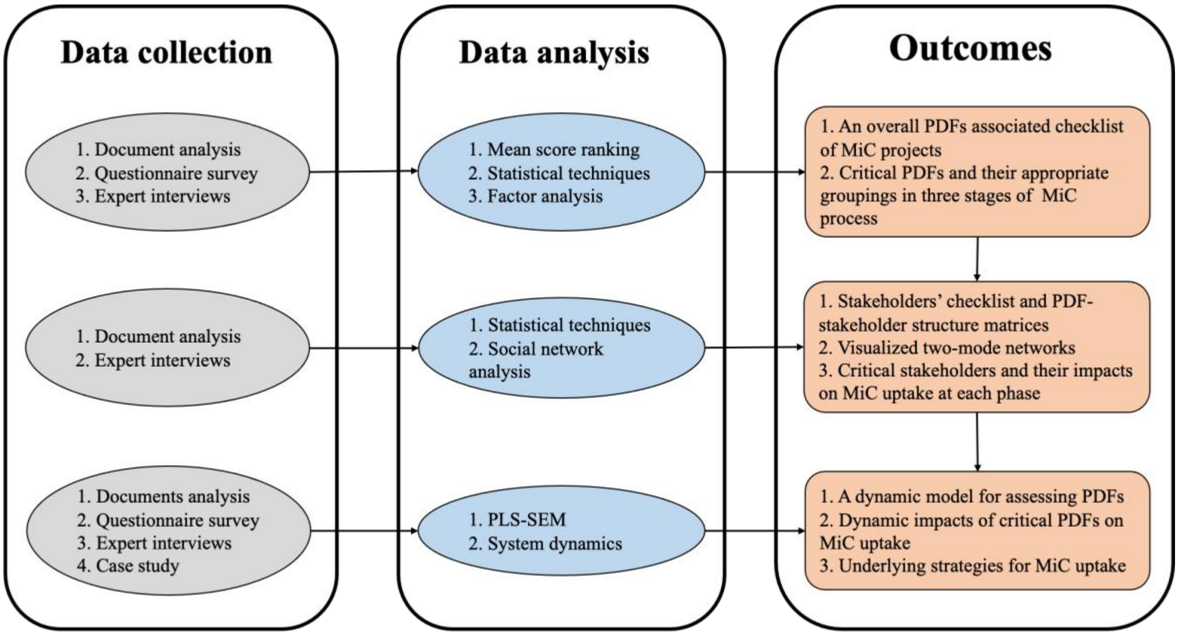

Figure 3.1 Connections between methods and contributions

3.3.1 Document analysis

Document analysis, a systematic process, is often used for reviewing and evaluating various documents in qualitative research (Corbin & Strauss, 2008). The analysis of documentary evidence is also a historical approach that is designed for the selection of problems and evaluation of proof. ‘Document’ is a term that refers to a paper or set of papers with written or printed information, especially for an official type. More generally, the analysis of photographs, videos, slides and other ‘social facts’ (Atkinson & Coffey, 1997) can also be categorised as documents. Unlike some projects in which documentary analysis is a central or even exclusive research method, document analysis is used to augment information obtained through other methods, for instance, to check the reliability of materials collected from questionnaire surveys and interviews (Bell & Waters, 2018). Given its apparent advantages such as efficiency, availability, stability and cost-effectiveness (Bowen, 2009), document analysis is applied to this study.

In the present research, the target documents for review contain academic publications, official documents issued by the government or in the case study, related MiC videos and other web-based resources. Content analysis study, a detailed and systematic inspection of the contents of specific materials to determine patterns, themes, or biases (Leedy & Ormrod, 2001), is the major form of this document analysis. In this study, a systematic classification and integration of previous studies on MiC-related policy research and analysis were conducted. Existing data from statistical records and web-based resources were analysed to understand the trends of MiC practice. MiC-related policy documents and regulations issued by national, central, local institutions were reviewed to recognize existing PDFs in the present construction industry. Current problems and research gaps were then identified and further summarized to confirm the research aim and objectives. When facilitating the establishment of the SD model in the framework, this method can investigate the actual conditions, which is necessary for model validation.

3.3.2 Questionnaire survey

Research questionnaire survey, developed by the Statistical Society of London in 1838, is a research instrument that consists of fixedly designed questions or other types of prompts to gather information from respondents (Hague, 1993). The great popularity of questionnaires is because it has many advantages different from other research methods, including easy to collect a lot of data in less time and cost, analysis of answers for closed questions is straightforward, less chance of any bias creeping, customized to reflect researcher's brand voice, respondents' anonymity, and provision of suggestive information to test hypotheses (Gillham, 2008). In addition to conventional modes of collecting data (e.g. face-to-face interviewing, paper distribution, and mail), the Internet has opened up new prospects for surveying with the swift developments of the Web and email (Fricker & Schonlau, 2002). These benefits make questionnaire surveys widely used in the research field of construction industrialization management (Jin et al., 2017; Li et al., 2017; Mao et al., 2015). As mentioned previously, a questionnaire survey was applied to this study as the main data collection method. The quantitative data collected in this way helps to get the attitudes and perceptions of the entire study population by taking a suitable sample size. Although there are some inevitable inherent shortcomings in questionnaire survey research (e.g. low response rate, data quality problems and uncorrectable misunderstanding), a well-designed questionnaire obtained by taking appropriate measures can still provide researchers with great research opportunities to conduct factor analysis (Labaw, 1980). Table 3.2 lists some primary considerations to be aware of before starting the actual questionnaire distribution.

Table 3.2 Key Issues in Questionnaire Development

Considerations	**Key issues**
What will the questionnaire measure?	Knowledge Attitude/beliefs/intention Cognition Emotion Behaviour
What types of scale can be used?	Frequency Thurstone Rasch Guttman Mokken Likert type

	Multiple choice
How do I generate items for my questionnaire?	Ensure relevance of items? Wording issues Which response format is best? Which types of questions are possible? Free text options? Does your measure have subscales? Questionnaire layout

**Modified from (Rattray & Jones, 2007, p. 236)*

The questionnaire here was used to solicit professional and practical opinions from academia and industry. The questionnaire survey in this research was specifically designed to

1) Identify the occurrence possibility of corresponding PDFs during the different MiC project phases for PDFs pattern establishment;
2) Determine the impact degree of corresponding PDFs during the different MiC project phases for subsequent SD modelling; and
3) Explore the variations of PDFs at different stages of MiC projects.

3.3.2.1 Questionnaire development

All questionnaires should initially be tested through a pilot study completed by a small group of sample recipients (Fellows & Liu, 2008). This piloting will test how long it takes respondents to complete questions, check whether all questions are intelligible, easy to answer, unambiguous and adequate. Based on the feedback from those respondents, an opportunity was obtained to improve the questionnaire, remove any items that do not yield practical data, fill in gaps, and have ease of completing the exercise. Five experts with rich experience and vast knowledge in MiC projects were invited for the conduction of the pilot study, providing a research-oriented view of the questions. Their comments and answers were incorporated into the finalized questionnaire. The background information of the five experts is shown in Table

3.3. The designed questionnaire includes two parts. The first part contains background-related information of the respondents, such as their current professional affiliation, working organization, years of experience in the construction industry in Hong Kong and educational background. The basic background information improves the credibility and reliability of the questionnaire and enriches the quality of the data obtained from the second segment of the questionnaire. The second part was developed on the basis of the preliminarily identified PDFs. To gather the professionals' opinions on this study, the *Likert scale*, as the most commonly utilised scaling technique over the past 70-plus years attributable to its simplicity, versatility and reliability (Dörnyei & Taguchi, 2010), was adopted in the main components of the questionnaire. *Likert scales* research contains two-, three-, four-, five-, six-, and seven-response options, considering that too many scale points on a Likert scale will lead to unreliable answers for many respondents (Dörnyei & Taguchi, 2010), as well as the most commonly used step numbers have been five among research on construction project management (Chan et al., 2018; Ekanayake et al., 2020; Ekanayake et al., 2020; Zhang et al., 2011), five-response options were selected for this study. In this research, the respondents were required to evaluate the occurrence possibility, and impact degree of each PDF during the three phases respectively mentioned above on a five-point Likert scale. Appendix A presents the finalized questionnaire.

Table 3.3 Backgrounds of the Five Experts in the Pilot Study

Experts	Organization	Working/Research experiences (years)	Education	Current position
1	Research institution	20	Doctoral	Director
2	Research institution	8	Doctoral	Senior manager
3	Research institution	5	Doctoral	Staff
4	Main contractor	25	Master's	Director
5	Consultant	18	Master's	Manager

3.3.2.2 Background information of the respondents

Several main approaches of data collection were considered in the questionnaire survey, including self-completion (Internet/email) and face-to-face paper completion; Considering the unstable situation of the Novel Coronavirus (COVID-19) in Hong Kong, this data collection is mainly completed in a web-based form (Internet/email). Non-probability sampling was employed, considering the actual situation that it is impossible to select any construction practitioners with the same probability from samples (Robson & McCartan, 2016). In this study, stratified sampling was necessary and selected to ensure the variety of samples from diverse sub-populations of construction organizations, such as government departments, clients, contractor companies, manufacturers, transporter, design and consultant companies, subcontractor companies, professional organizations, etc. Most of the participants were practitioners working or having vast knowledge and experience in MiC projects in Hong Kong, especially governments and contractors were preferred when inviting the respondents. The survey was conducted between February and April 2021. A total of 212 questionnaires were sent via email with online links and face-to-face distribution during this process, while the number of feedbacks collected was 89, 85 of which were deemed valid and could be used for further analysis. The valid return rate is 40%, which is reasonable, acceptable and higher than an average response rate for an online survey (33%) (Nulty, 2008). Table 3.4 shows the background information of the respondents in detail.

Table 3.4 Backgrounds of the Respondents

Characteristic	Category	Number of respondents	Frequency (%)
Professional affiliation	Public sector	38	44.71
	Private sector	32	37.65
	Both	15	17.65
Total		85	100.00
Working organisation	Government	3	3.53
	Client	3	3.53
	Main Contractor	17	20.00
	Manufacturer	3	3.53
	Transporter	3	3.53
	Designer	4	4.71
	Consultant	16	18.82
	Related Researcher	34	40.00
	Supplier of materials/equipment	2	2.35
Total		85	100.00
Working experience	5 years or less	33	38.82
	6-10 years	19	22.35
	11-15 years	13	15.29
	16-20 years	8	9.41
	21 years or more	12	14.12
Total		85	100.00
Education	Doctoral	33	38.82
	Master's	27	31.76
	Bachelor's	22	25.88
	Secondary school	3	3.53
Total		85	100.00
Current position	Director	13	15.29
	Senior Manager	11	12.94
	Manager	23	27.06
	Other Staff	38	44.71
Total		85	100.00

There are three principles to eliminate invalid questionnaires in this study, namely 1) incomplete answers; 2) too short time to complete the online questionnaire; 3) obviously wrong answers, such as multiple answers, are selected for the single choice question. Figure 3.2 shows the current professional affiliation of the respondents. 44.71% of the respondents were from the public sector, such as some educational institutions, government agencies, the Hong Kong

Housing Authority, etc. 37.65% came from the private sector (e.g. main contractors, sub-contractors and consulting companies), most of whom are directly influenced by the implementation of MiC policies in Hong Kong. The rest from both sectors means that some industry experts are doing related research in universities while also providing consulting services.

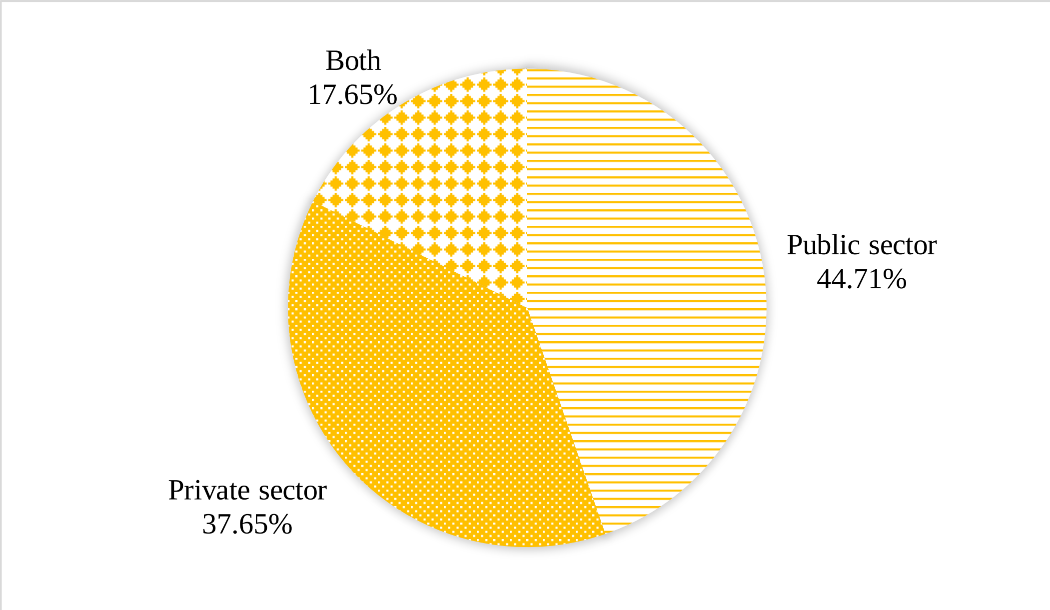

Figure 3.2 the Current Professional Affiliation of the Respondents

The distribution of the working organisations that the respondents belong to is presented in Figure 3.3. In the effective sample, this background of the respondents is diverse, including government (n=3, p=3.53%), client (n=3, p=3.53%), main contractor (n=17, p=20.00%), manufacturer (n=3, p=3.53%), transporter (n=3, p=3.53%), designer (n=4, p=4.71%), consultant (n=16, p=18.82%), related researcher (n=34, p=40.00%), and supplier of materials/equipment (n=2, p=2.35%). Although the stratified sampling strategy was adopted in data collection, most of the respondents were from research institutes; however, these relevant researchers all possessed recent hands-on experience in at least one MiC project in Hong Kong.

Considering that the MiC technology itself is relatively new, there are few experts in other organizations who knew MiC very well, but there are slightly more researchers exploring this technology. Therefore, this diversified sample distribution is generally reasonable and acceptable to derive meaningful conclusions concerning this MiC policy area.

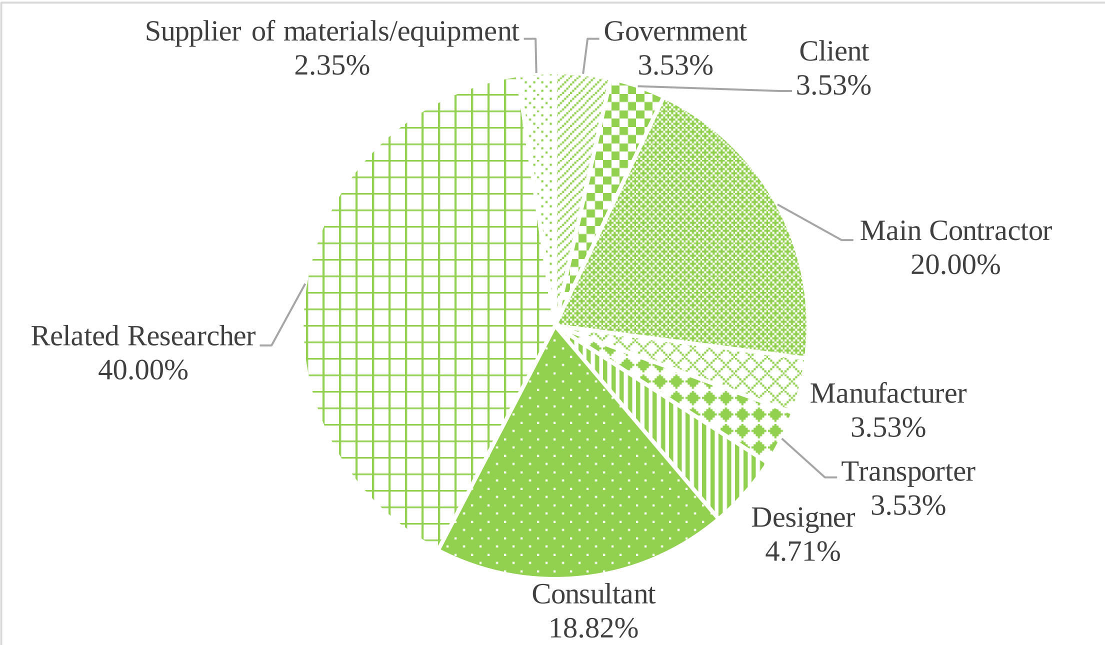

Figure 3.3 the Working Organisation of the Respondents

As shown in Figure 3.4, among the total valid sample, 22.35% of the respondents possessed 6 to 10 years working or research experience in MiC projects in Hong Kong, 38.82% had more than 10-year experience in the MiC industry, containing 14.12% with over 20-year experience. The working and/or research experience reflects the extent of familiarity that the respondents had in MiC project practices, as well as ensuring the reliability and sensibility of their responses. In terms of the current position in the organisation, Figure 3.5 indicates that 15.29% of the respondents were directors, 12.94% were senior managers, and 27.06% were managers. These results enhanced the reliability of the data for the relatively high positions of the respondents in their organisations. In addition, respondents' higher education enables them to deepen critical thinking on this study, which improves the professionalism and rigour of the data. As it is shown in Figure 3.6, 38.82% of the respondents had doctorates, and 31.76% had master's degrees. The working experience, positions and educational backgrounds demonstrate that the data collected in this survey is representative and trustworthy for further analysis.

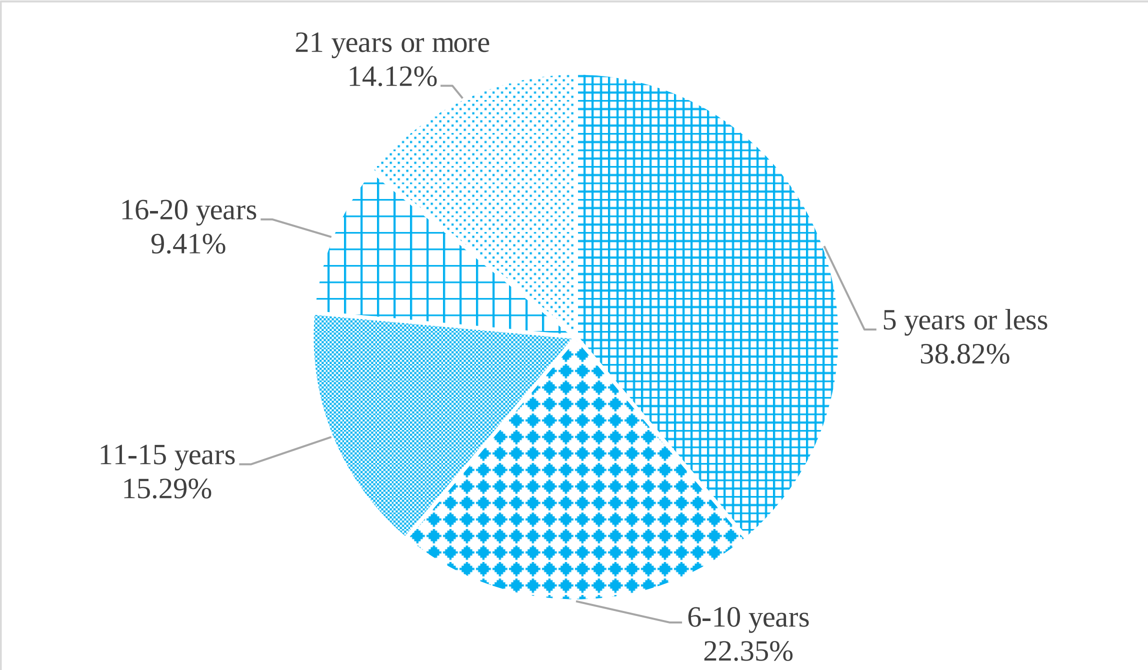

Figure 3.4 the Distribution of Respondents' Working/Research Experience

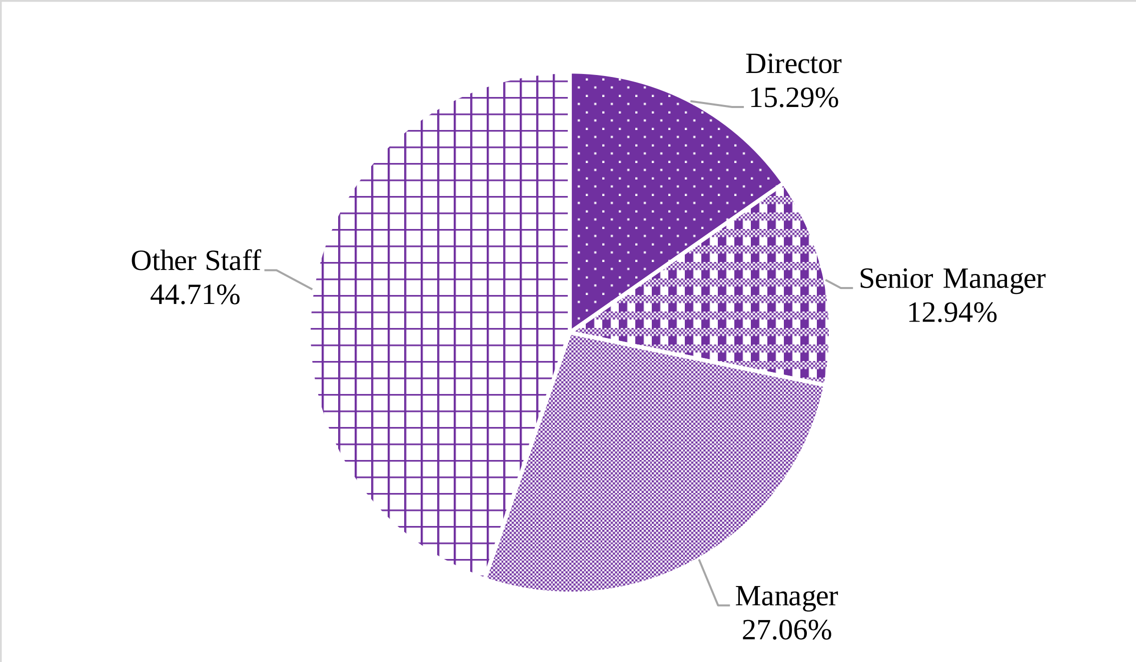

Figure 3.5 the Distribution of Respondents' Current Position

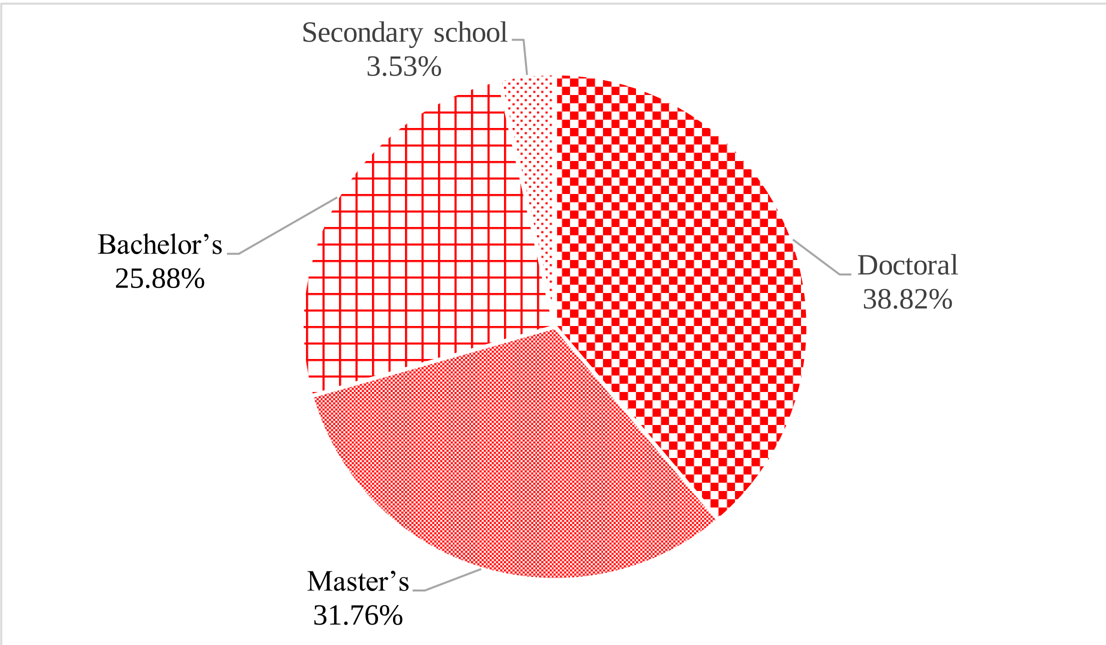

Figure 3.6 the Education Background of the Respondents

3.3.3 Expert interviews

From the social scientific perspective, an interview survey is a qualitative approach that involves two or more persons exchanging information through a structured conversation where a series of questions and answers are included for the purpose of data collection (Dane, 1990). The purpose of a qualitative research interview is to identify the core themes of the lived daily word of the topics by transcribing and analyzing the underlying implications from the interviewees' statements (Kvale & Brinkmann, 2009). This method has been widely adopted in construction industrialization management research (Li et al., 2017; Mao et al., 2015). The three different types of interviews are fully-structured, semi-structured, and unstructured interviews based on the degree of standardization (Robson & McCartan, 2016). Fully-structured interviews should follow a particular list of predetermined subjects and questions, while unstructured interviews where questions are not prepared in advance and emerge from the interview process (Hay & Hay, 2005). The semi-structured interview is open, allowing new ideas to be brought up during the interview, and participants can flexibly explore issues they consider important and interesting (Longhurst, 2003). Kvale and Brinkmann (2009) suggested seven stages when conducting an interview investigation, which includes thematizing an interview project, designing, interviewing, transcribing, analyzing, verifying and reporting. In the current study, expert interviews were conducted throughout this research, especially in the exploration of interrelationships among PDFs. In the preparation stage, the proposed conceptual framework of modelling PDFs in MiC projects can be modified and refined. For the objective 1, the PDFs in MiC projects were validated through a series of semi-structured interviews, which also provided a solid foundation and validation for the questionnaire design and survey. For the objective 2, expert interviews were carried out for collecting data on the examination of interrelationships between PDFs and relevant stakeholders during the different

MiC project phases- initiation, planning and design, and construction, which was indispensable for the subsequent SNA. For the objective 3, these MiC professionals could provide an unbiased and constructive assessment for the verification and validation of the SD model.

3.3.3.1 Process and criteria for the professionals' selection

An expert interview, in which the interviewees are professionals in a specific field, effectively captures specialised information and valuable comments. The selection of interview experts should be cautious and objective to ensure the validity of the research and the quality of the results, which has a direct and vital relationship with the selection process (Dorussen et al., 2005; Hsu & Sandford, 2007). The professionals' selection is generally dependent upon the disciplinary areas of expertise required by the specific issue under this study. Experts refer to experienced decision-making practitioners and researchers in relevant institutions, such as Construction Industry Council, Building Department, the Electrical and Mechanical Services Department, and 'construction management'-related departments in universities. To ensure the reliability of interview results, it is important to require experts to conduct the analysis objectively. Through the in-depth and thorough descriptions of the problem, objectivity can be achieved so that the fairness and consistency of its meanings can be judged (Charmaz, 1995). In this study, a two-step approach was applied in selecting the experts. After conducting the questionnaire survey, a number of industrial and academic professionals with rich experiences in the MiC project were accessed. Then from these respondents, some experts were selected for further interviews based on the predefined criteria, which are listed below.

1. Have extensive working or research experience (at least five years) and a good knowledge

of MiC management in Hong Kong;

2. Possess expertise and a good understanding of MiC policies in Hong Kong; and
3. Have recent hands-on experience in dealing with at least one modular integrated construction project in Hong Kong.

In this step, a pool of potential candidates for the detailed interviews was obtained. Then these target interviewers were contacted and asked if they were willing to accept further interviews and what time period would be convenient for them to be interviewed. 28 such practitioners agreed to participate in the further interviews.

3.3.3.2 Background information of the respondents

In this study, expert interviews were carried out mainly for collecting data on the investigation of interrelationships among PDFs during the different MiC project phases after the questionnaire survey, gathering suggestions for the conceptualization and development of the research framework and its related modules, as well as exploring comments on the effectiveness of the proposed SD model. A series of semi-structured interviews with 28 experts were carried out in Hong Kong via face-to-face or online mode (March and June 2021) to establish a PDF-stakeholder structure matrix that represents the interrelations among PDFs during the MiC project phases- initiation, planning and design, and construction. 10 out of the 28 interviewees possess more than ten years of working or research experience in MiC projects management and engineering. Given the strict confidentiality of the interviewees' specific profiles, only the general background information is shown in Table 3.5.

Table 3.5 Background information of the experts

Interviewees	Region	Organization (Stakeholder)	Working experiences (years)	Current position
1	Hong Kong	Consultant	18	Manager
2	Hong Kong	Clients/Manufacturer	19	Director
3	Hong Kong	Main contractor	25	Director
4	Foshan, Mainland China	Manufacturer	11	Senior manager
5	Shenzhen, Mainland China	Manufacturer	12	Manager
6	Hong Kong	Research institution	12	Senior manager
7	Hong Kong	Research institution	5	Staff
8	Shenzhen, Mainland China	Main contractor	6	Clerk
9	Shenzhen, Mainland China	Research institution	6	Staff
10	Hong Kong	Research institution	5	Staff
11	Guangzhou, Mainland China	Industry institutions	7	Clerk
12	Hong Kong	Research institution	6	Staff
13	Shenzhen, Mainland China	Main contractor	7	Manager
14	Shenzhen, Mainland China	Manufacturer	6	Clerk
15	Hong Kong	Research institution	5	Staff
16	Shenzhen, Mainland China	Manufacturer	7	Manager
17	Shenzhen, Mainland China	Specialist subcontractor	15	Manager
18	Hong Kong	Research institution	7	Staff
19	Shenzhen, Mainland China	Manufacturer	15	Director
20	Shenzhen, Mainland China	Research institution	6	Staff
21	Guangzhou, Mainland China	Manufacturer	7	Clerk
22	Shenzhen, Mainland China	Logistics enterprise	6	Manager
23	Shenzhen, Mainland China	Manufacturer	10	Senior manager
24	Ji’nan, Mainland	Designer	6	Clerk

	China			
25	Wuhan, Mainland China	Research institution	8	Staff
26	Shenzhen, Mainland China	Developer	7	Manager
27	Tsankiang, Mainland China	Logistics enterprise	8	Manager
28	Shenzhen, Mainland China	Specialist subcontractor	15	Manager

All these interviews lasted for 30-100 minutes and were conducted following a semi-structured interview guideline with rich feedback. The interview protocol was developed as the preparation, which included three main parts: brief introduction of the interviewer (e.g. interview purpose, research interests, process, and estimated period), several important considerations about the interview (e.g. ethical considerations and objectiveness of the interview) and a set of formal interview questions (formation of the PDFs structure matrix). In the formal interview part, two sections were included, namely, the interviewees' basic background information and opinions regarding the interrelationships among PDFs during the MiC project phases- initiation, planning and design, and construction. During the process of the interview, the interviewees were encouraged to express their views and add any details that they considered essential. Taking into account the high consistency of the experts' descriptions, the interview results are taken as being objective.

3.4 Data Analytical Tools

3.4.1 Statistical techniques

The data collected from the questionnaire survey were used for factor analysis to generate valuable findings and outcomes. At the same time, the gathered qualitative data from expert interviews were used to provide an empirical basis for quantitative results. The SPSS, which means '**S**tatistical **P**ackage for the **S**ocial **S**ciences', is a software officially known as IBM-SPSS-Statistics-26.0 for editing and analysing all sorts of data. These data may come from basically any source such as scientific research or a customer database, and SPSS can open all file formats that are commonly used for structured data: spreadsheets from Microsoft Excel, plain text files, relational databases. Considering the universality and convenience of SPSS, this research used it to analyse the questionnaire findings. Descriptive statistics, mean score ranking technique, Cronbach's alpha technique for reliability analysis, together with factor analysis, were employed in data analysis, which will be described in detail in the following sections.

3.4.1.1 Descriptive statistics

Descriptive statistics, which are typically distinguished from inferential statistics, are used to simply describe what is going on and the basic features of collected data in a study (Trochim & Donnelly, 2001). To be more specific, descriptive statistics are numerical practises or graphical techniques that many researchers applied to organising, presenting or describing, summarising, analysing and interpreting the characteristics or factors of a particular sample (Fisher & Marshall, 2009). Descriptive statistics facilitate us to simplify large amounts of data in an intelligent way and provide us with a useful strategy to do simple summaries about the sample and the measures. In this study, together with simple graphics analysis, descriptive statistics are utilised to demonstrate quantitative descriptions in a manageable form, which includes frequency distributions, means and standard deviations. Or, more precisely, the analysis of demographic and attitudinal data was used to determine the characteristics of specific groups and describe the similarities and differences between variables or groups.

3.4.1.2 Mean score ranking

In statistics, 'ranking' refers to a data transformation in which numerical or ordinal values are replaced by their rank when the data are sorted. In construction area research, the mean score ranking technique has been broadly adopted for driving forces understanding and relative importance of factors calculation and ranking (Assaf et al., 1995; Chan & Kumaraswamy, 1996; Ke et al., 2011). In this research, the mean score ranking technique was applied, on the basis of the five-point Likert scale described previously, to identify the comparative ranking of the PDFs along the different MiC stages - initiation, planning and design, construction phase. Mean score (*M*) is the average of a set of scores obtained by adding all scores together and dividing by the number of scores, which is determined in the form of a simple Equation (3.1). Where two or more factors received the same mean score, the factor with the smaller standard deviation (SD) will be assigned with a higher rank (Ekanayake et al., 2020). The significance of the *M* was evaluated by adopting the one-sample t-test with a P-value of 0.05 at a 95% confidence level. If the test value is lower than the stipulated P-value, using a standard significance level of 0.05, the null hypothesis of 'the data is normally distributed' for a factor should be rejected (Darko, 2018).

$$R_i = \frac{\sum_{j=1}^{n} \partial_{ij}}{n} \quad (3.1)$$

where R_i represents the mean score of the occurrence possibility/impact degree of the PDF i, n is the total number of respondents, ∂_{ij} is the occurrence possibility/impact degree of the

PDF i rated by respondent j.

3.4.1.3 Cronbach's alpha technique

Cronbach's alpha technique was developed by Lee Cronbach in 1951 (Cronbach, 1951), which provides a measure of the average correlation or internal consistency of items in a test or scale and is used as an index of reliability for a questionnaire set (Tavakol & Dennick, 2011). Cronbach's alpha technique is one of the most commonly used tools in the language testing literature, more flexible and provides soundly appropriate reliability estimate (Brown, 2002). Researchers indicated that the internal consistency reliability test is mandatory for the justification of the data analysis results (Adabre & Chan, 2019; Darko, 2018), especially when using Likert-type scales (Gliem & Gliem, 2003). Moreover, as one of the internal consistency reliability estimates, Cronbach's alpha is the easiest logistical strategy for estimating reliability when compared to the other methods, namely test-retest reliability and equivalent (or parallel) forms reliability (Brown, 1997). The value of Cronbach's alpha is expressed as a number that varies from 0.00 (for a totally unreliable measure) to 1.00 (for a measure that is 100% reliable) in accordance with the improvement in reliability (Brown, 1997; Santos, 1999). In general, the acceptable Cronbach's alpha values in different reports or research are not the same, ranging from 0.70 to 0.95 (Bland & Altman, 1997; DeVellis, 2017; Nunnally, 1994). 0.70 is commonly considered the lower limit of Cronbach's alpha value for a reliable questionnaire setting (Brown, 1997; Sasaki, 1996), while 0.90 has been recommended as the maximum alpha value (Streiner, 2003), because a high alpha value (> 0.90) may indicate redundancies and suggest that the test length should be reduced (Tavakol & Dennick, 2011). Therefore, the effective limit for

Cronbach's alpha values is between 0.70 and 0.90. The calculation of Cronbach's alpha test is typically done using the 'standardised item alpha' in SPSS software (DeVellis, 2017; Shen et al., 2011). In this study, the data collected through five-point Likert questionnaire survey were tested for their reliability and appropriateness using Cronbach's alpha technique. Cronbach's alpha can be written as a function of the number of test items and the average inter-correlation amongst the scale items. For conceptual purposes, the formula (3.2) for the Cronbach's alpha is shown as follows (Darko, 2018):

$$\partial = \frac{N\bar{c}}{\bar{v}+(N-1)\bar{c}} \tag{3.2}$$

where ∂ represents Cronbach's alpha coefficient value, N is equal to the number of scale items, $\bar{c}$ is the average inter-item covariance amongst the scale items and $\bar{v}$ equals the average variance of the scale items. When the factors are standardised and possess the same variance, the formula (3.2) above could be simplified as formula (3.3).

$$\partial = \frac{\bar{r}}{1+(N-1)\bar{r}} \tag{3.3}$$

where $\bar{r}$ is the average correlation amongst the scale items.

3.4.1.4 Factor analysis

Factor analysis, its origins can be traced back over 100 years through the work of Pearson (1901) and Spearman (1904), is a multivariate statistical procedure commonly used to describe variability among observed, correlated variables based on a potentially low number of hypothetically unobserved variables called factors (Kim & Mueller, 1978). This technique helps to find interrelationships among a large number of variables (usually called items) and categorize them into a smaller set of more significant and underlying variable constructs using factor points of responses (Pallant & Manual, 2010). Normally, factor analysis falls into two main classes: Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). As the title implies, EFA is exploratory in nature, so it is heuristic, whereas CFA (a form of structural equation modelling) has clear assumptions and expectations of the factor structure, so researchers used it to test a proposed theory (Williams et al., 2010). EFA is an extremely powerful and popular approach for identifying the response patterns of respondents in questionnaire surveys and revealing the underlying factor structure of a set of variables (De-Vaus, 2001; McNeish, 2017). An EFA uncovers the number of factors and the items belonging to a particular factor, to be more specific, which items are closely related to one another and the extent of relationships between observable items and the extracted latent factors could be investigated (Mooi et al., 2017). EFA does not rely on previous views of the factor structure that might be developed in earlier research or established within a certain subpopulation; that is, EFA is employed when the inherent structure is not well-known (McNeish, 2017). It is necessary to establish an underlying structure when testing hypotheses and building theories. In the construction management area, EFA has already been broadly adopted. For instance, Kingsford Owusu and Chan (2019) explored barriers affecting the effective application of anti-corruption measures in infrastructure projects in both developed and developing countries. Li et al. (2011) identified critical project management factors of architectural, engineering, and construction (AEC) firms for delivering green building projects in Singapore. Considering the exploratory nature of the current study, it is suitable to adopt the EFA method instead of CFA to determine the underlying structure of variables. Therefore, in this study, EFA was conducted to appropriately categorize and group the identified PDFs along the different MiC stages and to lay a foundation for the subsequent PLS-SEM. Generally, the following linear and sequential five-step EFA protocol can provide guidance for developing clear decision pathways in this research (Thompson, 2004; Williams et al., 2010):

- *Step 1*: Checking the suitability of data for factor analysis, including sample size, sample to a variable ratio (N: p ratio), factorability of the correlation matrix, and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy/Bartlett's Test of sphericity;
- *Step 2*: Finding the proper ways to extract factors, where the most common extraction methods include principal components analysis (PCA), principal axis factoring (PAF), maximum likelihood, unweighted least squares, generalised least squares, alpha factoring, and image factoring;
- *Step 3*: Identifying criteria that assist in determining factor extraction, where many extraction approaches and rules exist include Kaiser’s criteria (eigenvalue > 1 rule), the Scree test, the cumulative percentage of variance extracted, and parallel analysis;
- *Step 4*: Selecting rotational method, where the two common rotation techniques include orthogonal rotation and oblique rotation;
- *Step 5*: Interpreting and naming the categorized factors as underlying factors, where the labelling of factors is a subjective, theoretical, and inductive process.

Before applying EFA, the data verification should be conducted to evaluate the appropriateness of the respondent data for factor analysis. These tests utilised in this research include the KMO measure of sampling adequacy and Bartlett's Test of sphericity. The KMO statistic measures the sampling adequacy by using the size of partial correlation coefficients, representing the squared correlation's ratio to the corresponding squared partial correlation among the composing variables (Field, 2013). The use of KMO allows the investigator to assess individual variables and the overall quality of the correlation matrix that provides a preliminary insight into the correlation structures (Dziuban & Shirkey, 1974). Therefore, it can further indicate whether other variables in the dataset can explain the correlation between variables (Kaiser, 1970; Kaiser & Rice, 1974). The KMO index ranges from 0 to 1, where 0 shows that the dataset is improper for EFA and 1 indicates a perfectly suitable dataset for further EFA (Hair, 2019; Tabachnick et al., 2019); the required and necessary minimum value for satisfactory EFA is 0.50 (Kaiser, 1974). Bartlett's Test of sphericity is a statistical test that measures the degree of difference between the correlation matrix to be factored and the identity matrix (Tobias & Carlson, 1969). Bartlett's Test of sphericity was used in this study to check the variance homogeneity and to highlight the presence of correlations among variables. The Bartlett's Test of sphericity should be significant ($p<0.05$) before it is suitable for EFA (Bartlett, 1950). To summarize, as stipulated in the literature, only when the KMO value is above 0.50 and the Bartlett's Test of sphericity is significant ($p<0.05$) can the collected data be considered appropriate for EFA. EFA comprises finding appropriate ways to extract and rotate factors. The aim of the data extraction is to reduce a large number of variables into underlying factors, while the purpose of data rotation is to simplify the factor structure of a set of variables, thereby producing a more interpretable and simplified solution (Norušis, 2008). In addition, as one of the most commonly used extraction tools in EFA, PCA is the default technique in many statistical programs (Williams et al., 2010), which is really suitable for establishing preliminary solutions in EFA (Pett et al., 2003).

3.4.1.5 Partial Least Squares-Structural Equation Modelling (PLS-SEM)

Structural Equation Modelling (SEM) is a versatile multivariate statistical technique that has been used ever since its introduction in the 1980s (Xiong et al., 2015). As a quasi-conventional and even indivisible statistical analysis approach in social science, SEM has been widely accepted in many business disciplines for theoretical exploration and empirical verification (Kline, 2015). There are two types of methods considered in the SEM analysis, namely, covariance-based techniques (CB-SEM) and variance-based partial least squares (PLS-SEM), both of which share the same roots (Hair et al., 2012). The application of PLS-SEM in this study is attributed to three prominent justifications, including its ability to deal with non-normal data with small sample sizes and formatively measured constructs (Hair et al., 2014). Compared to other statistical tools, such as multivariate regression and factor analysis, SEM has the advantage of being able to perform path analysis and factor analysis simultaneously (Xiong et al., 2015). In view of these benefits, this PLS-SEM technology has been widely used in construction project management research to date. For example, Owusu et al. (2020) adopted PLS-SEM to reveal correlational impacts of anti-corruption barriers on the efficacy of anti-corruption measures in infrastructure projects with 62 valid responses. Based on SEM, Chen et al. (2012) explored the interrelationships among 46 critical success factors of construction projects. Zhao and Singhaputtangkul (2016) applied PLS-SEM to test the hypotheses formulated for investigating the effects of firm characteristics on enterprise risk management implementation with 35 respondents. Based on a sample size of 76, Ekanayake et al. (2021) established the underlying factor’s relationship between appropriate constructs of supply chain vulnerabilities and supply chain capabilities using the PLS-SEM in the industrialized construction area. These vindicated the PLS-SEM analysis in this study to verify the developed hypothetical models. The *SmartPLS 3.3.3* software was used to provide the environment to carry out the PLS-SEM research. Thus, the significant weighting score for each interconnection of PDFs was calculated from the PLS-SEM model, which was the basis for base run simulation within the SD system in this study.

3.4.2 Social Network Analysis (SNA)

3.4.2.1 An overview of SNA

Social network theory believes that the organic solidarity of a social system does not depend on the cognition of persons but on the interconnection and interaction between social relations that can be objectively determined (Liu, 2004a). A project can be regarded as a system composed of multiple relationship links, and social network theory can be used to investigate the causal relationship structures of these links and the influence of such relationship structure patterns on behaviour (Scott, 2000). SNA is intrinsically an interdisciplinary endeavour building upon the aforementioned theory, whose pioneers derived from sociology, social psychology and anthropology (Mitchell, 1969), with a consolidation of formal mathematical, statistical and computing informative methodologies (Wasserman & Faust, 1994). As a comprehensive and exemplary approach, SNA is always utilized to analyse the volume and patterns of social relationships that connect individual actors with each other (Scott & Carrington, 2011). SNA has always been an effective and popular tool for reflecting stakeholder patterns for scholars concentrated on the interaction analysis of groups (Chinowsky et al., 2008; Xue et al., 2020). Besides, this technique facilitates to distribute variably sticky messages among a crowd, increase the odds of presenting good ideas, gain more positive assessments and recognition and simplifies decision-making and interactional analysis (Burt et al., 2013). Given that, SNA has already been applied successfully to construction project management studies, especially in terms of analysing the issues of collaborative interaction among stakeholders. Through SNA, Gan et al. (2018) investigated the influencing power of stakeholders over the identified barriers in offsite construction. Liang et al. (2015) proposed an innovative approach based on SNA theory to examine the underlying relationships and interactions between the critical success factors for green retrofits and involved stakeholders. Mok et al. (2016) suggested a conceptual SNA-based model to analyse stakeholder relational structures and issue interdependencies in major construction projects from a network perspective. Luo et al. (2019) adopted SNA to prioritize the stakeholder-associated supply chain risks and explore their interactions in a MiC project in Hong Kong by developing a relevant risk network. Thus, these studies can support the reasonability and evaluability to employ SNA in this study. With its capability to analyse interrelationships, SNA has high application potential in exploring the impact of various driving forces in the complicated MiC project environments, taking a step forward from traditional modular construction project stakeholder analysis practices.

3.4.2.2 Network Models

A 'social network' can be described as a specific set composed of multiple social agents (social actors with subjective initiative) as nodes and linkages between these nodes (relationships between social agents) (Liu, 2004a), with the further property that the traits of these associations altogether can be used to explicate the social behaviour of the actors concerned (Mitchell, 1969). The actors mentioned in the SNA may be any social unit or entity, such as a state, city, village, school, organization, company, individual, etc. (Liu, 2004b). A node refers to any social actor, and the information about the node must be actual, which can be collected conventionally (e.g., snowball sampling, questionnaire surveys, structured interviews, and workshops), either static or dynamic. Links detect the relationships between social actors and affect the robustness and performance of the whole system (Wasserman & Faust, 1994). Generally speaking, when there is a tie between social actors, the 'tie' often represents the specific relational content or the substantial relationship that occurs in reality, which has a variety of manifestations (Liu, 2004b). Hanneman and Riddle (2005) pointed out that SNA focuses on the links that tie each social actor with other actors rather than individual actors and their attributes. In this context, applying SNA to explore how relevant stakeholders are involved in the critical PDFs and analyse their interactions and interdependencies across the three stages of MiC projects in this research is therefore practical – it enables researchers to objectively evaluate the roles and influences of stakeholders and PDFs, investigate embedded challenges in MiC, propose appropriate measures to utilize these identified PDFs and facilitate stakeholders engagement, and thereby further suggest practical policy implications and recommendations to promote the development of MiC.

There are two types of social networks for relational research, namely, one-mode network and two-mode network. The classical one-mode network refers to a network composed of a set of actors and the relationships among various actors within it (Liu, 2004b). For example, a network of friends among 20 students in a department is a one-mode network; the communication and negotiation between 15 stakeholders involved in a building project is also a one-mode network. However, many real-world networks are actually modelled naturally through a two-mode graph (Latapy et al., 2008). A two-mode network (also known as affiliation or bipartite network) consists of two distinct sets of nodes and relations that connect the two sets, and ties exist only between nodes belonging to different groups (Borgatti, 2009; Opsahl, 2013). Instances include the relationship network between supply chain risks and related stakeholders in the prefabricated building project and the interaction network between involved stakeholders and critical success factors for green retrofits. Considering that this study is to investigate the interrelationships between critical PDFs and stakeholders involved in MiC projects, it is appropriate to adopt a two-mode SNA. Although various tools and methods have been applied to understand classical one-mode networks, only a few approaches have been well developed to analyse two-mode networks (Latapy et al., 2008). Two typical approaches exist for two-mode SNA data. The first method is a ‘conversion method’, which aims to transfer the two-mode data into the one-mode network by projection, after which it can utilize fundamental measures defined for one-mode networks analysis (Lin et al., 2017). The second is a direct method, which designed some specific notions to directly analyse the two-mode weighted network (Borgatti & Everett, 1997). The latter approach has drawn more attention in recent studies. Both methods have their advantages and disadvantages, which are listed in detail in Table 3.6. Since this study is more concerned with the integrity of the information and mainly explores the interactions between PDFs and stakeholders rather than focusing on a single set, the second direct approach is adopted.

Table 3.6 Comparison between Conversion and Direct Method for Two-mode SNA

Methods for two-mode SNA		Advantages	Disadvantages
Conversion method	Projection	1. Using fundamental and recognized measures designed for one-mode network 2. Easy assessing and comparing the analytical results	Loss of the information in a two-mode network
Direct method	Some specific notions and measures (e.g. bipartite statistics)	1. Directly handling and measuring two-mode network 2. Information integrity	1. Lack of rigour and generality 2. Complicated analysis

3.4.2.3 Process of the two-mode SNA

Generally, there is a five-step process in a linear sequence to provide guidance for conducting a clear SNA in this study as follows (Yang & Zou, 2014):

- *Step 1*: Setting up the boundary of the network, where all the nodes should be identified. For the two-mode network model, two lists of PDFs and stakeholders need to be developed through several methods (literature review and experience-based approaches);
- *Step 2*: Establishing and assessing the meaningful and actionable interrelationships, where links that represent the interactions among nodes are evaluated. By adopting the five-point Likert scale, 'PDF-Stakeholder' evaluation structure matrixes for the three stages in MiC projects are formulated respectively from interviews and workshops with relevant stakeholders in MiC projects;
- *Step 3*: Visualising the network, where three 'PDF-Stakeholder' evaluation structure matrixes are imported into the SNA software named *Netminer 4* to visualize the two-mode

networks at different stages of MiC projects;

- *Step 4*: Deciphering the network structures, where quantitative analysis is carried out to mine interactive information of the PDF-Stakeholder in the network structural configurations through calculating two sets of SNA indicators, namely, network measures and node/link measures;
- *Step 5*: Presenting the network analysis results, where some innovative findings in the previous steps are discussed and summarized. Policy implications and recommendations to promote the development of MiC are suggested based on the results integrated with practical frontier experience.

3.4.3 System Dynamics (SD) model

3.4.3.1 An overview of SD

The system dynamics method, invented in the late 1950s by Professor Jay W. Forrester at the Massachusetts Institute of Technology, is a computer-aided approach for strategy and policy design based on feedback systems theory (Forrester, 1961). Wolstenholme (1997) provided a detailed definition for SD by describing its w*hat, why, how, and within* as follows:

What: SD is a rigorous way to help researchers think about, visualize, share and communicate with the future evolution of complex organizations and problems over time;

Why: SD can be used to solve problems and create more robust designs, thereby minimizing the possibility of unpleasant surprises and unintended consequences;

How: Through the creation of flowcharts and simulation models, organizational boundaries, policies, the interrelationships between physical and behavioural processes, information feedback and time delay could be captured; then by using these architectures to test the overall feasibility of alternative plans and scenarios;

Within: A framework that respects and promotes the requirements and values of responsibility, openness, equality and awareness of individuals and teams.

SD is widely applied to dynamic problems arising in public policy, economics, defence, environmental studies, engineering, construction management, theory-building in social science, as well as its home field. Dynamic modelling technique enables decision-makers to understand better, explore, analyse and identify solutions for complex nonlinear dynamical systems (Sterman, 2002). In contrast to other traditional approaches to system issues, which depict the underlying variable relationships and comprehensive system behaviour states from an isolated or narrow static perspective, the advantages of SD are prominent, namely, flexibility, continuous testing and learning, and ease of acceptance and adaptability (Winz et al., 2009). As an advanced scientific research tool, system dynamics modelling relies on its feedback loops and connections to assist in handling complex processes by simplifying complicated systems into operable units (Sterman, 2000). Within a controlled environment, interactive causality is where one variable with a changing value has a feedback-based effect on another variable, ultimately affecting the behaviour of the entire system. The SD theory is to qualitatively describe the organizational boundaries, information, processes and strategies of complex systems on the one hand, and quantitative simulation modelling and analysis on the other to promote exploration of system structure and control design (Wolstenholme, 1990). Therefore, SD modelling can be adopted to investigate the behaviour of complex systems over time with changes of variables. In recent studies, in the prefabricated construction industry, SD practices have been extensively applied to solve problems in policy applications. Li et al. (2014) proposed an SD model to measure the impact of offsite prefabrication on reducing construction waste, and assist policymakers in determining the optimal policy mix from the diverse scenarios generated by the model prior to production. With an example of the Singaporean government's policy to diffuse prefabrication to the private sector, Park et al. (2011b) concluded that the SD model-based method is valuable for decision-makers in a government or enterprise to formulate effective construction policies, from a comprehensive view of the policy application process, and facilitates them to examine the feasibility of alternative policies systematically. Based on the development of an SD model, after evaluating and comparing construction and demolition waste reduction strategies under various scenarios, policymakers can identify the best management strategies before actual implementation (Yuan et al., 2012). Although this approach is widely adopted to scrutinize project complexity and dynamics, there was no known effort to analyse PDFs in modular buildings employing SD modelling principles. Moreover, these abovementioned studies can support the reasonability and availability to apply SD in this study. With its capability to analyse dynamic interaction mechanisms involved, SD has high application potential in investigating the cumulative impacts of various PDFs in the complex MiC project environments, taking a step forward in instigating appropriate strategies to promote the excellent performance of MiC.

3.4.3.2 Basic tools for SD modelling

Essential analytical tools in SD include causal loop diagram and stock-flow diagram, which help to analyse feedback relationships from a dynamic and multi-dimensional perspective effectively.

Causal loop diagram

A causal loop diagram is a conceptual tool that reveals the causal relationships between variables and the general feedback mechanisms of a real-world system through articulating interrelations of a set of related elements that formulate a model (Ajayi, 2016; Li et al., 2014). The causal loop diagram consists of nodes and arrows, where nodes represent related defined variables and arrows refer to the cause-and-effect relationships amongst the variables. This diagram maintains three essential capabilities, including the ability to quickly capture assumptions about dynamic causes, simplify the mental model of individuals or organizations, and present significant feedback loops that can solve identified problems (Sterman, 2000). Bala et al. (2016) suggested the following seven steps to develop causal loop diagrams:

(1) Define the problem and objectives;

(2) Identify the primary variables affecting the behaviour of the systems;

(3) Identify the secondary important variables of the systems;

(4) Identify the tertiary variables within the system boundary;

(5) Describe the cause-effect relationships using arrows with polarity;

(6) Find the closed loops;

(7) Classify the balancing and reinforcing loops.

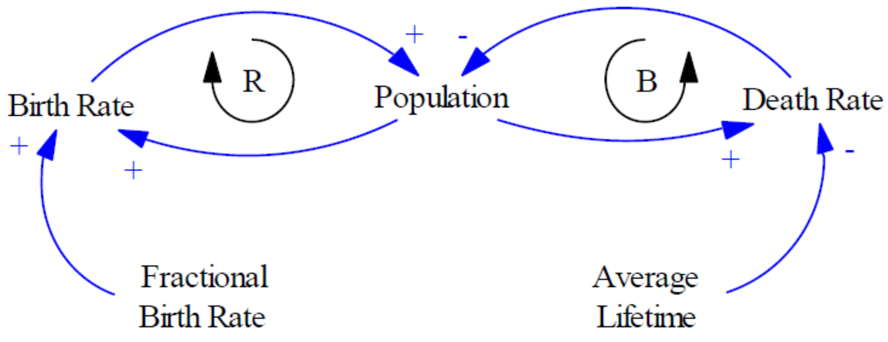

Figure 3.7 Example of A Causal Loop Diagram

Figure 3.7 displays an example of a causal loop diagram generated by *Vensim* software. The arrows here are called causal links, where polarity (either positive + or negative -) is assigned to each link to show how the dependent variable changes as the independent variable changes (Sterman, 2000). A positive link implies that a change in variable A causes a change in variable B in the same direction (meaning that it increases or decreases at the same time). In contrast, a negative link is when a change in variable B causes a change in variable C in the opposite direction (meaning that as B increases, C decreases) (Haraldsson, 2000). In general, there are two types of causal loops based on the direction in which the parameters influence each other, namely Reinforcing (R) or positive feedback and Balancing (B) or negative feedback. Due to the equivalent influence between the variables, reinforcing loops bring an escalating effect, which can be an ascent or a downward spiral. However, in a balancing loop, there are factors that control exponential growth or restrict growth, so it seeks to stabilize or restore control (Maani & Maharaj, 2004). It is worth noting that positive and negative loops should not be confused with good and bad. Whether the feedback loop is considered positive or negative depends on its effect on system changes (Richardson & Pugh, 1981).

Stock flow diagram

A stock and flow diagram is another intuitive method to visualize the causal interrelationships between variables and feedback processes in SD modelling (Sterman, 2000). To capture the stock and flow structure of the system, some algebraic expressions are written with equations and computer codes, which can be run on a computer, should be added to the causal loop diagram, which forms the stock-flow diagram (Ajayi, 2016). Hence, stock and flow diagram is designed to assist mathematical simulation and quantitative analysis of the SD model through professional software (Bala et al., 2016). The four structural elements in the stock-flow diagram include stock, flow, converter and connector (Yuan, 2012). An example of a stock and flow diagram is shown in Figure 3.8 below. Detailed explanations of these elements are presented in the following paragraphs.

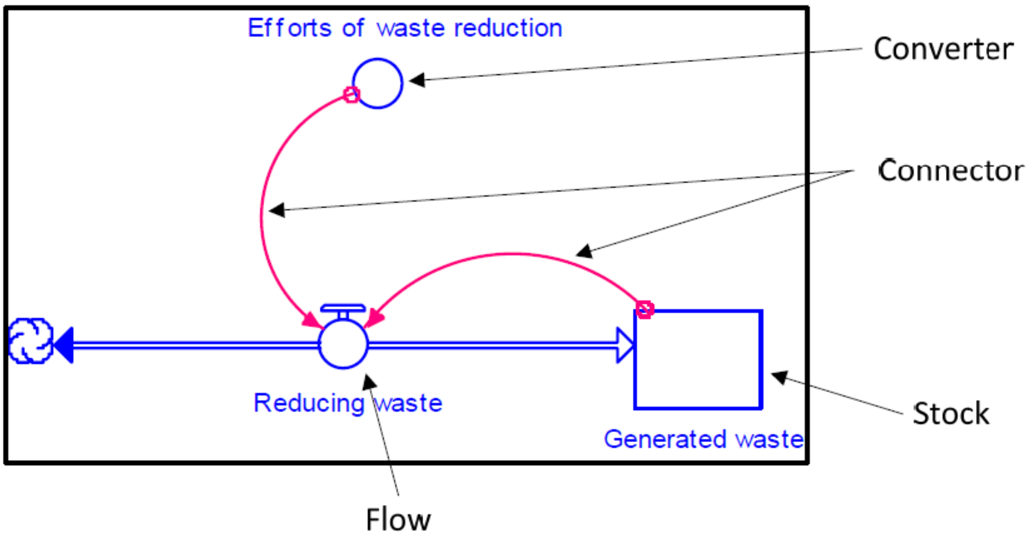

Figure 3.8 Example of A Stock and Flow Diagram (Yuan, 2011)

Stocks, symbolized by rectangles, are accumulations and characterize the system state. As the first basic element, it describes the conditions of the system at any given time. Stocks collect whatever flows into them and net everything that flows out of them. The net flow into the stock is the rate of change of the stock. Stocks are the memory of the system and sources of disequilibrium. The SD model works only with aggregates, which indicates that the stock’s items are indistinguishable. There are four kinds of stocks: reservoir, conveyer, queue and oven, of which the most commonly used type of stock is a reservoir. Stocks are typically expressed in quantities such as money, people, knowledge, or social performance.

Flows, represented by the block arrow symbol, are the rates at which these system states change. As the second key element, it serves as a tool to deliver or drain the information from the stocks (Yuan, 2012). The value of flows can be either positive or negative, where negative flow means outflow and will empty the stock, and positive flow is inflow and will fill in the stock. While stocks present how things are in a system, flows show how fast the stocks are changing. Flows are usually measurements of quantities in a given time period, such as dollars per year or clients per month.

Converters, represented by isolated circles, serve as an intermediate variable for miscellaneous calculations and convert input into output. It is a utilitarian role because it decomposes complex flow equations into simpler components, making the model easier to understand. Converters are significant components in the system structure as they help to understand how the system works and how it can be modelled (Maani & Maharaj, 2004). Connectors, symbolized as simple arrows, are the information transmitters connecting model elements and representing the model structure's causes and effects. It is important to note that connectors transmit information, but nothing flows through them. That is, it is just information input and output, not inflow and outflow.

3.4.3.3 Process of the SD modelling

In general, there is a five-step framework that provides direction for SD model construction and simulation in this study as follows (Yuan et al., 2012; Yuan, 2011), shown in Figure 3.9, which includes problem statement, system description, model establishment, model testing and validation, and model application.

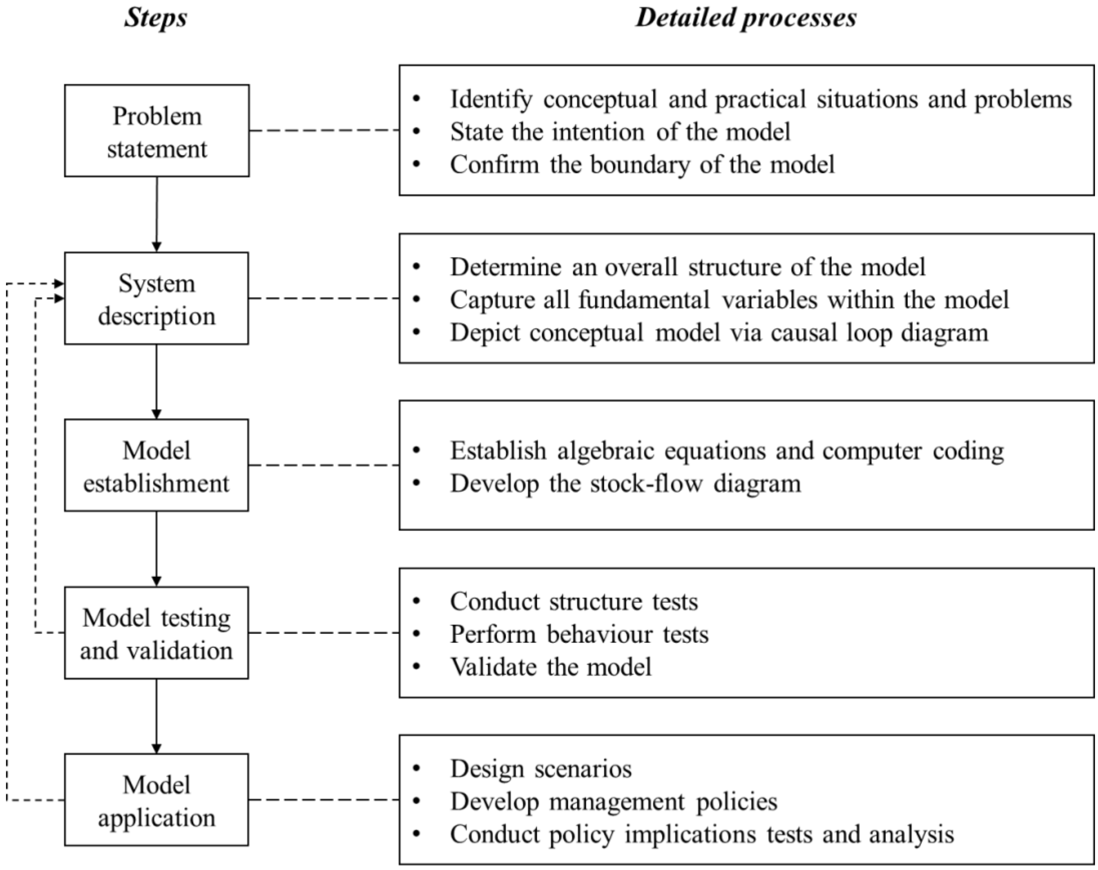

Figure 3.9 Five-step Framework of SD Modelling

<u>*Step 1: Problem statement*</u>

To develop an SD model, the first step requires understanding both conceptual and practical situations and problems in the real world, as issues are generally diverse and complex from the perspective of construction policy management. In this stage, figuring out 'what is the problem' and 'why the problem' is crucial (Sterman, 2000). Clearly expressing the intent of the model can focus on the initial research and assist in judging whether the verification of the result is reasonable (Richardson & Pugh, 1981). Confirming the boundary of the model by specifying what the model should contain and exclude is the final task that should be completed in this step (Richardson & Pugh, 1981).

Step 2: System description

After determining the problem to be approached, the overall structure of the model can be developed. On this basis, all fundamental variables included and applied in the model are identified and reviewed. Fundamental variables, which are captured and manipulated by researchers to solve problems, can significantly affect the behaviour of the whole system. In addition, only the fundamental variables should be included in the model to ensure that the critical behaviours of the system can proceed smoothly. To visually describe the complete structure of the system, a causal loop diagram is adopted (Coyle, 1997).

Step 3: Model establishment

The causal loop diagram can only be used for qualitative analysis to provide some general insights to solve problems. In order to describe the model more accurately, quantitative analysis is essential. Therefore, a stock-flow diagram needs to be formulated in this step. In fact, the causal loop diagram and stock-flow diagram are two different presentation forms of the SD model, both of which show the causal relationship between different variables in the SD modelling. However, their emphases are different. The causal loop diagram is articulated with text and arrows, which aims to form a conceptual model to help users better understand the situations; while the stock-flow diagram is written in algebraic equations and computer coding, which is used to assist quantitative analysis and mathematical simulation of models (Coyle, 1997; Wang et al., 2018).

Step 4: Model testing and validation

The SD model obtained in Steps 2 & 3 is an initial model, which requires to be adjusted and verified. Testing and validation are two important concepts to build confidence in SD modelling (Richardson & Pugh, 1981). Testing means applying the constructed model to empirical reality and conducting a comparative evaluation to accept or reject the model, whereas validation refers to the process of building confidence in the reliability and effectiveness of the model (Bala et al., 2016). In order to review and emphasize the usefulness of the model, a series of tests should be conducted after the model establishment to develop confidence in predictions (Sterman, 2002). According to Bala et al. (2016), the tests could be broadly classified as structure tests, behaviour tests, and policy implications tests, where structure and behaviour pattern tests of the model are essential, and policy implications tests provide a sufficient validation. Firstly, structure tests assess whether the SD model conforms to reality, which includes five aspects: 1) structure verification test; 2) parameter verification test; 3) extreme condition test; 4) boundary adequacy test; and 5) dimensional consistency test. Secondly, once the structural validation tests are successfully completed, the behaviour tests can begin to ensure that the variables are meaningful in the real world, including three parts: 1) behaviour reproduction test; 2) behaviour anomaly test; and 3) behaviour sensitivity test.

Step 5: Model application

After completing the structure and behaviour tests that are critical to the creditability of the model, the validated model could be applied to address definite issues, such as designing and evaluating management strategies for improvement. To strengthen confidence in the implication of the model on policy, testing of policy implications can be selectively performed, including 1) changed behaviour prediction test; and 2) policy sensitivity test.

3.5 Summary of the Chapter

This chapter expounds a concise research process, and comprehensively describes the proposed research practices and their detailed research steps and application processes, including descriptive statistics, mean score ranking, Cronbach's alpha, factor analysis, SNA and system dynamics modelling. This chapter also provides an overview of the data collection process and basic sample situation of questionnaire surveys and expert interviews. Through the appropriate combination and application of these methods, the three research objectives of this thesis can be achieved.

Chapter 4 Critical Policy-Driving Forces in MiC Projects in Hong Kong

4.1 Introduction

This chapter aims to analyse the data collected from the questionnaire survey to identify the critical PDFs for the success of MiC projects in Hong Kong. After drawing on the plentiful relevant literature and conducting a pilot study, an expert opinion survey was conducted to gather the necessary data for this study. Then, the collected data were analysed using relevant significance analysis and factor analysis to identify critical PDFs and appropriate groupings. Finally, the findings are structured and explained.

4.2 Research Design

Considering the positivist research philosophy, a deductive research approach was mainly used in this chapter. Figure 4.1 illustrates the research methods and their flow in this study.

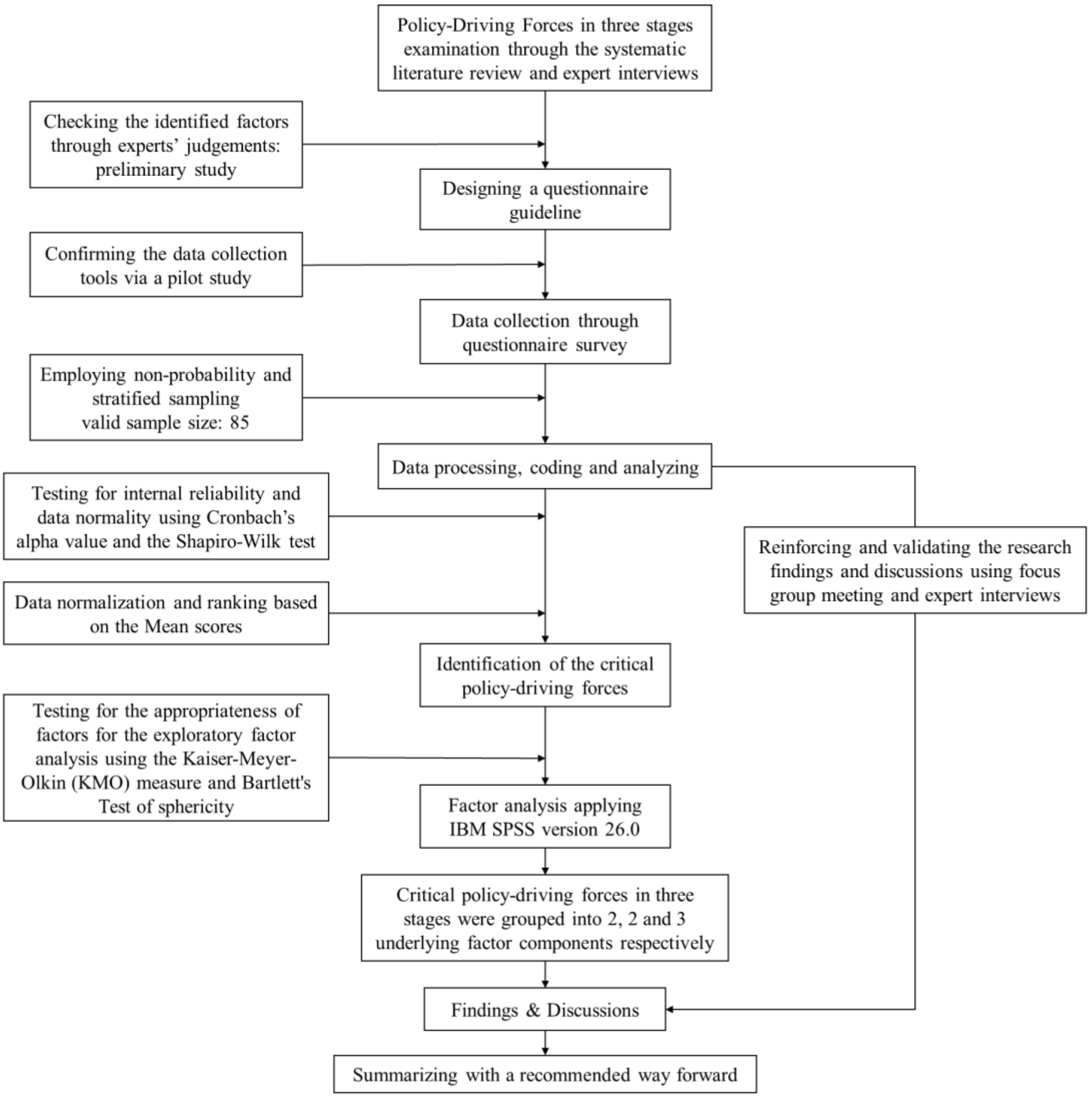

Figure 4.1 Research Methods and Flow in Chapter 4

4.3 Identification of PDFs

4.3.1 Option list of PDFs for the success of MiC projects in Hong Kong

A list of policy-driving forces for the success of MiC projects in Hong Kong was identified from the comprehensive literature review and expert interviews. On the whole, there are a total of 33 PDFs in the development of MiC in Hong Kong. Table 4.1 presents the identified potential PDFs.

Table 4.1 A list of PDFs that Improve MiC Uptake in Hong Kong

No.	**Policy-Driving Forces**	**Stage**	**Presentative references**
1	Change of the Government policy related to COVID-19 pandemic	I/II/III	Interview
2	Change of the Government policy related to economic factors	I	(Han & Wang, 2018; Luo et al., 2015)
3	Change of the Government policy related to finance	I/II/III	(Jiang et al., 2018)
4	Change of the Government policy related to taxation and revenue	I/II	(Liu et al., 2016)
5	Change of the Government policy related to the preferential interest of the MiC project	I/II	(Chen et al., 2017; Lu et al., 2018)
6	Change of the Government policy related to investment of the MiC project	I	(Chiang et al., 2006; Jiang et al., 2018)
7	Change of the Government policy related to the restriction of the property market	I	(Jiang et al., 2018; Mao et al., 2015)
8	Adjustment of the Government policy related to housing policy	I/II	(Huang et al., 2018; Mare, 2018)
9	Change of the Government policy related to land supply and usage	I/II	(Jiang et al., 2018; Jin et al., 2020)
10	Change of the Government policy related to the urban plan, e.g. site coverage, height restriction or green ratio	I/II	(Jiang et al., 2018; Jin et al., 2020)
11	Change of the Government policy related to the publicity of MiC	I	(Jiang et al., 2018; Zhang et al., 2017)
12	Change of the Government policy related to environmental protection	I/II/III	(Lehmann, 2011; Lu & Yuan, 2012)
13	Change of the Government policy related to MiC project tendering	III	Interview
14	Change of the Government policy related to construction waste disposal charging scheme	II/III	(Ghisellini et al., 2018; Lu & Yuan, 2012)
15	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	III	Interview

16	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	III	Interview
17	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	III	Interview
18	Change of the Government policy related to the Mainland and Hong Kong Closer Economic Partnership Arrangement (CEPA) and Professional Services in Greater Bay Area, such as extending the scope of mutual recognition of qualifications for construction professionals	III	Interview
19	Change of the Government policy related to the construction material supply and price	III	(Lu et al., 2018; Mao et al., 2013)
20	Change of the Government policy related to import of the construction material	III	(Oral et al., 2003; Pan et al., 2012)
21	Change of the Government policy related to labour policy	III	(Gao & Tian, 2020; Pan et al., 2012)
22	Change of the Government policy related to MiC technological support and innovation	III	(Han & Wang, 2018; Tykkä et al., 2009)
23	Change of the Government policy related to the sale of the MiC buildings	III	Interview
24	Change of the Government policy related to the proportion of prefabrication in public housing projects	II	(Chiang et al., 2006; Jiang et al., 2018)
25	Change of the Government policy related to scope/type of the prefabricated elements and components	III	(Chiang et al., 2006; Wuni & Shen, 2020)
26	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for MiC	III	(Han & Wang, 2018; Lu et al., 2018; Mao et al., 2013)
27	Change of the Government policy related to site selection criteria for new precast manufacturing sites	II/III	(Azman et al., 2012)
28	Change of the Government policy related to the restriction of the construction schedule	III	(Lu et al., 2018)
29	Change of the Government policy related to the multi-sector governance of MiC	III	(Luo et al., 2015; Zhang et al., 2017)

30	Change of the Government policy related to project/qualification supervision	III	(Jiang et al., 2018; Luo et al., 2015)
31	Change of the Government policy related to the standard of the acceptance of the completed construction quality	III	(Zhang et al., 2017)
32	Change of the condition on MiC project contracts	III	(Park et al., 2011)
33	Change of the Government policy related to the procurement system	II/III	(Guerzoni & Raiteri, 2015)

Because the impact of each PDF is not the same in different phases of MiC projects, the PDFs were appropriately distributed among three different stages of MiC projects, namely, initiation, planning and design, and the construction phase. By thoroughly analysing the influence and role of PDFs in the different stages, 33 identified PDFs were categorized into these three stages. Some PDFs occurred in different stages, while other PDFs appeared only in a specific stage. The staged PDFs were then itemized, as shown in Table 4.2. In stages I, II, and III, there were a total of 12, 12, and 23 identified PDFs, respectively. Stage I (Initiation Phase) includes the identification of potential prefabricated projects, financial analysis, the preparation of feasibility study reports and decision-making. Stage II (Planning and Design Phase) includes acquiring land-use rights, project design and planning approval. Stage III (Construction Phase) includes the tendering of project contractors, prefabricated module design /manufacturing /transportation/on-site installation, other construction work, acceptance of the completed construction quality and project handover. Further, stage III comprises the phases of MiC supply chains: manufacturing, logistics and on-site assembly, which is the main difference between MiC and traditional cast-in-place buildings. Remarkably, this study focuses on the MiC in HK. Due to the specific geographic location of HK (within the Greater Bay Area), coupled with high labour costs and limited land availability related to sustainable development issues, almost all manufacturing plants are located in various regions of Guangdong Province, such as Huizhou and Dongguan. Hence, prefabricated modules and components are manufactured in Mainland China, then transported to HK through customs, and finally installed on site.

Table 4.2 Option List of Staged PDFs

Stages	Policy-Driving Forces	Code	Source
Stage I: Initiation Phase	Change of the Government policy related to COVID-19 pandemic	A1	Interview
	Change of the Government policy related to economic factors	A2	Literature review
	Change of the Government policy related to finance	A3	Literature review
	Change of the Government policy related to taxation and revenue	A4	Literature review
	Change of the Government policy related to the preferential interest of the MiC project	A5	Literature review
	Change of the Government policy related to investment of the MiC project	A6	Literature review
	Change of the Government policy related to the restriction of the property market	A7	Literature review
	Adjustment of the Government policy related to housing policy	A8	Literature review
	Change of the Government policy related to land supply and usage	A9	Literature review
	Change of the Government policy related to the urban plan	A10	Literature review
	Change of the Government policy related to the publicity of MiC	A11	Literature review
	Change of the Government policy related to environmental protection	A12	Literature review
Stage II: Planning & Design Phase	Change of the Government policy related to COVID-19 pandemic	B1	Interview
	Change of the Government policy related to the proportion of prefabrication in public housing projects	B2	Literature review
	Change of the Government policy related to finance	B3	Literature

			review
	Change of the Government policy related to taxation and revenue	B4	Literature review
	Change of the Government policy related to the preferential interest of the MiC project	B5	Literature review
	Change of the Government policy related to construction waste disposal charging scheme	B6	Literature review
	Change of the Government policy related to site selection criteria for new precast manufacturing sites	B7	Literature review
	Change of the Government policy related to housing policy, the restriction on the type and the size of property development	B8	Literature review
	Change of the Government policy related to land supply and usage	B9	Literature review
	Change of the Government policy related to urban planning policy, e.g. plot ratio, site coverage, height restriction and green ratio	B10	Literature review
	Change of the Government policy related to the procurement system	B11	Literature review
	Change of the Government policy related to environmental protection	B12	Literature review
Stage III: Construction Phase	Change of the Government policy related to COVID-19 pandemic	C1	Interview
	Change of the Government policy related to MiC technological support and innovation	C2	Literature review
	Change of the Government policy related to finance	C3	Literature review
	Change of the Government policy related to the construction material supply and price	C4	Literature review
	Change of the Government policy related to import of the construction material	C5	Literature review
	Change of the Government policy related to construction waste disposal charging scheme	C6	Literature review
	Change of the Government policy related to site selection criteria for new precast manufacturing sites	C7	Literature review
	Change of the Government policy related to scope/type of the prefabricated elements and components	C8	Literature review
	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for MiC	C9	Literature review
	Change of the Government policy related to the multi-sector governance of MiC	C10	Literature review

	Change of the Government policy related to the procurement system	C11	Literature review
	Change of the Government policy related to environmental protection	C12	Literature review
	Change of the Government policy related to MiC project tendering	C13	Interview
	Change of the condition on MiC project contracts	C14	Literature review
	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	C15	Interview
	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	C16	Interview
	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	C17	Interview
	Change of the Government policy related to the Mainland and Hong Kong Closer Economic Partnership Arrangement (CEPA) and Professional Services in Greater Bay Area, such as extending the scope of mutual recognition of qualifications for construction professionals	C18	Interview
	Change of the Government policy related to the restrict of the construction schedule	C19	Literature review
	Change of the Government policy related to labour policy	C20	Literature review
	Change of the Government policy related to project/qualification supervision	C21	Literature review
	Change of the Government policy related to the standard of the acceptance of the completed construction quality	C22	Literature review
	Change of the Government policy related to the sale of the MiC buildings	C23	Interview

4.3.2 Ranking of PDFs across various stages in MiC project

Research data were collected by means of a questionnaire survey to get the experts' opinion on the occurrence possibility and impact degree of a specific PDF during the relevant MiC project phases- initiation, planning and design, and construction, then further to calculate the comprehensive impact degree of each PDF factor and analyze the significance of the list in Table 4.2. The detailed description of the questionnaire development, data collection process, and respondents' backgrounds were already explained in Section 3.2.2.

The Statistical Package for Social Sciences (SPSS), IBM-SPSS Version 26.0, was used to analyse the questionnaire data collected for the PDFs. The value of Cronbach's coefficient alpha for all the PDFs in the three stages was 0.937, and the Cronbach's coefficients of the individual Stage I, II, III were 0.840, 0.887 and 0.940, respectively. All Cronbach's coefficients were between the range of 0.70 to 0.95, indicating that the five-point scale measurement adopted has high reliability or consistency. Table 4.3 lists the results of Cronbach's alpha data obtained from SPSS V 26.0. Data normality test is another crucial test, which needs to be applied to decide the nature of the data distribution type. The most powerful and commonly used normality test should be the Shapiro-Wilk test (Owusu & Chan, 2019; Razali & Wah, 2011). Table 4.3 also shows the statistical results of the Shapiro-Wilk test, and from it, a conclusion could be drawn that the data in this research is non-normally distributed since the test value is less than the stipulated P-value (0.05). Scale ranking and factor analysis were then employed to analyse the data. The relevant procedure, findings and related discussion are provided in the following sections.

Table 4.3 Reliability Statistics and Normality Test of Data

Stages	Code	Cronbach's coefficient alpha	Shapiro-Wilk test
Stage I: Initiation Phase	A1	0.840	<0.001
	A2		<0.001
	A3		<0.001
	A4		0.002
	A5		<0.001
	A6		<0.001
	A7		0.001
	A8		<0.001
	A9		<0.001
	A10		0.012
	A11		<0.001
	A12		<0.001
Stage II: Planning & Design Phase	B1	0.887	<0.001
	B2		<0.001
	B3		0.005
	B4		0.021
	B5		<0.001
	B6		0.004
	B7		0.003
	B8		0.001
	B9		0.002
	B10		<0.001
	B11		0.003
	B12		<0.001
Stage III: Construction Phase	C1	0.940	<0.001
	C2		<0.001
	C3		<0.001
	C4		0.002
	C5		<0.001
	C6		0.005
	C7		<0.001
	C8		<0.001
	C9		<0.001
	C10		<0.001
	C11		0.002
	C12		<0.001
	C13		0.013

C14	0.005
C15	<0.001
C16	<0.001
C17	<0.001
C18	<0.001
C19	0.005
C20	<0.001
C21	0.001
C22	<0.001
C23	<0.001

Table 4.4 summarises the ranking of potential PDFs on different stages of MiC projects in Hong Kong. This research applied the descriptive statistics and normalization analysis to determine the critical PDF factors among the list of identified factors (Table 4.2) following the studies of Osei-Kyei and Chan (2017) and Adabre and Chan (2019). Therefore, the mean scores of occurrence possibility and impact degree of all the PDF factors in three stages were calculated, respectively. In order to reflect the comprehensive impact degree (CID) of each PDF factor on the MiC project, this study further adhered to the theories of Ameyaw and Chan (2016) and Owusu et al. (2020). After evaluating the average value of each PDF factor assessed by experts, the CID of PDFs' irregularities can be determined by the square root of the product of the mean occurrence probability and impact degree (Ameyaw & Chan, 2016). The comprehensive impact of the PDFs was then computed, referring to formula (4.1) in this study. The OP and ID were obtained from the questionnaire.

$$CID = \sqrt{OP \times ID} \tag{4.1}$$

Where CID is the comprehensive impact degree of each PDF factor, OP represents occurrence probability, and ID indicates impact degree.

All comprehensive mean scores and their respective normalized values were calculated then. Factor criticality was ascertained according to the normalization values. Osei-Kyei and Chan (2017) and Adabre and Chan (2019) suggested that the factors with a normalized value $\geqslant$ 0.50 can be viewed as critical factors for further analysis in the five-point questionnaire. This criterion is adopted in this research. Comprehensive statistical mean (*M*), standard deviation (SD) and the normalization (*N*) values for each PDF factor in different stages were computed and presented in Table 4.4. PDFs were ranked according to the comprehensive *M* value. If two or more factors obtain the same *M* value, then the factor with the least SD is ranked as the highest important factor. Based on the normalization values ($N \geq 0.50$), in Stage I, 7 out of 12 PDFs were identified as the critical PDFs; in Stage II, 6 out of 12 PDFs were identified as the critical PDFs; and in Stage III, 10 out of 23 PDFs were identified as the critical PDFs that significantly influence the success of MiC projects in Hong Kong and considered them in the subsequent factor analysis.

Table 4.4 Ranking of Potential PDFs in Three Stages of MiC Projects in HK

Stages	Code	Policy-Driving Forces	Mean-OP	Mean-ID	Mean-CID	SD	*N* value	Rank
Stage I: Initiation Phase	A1	Change of the Government policy related to COVID-19 pandemic	3.882	3.882	3.882	0.825	1.00[a]	1
	A6	Change of the Government policy related to investment of the MiC project	3.682	3.953	3.815	0.938	0.87[a]	2
	A12	Change of the Government policy related to environmental protection	3.682	3.776	3.729	0.908	0.71[a]	3
	A5	Change of the Government policy related to the preferential interest of the MiC project	3.659	3.800	3.729	0.856	0.70[a]	4
	A8	Adjustment of the Government policy related to housing policy	3.588	3.753	3.670	0.876	0.59[a]	5
	A11	Change of the Government policy related to the publicity of MiC	3.635	3.671	3.653	0.988	0.56[a]	6
	A4	Change of the Government policy related to taxation and revenue	3.412	3.871	3.634	0.891	0.52[a]	7
	A9	Change of the Government policy related to land supply and usage	3.412	3.706	3.556	0.971	0.37	8
	A3	Change of the Government policy related to finance	3.388	3.718	3.549	0.918	0.36	9
	A2	Change of the Government policy related to economic factors	3.459	3.635	3.546	0.856	0.35	10
	A7	Change of the Government policy related to the restriction of the property market	3.306	3.635	3.467	1.008	0.20	11
	A10	Change of the Government policy related to the urban plan	3.247	3.482	3.363	0.973	0.00	12

(Continued)

Stage II: Planning & Design Phase	B2	Change of the Government policy related to the proportion of prefabrication in public housing projects	3.671	3.906	3.786	0.887	1.00[a]	1
	B1	Change of the Government policy related to COVID-19 pandemic	3.671	3.647	3.659	1.017	0.74[a]	2
	B12	Change of the Government policy related to environmental protection	3.494	3.689	3.590	0.927	0.53[a]	3
	B6	Change of the Government policy related to construction waste disposal charging scheme	3.428	3.741	3.581	0.967	0.51[a]	4
	B8	Change of the Government policy related to housing policy, the restriction on the type and the size of property development	3.424	3.741	3.579	1.011	0.50[a]	5
	B11	Change of the Government policy related to the procurement system	3.447	3.698	3.570	0.924	0.50[a]	6
	B5	Change of the Government policy related to the preferential interest of the MiC project	3.412	3.624	3.516	0.833	0.35	7
	B7	Change of the Government policy related to site selection criteria for new precast manufacturing sites	3.365	3.647	3.503	1.020	0.32	8
	B10	Change of the Government policy related to urban planning policy, e.g. plot ratio, site coverage, height restriction and green ratio	3.329	3.671	3.496	1.022	0.31	9
	B3	Change of the Government policy related to finance	3.424	3.529	3.476	0.939	0.26	10
	B9	Change of the Government policy related to land supply and usage	3.306	3.635	3.467	0.952	0.24	11
	B4	Change of the Government policy related to taxation and revenue	3.247	3.494	3.368	0.991	0.00	12

(Continued)

Stage III: Construction Phase	C16	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	3.847	4.012	3.929	1.051	1.00[a]	1
	C3	Change of the Government policy related to finance	3.671	4.012	3.837	1.067	0.82[a]	2
	C1	Change of the Government policy related to COVID-19 pandemic	3.824	3.788	3.806	1.127	0.76[a]	3
	C15	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	3.776	3.824	3.800	1.065	0.75[a]	4
	C2	Change of the Government policy related to MiC technological support and innovation	3.718	3.859	3.788	0.993	0.72[a]	5
	C22	Change of the Government policy related to the standard of the acceptance of the completed construction quality	3.635	3.894	3.762	0.945	0.67[a]	6
	C23	Change of the Government policy related to the sale of the MiC buildings	3.635	3.788	3.711	1.011	0.57[a]	7
	C8	Change of the Government policy related to scope/type of the prefabricated elements and components	3.612	3.776	3.693	0.884	0.53[a]	8
	C17	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	3.659	3.706	3.682	1.025	0.51[a]	9
	C9	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for MiC	3.558	3.788	3.671	1.026	0.50[a]	10
	C4	Change of the Government policy related to the construction material supply and price	3.506	3.776	3.639	0.975	0.43	11

(Continued)

	C7	Change of the Government policy related to site selection criteria for new precast manufacturing sites	3.553	3.718	3.634	1.007	0.42	12
	C18	Change of the Government policy related to the Mainland and Hong Kong Closer Economic Partnership Arrangement (CEPA) and Professional Services in Greater Bay Area, such as extending the scope of mutual recognition of qualifications for construction professionals	3.647	3.576	3.612	0.975	0.37	13
	C10	Change of the Government policy related to the multi-sector governance of MiC	3.471	3.741	3.603	0.899	0.36	14
	C5	Change of the Government policy related to import of the construction material	3.494	3.694	3.593	1.108	0.34	15
Stage III: Construction Phase	C12	Change of the Government policy related to environmental protection	3.482	3.635	3.558	0.916	0.27	16
	C21	Change of the Government policy related to project/qualification supervision	3.447	3.635	3.540	0.947	0.23	17
	C20	Change of the Government policy related to labour policy	3.341	3.682	3.508	0.991	0.17	18
	C14	Change of the condition on MiC project contracts	3.353	3.553	3.451	0.933	0.06	19
	C19	Change of the Government policy related to the restrict of the construction schedule	3.294	3.612	3.449	1.016	0.05	20
	C11	Change of the Government policy related to the procurement system	3.388	3.494	3.441	0.906	0.03	21
	C6	Change of the Government policy related to construction waste disposal charging scheme	3.353	3.518	3.434	1.086	0.02	22
	C13	Change of the Government policy related to MiC project tendering	3.424	3.424	3.424	0.954	0.00	23

Note(s): OP=Occurrence Possibility; ID=Impact Degree; CID=Comprehensive Impact Degree= (OP* ID)^0.5; SD=Standard Deviation; N Value= Normalization Value = (Mean-Minimum Mean)/(Maximum Mean-Minimum Mean); a indicates the normalized value ≥0.50 and considered as a critical PDF.

4.4 Factor Analysis

There are 7, 6, and 10 critical PDFs in Stage I, II, III, respectively, which are not adequate to explicate MiC projects' success in Hong Kong. Therefore, factor analysis was employed to explore and identify potential relationships between critical PDFs in the various individual stages. As mentioned in Section 3.4.1.4, this statistical technique can be utilized to analyse the structure of the interconnections between quite a number of variables by defining a set of common fundamental factors (Hair et al., 1998). Exploratory factor analysis was conducted in this study to appropriately categorize and group the identified critical PDFs, for it attempts to discover the nature of the constructs influencing a set of responses. In this chapter, the five-step EFA protocol provides clear direction: firstly checking the suitability of data; secondly selecting a proper method for factor extraction, here principal components analysis (PCA) was adopted, which is a powerful tool that can mathematically identify patterns in data and highlight their similarities and differences to avoid the need for questionable causal models (Hair, 2009; Johnson, 1998; Smith, 2002); then finding Kaiser's criteria (eigenvalue > 1 rule) to assist factor extraction; next conducting the factor rotation to improve the interpretability of the factors, in which Varimax with Kaiser Normalization rotation method was used in this step for the rotated component matrixes produced in this technique are straightforward to interpret (Akintoye, 2000); lastly interpreting and naming the categorized PDFs. This approach is widely employed in the industrialized construction management research area in Hong Kong (Ekanayake et al., 2020). Table 4.5 presents the initial Eigenvalues of total variance explained by each factor in three stages. For instance, in Stage I, the variance of the linear combination formed by the combination of component 1 is 3.057, accounting for 43.667% of the total variance of the 7 factor variables.

Table 4.5 Variance Explained by the Critical PDFs Variables

Stages	Component	Eigenvalue	Percent of variance explained	Cumulative percent
Stage I: Initiation Phase	1	3.057	43.667	43.667
	2	1.068	15.258	58.925
	3	0.825	11.787	70.712
	4	0.612	8.746	79.457
	5	0.557	7.963	87.421
	6	0.491	7.017	94.438
	7	0.389	5.562	100.000
Stage II: Planning & Design Phase	1	2.805	46.750	46.750
	2	1.076	17.925	64.675
	3	0.654	10.908	75.584
	4	0.555	9.248	84.832
	5	0.494	8.226	93.058
	6	0.417	6.942	100.000
Stage III: Construction Phase	1	4.464	44.645	44.645
	2	1.648	16.478	61.122
	3	1.014	10.142	71.265
	4	0.867	8.667	79.932
	5	0.538	5.385	85.316
	6	0.428	4.276	89.592
	7	0.370	3.697	93.289
	8	0.265	2.648	95.936
	9	0.253	2.532	98.468
	10	0.153	1.532	100.000

The test statistics are illustrated more clearly in Table 4.6, which shows the cluster matrix after the Varimax rotation and the final statistics of the PCA. As stated in section 3.4.1.4, the KMO statistic measures the sampling adequacy by using the size of partial correlation coefficients and comparing their magnitudes (Lam et al., 2008). The values obtained for KMO in this study are 0.803, 0.778 and 0.798 in Stage I, II and III, respectively, which are all greater than the required minimum of 0.50. Additionally, the Bartlett's Test of sphericity statistics for Stage I, II and III are 140.521, 120.985, 413.195 with all the associated significance level of 0.000. These results imply that the sample data are acceptable and suitable for factor analysis, and the correlation matrixes were not identity matrixes.

The Eigenvalue was set as the criterion for variables selection, where variables with Eigenvalues more than one were extracted. Thus, Varimax rotation was conducted for the retained 7,6,10 critical PDFs (Eigenvalue>1) in Stage I, II, III, respectively, which yielded two, two and three clusters in each stage. In stage I, the two extracted clusters account for 58.925% of the total variance; In stage II, the two extracted clusters explain 64.675% of the total variance; In stage III, the three underlying components explain 71.265% of the total variance (as displayed in Table 4.6). According to the literature, the values of factor loadings greater than 0.50 are considered important and used in component interpretation (Chan et al., 2018). The factor loadings of all variables in Table 4.6 are above 0.50. After factor extraction and rotation, the extracted PDFs should be renamed as clusters in the interpretation of analysis results. The naming is done using the common theme on which the variables are based. However, when there is no obvious recognizable common theme, the latent theme of the variable is used for naming, and these variables have a higher factor loading (Le et al., 2014; Owusu & Chan, 2019; Zhang et al., 2017). These totally seven components in three stages are expounded in the forthcoming discussion.

Table 4.6 Cluster Matrix after Varimax Rotation & Final Statistic of PCA

Code	Stage I: Initiation Phase		Stage II: Planning & Design Phase		Stage III: Construction Phase			
	Components							$\bar{x} = \sum xi/n$
	1	2	1	2	1	2	3	
Component I-1								3.712
A5	0.840	-	-	-	-	-	-	3.729
A4	0.777	-	-	-	-	-	-	3.634
A6	0.722	-	-	-	-	-	-	3.815
A12	0.615	-	-	-	-	-	-	3.729
A11	0.536	-	-	-	-	-	-	3.653
Component I-2								3.776
A1	-	0.825	-	-	-	-	-	3.882
A8	-	0.790	-	-	-	-	-	3.670
Component II-1								3.583
B6	-	-	0.866	-	-	-	-	3.581
B8	-	-	0.734	-	-	-	-	3.579
B12	-	-	0.718	-	-	-	-	3.590
Component II-2								3.672
B2	-	-	-	0.881	-	-	-	3.786
B1	-	-	-	0.658	-	-	-	3.659
B11	-	-	-	0.653	-	-	-	3.570
Component III-1								3.804
C15	-	-	-	-	0.900	-	-	3.800
C16	-	-	-	-	0.867	-	-	3.929
C17	-	-	-	-	0.839	-	-	3.682
Component III-2								3.740
C9	-	-	-	-	-	0.839	-	3.671
C8	-	-	-	-	-	0.754	-	3.693
C2	-	-	-	-	-	0.683	-	3.788
C1	-	-	-	-	-	0.674	-	3.806

Component III-3									3.770
C3		-	-	-	-	-	-	0.794	3.837
C22		-	-	-	-	-	-	0.655	3.762
C23		-	-	-	-	-	-	0.566	3.711
Eigenvalue		3.057	1.068	2.805	1.076	4.464	1.648	1.014	
Variance (%)		43.667	15.258	46.750	17.925	44.645	16.478	10.142	
Cumulative Variance (%)		43.667	58.925	46.750	64.675	44.645	61.122	71.265	
KMO Measure of Sampling Adequacy		0.803		0.778		0.798			
Bartlett's Test of Sphericity	Approximated Chi-Square	140.521		120.985		413.195			
	df	21		15		45			
	Significance level	0.000		0.000		0.000			

Note(s): Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; $\bar{x} = \sum xi/n$; where $\bar{x}$= mean (CID), $\sum xi$= summation of sampled frequency; n= number of responses for a variable or the number of items in a specific component.

4.5 Discussion of Findings

According to previous literature findings, some studies have focused on the risk or barriers identification of the off-site and prefabricated construction. Han and Wang (2018) divided the 35 identified off-site construction barriers into five dimensions using questionnaire survey, focus group discussion and grey DEMATEL analysis, which include economic, technological, industrial, social and legal. Moreover, the authors indicated that government regulations and incentives are important aspects that should be taken into deeper consideration. A study conducted by Lu et al. (2018) developed an analytical framework to seek the optimal level of prefabrication adoption in a particular PEST (political, economic, social and technological) context, where political factors were highlighted. Luo et al. (2015) analysed 24 risk factors associated with industrialized buildings and emphasized the government's leading role in its enforcement of adequate policies and regulations in MiC promotion. In their further research, the 30 supply chain risks in prefabricated building projects were categorised into control, demand, external, process, and supply risks, in which the government policy change pertains to control risk (Luo et al., 2019). Mao et al. (2015) grouped the 18 critical factors influencing the use of off-site construction into five categories: government regulations and policies, technological innovation, industry supply chain, cost, and market demand, where government regulations and policies should be the most dominant grouping. However, all these studies involving risk or barrier analyses have just focused on these negative aspects, while the issue about the policy implications of the driving forces of MiC, which play a vital role in up-taking MiC adoption in Hong Kong, has not been explored to date. Not to mention the further detailed PDFs classification and analysis. Moreover, strictly speaking, MiC is not completely the same as off-site and prefabricated construction but represents the highest level of off-site or prefabricated construction (Gibb, 1999; Zheng et al., 2020). Focusing specifically on the policy of MiC itself, relevant policy categories have been classified in detail in the previous literature review (Chapter 2), namely, regulative policies, standardized policies, promotional policies, urbanized policies, technical policies, managerial & educational policies, and sustainable policies. Besides, this study identified PDFs during three stages of MiC projects through an empirical research exercise, specifically in Hong Kong. Based on the examination of the internal relationships among the main PDFs in the three stages of MiC, two, two and three clusters were extracted in the stages I, II and II respectively by means of factor analysis. Table 4.7 shows the details. Figure 4.2 presents an overall profile of critical PDFs with the level of criticality to MiC projects in Hong Kong derived from relevant significance analysis. Combined with the classification criteria of MiC policy in Chapter 2, the clusters include Promotional and Sustainable PDF, Regulative PDF, Sustainable PDF, Greater Bay Area development PDF, Technical and Regulative PDF, Promotional PDF as follows, where their underlying PDFs are discussed for each component.

Table 4.7 Clusters Extracted by Factor Analysis in Each Stage

Stages	Components	Code	Critical PDFs in MiC in HK
Stage I: Initiation Phase	Component I-1 Promotional & Sustainable PDF **(PSPDF)**	A5	Change of the Government policy related to the preferential interest of the MiC project
		A4	Change of the Government policy related to taxation and revenue
		A6	Change of the Government policy related to investment of the MiC project
		A12	Change of the Government policy related to environmental protection
		A11	Change of the Government policy related to the publicity of MiC
	Component I-2 Regulative PDF **(RPDF)**	A1	Change of the Government policy related to COVID-19 pandemic
		A8	Adjustment of the Government policy related to housing policy
Stage II: Planning & Design Phase	Component II-1 Sustainable PDF **(SPDF)**	B6	Change of the Government policy related to construction waste disposal charging scheme
		B8	Change of the Government policy related to housing policy, the restriction on the type and the size of property development
		B12	Change of the Government policy related to environmental protection

	Component II-2 Regulative PDF **(RPDF)**	B2	Change of the Government policy related to the proportion of prefabrication in public housing projects
		B1	Change of the Government policy related to COVID-19 pandemic
		B11	Change of the Government policy related to the procurement system
Stage III: Construction Phase	Component III-1 Greater Bay Area development PDF **(GBADPDF)**	C15	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods
		C16	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity
		C17	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information
	Component III-2 Technical and Regulative PDF **(TRPDF)**	C9	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for MiC
		C8	Change of the Government policy related to scope/type of the prefabricated elements and components
		C2	Change of the Government policy related to MiC technological support and innovation
		C1	Change of the Government policy related to COVID-19 pandemic
	Component III-3 Promotional PDF **(PPDF)**	C3	Change of the Government policy related to finance
		C22	Change of the Government policy related to the standard of the acceptance of the completed construction quality
		C23	Change of the Government policy related to the sale of the MiC buildings

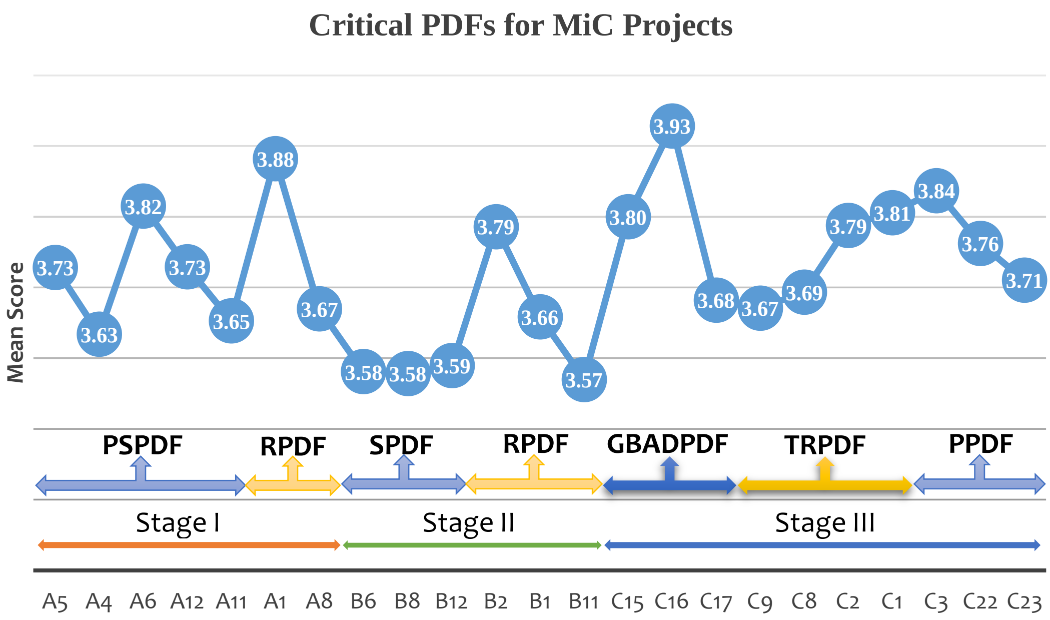

Figure 4.2 Mean Score (CID) of Critical PDFs for the success of MiC projects

4.5.1 Stage I: Initiation Phase

Generally, in MiC, the stage I initiation phase comprises these activities: Potential MiC building project identification; Information collection (including the information relevant to politics, urban planning, finance, transportation, real estate market, societal needs, environmental protection, etc.); Detailed site investigation (including the surroundings, the transport, the geological conditions, etc.); Project feasibility study report preparation and financial analysis; Project evaluation and negotiation with related government authorities; Detailed project feasibility study report and decision making.

4.5.1.1 Component I-1: Promotional & Sustainable PDF (PSPDF)

Component I-1 comprises five critical PDFs, three of which are closely related to the impacts of changes in economic incentives, namely ‘change of the government policy related to the preferential interest of the MiC project’, ‘change of the government policy related to taxation and revenue’, and ‘change of the government policy related to investment of the MiC project’; one of them is about the impact of adjustments in MiC publicity, which are all promotional policies; the other is ‘change of the government policy related to environmental protection’, which is relevant to sustainable policy; hence this component is named promotional and sustainable PDF (PSPDF). In stage I, this component accounts for the highest percentage of variance, 43.667%, with the highest variable content. However, the mean score value of this component is lower than component I-2. According to the respondents’ arguments, although these PDFs may affect the performance of MiC projects in Hong Kong to a large extent, these drivers have lower occurrence frequency, so they are often ignored in practice. Currently, the effect is not very high but substantial. The lack of preferential policy was considered to be a main obstacle and challenge for the widespread adoption of MiC (Li et al., 2017). In early 2002, the Hong Kong government began to offer some preferential interest to promote inchoate MiC adoption. For example, under the provisions of the Building Ordinance, green/innovative features such as MiC may be exempt from the calculations of Gross Floor Area (GFA) and Site Coverage (SC) when applied and subject to conditions (JPN 2, 2002). In China, the governmental preferential policies stimulated an increasing amount of contractors to invest in MiC housing production (Li et al., 2018). This may explain why this variable about preferential interest policy has the highest factor loading, as proven by Luo et al. (2015).

The adjustment of taxation and revenue in MiC also impacts its adoption, which occupies the second-highest factor loading but the lowest mean score. This may be because this adjustment is not frequent, such as the GFA/SC exemption has not been further adjusted since its implementation in 2002, but it cannot deny its significant influence. Based on an exhaustive review of 107 papers and 85 governmental documents, Jiang et al. (2018) encouraged the government to roll out a top-down policy covering taxation incentives such as applying enterprise tax reduction or exemption policies to accredited MiC enterprises and technology pioneers through a strengths, weaknesses, opportunities and threats (SWOT) analysis. Such viewpoint was also supported and recognized by Chen et al. (2017), who persisted in that construction companies paid more attention to direct economic benefits such as additional revenue exemption.

Investment in the MiC project is also another significant variable (Li et al., 2018; Luo et al., 2015) within the PSPDF component, with the highest mean score. This is not surprising since the government's direct investment in the MiC project is undoubtedly the most direct boost to its development, especially in Stage I, and the change of investment strategy will have a great impact on it. Despite the fact that MiC has various potential benefits, transferring from traditional on-site construction to modern off-site MiC requires a substantial initial investment in prefabrication plants and other fixed expenses (Gao & Tian, 2020; Luo et al., 2015; Steinhardt et al., 2013). In this case, the strongly up-front investment support from the government is particularly important. As Jin et al. (2018) also indicated that companies within the UK Architecture, Engineering, and Construction (AEC) market were uncertain about investment in MiC due to a currently predictability-continuity gap caused by governmental policies. On the other hand, increasing government investment in the research and development of MiC will accelerate the maturity of its technology (Mao et al., 2015). Hence, in the MiC project, the government investment strategy is a crucial factor in its Initiation Phase.

In addition to some economic stimulus measures, the government's vigorous promotion of MiC and its popularity in the industry cannot be ignored. Training and publicity on the advantages of MiC should be strengthened to enhance the perceived effectiveness of relevant MiC policies (Li et al., 2018). Liu et al. (2017) also pointed out that the government should bolster publicity and guidance of the MiC industry as a society lack timely awareness of the latest technical knowledge. Some existing policy documents such as 'Guidance on the development of Off-Site Construction' issued by the State Council in China have emphasized the importance of publicity work, where 'publish the programmatic documents of prefabricated buildings' and 'increasing policy support and promoting publicity and guidance' (Wang et al., 2019) could be seen. In Hong Kong, there are many avenues for publicity, such as publicity brochures accompanying iconic successful projects (e.g. MiC Display Centre in CIC - Zero Carbon Park), public propaganda activities within the construction industry, promotion of MiC on social networking platforms (e.g. Facebook, Instagram, Twitter), visiting organization to the

MiC factory and site, and setting up relevant MiC courses in universities.

Apart from the four promotional PDFs mentioned above, there is also another driving factor related to sustainability that was taken into account in Stage I. The Hong Kong Housing Authority has been actively promoting the development of public housing with mechanized MiC systems, whose purpose is not only to upgrade construction quality and safety, increase cost-effectiveness but also to strengthen environmental protection (Wong et al., 2015). Moreover, minimizing environmental effects and excellent sustainable performance are highlights of the MiC program (Chen et al., 2017; Jin et al., 2018; Luo et al., 2015). Therefore, the more the government pays attention to the environment-friendly development of the construction industry, which is reflected in the adjustment of environmental protection policies, the more inclined the entire construction industry will be to adopt MiC technology instead of using or using less traditional cast-in-situ construction technology. The most important process for environmental policy impact is the project feasibility study and project evaluation in Stage I.

4.5.1.2 Component I-2: Regulative PDF (RPDF)

Regulative PDF (RPDF) refers to mandatory government policies and regulations which have an impact on MiC in the initiation phase. Component I-2 includes two critical PDFs, namely, ‘change of the government policy related to COVID-19 pandemic’ and ‘adjustment of the government policy related to housing policy’, with a total variance of 15.258%. RPDF has a higher mean score than PSPDF, which indicates that these PDFs are influential and happen frequently. That should be reasonable because under the situation of the COVID-19 pandemic, some mandatory policies related to which frequently changed, especially in Hong Kong, so that the city can gradually return to normality and get through the pandemic as soon as possible. The highest factor loading in RPDF is the variable 'change of the government policy related to COVID-19 pandemic', showing high factor significance. According to the World Health Organization (WHO), COVID patients must be properly quarantined or isolated for treatment, which requires a comfortable and safe space to facilitate the rapid recovery of patients (WHO, 2021). However, due to the severity of the epidemic, many hospitals and clinics are inadequate; therefore, there is a need for new buildings that can quickly provide isolation in the short term. Compared with the traditional way of house construction, the advantages of MiC technology are more prominent, including rapid construction in a short time and excellent flexibility (Abdelmageed & Zayed, 2020; Luo et al., 2015; Wuni & Shen, 2019), which is in line with the requirements of the current epidemic. In other words, the use of MiC technology can be used as a panacea to fight against the impact of the COVID-19 crises (Tayo et al., 2020; Yatmo et al., 2021). Gbadamosi et al. (2020) also proposed off-site and modular solutions for the construction industry and the built environment to respond to emergencies. This is why respondents assigned a considerable mean value of 3.882 within the component RPDF to the variable 'change of the government policy related to COVID-19 pandemic', especially during this period.

Another significant variable is the adjustment related to the macro housing policy. Housing policies in other regions, such as 'measures of Beijing on the reward for Industrialized Housing Residential Projects' which issued in 2010 (Zhang & Skitmore, 2012) and some trials about introducing the MiC into the current construction system in Romania (Mare, 2018) and America (Goodman, 2017), as well as the adjusted rents and the focus rearrangement from hiring to ownership in the Czech Republic (Zarecor, 2012), are all dedicated to encouraging the rapidly future popularization of MiC proactively. Hong Kong has a unique housing market. Housing policy in Hong Kong is currently formulated, coordinated and monitored by the Secretary for Transport and Housing (Transport and Housing Bureasu, 2016). The Housing Department supports the Transport and Housing Bureau (THB) in handling all housing-related policies and issues. Based on the Long Term Housing Strategy (LTHS) promulgated by the Hong Kong Government, providing more public rental housing (PRH) units and subsidised sale flats (SSTs) and stabilising the residential property market are listed as three major strategic directions (LTHS Annual Progress Report 2020, 2021; THB, 2020), where transitional housing also received great attention (Legislative Council Panel on Housing, 2019). Modular Housing, as a modern and innovative housing type, is strongly recommended and considered to be used in Hong Kong, especially in public housing (Modular Social Housing, 2021). The public/private split of new housing supply for the 10-year period from 2019-20 to 2028-29 has been revised from 60:40 to 70:30 (Legislative Council Panel on Housing, 2019). Moreover, nowadays, MiC has been widely adopted in public housing to speed up the construction cycle so as to meet the housing policy requirements mentioned above. In general, the adjustment of macro housing policy has a considerable impact on MiC in its Stage I particularly in public housing (Chen et al., 2017; Chiang et al., 2006).

4.5.2 Stage II: Planning & Design Phase

The doings in Stage II planning and design phase include Acquisition of land use rights for the proposed MiC project; A detailed geological survey of the project site; General MiC scheme design; MiC project finance; Project planning permission issuance; Construction documents design, and approval.

4.5.2.1 Component II-1: Sustainable PDF (SPDF)

Component II-1 exhibits 46.750% of the variance in Stage II, including three underlying factors, and all reflect a socio-ecological process characterized by the pursuit of a sustainable ideal, hence named Sustainable PDF (SPDF). The sustainable policy aims to cause little or no damage to the environment and, therefore, is able to continue for a long time. SPDF specifically contains ‘change of the government policy related to construction waste disposal charging scheme’, ‘change of the government policy related to housing policy, the restriction on the type and the size of property development’, and ‘change of the government policy related to environmental protection’. This component possesses higher variable content but with a lower mean score value when compared with the other component in Stage II. Similar to the PSPDF in Stage I, that may be because these PDFs occur less frequently and are sometimes ignored in practice. The 'environmental protection' related PDF factor holds the highest mean score amongst SPDF, signifying the importance of this variable towards MiC projects. The environmental impact mainly includes three aspects: resource depletion, energy consumption and construction waste discharge (Cao et al., 2015). MiC can utilize resources more effectively (Han & Wang, 2018), and Cao et al. (2015) found that the use of MiC demonstrated a certain degree of benefits which includes a reduction in resource depletion by 35.82% when comparing two sample residential buildings. The extensive usage of prefabricated components in MiC enables the possibility to decrease energy consumption (Li et al., 2018). A study from Hong et al. (2016) observed that MiC could help to save 4%-14% of the total life-cycle energy consumption apart from reusability. A considerable amount of effort has been paid to lower the construction waste discharge, where MiC has outstanding performance (Jin et al., 2018; Li et al., 2018; Lu et al., 2018). Compared with traditional residential buildings, modular residential buildings have obvious advantages in minimizing waste, with the reduction of waste volume ranging from 24.91% to 81.25% based on empirical research (Cao et al., 2015). Compared with traditional cast-in-place construction technology, MiC technology has advantages in reducing the damage to the environment, so it is more environmentally friendly. The change of environmental policy mainly affects the process of construction documents design and approval in Stage II.

Based on the 'polluter pays' principle (Legislative Council, 2007), the Hong Kong legislation for the Construction Waste Disposal Charging Scheme (Charging Scheme) was enacted in January 2005 and came into operation on 1 December 2005, while charging for the disposal of construction waste has begun on 20 January 2006 (Environmental Protection Department, 2005). MiC buildings tend to produce less construction waste (Chen et al., 2017; Ghisellini et al., 2018), and adopting such technology allows construction contractors to pay less waste disposal charges to the government. Through a structured survey and case studies, Tam and Hao (2014) concluded that applying MiC of building modules was one of the most efficient technologies of waste minimization, and they further evinced that in addition to waste decrease from ‘poor workmanship’, waste generation can also be greatly reduced in a variety of on-site production activities, including plastering, wooden formwork, concreting and reinforcement, while plastering can reduce waste by 100% after the adoption of MiC. The Charging Scheme policy promoted waste minimization actions in the building industry in Hong Kong (Zhang et al., 2018). Moreover, MiC has been identified as an effective solution to tackle the issues of construction waste generation associated with conventionally cast on-site construction methods (Xie et al., 2020; Zhang et al., 2018), especially during the design phase of new building construction (Jaillon et al., 2009; Jaillon & Poon, 2010).

Change involving the micro-housing policy is another notable variable within the SPDF component, mainly reflected in housing type planning and residential/building density guidelines. The housing policy mentioned here ensures an appropriate balance between the resident population living in a certain area and the capacity of existing or planned facilities and infrastructure required to serve the area (Planning Department, 2018), which is a manifestation of sustainability. The housing types in Hong Kong fall into the following three categories: public rental housing, subsidized sales flats and private housing (Planning Department, 2018). Since the mid-1980s, the Hong Kong Housing Authority (HKHA) has recommended the use of prefabricated modules and reusable formwork in all public housing contracts, while the private sector still relies heavily on the traditional construction method of cast-in-situ (Jaillon & Poon, 2009). Therefore, in different types of areas in Hong Kong, planning restrictions on housing types will affect the application space of MiC to a certain extent. On the other hand, the constraint on the residential/building density is also a factor. The plot ratio is a way to guide the density of development in public and private residential areas in Hong Kong, and its controls govern the amount of GFA in buildings (Hui, 2001). For different types of area, including main urban areas, new towns and rural areas, their plot ratios, building heights, site coverage, flat size, and person per plat ratios vary under the first schedule of Building (Planning) Regulations (B(P)R) (Planning Department, 2018). These architectural indicators will affect the Planning & Design Phase of MiC, mainly the size design of prefabricated modules. Therefore, the micro-housing policy is a critical factor in Stage II.

4.5.2.2 Component II-2: Regulative PDF (RPDF)

Regulative PDF (RPDF) includes three critical PDFs, which requires the contractors and designers of MiC to comply with some compulsory regulations, with a total variance percentage of 17.925. In Stage II, RPDF is slightly different from Stage I, namely, ‘change of the government policy related to the proportion of prefabrication in public housing projects’, ‘change of the government policy related to COVID-19 pandemic’, and ‘change of the government policy related to the procurement system’. This is the component with a higher mean score value of 3.672, signifying the significance of the construct to the development of MiC in Hong Kong. Experts highlighted the factor ‘Proportion of prefabrication in public housing projects’ as a common PDF in MiC. Prefabricated modules are widely used in the construction of public housing blocks for better craft and quality control and to maximize construction efficiency (Jaillon & Poon, 2009). The application of prefabrication in public housing construction includes precast façade, precast staircase, precast ground floor water tank, precast panel wall, semi-precast slab, and volumetric precast bathroom (Housing Authority, 2019). As early as 2002, in all Harmony Block and Concord Block building contracts, the use of prefabricated facades must be mandatory (Chan & Chan, 2002). Based on a database of 179 prefabricated residential buildings and detailed case studies of five residential, Jaillon and Poon (2009) revealed that the precasting percentage by volume and types of precasting elements had been greatly increased over the years, and even a value of 65% was reached in a case building. Moreover, HKHA has announced that further MiC applications will raise the use of prefabricated concrete components (PCCs) from 70% to approximately 90% on plan (Hong Kong Housing Authority, 2019).

The improvement of this proportion further deepens the development of MiC housing in Hong Kong.

The increasingly global environment facilitates innovation, but at the same time, it also increases uncertainty caused by supply chain disruptions (Manuj & Mentzer, 2008). The COVID-19 epidemic situation in Hong Kong is unstable, and related mandatory policies have affected all walks of life, including the construction industry. This COVID-19 pandemic clearly shows that the supply chain is inelastic, and due to the failure of individual supply chain connections and nodes, disruptions may have an impact on the scale of the global network (Golan et al., 2020). Especially in the planning and design phase of MiC, designers and contractors need to focus on the impact of the COVID-19 epidemic on the entire modular supply chain and strive to mitigate losses as much as possible through some measures. Firstly, construction organizations need to address issues related to employees' safety and welfare to prevent widespread fear and economic uncertainty (Raoufi & Fayek, 2021). Previously, many cities, states and countries have been 'locked down' in order to prevent the spread of COVID-19 (Inoue et al., 2020). Then, under this circumstance, the construction corporations are required to evaluate the possibility of delay or suspension of the provision of the material from suppliers and ensure the availability of labour, equipment and materials (Raoufi & Fayek, 2021). Inoue et al. (2020) also suggested that inter-regional policy coordination is essential to reduce the economic losses caused by the lockdowns. Another way to achieve supply chain resilience is to design products with common components and decrease the use of custom components in different product offerings (McKinsey Global Institute, 2020). In this special period, the construction industry should accelerate the implementation of modular manufacturing platforms, where components can be shared across production lines and manufacturing sites.

Another factor in RPDF is related to the procurement system. The Designer Led procurement practice, which dominated the local construction industry in Hong Kong for more than 100 years, is still widely regarded as the most popular and commonly used procurement system in the world (Major Features, Advantages and Disadvantages of Generic Procurement Categories, 2004). According to the different basis of payment adopted, there are basically four sub-categories under the Designer led arrangement: Lump Sum Contract, Remeasurement Contract, Term Contract, and Prime Cost Contract (2004). Governments around the world are searching for innovative procurement systems, such as Public-Private-Partnership (PPP), Private Finance Initiatives (PFI), and their variations, to help effectively materialize construction projects (Lu et al., 2013). Through content analyses and semi-structured interviews, Lu et al. (2013) examined two state-of-the-art procurement systems, namely agent-construction system (ACS or in Chinese *Dai Jian Zhi*) and PPP, then revealed that the consistency between the procurement system and its external Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) conditions is critical for procurement innovation. The 'PESTEL -Procurement Innovation' framework proposed also proved to be a helpful tool for procurement innovation design. However, the

Design-Build (D&B) procurement method is still widely adopted in the public sector for four main reasons, namely, the transfer of risks to contractors, the need to utilise resources and expertise from contractors, better conforming the principles of public accountability, and avoiding variation (Lam et al., 2004). Different procurement systems will affect the planning and design phase of MiC for better project performance (Starr et al., 2016).

4.5.3 Stage III: Construction Phase

There are various descriptions about the stage III construction phase in the MiC, and a comprehensive and complete process should comprise: Tendering of the MiC project contractors; MiC project permission issuance and seeking statutory approvals; Manufacturing of prefabricated modules; Transportation of prefabricated modules to site; Prefabricated modules on-site installation and other project construction works; Construction supervision and cost control; Evaluation for construction quality of the project and relevant certification issuance; Final acceptance of completed MiC project and hand over.

4.5.3.1 Component III-1: Greater Bay Area development PDF (GBADPDF)

Greater Bay Area development PDF (GBADPDF) refers to the PDFs that are specific to Hong Kong MiC projects due to geographical and political advancement, which includes ‘change of the government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods', 'change of the government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity', and 'change of the government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information'. GBADPDF accounts for the highest variance percentage (44.645%) in Stage III, with the highest variable content. At the same time, this is the component with the highest mean score value (3.804) amongst the whole three project phases, indicating the significance of the construct to the MiC development in Hong Kong. GBADPDF, a quite special part that is completely different from other PDFs and other regions. As Patrick Nip Tak-Kuen, the secretary for Constitutional and Mainland Affairs Bureau, emphasized that development of the Greater Bay Area brings two major opportunities for Hong Kong: (1) To identify new growth areas for the Hong Kong economy and promote diversified development of its financial industries; (2) To expand the development and living space of Hong Kong residents (News. Gov. HK, 2018). On March 19, 2021, the Chief Executive of the Hong Kong Special Administrative Region Carrie Lam also said that the part of the '14th Five-Year Plan' outline related to the construction of the Greater Bay Area would bring unlimited opportunities for Hong Kong (News. Gov. HK, 2021), among which the MiC has received great attention. The inclination and support of the policy explain why the component GBADPDF is so important. The adjustment of customs clearance between the Mainland and Hong Kong has an important impact on the transportation process of MiC modules in the construction phase, because most of the manufacturing of prefabricated modules for MiC buildings are located in the Greater Bay Area (Luo et al., 2020). In terms of facilitating personnel exchange, the flexible deployment of e-Channels and the adoption of 'Smart Departure' for identity verification using face recognition technology provides visitors with greater travel convenience. In terms of enhancing the flow of goods, through the use of electronic locks and global positioning system (GPS), the need for repeated inspections of the same consignment by the two Customs authorities during import or export has been minimised, thus facilitating the flow of goods like prefabricated modules (Fang et al., 2020). Since May 2019, the number of clearance points under the 'Single E-Lock Scheme' in Guangdong Province has been increased to 52. Another measure is Mutual Recognition Arrangement for Authorised Economic Operators (AEOs), Goods consigned by enterprises accredited as AEOs by the C&ED and/or the Mainland Customs enjoy customs clearance facilitation, such as reduced and prioritised customs clearance, from both authorities (Zhan & Feng, 2019). However, now due to the impact of the COVID-19 epidemic, these two aspects will be affected more or less. For example, the closure of the main customs clearance points will affect the communication and negotiation of personnel in the supply chain (McKinsey Global Institute, 2020) and the timely delivery of prefabricated modules.

The transportation and logistics involved in cross-border supply chains are quite complex, leading to uncertainties that significantly affect the performance of MiC (Luo et al., 2019). This may be why the respondents gave the highest comprehensive mean score (3.929) to this variable factor in all three stages, as proven by Hsu et al. (2019) and Li et al. (2018). The Greater Bay Area has implemented many practical measures to speed up cross-border infrastructure connections. The Hong Kong Section of the Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL), which commenced operation in September 2018, connects with the national high-speed rail network and greatly shorten the travelling time between Hong Kong and Shenzhen, Guangzhou, and other cities in the PRD (Greater Bay Area, 2021). Passengers are also getting used to using the XRL as a cross-boundary transport mode. Since the commissioning of the Hong Kong-Zhuhai-Macao Bridge (HZMB) in October 2018, the operation has generally been smooth, and the vehicular flow has been gradually increasing (Greater Bay Area, 2021). The Liantang/Heung Yuen Wai Boundary Control Point (LT/HYW BCP) is the seventh land boundary-crossing between Hong Kong and Shenzhen boundary with direct access facilities for both passengers and vehicles. The new BCP facilitates smooth and efficient people and cargo flows across the boundary, alleviate the busy traffic at the existing BCPs and play an important strategic role in supporting Hong Kong's long-term economic growth (Greater Bay Area, 2021). The XRL, HZMB and BCPs are helpful for speeding up the transportation of prefabricated modules from the factory to the on-site installation. Additionally, in order to emphasize the importance of logistics and supply chain management, Liu et al. (2016) developed a dedicated simulation template based on Simphony platform to simplify the simulation modelling of module manufacturing, transportation, and assembly processes, which is of great significance for the cross-border transportation of prefabricated modules in Hong Kong. The establishment of a globally competitive modern industrial system and jointly cooperation platforms is a further step in taking forward the practice of MiC in Hong Kong. Luo et al. (2020) revealed that the flow of data and real-time information on prefabricated modules would be of great value to stakeholders in improving MiC supply chain performance. A mathematical model was conceived by Hsu (2019) to use clear data and information to manage the production buffers in MiC projects effectively and to integrate and optimize the allocations of resources and capital across the entire operating portfolio. While some legal obstacles restrict the construction of regional data platforms in the Greater Bay Area, including the lack of legal basis and explicit authorization for cross-border network cooperation, some restrictions on administrative divisions and government departmentalism, and internet segregation (Han et al., 2019). The MiC practitioners of the Great Bay Area should explore the mode of collaborative legislation under the central authority, connect the administrative network of the Great Bay Area, promote the soft rule of law of data platform establishment, and constantly improve the mediation system to deal with administrative disputes arising from the data platform (Xu & Feng, 2019).

4.5.3.2 Component III-2: Technical and Regulative PDF (TRPDF)

Technical and Regulative PDF (TRPDF) refers to the application of technological innovation on MiC, as well as mandatory government regulations/policies which have an impact on MiC in the construction phase, which specifically contain ‘change of the government policy related to MiC technological support and innovation', 'change of the government policy related to the authoritatively designed standards, codes and guidelines for MiC', 'change of the government policy related to scope/type of the prefabricated elements and components', and 'change of the government policy related to COVID-19 pandemic'. The first factor is the technical PDF, and the remaining three are the regulative PDF. Component III-2 includes four factors with a total variance of 16.478%, but a least mean score value amongst the three components in Stage III. This may be because the probability of these factors changing is relatively small, but the effect is still considerable. As Jean-Louis Cohen asserted in a press release statement, Technological Innovation (TI) and production would bring about the supremacy of modernism in architecture (Lobsinger, 2011). Rot et al. (2003) indicated that technologies with a higher degree of offsite work, with an ascending order from component and subassembly, non-volumetric preassembly, volumetric preassembly to the modular building (Gibb & Pendlebury, 2005), will be more likely to challenge traditional housing construction practices. Nowadays, the accurate allocation of systems and technologies into the different sector-specific categories should be carefully checked because some technologies are mature (e.g. precast concrete for all buildings) while some are only appropriate for certain application areas (e.g. structurally insulated panels are designed for low- and mid-rise residential applications). Moreover, Pan et al. (2012) scrutinized the uptake of MiC technologies and proposed strategies of how to best integrate their use into business processes at the organizational level, where real-time information sharing will support the adoption of offsite technology was highlighted. Building Information Modelling (BIM) and Radio Frequency Identification (RFID) enabled Information Technology (IT) platforms were used to help achieve real-time visibility and traceability of the MiC supply chain (Ekanayake et al., 2020). With the combination of progressive Internet of Things (IoT) technology and BIM technology, Zhai et al. (2019) developed an Internet of Things-enabled BIM platform (IBIMP) for the MiC projects to fulfil accurate information collection, timely information exchange, and automatic decision support throughout the project life cycle. Also, a VP-based IKEA model was suggested by Li. et al. (2011), which can improve the efficiency and safety of MiC as well as lowering cost and time. Therefore, the government adjustment to the policies related to such TI (e.g. expanding their scopes of application) will promote the MiC development.

Numerous studies were showing that the inappropriate or even absence of design codes and standards for prefabricated components in MiC buildings is identified as a critical political factor related to inefficient adoption and poor performance of MiC (Han & Wang, 2018; Lu et al., 2018; Luo et al., 2015; Mao et al., 2015; Zhang et al., 2014). The Buildings Department in Hong Kong has issued the Code of Practice for Precast Concrete Construction 2003 (the 2003 Code), and to keep the Code of Practice in pace with the advancement in design, technology and construction practice, the Code of Practice for Precast Concrete Construction 2016 (the 2016 Code) was issued (2016). Also, a ‘Precast Concrete Construction Handbook’ was prepared by the Hong Kong

Institution of Engineers (Precast Concrete Construction Handbook 2003, 2015) in Hong Kong. These are strong proofs that the government has promoted the orderly and smooth progress of MiC. As Lu et al. (2018) also mentioned that the political factors, including policy and standards, codes and guidelines relevant to MiC, has been regarded as the significant factor that would directly raise the incentive of the MiC adoption.

Architectural elements such as façades, slabs, stairs, partition walls, beams and prefabricated blocks for public housing construction are good examples of the prefabricated components that help improve construction efficiency (HKHA, 2016; Mak, 2013). Expanding the types and scope of precast concrete structural elements is particularly suitable for MiC buildings in Hong Kong because precast technology can achieve better quality control (Dinelli et al., 1996). A study has sorted out the overall proportion of the most frequently used precast components based on the database of 179 prefabricated residential projects in Hong Kong, including precast façade (51%), precast staircase (22%), semi-precast slab (9%), and semi-precast balcony (7%) (Jaillon & Poon, 2009). On the website of HA, the widely used prefabricated components included precast panel walls and volumetric precast bathrooms. Since 2011, aiming to satisfy different projects requirements, HA also attempted to adopt precast ground floor water tanks, precast roof water tanks, and precast roof parapets into the applicable buildings and review and refine their designs for further adoption in future projects. Precast acoustic balconies were also introduced to a pilot project in 2013. Earlier in the Annual Report (2013) issued by HKHA, precast lift machine rooms, roof parapets, manholes and drainage channels, as well as prefabricated electrical trunking, were also being explored for possibly extendable use. In summary, for promoting the further development and application of MiC, the Hong Kong government is devoted to ensuring the durability of whole housing stock through extensive use of prefabricated components and precast elements, which is reflected by the percentage of precasting volumn and the different kinds of precasting assembly units.

The factor related to the ‘COVID-19 pandemic’ in this TRPDF component occupies the highest mean score value, i.e. 3.806, evincing its importance to the MiC in Stage III. As the COVID-19 epidemic situation in Hong Kong remains volatile, the Hong Kong government has either urgently extended further or relaxed social distancing measures in a gradual and orderly manner multiple times under the Prevention and Control of Disease Ordinance (Government Announces Latest Social Distancing Measures, 2021). Some other adjustments during this special period, for example, the government tightened compulsory quarantine requirements for persons arriving in Hong Kong who have stayed in high-risk regions, strengthened restrictions and testing requirements to persons arriving at Hong Kong from foreign places, as well as regulations of cross-boundary conveyances and travellers (Compulsory Quarantine of Certain Persons Arriving at Hong Kong Regulation, 2020). All these social distancing measures and mandatory immigration isolation regulations can interfere with regular face-to-face meetings, especially during the construction phase, where many flows need to be coordinated, communicated, and discussed, especially when it comes to cross-border transportation modules. It is crucial to maintain regular communication and coordination between the project teams (Raoufi & Fayek, 2021). Therefore, there is a necessity to encourage the use of new communication modes like video conferencing within the organization. Innovative methods of remote communication need to be considered and implemented, such as Zoom, Tencent Conference, Microsoft Teams. At the same time, the contractors need to improve staff morale and provide support to maintain the physical and mental health of on-site construction workers to ensure the smooth progress of the project (Raoufi & Fayek, 2021).

4.5.3.3 Component III-3: Promotional PDF (PPDF)

Promotional PDF (PPDF), as the third component in Stage III, includes three critical policy factors, accounting for a 3.770 mean score and 10.142% variance percentage. Two of PPDF are closely related to the impacts of economic changes, namely 'change of the government policy related to finance' and 'change of the government policy related to the sale of the MiC buildings'; while the PDF 'change of the government policy related to the standard of the acceptance of the completed construction quality' promote the MiC indirectly by taking advantage of its quality. As the largest contributing factor of this component, financial policy changes occupy the highest factor loading, which also with the greatest mean value within this construct. Although there are numerous advantages of using MiC, large upfront capital requirements is an inherent barrier when compared to financing traditional construction (Salama et al., 2020). Financing MiC is challenging because banks are not familiar with the characteristics of this modern industry, which is all about uncertainty and return (Salama et al., 2018). Common financial policies related to MiC generally include: notifying banks (lenders) of accredited MiC enterprises (borrowers), loosening the covenants/conditions of loans for borrowers, offering special subsidies to approved MiC projects and enterprises; rewarding MiC enterprises; etc. (Jiang et al., 2018). To encourage the MiC adoption effectively, financial support such as tax deduction could be offered if a project has reached several requirements when applying MiC (Lu et al., 2018). Financing supporting schemes in the European Union was essential to speed up deep reformation in the MiC market (D'Oca et al., 2018). Singaporean prefabrication policy included the interest-free finance provided to the MiC projects contractors, manufacturers and purchasers, leading to the successful application of MiC in public housing (Park et al., 2011a). As MiC is still in its early stages, all of these can be used for reference in the further development of MiC in Hong Kong.

Another economic PDF is related to the sale of MiC buildings. MiC is now used in a variety of high-end commercial real estate projects. In fact, the MiC market is projected to reach as high as US$157 billion by 2023 (Woollard, 2020). At the same time, the latest Globe Newswire reported that the global market for modular and prefabricated construction accounted for US$149.7 billion in 2019 and is expected to reach US$287.2 billion by 2029, with an anticipated CAGR of 6.8% (PMI, 2020). Central, provincial and autonomous regional governments of China have issued several policies and regulations, many of which offered incentive measures, including pre-sale discounts, to enterprises that apply prefabricated components (Jiang et al., 2018). People in Hong Kong often purchase flats before the buildings in which the flats are located been constructed. The Consent Scheme and the Non-Consent Scheme exist to protect purchasers in case the developer becomes bankrupt before the property is constructed (Community Legal Information Centre, 2020). In August 2010, the Hong Kong Government put a ban on confirmor transactions on uncompleted properties. Confirmors are investors who buy a property and resell it before completing the Formal Sale and Purchase Agreement. On the other hand, developers are looking to reduce construction costs and shorten construction deadlines to reach a successful flats transaction. This preference of developers is driving the growth of prefabricated and modular buildings.

After a thorough literature review and an in-depth interview with MiC industry professionals, Han and Wang (2018) added the lack of construction quality acceptance criteria as the identified obstacle to MiC adoption. Quality control and safety represent increasingly essential concerns for the government and matter to everyone in the construction business. The 'Code of Quality Management' issued by CIOB (2019) aims at providing a single point of information on construction quality management. It should help project stakeholders improve construction quality by establishing best practices in quality management and quality planning processes. While higher quality and excellent performance is a significant inherent feature of MiC construction (Chiang et al., 2006; Luo et al., 2015; Mao et al., 2015), to a certain extent, the government's improvement of housing acceptance quality standards will also promote more owners to adopt MiC.

4.5.4 The changing pattern of critical PDFs across various stages

PDFs at different stages have their own characteristics, but there are also commonalities. Table 4.8 shows that the components of the critical PDFs vary in different project stages. The component 'Regulative PDF' is involved in all three stages, indicating the magnitude of this construct to the MiC in Hong Kong. While 'Promotional PDF' is included in Stage I and III, but not mentioned in Stage II. 'Sustainable PDF' is identified as an important component in Stage I and II, but little attention is paid to it in Stage III. Due to geographical and political superiority, it is believed that the 'Greater Bay Area development PDF' and 'Technical PDF' have had a significant impact on the MiC in Stage III rather than Stage I or II.

Table 4.8 Longitudinal Distribution Pattern of PDFs Across Various Stages of MiC

	PPDF	SPDF	RPDF	GBADPDF	TPDF
Stage I: Initiation Phase	☑	☑	☑		
Stage II: Planning & Design Phase		☑	☑		
Stage III: Construction Phase	☑		☑	☑	☑

The compulsory administrative instruments include specific policies and measures of laws, regulations, standards, codes and norms (Shen et al., 2016). RPDF is considered to be a factor that affects the entire MiC three phases, which is understandable. Different from economic incentives or voluntary scheme instruments, government regulations are mandatory. In Stage I, housing policies will mainly affect the MiC project feasibility study; In Stage II, policies on procurement systems and prefabrication rates will have an impact on the MiC project planning and financial design (Pan et al., 2012); In Stage III, scope and types of prefabricated modules and their designed standards, codes, guidelines will largely influence the tendering and manufacturing process of MiC projects. In addition, the policy related to COVID-19, such as compulsory quarantine requirements and social distancing measures under the Prevention and Control of Disease Ordinance, is the only PDF that appears in all three stages, considering the supply chain vulnerabilities affecting supply chain resilience of MiC in Hong Kong because of the pandemic (Ekanayake et al., 2020). PPDF of MiC universally focuses on economic incentive schemes, such as preferential interest, taxation and revenue, investment and finance. Promotion of MiC mainly influences Stage I, about the clients, consider whether to adopt this advanced construction method and Stage III, on how to apply MiC to maximize benefits during construction. While in Stage II, there is little impact of the promotion on the design part. From the analysis, it could be concluded that SPDF has an impact on the decision making of Stage I and II, while during the Construction Phase (Stage III), little attention has been paid. MiC has been commonly regarded as a sustainable construction method for its outstanding performance on environmental protection (Chen et al., 2017; Nikmehr et al., 2017). Therefore, in the initiation and planning stages, stakeholders will pay special attention to consider various decisions from the perspective of sustainability in order to cater to society's pursuit of sustainability. However, according to experts' opinions, in the construction phase, contractors are more likely just to complete construction tasks on time with good performance but rarely consider environmental issues such as 'zero-waste' (Lehmann, 2011b). GBADPDF is a special presence in Hong Kong for its geography and politics. The cross-border supply chains and information/data exchange it involves are mainly in Stage III. TPDF refers to some advanced technological innovations (e.g. RFID, BIM, IoT) applied in MiC, which reflects its value of information real-time tracking in the Construction Phase (Zhou et al., 2021).

4.6 Summary of the Chapter

This chapter determines and ranks critical PDFs for the success of MiC projects in Hong Kong based on their importance. Stages I, II and III have 12, 12 and 23 optional PDFs, respectively, generated from comprehensive literature review and professional interviews. The list is reduced to 7, 6 and 10 critical PDFs in Stages I, II and III, respectively, according to the survey outcomes. Thereafter, they are ranked independently in stages based on importance. The identified critical PDFs are grouped into seven components in three stages through factor analysis. Stage I has two components: Promotional and Sustainable PDF and Regulative PDF. Stage II includes Sustainable PDF and Regulative PDF. Stage III has three components, namely, Greater Bay Area development PDF, Technical and Regulative PDF and Promotional PDF.

Chapter 5 Social Network Analysis of Stakeholders associated with PDFs in MiC

5.1 Introduction

This chapter uses the SNA methods to investigate the interrelationships between the relevant stakeholders and critical PDFs identified in Chapter 4 in each of the three stages. The role of stakeholders varies from one stage to another, and their dynamic fluctuations in each stage are explored, amongst which key stakeholders are revealed and explained in detail. Some valuable recommendations are also proposed on improving the application and practicality of modular buildings in Hong Kong in terms of policies from the perspectives of different stakeholders.

5.2 Research design

Considering the positivist research philosophy, an SNA research approach was mainly adopted in this chapter. Figure 5.1 demonstrates the research framework of the critical PDFs evaluation in this study.

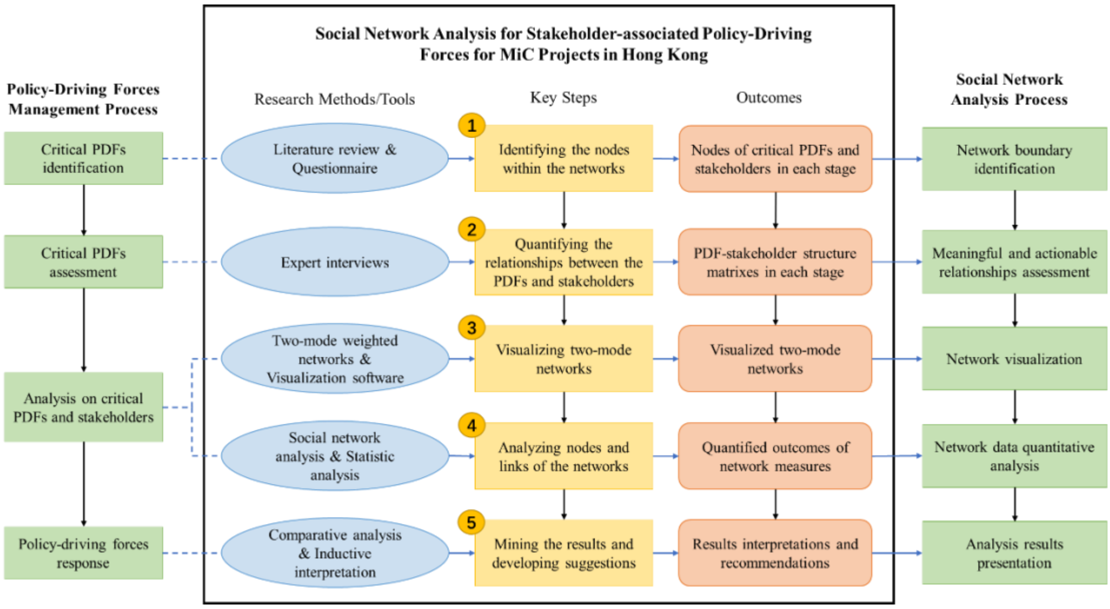

Figure 5.1 Research Framework of the Critical PDFs Evaluation based on SNA

5.3 Influence of Stakeholders on the success of MiC projects

The term stakeholders first appeared in the management literature in an internal memorandum at the Stanford Research Institute International, referring to groups that can make a difference (Thompson, 1967), and without their support, the organization would cease to exist (Freeman, 2010). In this Chapter, a stakeholder is defined as any group or individual that may influence or be affected by the achievement of the objectives in MiC projects (Freeman, 2010). Stakeholder management is becoming increasingly important to achieve socio-political and economic objectives in a construction project (Chinyio & Olomolaiye, 2010). Guide (2001) indicated that the substance of stakeholder management is to formulate strategies to increase the support of stakeholders throughout the project life cycle and minimize their negative and neutral side effects, thereby contributing to the project success. Negotiation and renegotiation between stakeholders are crucial and essential in order to determine all the project deliverables and the exact project scope precisely, because projects can be regarded as temporary organizations of stakeholders created to generate benefits for an organization (the base organization) (Eskerod et al., 2013). Lin et al. (2017) emphasized that multiple stakeholders involved in construction projects are closely related to the successful implementation of specific policies and regulations. Therefore, exploring how stakeholders influence the success of MiC projects is an important and fundamental viewpoint of stakeholder management. This Chapter focuses on the interrelationships between stakeholders and the MiC policy-driving forces.

MiC is a relatively new field that is still developing from a global perspective (Cameron & Carlo, 2007; Lawson et al., 2014; Sun et al., 2020). In Hong Kong, MiC is still in its early stages (Ng, 2020). Previous studies mostly utilized the direct ranking method to analyze the priority of stakeholders and critical factors or directly link stakeholders with risks or key success factors, but few researchers identify and further analyze the underlying relationships between stakeholders and detailed policy-driving forces, especially in MiC projects. Luo et al. (2019) made a connection between associated stakeholders and dynamic risk interdependency to prioritize the stakeholder-associated supply chain risks in MiC. Mao et al. (2015) identified 18 critical factors through ranking analysis and grouped them into five categories by factor analysis in modular buildings. They further highlighted that ‘regulations and policies’ was the most dominant and influential cluster while did not explore it in detail. A recent study indicated the interrelations amongst eight driving forces in modular construction and presented that governments and corporations play significant roles in MiC development (Mao et al., 2018). Traditional studies only explore the problem 'what', that is, which factors/barriers/driving forces significantly affect the success of MiC projects, rather than how they affect the success and the internal relationships between them. In order to bridge these research gaps, stakeholders are presented as intermediate variables because the influence of driving forces on MiC projects success is reflected and supported through various stakeholders. Figure 5.2 illustrates the proposed model for this research, where the research question consists of three sections: how stakeholders contribute to the success of projects, and how PDFs facilitate the success of projects, as well as how stakeholders play roles in policy-driving forces. As the first two problems are relatively straightforward and have been thoroughly elucidated by previous studies on stakeholder management (Chinyio & Olomolaiye, 2010; Eskerod et al., 2013; Oliveira & Rabechini, 2019; Post et al., 2002) and key factor analysis in MiC (Zakaria et al., 2018; Gan et al., 2018; Jiang et al., 2018; Mao et al., 2018), this current study concentrates on the analysis of interrelationships between stakeholders and critical PDFs, as highlighted within the shaded area in Figure 5.2. The main contribution of this Chapter is the analysis of this correlation.

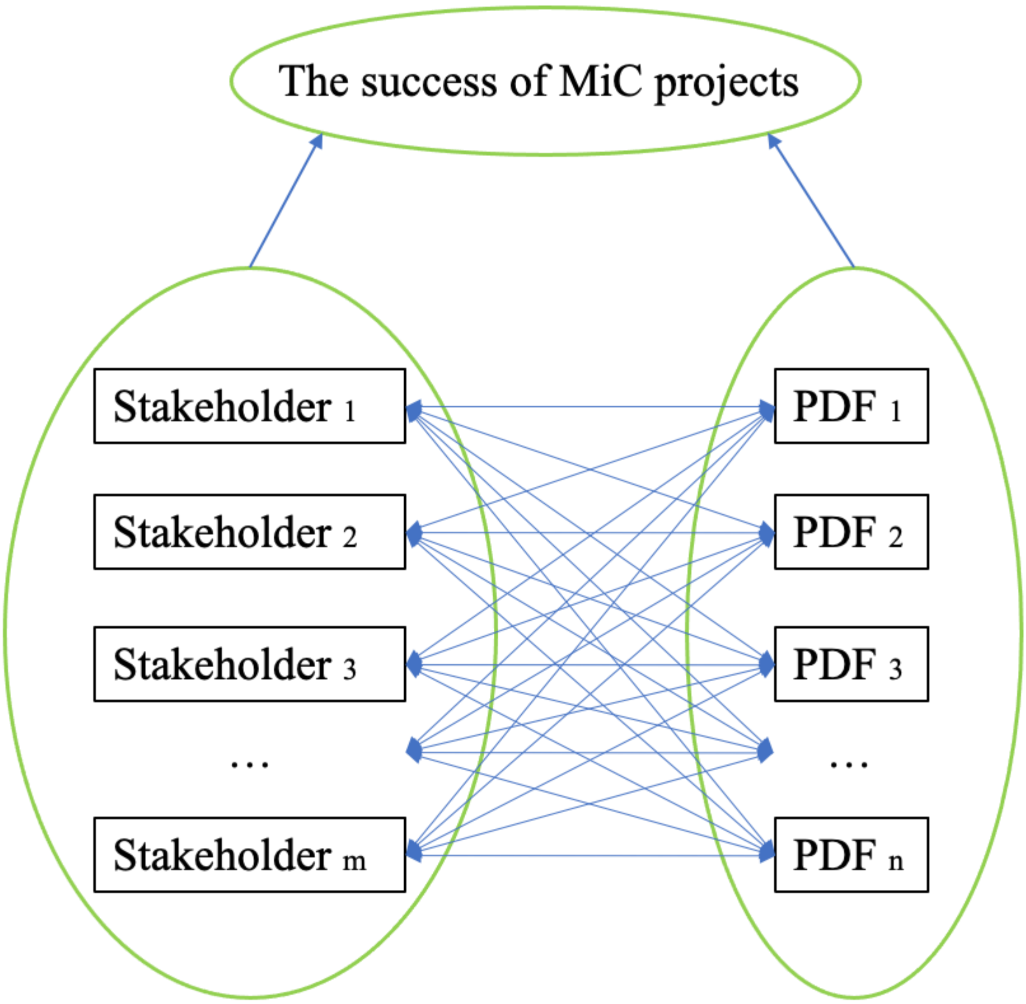

Figure 5.2 Conceptual Model of Stakeholders'/PDFs' Influence on Success of MiC Projects

The interrelationships between stakeholders and PDFs in Figure 5.2 can be explored by means of SNA, which is a recognized effective and universal method in project stakeholder management research (Rowley, 1997; Xue et al., 2020), especially to assist in understanding the latent relationship structure and effectively promote the stakeholder collaboration in construction area (Gan et al., 2018; Mok et al., 2017; Yang & Zou, 2014). Compared with traditional social sciences, SNA provides an opportunity to capture and visualize the relationships, interactions, contrasts, and attributes of and between network constituents (Chinowsky et al., 2008), and SNA has the potential to make these originally 'invisible' interactive patterns visible (Cross et al., 2002), thus in-depth analyzing the quantitative relationships of the whole network topology can be achieved. Therefore, SNA is a suitable approach for the detailed and intuitive presentation of complicated interactions between stakeholders and PDFs, and further revealing how the two affect the success of MiC projects.

5.4 Two-Mode Network Model Establishment

Considering that this study is to investigate the interrelationships between critical PDFs and stakeholders involved in MiC projects, it is appropriate to adopt a two-mode network for analysis. It helps to explore the links between two distinct sets of nodes by representing a bipartite network. This SNA method facilitates easy access to the data, simplicity of design, the use of limited sample size, and decisional and interactional analysis (Tichy et al., 1979). Also, many existing studies have justified SNA as an effective method to explore the influence of a wide-ranging array of factors in construction industry. As detailed described in Section 3.4.2, the five steps involved in this two-mode SNA are: 1) setting up the boundary of the network, 2) establishing and assessing the meaningful and actionable interrelationships, 3) visualising the network, 4) deciphering the network structures, 5) presenting the network analysis results. The first two steps are followed in a stepwise manner.

5.4.1 Nodes identification

This study identified the critical PDFs from the comprehensive literature review, expert interviews and questionnaire survey. The list of critical PDFs was summarized, as shown in Table 4.7. For the relevant stakeholders involved in the three stages of MiC projects in Hong Kong, literature review and real case studies were used to confirm, refine and categorize a list of stakeholders. In follow-up expert interviews, the experts also acknowledged these stakeholder groups identified initially. After integrating all information, Table 5.1 presents all the stakeholders for three stages. The stakeholders involved in different stages are slightly different, with a relatively large number at the construction phase. The 32 stakeholders include S1 (the government of the Hong Kong SAR), S2 (the government of Guangdong Province), S3 (developers/clients), S4 (designers/architects/urban planners), S5 (consultants), S6 (survey engineers), S7 (general public), S8 (media), S9 (research institutions), S10 (industry institutions), S11 (non-government organizations (NGOs)/local communities), S12 (financial institutions/banks), S13 (contract managers), S14 (tenderer), S15 (main contractors), S16 (sub-contractors), S17 (suppliers of equipment and materials), S18 (manufacturers), S19 (production managers), S20 (production project directors), S21 (modules producing workers), S22 (modules testing organizations), S23 (quality control inspectors), S24 (purchasing staff), S25 (logistics-fleet manager), S26 (logistics-truck drivers), S27 (customs), S28 (on-site project managers), S29 (on-site engineers), S30 (foreman & supervisor/ inspectors), S31 (on-site operators (erection & lifting & buffer)), S32 (occupier/end user).

Table 5.1 Main Stakeholders in Three Stages of MiC Projects in HK

Stages	**Code**	**Relevant Stakeholder**	Luo et al. (2019)	Liang et al. (2015)	Lin et al. (2017)	Gan et al. (2018)	Xue et al. (2020)	Xue et al. (2018)	Yang and Zou (2014)	Li et al. (2016)	Mok et al. (2017)	Case Studies
Stage I: Initiation Phase	S1	the Government of the Hong Kong SAR	√	√	√	√	√		√	√	√	√
	S3	Developers/clients	√	√	√	√	√	√	√	√	√	√
	S4	Designers/architects/urban planners	√	√		√		√		√		√
	S5	Consultants			√	√	√		√		√	√
	S6	Survey engineers					√					√
	S7	General public			√	√	√		√		√	
	S8	Media				√	√		√		√	
	S9	Research institutions		√		√			√		√	√
	S10	Industry institutions		√	√		√		√		√	
	S11	NGOs/local communities		√	√		√		√		√	√
Stage II: Planning & Design Phase	S1	the Government of the Hong Kong SAR	√	√	√	√	√		√	√	√	√
	S3	Developers/clients	√	√	√	√	√	√	√	√	√	√
	S4	Designers/architects/urban planners	√	√		√		√		√		
	S5	Consultants			√	√	√		√		√	√
	S6	Survey engineers					√					√

	S7	General public			√	√	√		√		√	
	S8	Media				√	√		√		√	
	S9	Research institutions		√		√			√		√	√
	S10	Industry institutions		√	√		√		√		√	
	S11	NGOs/local communities		√	√		√		√		√	√
	S12	Financial institutions/banks		√	√	√	√		√		√	
	S13	Contract managers										√
	S15	Main contractors	√	√	√	√	√	√	√	√	√	√
	S18	Manufacturer	√			√		√		√		√
Stage III: Construction Phase	S1	the Government of the Hong Kong SAR	√	√	√	√	√		√	√	√	√
	S2	the Government of Guangdong Province		√	√	√	√		√	√	√	√
	S3	Developers/clients	√	√	√	√	√	√	√	√	√	√
	S4	Designers/architects/urban planners	√	√		√		√		√		√
	S5	Consultants			√	√	√		√		√	
	S7	General public			√	√	√		√		√	
	S8	Media				√	√		√		√	
	S9	Research institutions		√		√			√		√	√
	S10	Industry institutions		√	√		√		√		√	
	S11	NGOs/local communities		√	√		√		√		√	√
	S12	Financial institutions/banks		√	√	√	√		√		√	
	S13	Contract manager										√

S14	Tenderers					√					
S15	Main contractors	√	√	√	√	√	√	√	√	√	√
S16	Sub-contractors	√	√	√	√	√	√	√		√	√
S17	Suppliers of equipment and materials		√	√	√	√		√		√	√
S18	CEO of MiC manufacturer	√			√		√		√		√
S19	Production managers										√
S20	Production project directors										√
S21	Modules producing workers					√					√
S22	Modules testing organizations										√
S23	Quality control inspectors										√
S24	Purchasing staff										√
S25	Logistics-fleet manager	√			√	√			√		√
S26	Logistics-truck drivers	√			√	√			√		√
S27	Customs					√					√
S28	On-site project managers	√							√	√	√
S29	On-site engineers										√
S30	Foreman & supervisor/ inspectors	√			√	√	√		√	√	√
S31	On-site operators (erection & lifting & buffer)			√		√					√
S32	Occupier/end-user		√	√				√		√	√

5.4.2 Relationship assessment

In this step, the interactions between the critical PDFs and relevant stakeholders identified previously were evaluated through a 10*7 matrix with 70 links in Stage I (Initiation Phase) and a 14*6 matrix with 84 links in Stage II (Planning & Design Phase), as well as a 31*10 matrix with 310 links in Stage III (Construction Phase). For this purpose and due to the COVID-19 pandemic, face-to-face or online (VooV Meeting via Tencent Cloud) interviews were conducted to collect the empirical information from the professionals within the 32 stakeholder groups. Ideally, all the 32 stakeholders identified in step 1 should be involved in this assessment period to reach a consensus and unity, but in the actual cases, only a majority of stakeholders can participate in the process due to practical difficulties. Nevertheless, all efforts have been made to include all key and representative stakeholders. To minimize haziness, very detailed verbal explanations were provided to interviewees when they had doubts about a particular PDF or were unclear about certain interview questions. This assessment adopted a five-point Likert scale, where 4 denotes an extremely strong influence, 3 is a strong influence, 2 represents medium influence, 1 shows relatively small influence, and 0 denotes no influence. The mean value of the evaluation results was used to reflect the weight of these links. Through interviews with 28 experts involved in MiC projects and a focus group meeting of four doctoral specialists, three separate evaluation matrixes of interrelationships between critical PDFs and stakeholders at different stages were developed, as shown in Table 5.2, 5.3 and 5.4.

Table 5.2 Relational Matrix between Stakeholders and PDFs in Stage I

Stakeholders \ Critical PDFs	A5	A4	A6	A12	A11	A1	A8
S1	4.00	3.57	3.57	3.43	3.71	3.86	4.00
S3	3.43	3.00	3.57	2.57	2.57	2.00	3.43
S4	2.43	1.57	1.71	2.57	2.29	2.00	3.14
S5	2.86	0.86	2.86	2.29	2.57	1.57	3.00
S6	1.00	0.57	0.71	2.43	0.86	1.00	1.00
S7	2.71	1.00	2.14	2.29	2.71	2.29	3.00
S8	2.57	2.00	2.71	3.00	3.57	3.29	3.14
S9	3.14	1.86	3.00	3.57	3.14	3.29	3.43
S10	3.29	2.29	3.43	2.57	2.57	2.29	3.29
S11	2.43	2.00	2.29	3.00	2.71	2.29	2.57

Table 5.3 Relational Matrix between Stakeholders and PDFs in Stage II

Stakeholders \ Critical PDFs	B6	B8	B12	B2	B1	B11
S1	4.00	4.00	3.57	3.86	3.71	3.29
S3	3.29	3.57	2.86	3.43	2.71	3.29
S4	1.71	2.86	2.43	3.29	2.43	2.43
S5	2.29	2.57	2.71	2.71	2.29	2.57
S6	0.71	1.14	1.86	1.14	1.29	1.43
S7	2.57	2.86	2.71	1.43	3.00	0.57
S8	1.71	2.57	2.57	2.14	3.29	0.71
S9	3.29	2.86	3.29	3.14	3.00	1.71
S10	3.14	3.29	2.86	3.14	2.57	2.86
S11	2.57	2.29	3.14	1.86	2.57	1.43
S12	1.43	1.57	1.43	2.14	2.43	2.29
S13	3.43	1.57	1.71	1.14	1.43	3.43
S15	3.57	2.43	2.29	2.86	2.43	3.29
S18	2.29	1.43	1.71	3.00	2.29	2.29

Table 5.4 Relational Matrix between Stakeholders and PDFs in Stage III

Critical PDFs / Stakeholders	C15	C16	C17	C9	C8	C2	C1	C3	C22	C23
S1	3.33	3.38	3.46	3.33	3.25	3.29	3.46	3.33	3.21	2.83
S2	3.58	3.42	3.46	2.46	1.67	3.08	2.38	1.29	2.75	1.79
S3	2.93	2.87	3.20	3.00	3.27	3.20	2.53	3.33	3.60	3.40
S4	1.58	1.33	1.67	3.33	3.42	3.33	1.67	2.50	3.17	2.58
S5	0.78	1.33	2.33	3.22	2.78	3.11	1.22	2.56	2.89	2.56
S7	1.54	1.23	1.69	1.77	1.38	1.85	3.38	2.08	2.46	3.15
S8	1.22	1.22	2.78	1.11	1.11	2.22	2.11	1.56	1.67	3.22
S9	1.33	1.33	2.78	2.78	3.00	3.56	1.56	2.67	3.11	2.00
S10	1.00	1.00	3.33	3.67	3.33	3.67	1.33	3.33	3.33	1.00
S11	2.22	1.56	2.78	2.11	2.22	3.33	1.44	2.56	2.44	1.89
S12	1.20	1.40	1.40	1.10	0.90	2.30	1.90	3.50	2.00	3.20
S13	0.67	1.17	1.17	1.67	1.67	1.67	1.17	1.50	3.33	1.83
S14	1.22	1.78	2.22	2.00	2.56	2.33	2.22	2.22	2.67	2.11
S15	2.19	2.63	2.81	3.06	2.81	3.44	2.81	2.31	3.00	1.75
S16	1.36	2.09	2.18	2.36	2.55	2.27	2.18	2.18	2.18	1.82
S17	3.00	3.00	2.30	2.40	2.50	2.10	2.10	1.80	2.30	1.60
S18	3.07	3.20	3.07	3.20	3.00	3.07	2.20	2.20	3.07	2.20
S19	2.00	2.10	2.20	2.10	3.00	2.90	2.20	1.50	3.00	1.50
S20	2.00	1.20	1.60	2.00	2.50	1.90	2.10	1.50	2.70	0.70
S21	0.80	0.50	0.90	1.00	2.20	1.30	1.50	1.00	2.00	0.50
S22	0.88	0.25	0.88	0.38	1.88	1.13	1.38	0.38	3.38	0.00
S23	0.38	1.25	0.88	0.50	3.13	1.88	1.13	0.50	3.38	0.38
S24	3.00	2.54	1.15	0.92	1.46	1.31	1.69	2.08	1.31	0.85
S25	3.57	3.64	2.93	1.36	2.86	1.36	2.00	1.07	2.36	0.57
S26	3.38	3.50	2.25	0.38	0.88	0.00	2.50	0.00	0.00	0.00
S27	3.44	3.22	0.89	0.78	1.89	0.44	3.11	0.11	2.00	1.67
S28	2.36	2.43	1.29	2.64	2.86	3.00	2.79	1.71	3.29	1.14
S29	0.55	1.00	0.73	1.55	2.27	1.73	2.45	0.45	2.91	0.36
S30	0.45	0.36	1.18	1.36	1.27	1.00	2.64	0.64	2.55	0.27
S31	0.45	0.55	0.55	0.91	1.36	0.82	2.55	0.64	2.36	0.36
S32	0.00	0.17	0.67	0.50	1.17	0.67	2.00	1.50	2.83	3.17

5.5 Results of Two-Mode Social Network Analysis

Based on the previous two-step data collection, three datasets depicting the relationships between critical PDFs and stakeholders at different stages were obtained. All results of the analysis were generated by importing datasets into the *Cyram*

NetMiner version 4.4.3.g, an innovative and reputable software tool for exploratory network data analysis with modern network visualization.

5.5.1 Visualization of PDF-stakeholder network

5.5.1.1 Spring embedding networks

The visualizations of spring embedding networks between critical PDFs and relevant stakeholders in Stage I, II and III, respectively, display the layout of nodes/links and the overall relationships between these nodes, which are generated by Netminer 4.4 and graphically represented in Figure 5.3, 5.4 and 5.5. Figure 5.3 reflects that the network in Stage I comprises 17 nodes linked by 70 weighted ties. Figure 5.4 reveals that the network in Stage II comprises 20 nodes linked by 84 weighted ties. Figure 5.5 signifies that the network in Stage III comprises 41 nodes linked by 310 weighted ties. Here, the red circles represent the nodes for all the stakeholders, while the squares in different colours signify the nodes for the critical PDFs at the corresponding stage. The lines denote ties between different node sets. The size of the circles, representing the value of degree centrality in the network, reflects the impact status of stakeholders. If the size is bigger and closer to the centre, the stakeholder or the critical PDF is more important to the whole network. While the distance between nodes in these graphs is not easy to interpret, subsequent correspondence analysis can make up for this deficiency. More relevant quantitative analysis is described in detail in the next section.

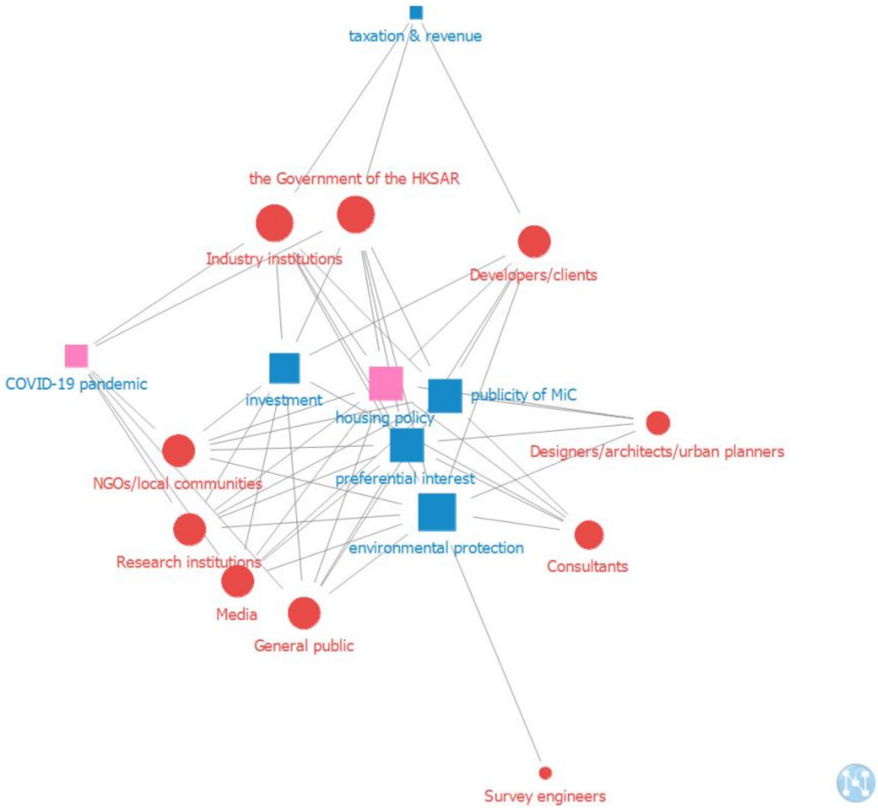

Figure 5.3 Visualization of PDF-stakeholder network in Stage I

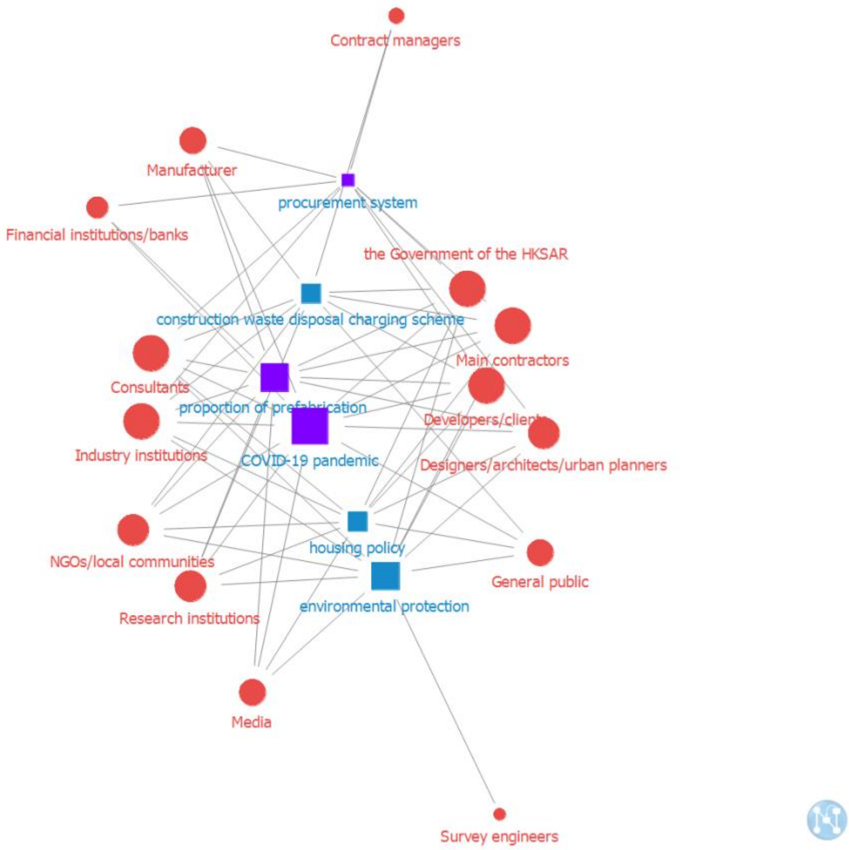

Figure 5.4 Visualization of PDF-stakeholder network in Stage II

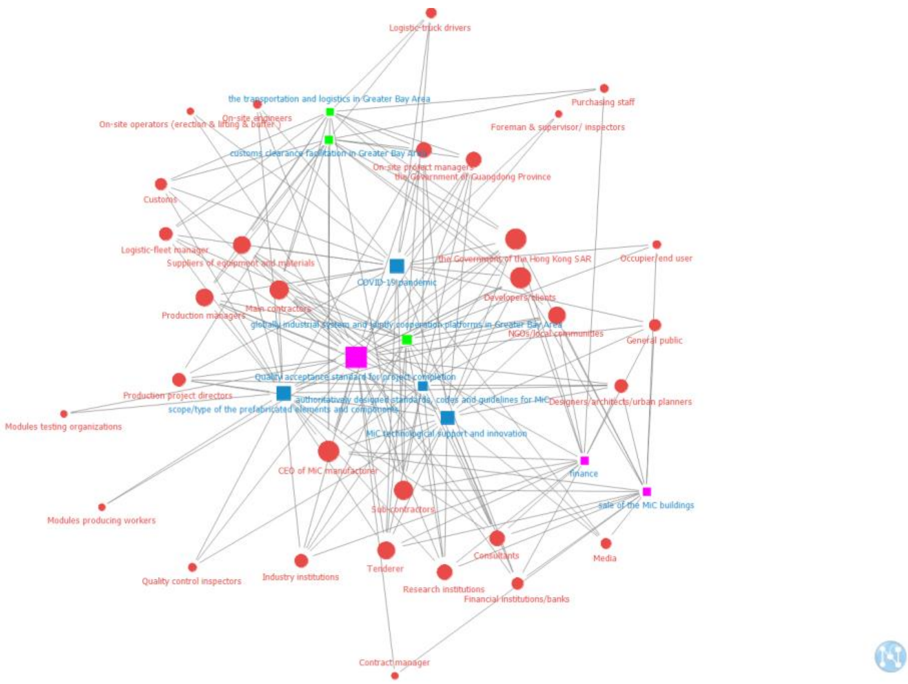

Figure 5.5 Visualization of PDF-stakeholder network in Stage III

5.5.1.2 Correspondence mapping

Correspondence analysis is an appropriate technique specially designed to analyze the relationship between two modes (Roberts, 2000). This is a geometric way to visually represent both the rows and columns of a two-mode matrix as points in the metric space, making the distance between these nodes meaningful (Borgatti & Everett, 1997). Such that the positions of the row and column points are consistent with their associations in the matrix. Although correspondence analysis is intended to model frequency data (Borgatti & Everett, 1997), this method is extremely useful as the main interest of this research is to assess the structural equivalence of stakeholders or PDFs. Correspondence analysis of two-mode data can yield quite a few substantive insights (Roberts, 2000). While one impediment to getting noticed is the possible reduction of readability, as vertices inevitably occlude each other in the network, the aforementioned spring embedded network can be used as a supplement. The correspondence coordinate map reveals a macro view of the stakeholder distribution among the relevant critical PDFs (square points) at the corresponding stages, as shown in Figures 5.6, 5.7 and 5.8. Three general principles interpreting the relationships between stakeholders and critical PDFs are as follows: 1) the codes representing the stakeholders are placed close together if similar PDFs have an influence on them; 2) the codes representing the critical PDFs are located near each other if they have influence over similar stakeholders; 3) the angle formed by connecting a stakeholder-code and PDFs-code to the origin, and really small angle indicates association, 90 degrees angle means no relationship, while angle near 180 degrees indicates negative associations. In simplified terms, proximity between codes in the same group indicates similarity, and the proximity of codes within different groups means a considerably strong influence relationship.

For Stage I, in Figure 5.6, the stakeholders are automatically separated by the vertical axis due to their distinctive territories affected by critical PDFs. The stakeholder group on the right plot includes the government of the Hong Kong SAR (S1), developers/clients (S3), consultants (S5), and industry institutions (S10), who has direct influence and decision-making capability on the MiC projects during the Stage I-initiation phase. To a certain extent, they are more concerned with the dynamics of policies because these can affect their decision-making and judgment on the whole MiC project in the initiation phase. Notably, this group is closely associated with the promotional PDFs, especially economic incentives such as preferential interest and investment of MiC projects, taxation and revenue. On the left side of the axis, the stakeholders contain designers/architects/urban planners (S4), survey engineers (S6), general public (S7), media (S8), research institutions (S9), and NGOs/local communities (S11), who are more likely to be affected by the PDFs and have an indirect or inconspicuous impact on the MiC project in Stage I. The PDFs that influence them are related to the publicity of MiC, the regulative PDF concerning the COVID-19 pandemic, and the sustainable PDF about environmental protection, which may affect the life or work of closely related organizations. The separation of the PDF domains indicates that different stakeholder groups have their own unique scopes of concern and influence on MiC projects in Stage I.

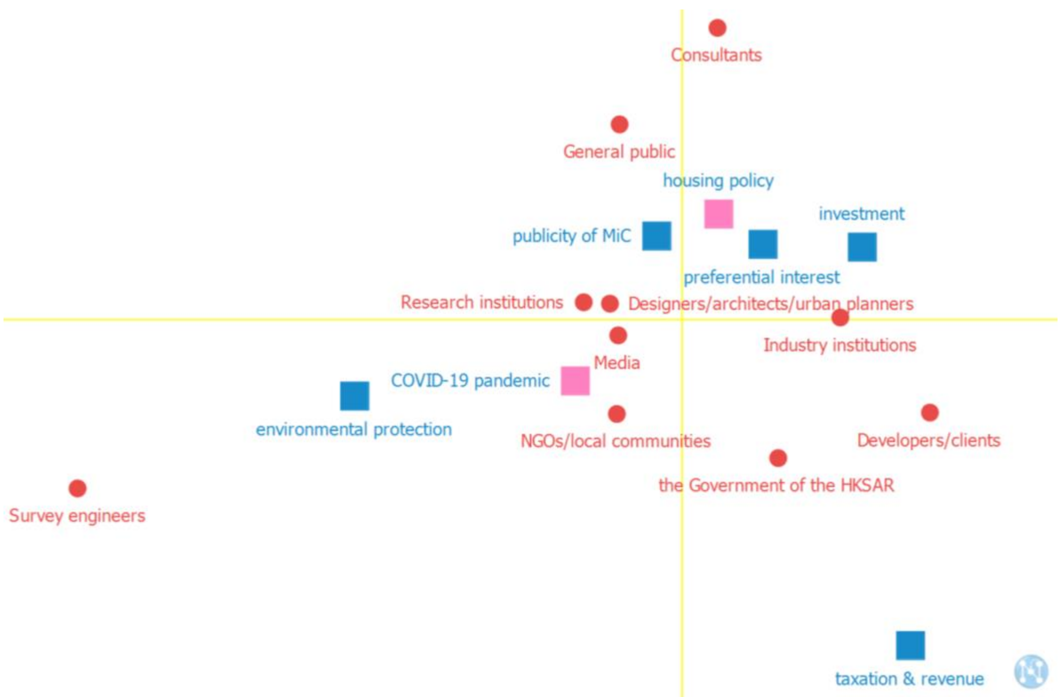

Figure 5.6 Correspondence mapping of PDF-stakeholder network in Stage I

For Stage II, in Figure 5.7, the stakeholder group on the right plot includes designers/architects/urban planners (S4), survey engineers (S6), general public (S7), media (S8), research institutions (S9), and NGOs/local communities (S11), which is exactly the same as the grouping in Stage I. Moreover, in Stage II, the PDFs that are closely associated with this group contain the regulative PDF on the COVID-19 pandemic and the sustainable PDF about environmental protection, and housing policy, which are also similar to the situation in Stage I. Stakeholders on the right axis are external stakeholders, who are more passively affected by policies and have an implicit influence on MiC projects. The relevant PDFs are related to the externalities of the MiC projects in the planning and design phase. On the left side, the stakeholder group includes the government of the Hong Kong SAR (S1), developers/clients (S3), consultants (S5), industry institutions (S10), financial institutions/banks (S12), contract manager (S13), main contractors (S15), and manufacturer (S18), most of whom are internal stakeholders. Stakeholders in this segment are directly involved in the policy implementation or have formal or contractual associations within MiC projects. They pay more attention to the PDFs related to the internal management of MiC projects, such as construction waste disposal charging scheme, the proportion of prefabrication in public housing projects, and procurement system. These policies, which are closely related to the internalities of MiC, are closely linked with internal stakeholders. What is remarkable is that the stakeholder-government of the Hong Kong SAR is precisely at the origin, which indicates that the Hong Kong government has a strong relationship with all critical PDFs at this stage.

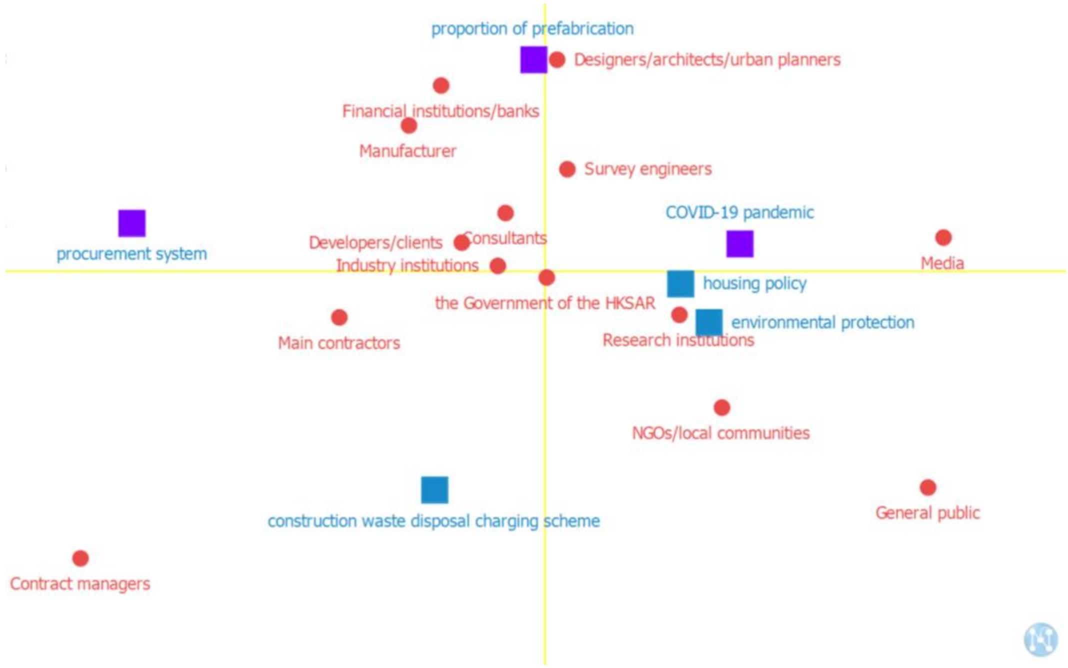

Figure 5.7 Correspondence mapping of PDF-stakeholder network in Stage II

For Stage III, the number of stakeholders increases, and the correspondence map is somewhat different from the previous two stages. In Figure 5.8, the stakeholder group in the lower right area is basically external stakeholders, including designers/architects/urban planners (S4), consultants (S5), general public (S7), media (S8), research institutions (S9), industry institutions (S10), NGOs/local communities (S11), financial institutions/banks (S12), contract manager (S13), tenderer (S14), developers/clients (S3), sub-contractors (S16), and occupier/end-user (S32), who are more concerned about the promotional PDFs with respect to financing and sales of MiC buildings, as well as the technical and regulative PDFs on MiC technological support and innovation and authoritatively designed standards, codes and guidelines for MiC. To be more precise, those PDFs are more relevant to the lives of these stakeholders and have more influence on them. For example, how well the MiC buildings sell is of great significance to the financial institutions or banks, because it is related to the return of funds. While the designers/architects/urban planners should pay close attention to the adjustment of authoritatively designed standards, codes and guidelines for MiC. In the upper right plot, modules producing workers (S21), modules testing organizations (S22), quality control inspectors (S23), on-site engineers (S29), foreman & supervisor/ inspectors (S30), and on-site operators (erection & lifting & buffer) (S31) are internal stakeholders closely related to module production and installation. So the quality acceptance standard for project completion and scope/type of the prefabricated elements and components means a lot to them. They should try their best to conform to these relevant regulations. The critical PDFs are associated with Greater Bay Area development and the COVID-19 pandemic on the left side. Therefore, the relevant stakeholders in this territory are mainly involved in cross-border transportation, such as the government of the Hong Kong SAR (S1), the government of Guangdong Province (S2),

main contractors (S15), suppliers of equipment and materials (S17), CEO of MiC manufacturer (S18), production managers (S19), production project directors (S20), purchasing staff (S24), logistics-fleet manager (S25), logistics-truck drivers (S26), customs (S27), and on-site project managers (S28). Both governments in Hong Kong and Guangdong have shown great interest in establishing globally industrial systems and jointly cooperation platforms in Greater Bay Area, which can facilitate information exchanges. Logistics companies always worry about the speed of customs clearance and logistics in the Greater Bay Area so that they will be more aware of changes or improvements in relevant policies. As managers and directors need frequent communication and coordination during the construction phase to ensure the smooth progress of the project, the inconvenience caused by the COVID-19 pandemic will affect the process seriously. It is worth noting that, different from Stage II, in the correspondence map of Stage III, the main contractor falls precisely at the origin, which indicates that the main contractor is the most critical stakeholder in the construction stage, and all critical PDFs have a great impact on it.

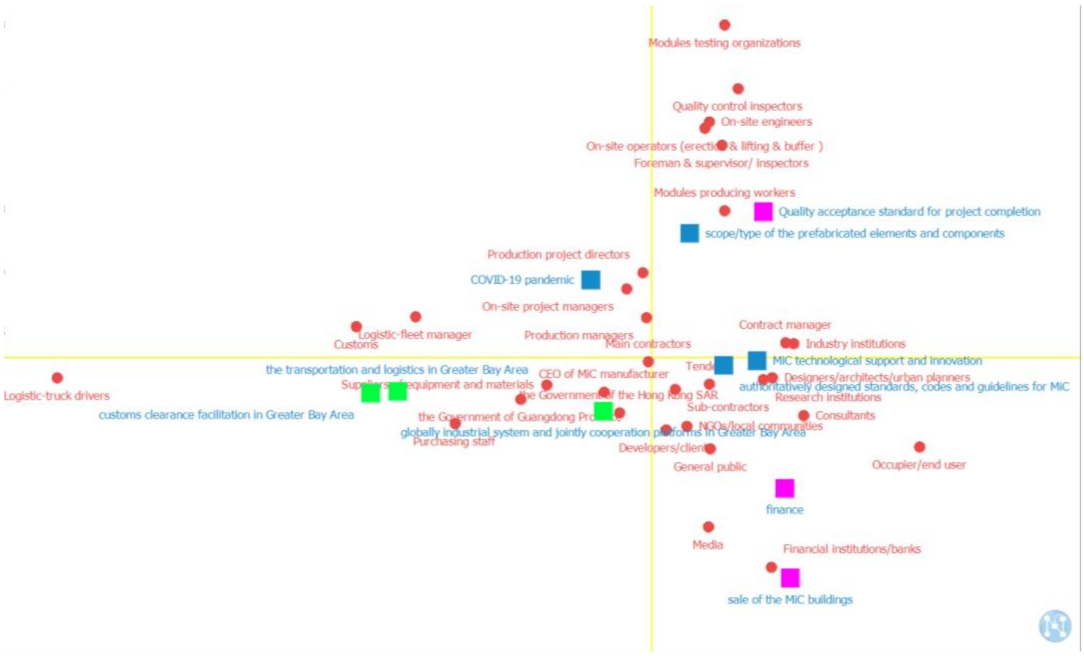

Figure 5.8 Correspondence mapping of PDF-stakeholder network in Stage III

5.5.2 Network quantitative analysis

In Stage I, a total of 10 stakeholders related to seven critical PDFs are identified; in Stage II, 14 stakeholders related to six critical PDFs are determined; in Stage III, a total of 31 stakeholders related to ten critical PDFs are confirmed. Two-mode node and link measures are conducted to calculate critical SNA indicators of these three networks. Two-mode network quantitative analysis is conducted by computing the critical indicators of the three networks, including degree, degree centrality, node betweenness centrality, link betweenness centrality, closeness centrality, and eigenvector centrality, which could reflect the complexity and interconnectedness of these networks in a quantitative manner and determine critical stakeholders and their relations. Since the critical PFDs have already been thoroughly explained and discussed in Chapter 4, this section will focus on the stakeholders and how they relate to the critical PDFs. The results of network analysis are described as follows.

5.5.2.1 Degree

The degree is a primary indicator, which usually is the first step in exploring the network, reflecting the direct connection features of nodes (Freeman, 2004; Mcpherson et al., 2001). If there is a line between two nodes, they are 'adjacent'. If a node is one of a pair of nodes that define a line, then the node is the 'incident' of the line. The nodal degree of connection is the number of lines incident with it, which measures the size of its immediate neighbourhood (Freeman, 1978). To avoid minor complications, in two-mode networks, degree refers to the number of ties a node has or the number of other sub-nodes connected to the main node, and vice versa (Opsahl et al., 2010). Since this study involves weighted networks analysis, degree measure has been extended to compute the weighted sum of links with the immediate neighbourhood (Barrat et al., 2004; Newman, 2004; Opsahl et al., 2008).

The priority rankings of stakeholders and critical PDFs during Stage I, II, and III according to the degree are shown in Table 5.5. The top five stakeholders were highlighted, showing they received higher impacts from the critical PDFs in their corresponding stage compared with other stakeholders. The government of the Hong Kong SAR (S1) has the highest degree value in three stages, namely, 26.14 in Stage I, 22.43 in Stage II, and 32.87 in Stage III, which indicates it has the strongest direct relationship with the identified critical PDFs. The government has the right to participate directly and make decisions on policies. At the same time, it will be influenced by the policies and constantly amend and improve some policies to conform to social development. Another important stakeholder is the developer/client (S3), who are among the top three in all three stages, indicating that they received a high impact from critical PDFs, because the developer is generally the main funder of MiC projects. Other secondary important stakeholders include research institutions (S9), industry institutions (S10), who often provide effective advice for policy implementation. Remarkably, the media (S8) and general public (S7) had a relatively strong relationship with critical PDFs in Stage I, but this connection continued to weaken in Stage II and Stage III. It can be seen that the media and public opinion mainly plays a role in the early stage of the project. The governments, clients, and contractors need consideration, especially in Stage III, as they significantly lead to an increase in overall network complexity. For the critical PDFs, in Stage I, the housing policy received the closest attention; in Stage II, the construction waste disposal charging scheme has the highest degree value; in Stage III, the quality acceptance standard for project completion has the greatest impact on the stakeholders.

Table 5.5 Stakeholders and Critical PDFs Prioritization based on Degree

<table>
<tr><th>Stages</th><th>Rank</th><th>Code</th><th>Stakeholder</th><th>Degree</th><th>Code</th><th>Critical PDFs</th><th>Degree</th></tr>
<tr><td rowspan="10">Stage I: Initiation Phase</td><td>1</td><td>S1</td><td>the Government of the HKSAR</td><td>26.14</td><td>A8</td><td>Housing policy</td><td>30.00</td></tr>
<tr><td>2</td><td>S9</td><td>Research institutions</td><td>21.43</td><td rowspan="2">A5</td><td rowspan="2">Preferential interest of the MiC project</td><td rowspan="2">27.86</td></tr>
<tr><td>3</td><td>S3</td><td>Developers/ clients</td><td>20.57</td></tr>
<tr><td>4</td><td>S8</td><td>Media</td><td>20.28</td><td rowspan="2">A12</td><td rowspan="2">Environment al protection</td><td rowspan="2">27.72</td></tr>
<tr><td>5</td><td>S10</td><td>Industry institutions</td><td>19.73</td></tr>
<tr><td>6</td><td>S11</td><td>NGOs/local communities</td><td>17.29</td><td>A11</td><td>Publicity of MiC</td><td>26.70</td></tr>
<tr><td>7</td><td>S7</td><td>General public</td><td>16.14</td><td rowspan="2">A6</td><td rowspan="2">Investment in MiC projects</td><td rowspan="2">25.99</td></tr>
<tr><td>8</td><td>S5</td><td>Consultants</td><td>16.01</td></tr>
<tr><td>9</td><td>S4</td><td>Designers/ architects/ urban planners</td><td>15.71</td><td>A1</td><td>COVID-19 pandemic</td><td>23.88</td></tr>
<tr><td>10</td><td>S6</td><td>Survey engineers</td><td>7.57</td><td>A4</td><td>Taxation& Revenue</td><td>18.72</td></tr>
<tr><td rowspan="8">Stage II: Planning & Design Phase</td><td>1</td><td>S1</td><td>the Government of the HKSAR</td><td>22.43</td><td rowspan="3">B6</td><td rowspan="3">Construction waste disposal charging scheme</td><td rowspan="3">36.00</td></tr>
<tr><td>2</td><td>S3</td><td>Developers/ clients</td><td>19.15</td></tr>
<tr><td>3</td><td>S10</td><td>Industry institutions</td><td>17.86</td></tr>
<tr><td>4</td><td>S9</td><td>Research institutions</td><td>17.29</td><td>B1</td><td>COVID-19 pandemic</td><td>35.44</td></tr>
<tr><td>5</td><td>S15</td><td>Main contractors</td><td>16.87</td><td rowspan="2">B2</td><td rowspan="2">Proportion of prefabrication</td><td rowspan="2">35.28</td></tr>
<tr><td>6</td><td>S4</td><td>Designers/ architects/ urban planners</td><td>15.15</td></tr>
<tr><td>7</td><td>S5</td><td>Consultants</td><td>15.14</td><td rowspan="2">B12</td><td rowspan="2">Environment al protection</td><td rowspan="2">35.14</td></tr>
<tr><td>8</td><td>S11</td><td>NGOs/local</td><td>13.86</td></tr>
</table>

			communities				
	9	S7	General public	13.14	B8	Housing policy	35.01
	10	S18	Manufacturer	13.01			
	11	S8	Media	12.99	B11	Procurement system	31.59
	12	S13	Contract managers	12.71			
	13	S12	Financial institutions/ banks	11.29			
	14	S6	Survey engineers	7.57			
Stage III: Construction Phase	1	S1	the Government of the HKSAR	32.87	C22	Quality acceptance standard for project completion	81.25
	2	S3	Developers/ clients	31.33			
	3	S18	CEO of MiC manufacturer	28.28			
	4	S15	Main contractors	26.81	C8	Scope/type of the prefabricated elements and components	70.15
	5	S2	the Government of Guangdong Province	25.88			
	6	S10	Industry institutions	24.99			
	7	S4	Designers/ architects/ urban planners	24.58	C2	MiC technological support and innovation	67.26
	8	S9	Research institutions	24.12			
	9	S28	On-site project managers	23.51			
	10	S17	Suppliers of equipment and materials	23.10	C1	COVID-19 pandemic	65.70
	11	S5	Consultants	22.78	C17	Globally industrial system and jointly cooperation platforms in Greater Bay Area	60.73
	12	S11	NGOs/local communities	22.55			
	13	S19	Production managers	22.50			
	14	S25	Logistics-fleet manager	21.72			
	15	S14	Tenderer	21.33			
	16	S16	Sub-contractors	21.17			
	17	S7	General public	20.53	C9	Authoritative	58.95

18	S12	Financial institutions/ banks	18.90		ly designed standards, codes and guidelines for MiC	
19	S8	Media	18.22			
20	S20	Production project directors	18.20			
21	S27	Customs	17.55			
22	S24	Purchasing staff	16.31			
23	S13	Contract manager	15.85	C16	Transportation and logistics in Greater Bay Area	56.65
24	S29	On-site engineers	14.00			
25	S23	Quality control inspectors	13.41			
26	S26	Logistics-truck drivers	12.89	C15	Customs clearance facilitation in Greater Bay Area	55.48
27	S32	Occupier/ end user	12.68			
28	S30	Foreman & supervisor/ inspectors	11.72			
29	S21	Modules producing workers	11.70			
30	S31	On-site operators (erection & lifting & buffer)	10.55	C3	Finance	54.00
31	S22	Modules testing organizations	10.54	C23	Sale of MiC buildings	50.40

5.5.2.2 Degree Centrality

Degree centrality reflects the level of structural importance of a particular node in the two-mode network, and this measure is based on the degree of connectivity (Freeman, 1978). Conceptually, when focusing on a bipartite graph, degree centrality is defined as the number of edges incident upon a node (Faust, 1997; Lin et al., 2017), which can be calculated by the portion of nodes adjacent to each node (Borgatti & Everett, 1997). In this study, the degree centrality of a stakeholder is the sum of the sizes of critical PDFs with which it is affiliated. The degree centrality of a critical PDF is the number of stakeholders affiliated with it. The interpretation for degree centrality is that stakeholders are important because of their influence level or the number of interactions they have, while PDFs are significant because of their membership size. The degree centralization index is an indicator to measure the variability of individual centrality scores. The more extensive degree concentration index means the higher network concentration.

Stakeholders and critical PDFs in the three stages are ranked according to the priority of degree centrality, as shown in Table 5.6. When combined with visualized graphs (Figure 5.3, 5.4 and 5.5), many interesting conclusions can be drawn. The most influential and important stakeholder is the government of the Hong Kong SAR (S1), with a degree centrality value of 1.00 in Stages I, II and III. Also, the stakeholder with greater influence in all three stages is the developer/client (S3), who dominates the entire process of the MiC project. The research institutions (S9) and NGOs/local communities (S11) have always maintained a position of medium importance (degree centrality is between 0.70 and 0.86). The industry institutions (S10) is notable in Stage I and II, with a degree centrality value of 1.00, while its importance has dropped significantly (degree centrality is 0.60) in Stage III. A similar situation could be seen with the media (S8) and general public (S7), indicating that these external stakeholders have a relatively high degree of participation in policy implementation in the initiation and planning phases. Still, their relationship weakens in the construction phase. Interestingly, the direct participants, namely the manufacturer (S18), main contractors (S15), and sub-contractors (S16), with degree centralities of no less than 0.90, are of great importance during the module production and installation process in the construction phase. They are very concerned about and influenced by critical PDFs. The two-mode degree centralization index of stakeholder nodes increases from 0.296 in Stage I to 0.323 in Stage II, and then to 0.493 in Stage III, indicating that the network concentration is getting higher and higher with the progress of projects, which also means that all relevant stakeholders are more closely connected. From the perspective of the critical PDFs, in Stage I, the environmental protection policy has the highest value of degree centrality (1.0), which is located in the middle of Figure 5.3, while ‘preferential interest of the MiC project’, ‘publicity of MiC’ and ‘housing policy’ also received close attention. In Stage II, the COVID-19 pandemic has greatly affected the activities and lives of the stakeholders involved; as shown in Figure 5.4, ‘environmental protection policy’ and ‘proportion of prefabrication in housing’ also make a difference. In Stage III, the quality acceptance standard for project completion shows the greatest impact on the stakeholders, followed by ‘scope/type of the prefabricated elements and components’, ‘COVID-19 pandemic’ and ‘MiC technological support and innovation’, which can also be observed in Figure 5.5.

Table 5.6 Stakeholders and Critical PDFs Prioritization based on Degree Centrality

Stages	Rank	Code	Stakeholder	Degree Centrality	Code	Critical PDFs	Degree Centrality
Stage I: Initiation Phase	1	S1	the Government of the HKSAR	1.000000	A12	Environmental protection	1.00
	2	S10	Industry institutions	1.000000	A5	Preferential interest of the MiC project	0.90
	3	S3	Developers/ clients	0.857143			
	4	S7	General public	0.857143	A11	Publicity of MiC	0.90
	5	S8	Media	0.857143			
	6	S9	Research institutions	0.857143	A8	Housing policy	0.90
	7	S11	NGOs/local communities	0.857143	A6	Investment to MiC projects	0.80
	8	S5	Consultants	0.714286			
	9	S4	Designers/ architects/ urban planners	0.571429	A1	COVID-19 pandemic	0.60
	10	S6	Survey engineers	0.142857	A4	Taxation& Revenue	0.30
Stage II: Planning & Design Phase	1	S1	the Government of the HKSAR	1.000000	B1	COVID-19 pandemic	0.857143
	2	S3	Developers/ clients	1.000000			
	3	S5	Consultants	1.000000	B12	Environmental protection	0.785714
	4	S10	Industry institutions	1.000000			
	5	S15	Main contractors	1.000000	B2	Proportion of prefabrication	0.785714
	6	S4	Designers/ architects/ urban planners	0.833333			
	7	S9	Research institutions	0.833333	B6	Construction waste disposal charging scheme	0.714286
	8	S11	NGOs/local communities	0.833333			
	9	S7	General public	0.666667			
	10	S8	Media	0.666667	B8	Housing policy	0.714286
	11	S18	Manufacturer	0.666667			
	12	S12	Financial institutions/ banks	0.500000	B11	Procurement system	0.642857

	13	S13	Contract managers	0.333333			
	14	S6	Survey engineers	0.166667			
	1	S1	the Government of the HKSAR	1.00			
	2	S3	Developers/ clients	1.00	C22	Quality acceptance standard for project completion	0.903226
	3	S18	CEO of MiC manufacturer	1.00			
	4	S15	Main contractors	0.90			
	5	S16	Sub-contractors	0.90	C8	Scope/type of the prefabricated elements and components	0.677419
	6	S11	NGOs/local communities	0.80			
	7	S14	Tenderer	0.80			
	8	S17	Suppliers of equipment and materials	0.80	C1	COVID-19 pandemic	0.677419
	9	S19	Production managers	0.80			
Stage III: Construction Phase	10	S2	the Government of Guangdong Province	0.70	C2	MiC technological support and innovation	0.645161
	11	S5	Consultants	0.70			
	12	S9	Research institutions	0.70			
	13	S28	On-site project managers	0.70			
	14	S4	Designers/ architects/ urban planners	0.60			
	15	S10	Industry institutions	0.60	C17	Globally industrial system and jointly cooperation platforms in Greater Bay Area	0.516129
	16	S20	Production project directors	0.60			
	17	S25	Logistics-fleet manager	0.60			
	18	S7	General public	0.50			
	19	S12	Financial institutions/ banks	0.50	C9	Authoritatively designed standards, codes and guidelines for MiC	0.516129
	20	S27	Customs	0.50			

21	S8	Media	0.40			
22	S26	Logistics-truck drivers	0.40			
23	S23	Quality control inspectors	0.30	C15	Customs clearance facilitation in Greater Bay Area	0.451613
24	S24	Purchasing staff	0.30			
25	S29	On-site engineers	0.30	C3	Finance	0.451613
26	S32	Occupier/ end user	0.30			
27	S13	Contract manager	0.20	C23	Sale of Mic buildings	0.451613
28	S21	Modules producing workers	0.20			
29	S22	Modules testing organizations	0.20			
30	S30	Foreman & supervisor/ inspectors	0.20	C16	Transportation and logistics in Greater Bay Area	0.419355
31	S31	On-site operators (erection & lifting & buffer)	0.20			

5.5.2.3 Node Betweenness Centrality

The betweenness centrality analysis of a network structure is based on pair-dependency among nodes. The node betweenness centrality refers to the number of times a node acts as a bridge along the shortest path between other pairs of non-interlinked nodes (Freeman, 1978), which can be computed by the extent to which a specific node falls between all other pairs of nodes on their geodesic paths (Yang & Zou, 2014). Simply put, the more times a node is treated as an intermediary in the paths, the higher its betweenness centrality. Generally speaking, betweenness centrality could be used to represent the power of nodes as a valuable index of the potential to control or change the flow of information crossing them (Liang et al., 2015).

Stakeholders and critical PDFs at three stages are prioritized by node betweenness centrality, as shown in Table 5.7. The government of the Hong Kong SAR (S1) ranks the highest in the prioritization of betweenness centrality, namely, 0.073 in Stage I, 0.039 in Stage II, and 0.033 in Stage III, indicating that it has the strongest potential influence on critical PDFs. The developer/client (S3) also has a relatively strong potential, especially in Stage II and III, where the betweenness centrality value is the same as that of S1. The intermediate influence of industry institutions (S10) is particularly high in Stage I (0.073) and II (0.039) but declines a lot in Stage III (0.008). While the media (S8) and general public (S7) just embodied their potential influence value in Stage I (0.03) and became mediocre in Stage II and III. The research institutions (S9) and NGOs/local communities (S11) have always maintained a weak underlying power in connecting the critical PDFs during all three stages. In the construction phase, the internal stakeholders, including the manufacturer (S18), main contractors (S15), and sub-contractors (S16), are members of the core authority who have power over all critical PDFs. As for the critical PDFs that connects the relevant stakeholders, in Stage I and II, the policy on environmental protection have attracted the most attention, showing that environmental friendliness is the connecting link between all stakeholders. In Stage III, the ‘quality acceptance standard for project completion’ is the focus during the construction phase. After all, the quality of buildings is what matters most.

Table 5.7 Stakeholders and Critical PDFs Prioritization based on Betweenness Centrality

Stages	Rank	Code	Stakeholder	Betweenness Centrality	Code	Critical PDFs	Betweenness Centrality
Stage I: Initiation Phase	1	S1	the Government of the HKSAR	0.072678	A12	Environmental protection	0.210990
	2	S10	Industry institutions	0.072678	A5	Preferential interest of the MiC project	0.079411
	3	S3	Developers/ clients	0.051788			
	4	S7	General public	0.029996	A11	Publicity of MiC	0.079411
	5	S8	Media	0.029996			
	6	S9	Research institutions	0.029996	A8	Housing policy	0.079411
	7	S11	NGOs/local communities	0.029996	A6	Investment to MiC projects	0.055289
	8	S5	Consultants	0.016204			
	9	S4	Designers/ architects/ urban planners	0.009259	A1	COVID-19 pandemic	0.025849
	10	S6	Survey engineers	0.000000	A4	Taxation& Revenue	0.004725
Stage II: Planning & Design Phase	1	S1	the Government of the HKSAR	0.038540	B12	Environmental protection	0.177578
	2	S3	Developers/ clients	0.038540			
	3	S5	Consultants	0.038540			
	4	S10	Industry institutions	0.038540	B1	COVID-19 pandemic	0.135323
	5	S15	Main contractors	0.038540			
	6	S4	Designers/ architects/ urban planners	0.025167	B6	Construction waste disposal charging scheme	0.113980
	7	S9	Research institutions	0.022015			
	8	S11	NGOs/local communities	0.022015			
	9	S7	General public	0.013983	B2	Proportion of prefabrication	0.106199
	10	S18	Manufacturer	0.012767			
	11	S8	Media	0.010978	B11	Procurement system	0.096571
	12	S12	Financial institutions/ banks	0.005729			
	13	S13	Contract	0.002336	B8	Housing	0.069144

			managers			policy	
	14	S6	Survey engineers	0.000000			
Stage III: Construction Phase	1	S1	the Government of the HKSAR	0.033077	C22	Quality acceptance standard for project completion	0.257345
	2	S3	Developers/ clients	0.033077			
	3	S18	CEO of MiC manufacturer	0.033077			
	4	S16	Sub-contractors	0.025705			
	5	S15	Main contractors	0.024915	C1	COVID-19 pandemic	0.123950
	6	S11	NGOs/local communities	0.019203			
	7	S17	Suppliers of equipment and materials	0.018670	C8	Scope/type of the prefabricated elements and components	0.104176
	8	S19	Production managers	0.018670			
	9	S14	Tenderer	0.018250			
	10	S28	On-site project managers	0.014648			
	11	S2	the Government of Guangdong Province	0.014162	C2	MiC technological support and innovation	0.072761
	12	S5	Consultants	0.012859			
	13	S9	Research institutions	0.012859			
	14	S25	Logistics-fleet manager	0.011601	C17	Globally industrial system and jointly cooperation platforms in Greater Bay Area	0.045992
	15	S20	Production project directors	0.009755			
	16	S4	Designers/ architects/ urban planners	0.009228			
	17	S10	Industry institutions	0.008535			
	18	S27	Customs	0.008300	C23	Sale of Mic buildings	0.043794
	19	S7	General public	0.007481			
	20	S12	Financial institutions/ banks	0.007481	C3	Finance	0.041842
	21	S8	Media	0.003761	C15	Customs clearance facilitation in	0.040414
	22	S26	Logistics-truck drivers	0.003502			

23	S32	Occupier/ end user	0.002489		Greater Bay Area	
24	S24	Purchasing staff	0.001904	C16	Transportation and logistics in Greater Bay Area	0.033640
25	S29	On-site engineers	0.001772			
26	S23	Quality control inspectors	0.001387			
27	S13	Contract manager	0.000941			
28	S30	Foreman & supervisor/ inspectors	0.000602	C9	Authoritatively designed standards, codes and guidelines for MiC	0.032455
29	S31	On-site operators (erection & lifting & buffer)	0.000602			
30	S21	Modules producing workers	0.000374			
31	S22	Modules testing organizations	0.000374			

5.5.2.4 Link Betweenness Centrality

Similar to node betweenness centrality, link betweenness centrality reflects the degree to which the link lies between all other pairs of nodes located on its geodesic path (Brandes, 2001; Freeman, 1978). Therefore, the more times a link appears in the paths, the higher betweenness centrality it gets. In this study, the link betweenness centrality analysis would be used as an auxiliary measure to intuitive present and further interpret and validate the results of node betweenness centrality.

The link betweenness the centrality matrix between stakeholders and critical PDFs at three stages is shown in Table 5.8. In Stage I, the minimum values of link betweenness centrality are most related to survey engineers (S6) and 'policy about taxation and revenue' (A4), indicating that this stakeholder and PDF are the nodes with the least importance and potential influence in the network. While the designers/architects/urban planners (S4) and 'policy on COVID-19 pandemic' (A1) are also less important as they have some zero values in the matrix. In Stage II, the survey engineers (S6) have the least potential power to connect the critical PDFs, followed by the contract managers (S13), who are the second least influential stakeholder. As for the critical PDFs, stakeholders put the least considerations on procurement system (B11) and housing policy (B8) when compared with other policies during the planning and design phase. In Stage III, modules producing workers (S21), modules testing organizations (S22), quality control inspectors (S23), on-site engineers (S29), foreman & supervisor/ inspectors (S30), and on-site operators (erection & lifting & buffer) (S31) are internal stakeholders closely related to module production and installation, who are also grass-roots workers, so they have little impact on the interconnectedness of policies. In addition, they are all in the upper right plot of Figure 5.8. On the whole, 'authoritatively designed standards, codes and guidelines for MiC' (C9) and 'transportation and logistics in Greater Bay Area' (C16) do not have a strong immediate influence on stakeholder interactions.

Table 5.8 Link Betweenness Centrality Matrix between Stakeholders and Critical PDFs

Stage I	A5	A4	A6	A12	A11	A1	A8
S1	4.02	5.92	3.79	5.87	4.02	4.07	4.02
S3	4.09	5.24	3.91	5.77	4.09	0.00	4.09
S4	4.19	0.00	0.00	5.42	4.19	0.00	4.19
S5	3.65	0.00	3.55	5.00	3.65	0.00	3.65
S6	0.00	0.00	0.00	16.00	0.00	0.00	0.00
S7	3.53	0.00	3.39	5.05	3.53	3.44	3.53

S8	3.53	0.00	3.39	5.05	3.53	3.44	3.53
S9	3.53	0.00	3.39	5.05	3.53	3.44	3.53
S10	4.02	5.92	3.79	5.87	4.02	4.07	4.02
S11	3.53	0.00	3.39	5.05	3.53	3.44	3.53

Stage II	**B6**	**B8**	**B12**	**B2**	**B1**	**B11**
S1	4.81	4.10	5.99	4.44	4.59	5.10
S3	4.81	4.10	5.99	4.44	4.59	5.10
S4	0.00	4.32	5.98	4.63	4.93	5.69
S5	4.81	4.10	5.99	4.44	4.59	5.10
S6	0.00	0.00	19.00	0.00	0.00	0.00
S7	5.83	4.55	5.95	0.00	6.30	0.00
S8	0.00	4.60	5.95	5.51	5.80	0.00
S9	5.42	4.00	5.58	4.81	4.92	0.00
S10	4.81	4.10	5.99	4.44	4.59	5.10
S11	5.42	4.00	5.58	4.81	4.92	0.00
S12	0.00	0.00	0.00	6.66	7.86	5.97
S13	10.59	0.00	0.00	0.00	0.00	9.02
S15	4.81	4.10	5.99	4.44	4.59	5.10
S18	5.56	0.00	0.00	5.64	6.22	4.89

Stage III	**C15**	**C16**	**C17**	**C9**	**C8**	**C2**	**C1**	**C3**	**C22**	**C23**
S1	7.07	7.06	6.05	5.45	8.28	6.56	8.96	6.70	11.68	7.90
S2	6.16	6.05	6.20	6.01	0.00	7.75	8.92	0.00	14.19	0.00
S3	7.07	7.06	6.05	5.45	8.28	6.56	8.96	6.70	11.68	7.90
S4	0.00	0.00	0.00	6.23	9.14	7.55	0.00	6.69	13.55	6.79
S5	0.00	0.00	7.08	5.56	8.54	6.71	0.00	6.46	12.97	6.57
S7	0.00	0.00	0.00	0.00	0.00	8.59	11.16	7.36	14.38	6.58
S8	0.00	0.00	9.28	0.00	0.00	11.72	14.39	0.00	0.00	8.68
S9	0.00	0.00	7.08	5.56	8.54	6.71	0.00	6.46	12.97	6.57
S10	0.00	0.00	7.21	5.60	8.40	7.20	0.00	6.72	14.08	0.00
S11	7.75	0.00	6.38	5.35	8.30	6.62	0.00	6.21	12.92	7.21
S12	0.00	0.00	0.00	0.00	0.00	8.59	11.16	7.36	14.38	6.58
S13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.11	11.91
S14	0.00	0.00	6.34	5.46	8.08	6.32	9.22	6.75	11.01	6.53
S15	6.38	6.36	5.98	5.38	8.02	6.77	8.96	6.79	12.26	0.00
S16	0.00	7.52	6.11	5.45	8.17	6.44	8.99	6.54	11.33	7.21
S17	6.24	6.23	6.02	5.57	8.00	7.14	8.73	0.00	12.24	0.00
S18	7.07	7.06	6.05	5.45	8.28	6.56	8.96	6.70	11.68	7.90
S19	6.24	6.23	6.02	5.57	8.00	7.14	8.73	0.00	12.24	0.00
S20	7.39	0.00	0.00	6.02	8.16	7.62	9.29	0.00	12.05	0.00
S21	0.00	0.00	0.00	0.00	16.22	0.00	0.00	0.00	24.18	0.00
S22	0.00	0.00	0.00	0.00	16.22	0.00	0.00	0.00	24.18	0.00
S23	0.00	0.00	0.00	0.00	11.73	11.97	0.00	0.00	17.80	0.00
S24	13.15	11.84	0.00	0.00	0.00	0.00	0.00	17.07	0.00	0.00
S25	6.36	6.13	7.15	0.00	9.45	0.00	9.50	0.00	13.94	0.00
S26	8.33	7.49	11.91	0.00	0.00	0.00	16.05	0.00	0.00	0.00
S27	6.76	6.50	0.00	0.00	10.40	0.00	10.47	0.00	14.83	0.00

S28	6.35	6.34	0.00	5.93	8.20	7.66	9.02	0.00	12.31	0.00
S29	0.00	0.00	0.00	0.00	12.22	0.00	13.18	0.00	16.52	0.00
S30	0.00	0.00	0.00	0.00	0.00	0.00	16.28	0.00	24.37	0.00
S31	0.00	0.00	0.00	0.00	0.00	0.00	16.28	0.00	24.37	0.00
S32	0.00	0.00	0.00	0.00	0.00	0.00	13.92	0.00	19.58	9.19

5.5.2.5 Closeness Centrality

The closeness centrality analysis of a network structure is based on geodesic distances among nodes. The closeness centrality refers to the average length of the shortest path between a specific node and all other nodes in the network (Freeman, 1978), which is calculated by the inverse of the total distances from one node to all other nodes, and then normalized by multiplying it by (n-1) (Faust, 1997; Opsahl et al., 2010). Simply put, the closer a node is to the centre of the network, the closer it is to all the other nodes, which means that more attention should be paid to the stakeholders or critical PDFs with higher closeness (Mok & Shen, 2016). Generally speaking, closeness centrality is helpful to evaluate how closely the two nodes are, which shows the degree of close influence among nodes (Xue et al., 2020).

The priority rankings of stakeholders and critical PDFs during the three stages following closeness centrality are shown in Table 5.9. The government of the Hong Kong SAR (S1) has the highest priority of closeness centrality, with the same value of 1.00 in all three stages, implying that the government has the closest relationship with the implementation of critical PDFs. On the other hand, it also suggests the difficulty of the government acting alone to implement related policies, which requires support from other sectors. The developer/client (S3) has a really strong connection with critical

PDFs in Stage II (1.00) and III (1.00) but is a little weaker in Stage I (0.93). While the industry institutions (S10) showed a strong correlation with critical PDFs in Stage I (1.00) and II (1.00), but a little weak in Stage III (0.90). The research institutions (S9) and NGOs/local communities (S11) have maintained a moderate distance and closeness in linking critical PDFs during all three stages. The media (S8) and general public (S7) are closely related to critical PDFs in Stage I but continuously reduce this influence and intimacy in Stage II and III. The consultant (S5) plays an important connecting role in Stage II. In Stage III, the main internal participants of MiC buildings are very sensitive to policy adjustments, including the manufacturer (S18), main contractors (S15), and sub-contractors (S16), so their closeness centrality values are higher. In terms of critical PDFs, in Stage I, policy on environmental protection has received the most attention; in stage II, this focus shifted to the COVID-19 pandemic policy, while environmental friendliness is still more concerned; in Stage III, 'quality acceptance standard for project completion' is the emphasis during the construction phase, which is the eternal topic concerned by all stakeholders.

Table 5.9 Stakeholders and Critical PDFs Prioritization based on Closeness Centrality

Stages	Rank	Code	Stakeholder	Closeness Centrality	Code	Critical PDFs	Closeness Centrality
Stage I: Initiation Phase	1	S1	the Government of the HKSAR	1.000000	A12	Environmental protection	1.000000
	2	S10	Industry institutions	1.000000	A5	Preferential interest of the MiC project	0.916667
	3	S3	Developers/ clients	0.925926			
	4	S7	General public	0.925926	A11	Publicity of MiC	0.916667
	5	S8	Media	0.925926			

	6	S9	Research institutions	0.925926	A8	Housing policy	0.916667
	7	S11	NGOs/local communities	0.925926	A6	Investment to MiC projects	0.846154
	8	S5	Consultants	0.862069			
	9	S4	Designers/ architects/ urban planners	0.806452	A1	COVID-19 pandemic	0.733333
	10	S6	Survey engineers	0.675676	A4	Taxation& Revenue	0.611111
Stage II: Planning & Design Phase	1	S1	the Government of the HKSAR	1.000000	B1	COVID-19 pandemic	0.857143
	2	S3	Developers/ clients	1.000000			
	3	S5	Consultants	1.000000	B12	Environmental protection	0.800000
	4	S10	Industry institutions	1.000000			
	5	S15	Main contractors	1.000000			
	6	S4	Designers/ architects/ urban planners	0.941176	B2	Proportion of prefabrication	0.800000
	7	S9	Research institutions	0.941176			
	8	S11	NGOs/local communities	0.941176	B6	Construction waste disposal charging scheme	0.750000
	9	S7	General public	0.888889			
	10	S8	Media	0.842105	B8	Housing policy	0.750000
	11	S18	Manufacturer	0.842105			
	12	S12	Financial institutions/ banks	0.800000			
	13	S13	Contract managers	0.727273	B11	Procurement system	0.705882
	14	S6	Survey engineers	0.666667			
Stage III: Construction Phase	1	S1	the Government of the HKSAR	1.000000	C22	Quality acceptance standard for project completion	0.890909
	2	S3	Developers/ clients	1.000000			
	3	S18	CEO of MiC manufacturer	1.000000			
	4	S15	Main contractors	0.972222	C8	Scope/type of the	0.710145

5	S16	Sub-contractors	0.972222		prefabricated elements and components	
6	S11	NGOs/local communities	0.945946			
7	S14	Tenderer	0.945946			
8	S17	Suppliers of equipment and materials	0.945946	C1	COVID-19 pandemic	0.710145
9	S19	Production managers	0.945946			
10	S2	the Government of Guangdong Province	0.921053	C2	MiC technological support and innovation	0.690141
11	S5	Consultants	0.921053			
12	S9	Research institutions	0.921053			
13	S28	On-site project managers	0.921053	C17	Globally industrial system and jointly cooperation platforms in Greater Bay Area	0.620253
14	S10	Industry institutions	0.897436			
15	S20	Production project directors	0.897436			
16	S25	Logistics-fleet manager	0.897436			
17	S4	Designers/ architects/ urban planners	0.875000	C9	Authoritatively designed standards, codes and guidelines for MiC	0.620253
18	S7	General public	0.875000			
19	S12	Financial institutions/ banks	0.875000			
20	S27	Customs	0.875000			
21	S29	On-site engineers	0.813953	C15	Customs clearance facilitation in Greater Bay Area	0.590361
22	S32	Occupier/ end user	0.813953			
23	S8	Media	0.795455			
24	S23	Quality control inspectors	0.795455	C3	Finance	0.590361
25	S30	Foreman & supervisor/ inspectors	0.795455	C23	Sale of Mic buildings	0.590361
26	S31	On-site operators (erection &	0.795455			

		lifting & buffer)				
27	S13	Contract manager	0.777778			
28	S21	Modules producing workers	0.760870	C16	Transportation and logistics in Greater Bay Area	0.576471
29	S22	Modules testing organizations	0.760870			
30	S26	Logistics-truck drivers	0.760870			
31	S24	Purchasing staff	0.686275			

5.5.2.6 Eigenvector Centrality

The eigenvector centrality analysis of a network structure is based on the iteratively weighted degree of the nodes. Eigenvector centrality, as defined by Bonacich (1972), can be viewed as a weighted sum of direct and indirect connections of each length (Bonacich, 2007), which is recursively proportional to the sum of centralities of its adjacent nodes (Borgatti & Everett, 1997). In two-mode networks, it is calculated by computing the principal eigenvector (which has the largest eigenvalue among every eigenvector) of the adjacency matrix (Borgatti & Everett, 1997). Eigenvector centrality measures the importance of a node by considering the importance of its neighbours (Golbeck, 2013). In other words, a node is important if it is linked to other important nodes. As a ranking measure, eigenvector centrality is practical to assess the influence of a node in a network.

The priorities of stakeholders and critical PDFs at Stage I, II, and III are arranged according to eigenvector centrality, as shown in Table 5.10. The most influential and important stakeholder is the government of the Hong Kong SAR (S1), whose eigenvector centrality value is 0.438 in Stage I, 0.392 in Stage II, and 0.279 in Stage III. The developer/client (S3) is the second most crucial stakeholder in Stage II (0.334) and III (0.267) but drops to third in Stage I (0.350). These indicate that both S1 and S3 are in a leading position throughout the whole period. The media (S8) and research institutions (S9) show strong influence in Stage I, but as the project progressed, its influence gradually diminished (the ranking continued to decline). The industry institutions (S10) is noteworthy in Stage II, with the eigenvector centrality ranking at three, while its importance becomes medium in Stage I and III. The NGOs/local communities (S11) have always maintained a position of medium importance. While the influence of general public (S7) has constantly been at a relatively low level. Interestingly, the direct participants, namely the manufacturer (S18) and main contractors (S15), whose eigenvector centralities are 0.242 and 0.231, respectively, are of great importance during the construction phase. They are very concerned about and affected by critical PDFs. Moreover, the government of Guangdong Province (S2) also played an important linking role in Stage III. Regarding critical PDFs, in Stage I, Housing policy has the greatest impact when compared with other PDFs, and the preferential policy of MiC projects also receives much attention; in Stage II, the construction waste disposal charging scheme has the highest eigenvector centrality value, indicating its big influence; in Stage III, the ‘quality acceptance standard for project completion’ always attracts the most attention due to its highly recognized importance.

Table 5.10 Stakeholders and Critical PDFs Prioritization based on Eigenvector Centrality

Stages	Rank	Code	Stakeholder	Eigenvector Centrality	Code	Critical PDFs	Eigenvector Centrality
Stage I: Initiation Phase	1	S1	the Government of the HKSAR	0.437867	A8	Housing policy	0.433588
	2	S9	Research institutions	0.364011	A5	Preferential interest of the MiC project	0.404611
	3	S3	Developers/ clients	0.345949			
	4	S8	Media	0.342564	A12	Environmental protection	0.388137
	5	S10	Industry institutions	0.333989			
	6	S11	NGOs/local communities	0.291490	A11	Publicity of MiC	0.387850
	7	S7	General public	0.277505	A6	Investment to MiC projects	0.381230
	8	S5	Consultants	0.277026			
	9	S4	Designers/ architects/ urban planners	0.268071	A1	COVID-19 pandemic	0.350382
	10	S6	Survey engineers	0.128874	A4	Taxation&Revenue	0.281264
Stage II: Planning & Design Phase	1	S1	the Government of the HKSAR	0.391936	B6	Construction waste disposal charging scheme	0.427427
	2	S3	Developers/ clients	0.333802			
	3	S10	Industry institutions	0.311684			
	4	S9	Research institutions	0.303667			
	5	S15	Main contractors	0.293662	B2	Proportion of prefabrication	0.418026
	6	S4	Designers/ architects/ urban planners	0.263898			
	7	S5	Consultants	0.263612	B8	Housing policy	0.415808
	8	S11	NGOs/local communities	0.242987			
	9	S7	General public	0.231912	B1	COVID-19 pandemic	0.409285
	10	S8	Media	0.228575			

	11	S18	Manufacturer	0.226714	B12	Environmental protection	0.407532
	12	S13	Contract managers	0.219728			
	13	S12	Financial institutions/ banks	0.195709	B11	Procurement system	0.368873
	14	S6	Survey engineers	0.131060			
Stage III: Construction Phase	1	S1	the Government of the HKSAR	0.279008	C22	Quality acceptance standard for project completion	0.391951
	2	S3	Developers/ clients	0.266610			
	3	S18	CEO of MiC manufacturer	0.241692			
	4	S15	Main contractors	0.230949			
	5	S2	the Government of Guangdong Province	0.220284	C2	MiC technological support and innovation	0.349431
	6	S10	Industry institutions	0.219327			
	7	S4	Designers/ architects/ urban planners	0.212902			
	8	S9	Research institutions	0.209687	C8	Scope/type of the prefabricated elements and components	0.349322
	9	S28	On-site project managers	0.204657			
	10	S5	Consultants	0.196926			
	11	S17	Suppliers of equipment and materials	0.196251			
	12	S19	Production managers	0.195775	C17	Globally industrial system and jointly cooperation platforms in Greater Bay Area	0.314274
	13	S11	NGOs/local communities	0.193404			
	14	S25	Logistics-fleet manager	0.185661			
	15	S14	Tenderer	0.183542	C1	COVID-19 pandemic	0.312066
	16	S16	Sub-contractors	0.181200			
	17	S7	General public	0.173349	C9	Authoritatively designed	0.311129
	18	S20	Production	0.159073			

		project directors			standards, codes and guidelines for MiC	
19	S12	Financial institutions/ banks	0.157522			
20	S8	Media	0.152949			
21	S27	Customs	0.147294	C16	Transportation and logistics in Greater Bay Area	0.288714
22	S13	Contract manager	0.138990			
23	S24	Purchasing staff	0.136169			
24	S29	On-site engineers	0.126328	C15	Customs clearance facilitation in Greater Bay Area	0.282438
25	S23	Quality control inspectors	0.123330			
26	S32	Occupier/ end user	0.108912			
27	S30	Foreman & supervisor/ inspectors	0.105085			
28	S26	Logistics-truck drivers	0.104722	C3	Finance	0.281753
29	S21	Modules producing workers	0.103965	C23	Sale of Mic buildings	0.258419
30	S22	Modules testing organizations	0.098013			
31	S31	On-site operators (erection & lifting & buffer)	0.094448			

5.5.3 Findings and discussion

There is a strong underlying trend in the real estate industry to build more things away from construction sites, among which MiC is one modern and popular approach (Luo et al., 2020). The further extension of construction industrialization policy management has received considerable attention, and some studies on MiC have revealed its high priority from various aspects (Mao et al., 2015). Despite this, stakeholder management as a crucial element of effective policy practice has been neglected, and it remains unclear the extent to which different stakeholders are affected by the driving forces of policy at different stages. Efficient stakeholder collaboration can well aggregate policy concerns, development directions, and actual needs in the construction industry so as to contribute to the smooth implementation of policies, thus further promoting the development and excellent performance of MiC. Most previous studies just investigated the influence of general stakeholders on the construction phase (Yang et al., 2009) and their interactions with critical success factors or barriers (Gan et al., 2018; Li et al., 2016), but did not consider the roles of all stakeholders (internal and external) involved and their dynamic changes between phases from the perspective of major project phases. Relationship matrices were formed by linking all involved stakeholders with the critical PDFs corresponding to each of the three different stages (seven critical PDFs and ten stakeholders in stage II; six critical PDFs and 14 stakeholders in Stage II; 10 critical PDFs and 31 stakeholders in Stage III) and quantitatively evaluate and analyze the interaction between different factors. From an innovative perspective, this study explores the dynamic changes and effects of stakeholder collaboration under the influence of critical PDFs at various stages of MiC. The results of the two-mode network analysis revealed the most important PDFs in each stage and important stakeholders associated with them. Meanwhile, theoretically and practically, some existing challenges related to the MiC policies are explored, and implications are recommended.

5.5.3.1 The most prominent PDFs in each stage

Governmental regulations and incentives are considered as an important driver to promote stakeholders to implement MiC projects and are in need of further in-depth exploration (Han & Wang, 2018). In combination with the above SNA indicators, which provide a comprehensive profile of critical PDFs related to stakeholders and their interactions, the most prominent PDFs in each of the three stages are determined, while associated challenges in MiC are fully considered.

In Stage I, measured from the classic three distinct intuitive conceptions of centrality proposed by Freeman (1978)- degree centrality, betweenness centrality, and closeness centrality- environmental protection policy (A12) are closely followed by all stakeholders and has the greatest influence. According to Gao and Tian (2020), environmental concern is one of the driving forces of housing industrialization policies because the rapid environmental deterioration can be well alleviated by MiC technology (Zhou & Ren, 2020). Therefore, the relevant government policies with substantial supporting measures on MiC can accelerate the realization of environmental friendliness. In addition, housing policy (A8) and preferential interest of the MiC project (A5) receive close attention from the stakeholders. High-priced housing is one of the most important social issues in the compact city of Hong Kong. Housing policies could considerably influence both the public sector and private developers to initiate MiC projects. Social housing has always been an important engine of innovative architectural thinking since the 20th century (Mare, 2018). Also, stakeholders are always profit-driven; the construction enterprises expect to gain more profits by developing MiC projects under the government's preferential policies (Chen et al., 2017; Li et al., 2017).

In Stage II, under different indicators, the most influential PDFs are not the same. Taken together, Environmental protection (B12), COVID-19 pandemic (B1) and construction waste disposal charging scheme (B6) are the top three PDFs that attract the most attention from stakeholders in the design and planning stage. The building design phase will affect the disassembly of the modules/components, which can reduce the environmental load brought by the construction industry (Zhou & Ren, 2020). The outbreak of the COVID-19 pandemic globally has further promoted an innovative MiC approach to design and construct, especially in emergency-related engineering projects, which can not only minimize pollution and waste, enhance social impact but also shorten the construction duration to quickly provide space for the proper isolation of infected patients (Yatmo et al., 2021; Zhang et al., 2020). The Lei Yue Mun quarantine camp in Hong Kong and Huoshenshan and Leishenshan hospitals in Wuhan are good examples of MiC adoption in such an emergency. For the waste minimization strategy at the planning and design stage, one of the driving factors in waste management policies and legislation, while the standardization and modularization of building elements are one of the top three strategies adopted by architects (Olanrewaju & Ogunmakinde, 2020). Based on the 'polluter pays principle', the success of the construction waste management program in Hong Kong is mainly attributed to the continuous policy support of the government (Lu & Yuan, 2012).

In Stage III, from the above six measurement dimensions, the 'quality acceptance standard for project completion' (C22) is widely regarded by the stakeholders as the most important PDF. Controlling the quality of MiC projects has always been the key work of stakeholders. Therefore, this PDF node is in the centre of the network. The 'scope/type of the prefabricated elements and components' (C8) that closes behind cannot be ignored. With the real estate market becoming more mature, consumers increasingly demand high-quality housing (Zhou et al., 2019). Since MiC technology has been heavily promoted due to its high quality and good flexibility (Cao et al., 2015; Luo et al., 2015), real estate companies always give priority to MiC when the government rewards high-quality projects (Zhou et al., 2019). The reputational incentive mechanism has a powerful incentive effect on contractors and other project participants (Chen & Ma, 2008). Therefore, real estate companies will enthusiastically strive for demonstration projects, continue to build high-quality projects, establish a good brand image, and guide consumers to purchase MiC houses (Zhou et al., 2019). The scope/type of the prefabricated elements and components is also included in political factors affecting the MiC adoption (Lu et al., 2018). Moreover, expanding the types and scope of precast concrete structural elements is particularly suitable for MiC buildings in Hong Kong because precast technology can achieve better quality control (Dinelli et al., 1996). Earlier in the Annual Report (2013) issued by HKHA, precast lift machine rooms, roof parapets, manholes and drainage channels, as well as prefabricated electrical trunking, were being explored for possibly extendable use.

5.5.3.2 The most prominent stakeholders

Three separate evaluation matrixes and quantitative analysis of interrelationships between critical PDFs and stakeholders at different stages reflected the influence distribution of common stakeholders over PDFs at various stages. As shown in Table 5.1, there are nine common stakeholders in all three stages, including S1 (the government of the HKSAR), S3 (developers/clients), S4 (designers/architects/urban planners), S5 (consultants), S7 (general public), S8 (media), S9 (research institutions), S10 (industry institutions) and S11 (NGOs/local communities). The analysis results of the stakeholders-critical PDFs networks highlight two stakeholders, namely the government of the HKSAR (S1) and developers/clients (S3), are the stakeholders that have the greatest influence in the implementation of relevant policies.

In the three stages of MiC projects, the HK government ranks the first with the highest degree and degree centrality, indicating its power to influence more critical PDFs. Its highest betweenness centrality value means that the government can serve as an important bridge for exchanging information and resources among the stakeholders in the network. Also, it is located in the centre of the network as revealed by the high closeness centrality and eigenvector centrality value, and therefore could frequently interact with other nodes like stakeholders and critical PDFs, indicating the key role of the government in developing and implementing policies relevant to widespread application of MiC (Gao & Tian, 2020) and coordinating the various parties involved. Luo et al. (2015) emphasized the government's leading role in promoting the introduction and enforcement of appropriate policies and regulations for the new MiC technology. Without the support of government bodies for existing market mechanisms, it would be difficult for MiC to achieve the desired economies of scale (Mao et al., 2015).

The developer/client (S3) ranked next to the HK government (S1) at Stage II and III but dropped to third in Stage I. For real estate developers, although their willingness to develop MiC houses is high, due to the low purchase motivation of consumers and the high initial cost of implementing MiC buildings, they may diminish the chance of deciding to choose MiC projects at the initiation phase (Zhou et al., 2019). However, once they gain the support of PDFs, they will actively participate in promoting these green MiC practices. On the other hand, it also helps them improve their market competitiveness (Gan et al., 2018). It can be seen that the dual-key network structure needs harmonious stakeholder collaboration initiated by the government of the HKSAR (S1) and developers/clients (S3). Therefore, it is recommended to develop and promote the successful business model of MiC through more collaboration between the government and developers.

5.5.3.3 Impact dynamics of stakeholders at each stage

As shown in Table 5.5 to Table 5.10, the interaction and impact between the other seven common stakeholders and critical PDFs vary from stage to stage, with some of their roles fluctuating dynamically in different stages. The designers/architects/urban planners (S4) are less likely to be affected by the critical PDFs in Stage I, as the initial phase focuses on the feasibility study report, and some of the related promotional PDFs have little relevance to them. Their status is elevated in Stage II and III because architects/designers assume the primary responsibility during the design phase, while in the construction phase, it is necessary to maintain effective communication and with the clients and provide professional advice to achieve effective design change management (Olanrewaju & Ogunmakinde, 2020). According to the three classical centrality theories (degree /betweenness /closeness centrality) of Freeman (1978), the influence of consultants (S5) during the design and construction phases should be appreciated, even though they are regarded as periphery stakeholders and receive less attention in Stage I. Learned through interviews, in Hong Kong, consultants usually collaborate with architects to participate in some architectural design and provide consulting services. Hence, their roles are somewhat similar to those of architects.

MiC is a kind of green building technology. As Yang and Zou (2014) pointed out, media also plays a considerable role in green building projects. The general public (S7) and media (S8) are closely related to critical PDFs in Stage I, which shows that these external stakeholders have a relatively high degree of participation in policy implementation. Still, as the project progressed, the interaction and connection between them became diminished. In the project's initiation phase, the media has critical connections with the government and consultants, especially on large-scale projects

(Xue et al., 2020). In contrast, the research institutions (S9) and NGOs/local communities (S11) showed a weak underlying correlation with critical PDFs in Stage I and II, while this link improved slightly in Stage III. The technology and management involved are more complicated when it comes to the construction stage, and researchers can provide more assistance. While the local communities are equivalent to the communication bridge between the government and people in need of housing (Lin et al., 2017). NGOs are considered to be an essential driving force for the adjustment and implementation of policies related to the building environment (Lin et al., 2017; Thijssens et al., 2015).

Among these stakeholders, the importance of industry institutions (S10) needs to be highlighted, who showed a strong relevance with critical PDFs in Stage I but unceasingly diminishing their influence in Stage II and III as the priority ranking continued to decline. Most industry institutions have the capability and authority to provide practical recommendations on the definition and adjustment of industry standards and evaluate projects in a comprehensive manner (Liang et al., 2015). In Hong Kong, such organizations include the Hong Kong Contractors Association, the Council of Hong Kong Professional Associations, the Construction Industry Council, etc. Therefore, in the initiation phase, their advice and insights are crucial. As the project unfolds, the influence of internal stakeholders on the project gradually increased, and the interaction between industry institutions and critical PDFs weakened. Furthermore, combined with the correspondence maps (Figure 5.6, 5.7 and 5.8), a conclusion can be drawn that during all three stages, with high degree centrality, betweenness centrality and closeness centrality, the government of the HKSAR (S1), developers/clients (S3) and industry institutions (S10) constitute the core stakeholder structure. This also implies that these core stakeholders should collaborate to encourage the development of critical PDFs and achieve superior performance of MiC.

5.5.3.4 Core stakeholders in construction Stage

Visualization of the PDF-stakeholder network in Stage III is presented in Figures 5.5 and 5.8. The stakeholders involved in the construction phase are the most complex, with a total of 31. Compared with the previous two stages, the workforce and material resources invested are the largest, and the period from construction commencement to final delivery is the longest. Previous studies always identified the top three or five factors from different measurement dimensions/indicators for crucial factor analysis, with detailed explanations and explorations (Luo et al., 2019; Yang et al., 2016; Yu et al., 2019), because they played a decisive role in the complexity of two-mode networks. Therefore, the top five stakeholders in each priority list were selected or detailed consideration in this study. When examining degree centrality, betweenness centrality and closeness centrality, the critical stakeholders include the government of the HKSAR (S1), developers/clients (S3), manufacturer (S18), main contractors (S15), and sub-contractors (S16). Regarding degree and eigenvector centrality, the Government of Guangdong Province (S2) is added. In MiC, special attention is paid to manufacturers, who are responsible for producing prefabricated modules but are often overlooked in traditional on-site construction (Gan et al., 2018). The module manufacturing process is critical in cross-border supply chains (Luo et al., 2019). Several studies argued that the lack of manufacturers is a serious issue (Durdyev & Ismail, 2019; Hu & Chong, 2019; Mao et al., 2015), and its support for policy adjustments is really necessary. These views have been further verified in the interviewers' expressions during the interviews. In Hong Kong, due to high labour costs and limited available land, most of the manufacturing plants are located in various parts of Guangdong Province in the Greater Bay Area, such as Huizhou and Dongguan. This also explains why the Guangdong Provincial Government also plays a vital role in the regulation and influence of the MiC-related PDFs, and its degree of participation and cooperation will affect the construction progress of the MiC projects in Hong Kong. The main contractors (S15) and sub-contractors (S16) are of great importance during the module transportation and installation process in the construction phase. They are very concerned about and influenced by critical PDFs. Sometimes contractors and manufacturers do not negotiate in time, which can easily lead to serious time delays and cost overruns (Luo et al., 2015). According to Luo et al. (2019), the significant challenges faced by the MiC supply chain in Hong Kong include poor supply chain planning, poor management of working flows and untimely information sharing among stakeholders, of which contractors are the main participants. Moreover, all the challenges are closed related to the critical PDFs on Greater Bay Area development or technology. Thus main contractors and sub-contractors would be sensitive to these critical PDFs for the successful delivery of projects.

5.5.3.5 Implications of promoting MiC

In interviews with 28 different stakeholders, when it comes to how to improve the application and practicality of modular buildings in Hong Kong from the policy perspective, different participants put forward some valuable suggestions and thoughts from their own views. From the standpoint of the government, they hope that under their leadership, industry institutions will be willing to respond, and developers, contractors and suppliers of equipment and materials are eager to take the initiative to participate and jointly promote MiC speedily. In this way, more public housing can be provided for Hong Kong residents in a faster manner, which facilitates the society to progress and develop harmoniously.

From the perspective of developers/clients, in particular to private developers, in consideration of cost and profit, in addition to some mandatory policy requirements, they expect to be given continuous preferential policies or financial support to the units applying MiC technology, and they also look forward to the designated policies tailored to local conditions in the Greater Bay Area, so that their enthusiasm for adopting MiC will be enhanced. From the perspective of industry institutions, improving relevant authoritatively designed standards, codes, and industry guidelines are considered to be a way to enhance the universality of MiC. Additionally, they expect to integrate lean construction on the basis of MiC to promote the development of the entire construction industry.

From the perspective of the manufacturer, main contractors, and sub-contractors, in addition to financial support and policy incentives, they also hope to have a sound reputation incentive mechanism because a good reputation can help them develop better in the long run. While some contractors expressed their aspiration to have factory producing modules in Hong Kong, which can reduce transportation costs and save construction time. On the other hand, some public does not understand what MiC is, so that they might worry about the quality and safety of MiC houses. Government departments, consulting agencies and construction industries are well encouraged to fully use their social media platforms or channels, such as Facebook, YouTube, WeChat, Weibo, and News clients, to release the latest information about MiC, to help change the inherent misperceptions of the public toward MiC. Last but certainly not least, the improvement of the quality of project completion acceptance is the common inclination of all interviewees.

5.6 Summary of the Chapter

This chapter identifies the relevant stakeholders involved in the three stages of MiC projects in Hong Kong based on literature review and real case studies. A total of 10, 14, and 31 stakeholders are present in Stages I, II and III, respectively. Two-mode networks in different stages were established after assessing the interactions between critical PDFs identified previously and relevant stakeholders through interviews with professionals. Visualisation of PDF-stakeholder networks is displayed via NetMiner 4.4.3.g, including embedding network spring and correspondence mapping. Critical stakeholders and their relations with critical PDFs could be concluded from the two-mode network quantitative analysis conducted from six measurement indicators: degree, degree centrality, node betweenness centrality, link betweenness centrality, closeness centrality and eigenvector centrality. From an innovative perspective, the dynamic changes and effects of stakeholder collaboration under the influence of critical PDFs in the different stages of MiC were explored. The results of the two-mode SNA reveal the most important PDFs in each stage and key stakeholders associated with them. The environmental protection policy (A12), COVID-19 pandemic (B1) and construction waste disposal charging scheme (B6) and quality acceptance standard for project completion (C22) are considered the most important PDFs in Stages I, II and III, respectively. The Hong Kong SAR government (S1) and developers/clients (S3) are highlighted and have the greatest influence in the implementation of policies and play the most important role in the development of stakeholder collaboration in the three stages. The dynamic changes and impact of stakeholders under the influence of critical PDFs at different stages of MiC are discussed. Additionally, in the construction phase, manufacturer (S18), main contractors (S15), sub-contractors (S16) and the Guangdong Province government (S2) are added to form the core authority. From the perspectives of different stakeholders, such as the government, developers/clients, industry institutions, manufacturers, main contractors, sub-contractors and the general public, valuable recommendations are also proposed on improving the application and practicality of modular buildings in Hong Kong in terms of policies.

Chapter 6 A System Dynamics Model for Simulating PDFs for MiC Uptake

6.1 Introduction

This chapter provides an SD approach to simulate the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong. Firstly, this study illustrates the steps of developing the model with a schematic diagram to briefly understand the establishment of the SD model, which is followed by a specific model description. Secondly, the model establishment details, where the conceptual model and two essential analytical diagrams are explained. Thirdly, the model is tested to build confidence in it. Lastly, base run simulation and various policy scenario analyses are performed to determine the underlying strategies for MiC uptake.

6.2 Research Design

Considering the positivist research philosophy, an SD research approach was mainly applied in this chapter. Figure 6.1 portrays a research framework that simulates the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong in this study.

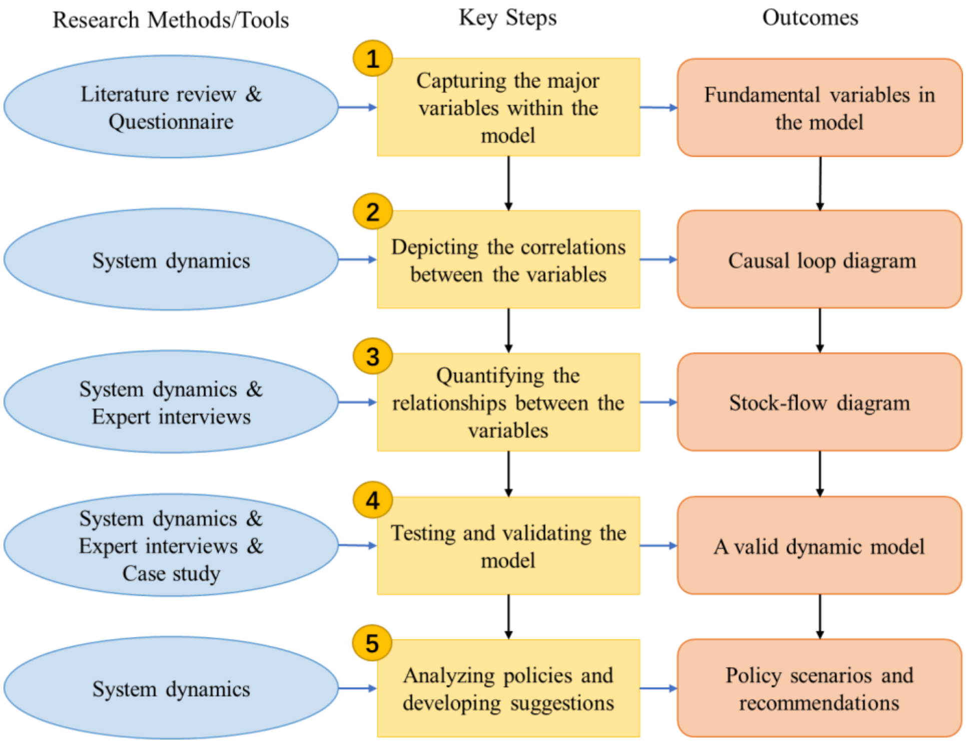

Figure 6.1 Research Framework of the System Dynamics Modelling

6.3 Model Description

6.3.1 Purpose of the model

Dynamic modeling of construction activities enabled identifying solutions for several complex problems where non-linear relationships and multiple interdependent connections existed (Sterman, 2001). Further, SD modelling can correlate several factors and allow experiments within a controlled environment (Love et al., 2000). As an advanced research tool, SD modelling facilitates managing complex processes, relying upon its feedback loops and connections. Hence, SD modelling is employed in this study to investigate the accumulated impacts of PDFs to help instigate appropriate measures to promote MiC uptake in HK. The developed model employed SD theory to simulate the MiC uptake in Hong Kong with the critical policy-driving forces being considered. The model established in this study aims to achieve three purposes. Firstly, the establishment of the model enables researchers and practitioners in the construction industry to understand the dynamics of the MiC uptake system, especially considering the effects of policy-driving forces. The SD model is developed as an experimental platform to investigate the impact of implementing different PDF measures on enhancing the success level of MiC uptake. Secondly, this SD model aims to provide a solid foundation for insight into how the MiC uptake responds to the collaboration and interaction or dynamic behaviour of the critical PDFs at different stages in the system. What the model studied is how the major variables in the system affect the successful application of the MiC projects. Thirdly, the application of the model can be a useful tool for demonstrating the potential impact or adjustments of PDF measures, thereby suggesting effective avenues to improve the MiC uptake. In addition, on the basis of evaluating the relative feedbacks of the MiC all-stage system, the model is employed to explain the behaviour of the system under the proposed propositions of the PDF strategies formulated to improve the MiC uptake process. When researchers and decision-makers try to enhance the success of MiC uptake through experiments, they can choose the model established in this research to simulate different or combined policy scenarios to forecast the trend of policies and provide their findings to other practitioners for reference.

6.3.2 Overview structure of the model

It is necessary and significant to determine the boundary of the SD model from the outset (Sterman, 2000). During this confirmation process, which variables the model should include and exclude ought to be specified (Richardson & Pugh, 1981; Yuan, 2012). As identified in Chapter 4, the critical PDFs at different stages can have a significant impact on the success of MiC projects in Hong Kong. Therefore, in this study, the author considered all the critical factors in the three stages to examine their impact on the successful uptake of MiC projects. Consistent with the model boundary, the main system refers to the MiC uptake in Hong Kong. Meanwhile, the author takes three different phases of MiC projects in this system into consideration, namely policy support via the initiation phase, the planning & design phase and the construction phase. Figure 6.2 intuitively displays the interrelationships between these subsystems.

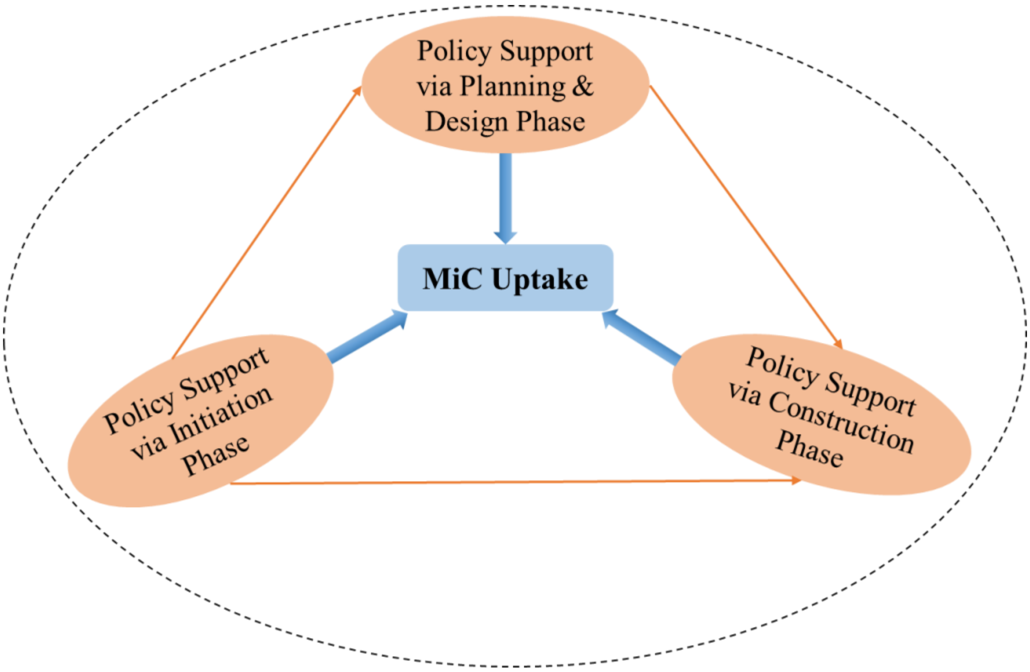

Figure 6.2 Overview Structure of the System Dynamics Modelling

6.4 Model Establishment

6.4.1 Conceptual model of MiC uptake

The multiple benefits (e.g. cleaner, high quality, circular economy) of the modular building are leading to increased MiC recognition and significant investment in more and more countries, especially Hong Kong, which includes the initiation of relevant policies and incentives to boost the MiC uptake (Wuni & Shen, 2020). This model was established to measure the impacts of the critical PDFs on the MiC uptake, which mainly involved regulation, promotion, sustainability, Greater Bay Area development, and technology aspects. Many existing studies have already shown that the relevant PDFs can effectively improve the implementation of MiC policies and ultimately facilitate the achievement of the further large-scale adoption of MiC (Gao & Tian, 2020;

Mao et al., 2015).

The policy support in the initiation phase, planning and design phase, and construction phase are conducive to the further MiC uptake in Hong Kong. Each of these three components is composed of various other underlying factors, which determine their overall effectiveness. A construction project starts from the initiation phase when the client or developer carries out potential project identification and detailed project feasibility study analysis to determine whether and to what extent modularisation technology should be adopted. After the decision to adopt MiC, it moves to the planning and design phase, during which the scheme design, finance and construction documents design needs to be completed. The design needs to comply with the Buildings Ordinance and other relevant requirements and procedures to seek statutory approvals. Early engagement of module suppliers and the local contractor is required in some public projects. As the MiC project officially unfolds, the construction phase is the most critical section. In this phase, all construction activities will be completed until the project is successfully delivered. During offsite construction activities (such as the production of modules), on-site construction activities, such as piling/foundation works, external underground utility works, etc., can be carried out concurrently. In summary, the initiation phase is the premise of the planning and design phase and the construction phase, and the planning and design phase promotes the completion of the construction phase. All three stages have made corresponding efforts for the further uptake of MiC. The variable system of critical PDFs depicts the impacts of PDFs on the uptake of MiC.

Multiple PDFs are embedded in the different stages of MiC architecture, driving the wide range of MiC applications. After factor analysis, there are seven, six, ten identified critical PDFs in Stage I, II, III, respectively. The author categorised PDFs into regulative, promotional, sustainable, Greater Bay Area development and technical PDF to better understand the policy mechanism. PDFs do not exist individually but are closely causal to each other, which leads to varying degrees of impact on the MiC uptake. The detailed description and explanation of these variables, which are based on the findings of Chapter 4, will not be repeated here. According to the established interactions between different variables, the relationships between measurements were modelled by using *Vensim PLE* software.

6.4.2 Causal loop diagram

A causal loop diagram is an intuitional representation that portrays the interconnectedness of various variables and the structure of an SD model (Sterman, 2000; Yuan, 2012). It can dynamically track the chain effects of the cause through a series of related variables and then trace back to the original cause (Yuan, 2012). The causal loop diagram consists of nodes and arrows, where nodes represent related defined variables and arrows refer to the cause-and-effect relationships amongst the variables. A positively marked causal link implies that a change in the first variable A causes a change in the other variable B in the same direction (meaning that it increases or decreases at the same time), and the polarity on the arrowheads will be signed (+). The MiC uptake in this research is measured to increase the effectiveness of critical

PDF measures. Additionally, variables at three stages were discussed. Thus, the main loop considered here includes the positive indicators (+): PDF, which enhance adoption and accumulate the impact of MiC uptake. The positive loops are the three-stage critical PDFs (seven, six, ten identified critical PDFs in Stage I, II, III, respectively), which can promote the smooth uptake of MiC in Hong Kong. Figure 6.3 shows these causal interactions within the causal loop diagram to uncover the PDF impacts in MiC. The variables in each stage are indicated and signified by nodes, and links are used to indicate their relative dependencies. Since the critical PDFs are all positively promoting the adoption of MiC, the feedback circles in this study are all positive. This figure aims to depicted how the critical PDFs at different stages interact to influence the uptake of MiC in the model.

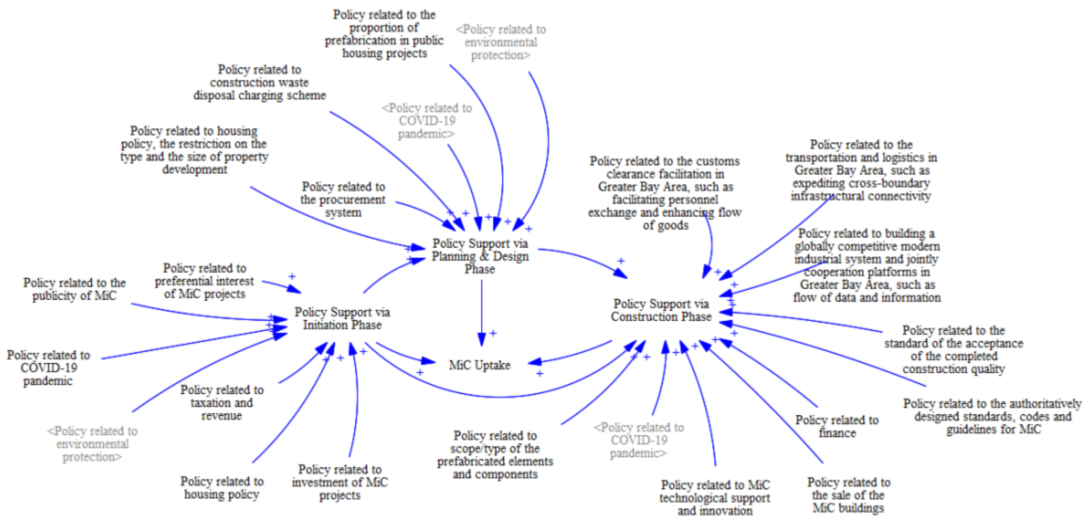

Figure 6.3 Causal Loop Diagram of the PDFs for MiC Uptake

6.4.3 Stock-flow diagram

A stock and flow diagram is another intuitive method to visualise the causal interrelationships between variables and feedback processes in SD modelling (Sterman, 2000). Subsequent to determining the relationships between the main variables defined in the causal loop diagram, this study's stock and flow diagram was performed using *Vensim PLE* software to quantify their impacts. Unlike causal loop diagram, which is limited to assisting problem understanding and displaying causality, stock and flow diagram further enhances mathematical simulation and quantitative analysis of the elements in SD models on this basis (Wang et al., 2015). With some algebraic expressions written with equations and computer codes, the stock and flow diagram was developed to simulate the dynamic relationships among various policies for MiC uptake. Figure 6.4 presents the stock-flow diagram of the PDFs for MiC uptake, and descriptions of all the notations used in this model are detailed in Table 6.1, including stocks, flows, auxiliary variables, and constant indicators. It provides a boulevard to simulate the influence of a variable on different components of the model and the model as a whole. In this way, the impact of adopting strategies at different stages on the MiC uptake was simulated.

Table 6.1 Descriptions of the Model Variables

Acronym	Variable name	Variable type
CCFiGBA	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	Constant
CCQ	Change of the Government policy related to the standard of the acceptance of the completed construction quality	Constant
CioCON	Combined impact of Construction Phase	Auxiliary
CioINI	Combined impact of Initiation Phase	Auxiliary
CioP&D	Combined impact of Planning & Design Phase	Auxiliary
COverallIPD FoMiC	Combined Overall impact of PDFs on MiC	Auxiliary
CWDCS	Change of the Government policy related to construction waste disposal charging scheme	Constant
EPI	Change of the Government policy related to environmental protection in Initiation Phase	Constant
EPP	Change of the Government policy related to environmental protection in Planning & Design Phase	Constant
HP	Adjustment of the Government policy related to housing policy	Constant
HP&RPD	Change of the Government policy related to housing policy, the restriction on the type and the size of property development	Constant
IoMiCP	Change of the Government policy related to investment of the MiC project	Constant
IPDFfC	Impact of PDFs on MiC for Construction Phase	Stock
IPDFfI	Impact of PDFs on MiC for Initiation Phase	Stock
IPDFfPD	Impact of PDFs on MiC for Planning & Design Phase	Stock
IS&CPiGBA	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	Constant
OverallIPDF oMiC	Overall impact of PDFs on MiC	Stock
PCPC	Change of the Government policy related to COVID-19 pandemic in Construction Phase	Constant
PCPI	Change of the Government policy related to COVID-19 pandemic in Initiation Phase	Constant
PCPP	Change of the Government policy related to COVID-19 pandemic in Planning & Design Phase	Constant
PI	Change of the Government policy related to the preferential interest of the MiC project	Constant
PoMiC	Change of the Government policy related to the publicity of MiC	Constant
PPPHP	Change of the Government policy related to the proportion of prefabrication in public housing projects	Constant
PrF	Change of the Government policy related to finance	Constant
PS	Change of the Government policy related to the procurement system	Constant
SC&GfMiC	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for MiC	Constant

SoMiC	Change of the Government policy related to the sale of the MiC buildings	Constant
SPC	Change of the Government policy related to scope/type of the prefabricated elements and components	Constant
T&LiGBA	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	Constant
T&R	Change of the Government policy related to taxation and revenue	Constant
TSI	Change of the Government policy related to MiC technological support and innovation	Constant
VIPDFfC	Values (adoption level) of IPDFfC	Flow
VIPDFfI	Values (adoption level) of IPDFfI	Flow
VIPDFfPD	Values (adoption level) of IPDFfPD	Flow
VOverallIPD FoMiC	Values (adoption level) of OverallIPDFoMiC	Flow

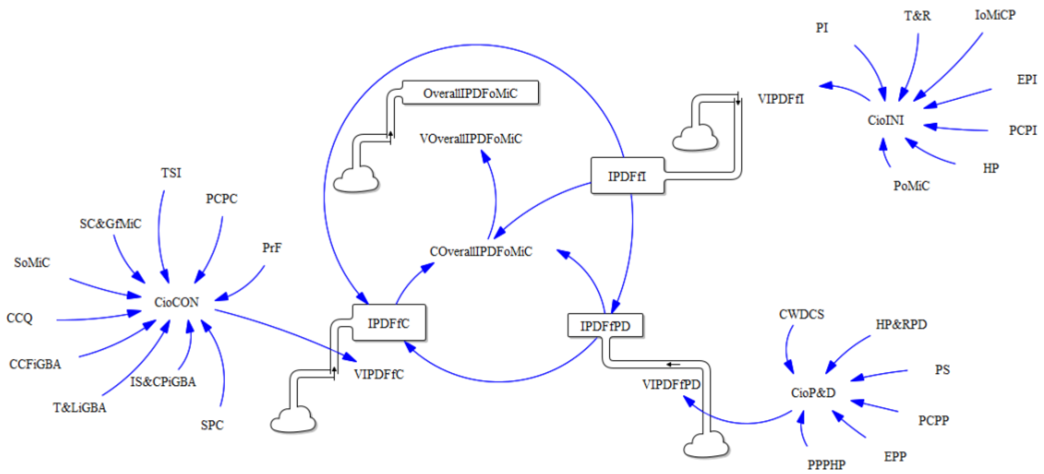

Figure 6.4 Stock-flow Diagram of the PDFs for MiC Uptake

6.5 Model Testing and Validation

Prior to quantitative analysis and simulation, model testing and validation is an indispensable section of the modelling process in SD modelling (Sterman, 2000), which is utilised to ensure that the constructed model can well reflect the accuracy of the actual conditions in a reasonable mode (Richardson & Pugh, 1981). In order to build confidence in the model, various structural and behavioural tests were performed to review and confirm the validity of the SD model. A series of model tests proposed by Qudrat-Ullah and Seong (2010) includes five aspects: 1) structure verification test, which verifies whether the structure of the established model is logically consistent with the relevant real description knowledge simulated in the system; 2) boundary adequacy test, which confirms whether all the essential structures and concepts are included into the model; 3) parameter verification test, which examines whether the parameter values correspond to the system knowledge numerically and descriptively; 4) dimensional consistency test, which evaluates whether the measurement unit of each equation in the model is in line with the use of parameters; and 5) extreme condition test, which tests whether the model behaves logically when its input is under extreme conditions. These tests are adopted in this study to review and highlight the reliability and robustness of the model.

Test 1 (structure verification test) checks the logic of the model structure, and the verification can be supported by existing literature or actual data (Ding et al., 2016). As shown in Figures 6.3 and 6.4, the relationship structure involved in the causal loop diagram and the stock-flow diagram is matched with existing professional knowledge and practice. Moreover, since the causalities are based on the empirical knowledge of MiC in Hong Kong or determined from the literature, the model is deemed to be a reasonable and realistic reflection of the real world.

Test 2 (boundary adequacy test) focuses on whether all significant variables have been input and computed into the model and are in line with the research objectives (Qudrat-Ullah & Seong, 2010). A field investigation was conducted in this study, and two experts in the construction industry and three scholars in academia were invited to evaluate whether all important elements that constitute the system were considered in the SD model. Through a comprehensive review of the stock-flow diagram, the research ensures that all fundamental variables in the three stages are considered in the model, along with meeting the research objectives.

Test 3 (parameter verification test) verifies whether the parameter settings are suitable for the actual circumstances of practical MiC projects. In this model, the values of parameters used are based on factors rigorously confirmed by literature and the experience of professionals in real life. Therefore, the model within this study can pass Test 3 via *Vensim PLE* software because it reflects the real situation of existing MiC adoption.

Test 4 (dimensional consistency test) examines the unit consistency of all variables in the model. It is necessary to check the measurement units of any variables and equations involved to confirm the consistency of the model dimensions (Sterman, 2001). The modelling tool, *Vensim PLE* software, has a built-in capacity to validate the dimensional consistency of the model. Thus, with the help of the *Vensim PLE*, this test function can be automatically executed after the user has determined the units of all variables. Only when the dimensional consistency test passes will the software model continue to process subsequent simulations in the system.

Test 5 (extreme condition test) inspects the behaviours of the system under extreme conditions (Bala et al., 2016). According to interviews, construction practitioners believe that without any policy support, the adoption rate of modular buildings is expected to drop to nearly zero, as the construction industry prefers and is more familiar with the traditional mode. In this study, the behaviour of this model under extreme conditions was simulated with 0% execution of all strategies and 100% execution of all strategies. As indicated in Figure 6.6, the results illustrated the effectiveness of this model. When all strategies are adopted at 0%, the overall impact efficiency of critical PDFs on MiC uptake is about 38%; when all strategies are adopted at 100%, the overall impact efficiency of critical PDFs on MiC uptake increases to 99.9%.

The above analysis reveals that the model has passed all necessary tests, so it is suitable for further base run simulation and sensitivity analysis to derive the research results.

6.6 Results and discussions

6.6.1 Base run simulation

In this model, two typical modular buildings under construction in Hong Kong are used to verify the model's accuracy and universality. Case A is the BoxPod and OPod by James Law Cybertecture architects, and Case B is the Student Residence at Wong Chuk Hang Site for the University of Hong Kong. Details are as follows.

6.6.1.1 Background of two cases

After the stock and flow diagram was developed, the appropriate modular construction project needs to be carefully selected, accompanied by data collection and case analysis to generate the values of the quantified variable. To achieve this objective and avoid occasionality, two case studies of typical residential projects under construction in Hong Kong were selected based on knowledge of projects background and in-depth interviews with main stakeholders involved in these projects.

Case A, BoxPod and OPod by James Law Cybertecture architects, is a proprietary, stackable, fully fitted out, low-cost, micro-living MiC housing module designed to alleviate the affordable housing problems in Hong Kong (James Law Cybertecture, 2020, 2021a). It is a very representative MiC building in Hong Kong. BoxPod can be used as transient public housing, fast-constructed accommodation and disaster relief shelters (James Law Cybertecture, 2021a). Constructed out of low cost and readily available reinforced concrete box culvert sections, each BoxPod contains living space, pantry and toilet for up to four persons to live. Designed with high ceilings, BoxPod provides storage areas at high levels and ample cross ventilation via openable windows. BoxPod is completely manufactured and fitted out in the factory, delivered to the site by lorry. BoxPod can be stacked up to 5 levels without modifications, whilst a further number of floors can be achieved with additional structural supports. OPod is constructed out of low cost, and readily available 3.1m diameter concrete water pipe; the design utilises the solid concrete structure to house a micro-living apartment for one/two persons with fully kitted out living, cooking and bathroom spaces inside 165 sq.ft. Each OPod is equipped with smartphone locks for online access and space-saving furniture that maximises the space inside (James Law Cybertecture, 2021b). OPod can be stacked to become a low-rise building and a modular community in a short time and can also be located/relocated to different sites in the city.

Case B, Student Residence at Wong Chuk Hang Site for the University of Hong Kong, is one of the Pilot MiC Projects selected by the Development Bureau. It comprises two 17-storey towers of student residences, providing 1,224 hostel places, each with a single room of about 6.5 square metres. This project is expected to be assembled in 6 types of modules, with a total of 884 modules. Podium transfer plate and core wall will be built using cast-in reinforced concrete construction. MiC will be adopted for the floors above the transfer plate and the multi-unit bedroom, combined with the core walls. Prefabricated polished-flooring, anti-mould emulsion paint walls and ceiling for each room will be completed in the factory. All fixed furniture modules will be installed in the factory. Table 6.2 provides further detailed information about these two cases.

Table 6.2 Detailed Characteristics of Selected Cases

Features	**Project description**	
	Case A	**Case B**
Project type	Newly built public housing	Newly built public housing
Building type	MiC	MiC
Usage	Mirco-living apartment	Student dormitory
Construction commencement date	Jan. 2020	Aug. 2019
Estimated project duration	50 months	65 months
Scope of construction	Over 300 units of fast housing units	Two 17-floor with 1224 hostel places
Location	Tsuen Wan	Police School Road, Wong Chuk Hang

The data used in this model was collected through in-depth interviews with several key members within the two case projects. In Case A, the three main members are the director, project assistant manager, and project architect. Case B has three main members, including the project manager, MiC supplier manager, and a sub-contractor representative. From the project initiation phase to the design and planning phase, and then to the official commencement of the project construction phase, the six participants involved have comprehensive familiarity or direct participation. They are all experienced and have a deep understanding of MiC and its policies in Hong Kong. A questionnaire was intended to determine the extent to which PDF have influenced the project processes in both two cases, which only included an assessment of the critical PDFs previously identified through factor analysis. The involved participants were asked to rate the comprehensive probability impact of each critical PDF in each phase on a scale of 1 to 5, where 1 means slight influence and 5 signifies the impact is great. A case study template used for the data collection of these two cases is available in Appendix B.

6.6.1.2 Processes and results of base scenarios

To calculate the relative impact value for each PDF, with reference to Ajayi's research (2016), mathematical models for this system were developed for the various potential variables contained in the model. The main steps involved are explained as follows.

I. Compute the significance index of each primary variable

First, a PLS-SEM model was developed based on the data collected by the previous questionnaire survey, reflecting the correlations between critical PDFs and various phases. The weighting score for each interconnection within the system was calculated from the PLS-SEM model. Specific details of the calculated values are provided in Appendix C. Based on these factor weights, relative weight for each primary variable was calculated using the following Equation 6.1:

$$R_{x_i} = \frac{w_{x_i}}{\sum_{j=1}^{n} w_{x_i}} \tag{6.1}$$

where w_{x_i} is the factor weight of x_i derived from the PLS-SEM model, R_{x_i} represents the significance index of the primary variable x_i, implying the contribution of x_i to its latent variable.

For example, a latent factor 'policy support via Initiation phase' where x_1=PI, x_2 =T &R, x_3 =IoMiCP, x_4 =EPI, x_5=PoMiC, x_6 =PCPI, x_7 =HP, and w_{x_1}=0.746, w_{x_2}=0.710, w_{x_3}=0.712, w_{x_4}=0.687, w_{x_5}=0.728, w_{x_6}=0.499, w_{x_7}=0.432. Then, as Equation 6.1, the relative weight of PI, $R_{PI} = \frac{0.746}{4.514} = 0.17$.

II. Compute the impact level of first-order latent variables

Next, the impact levels of first-order latent variables such as 'policy support via Initiation phase' were calculated using the following Equation 6.2:

$$IL(X) = \sum_{i=1}^{n} L_{x_i} \times R_{x_i} \tag{6.2}$$

where $IL(X)$ denotes the impact level of a latent variable (X), L_{x_i} is the impact level of the primary variable x_i that contributes to the latent variable (X), and R_{x_i} represents the significance index of the primary variable x_i as calculated through Equation 6.1.

III. Compute the significance index of all latent variables

Thereafter, the significance index of each latent variable was calculated using the following Equation 6.3, and this step is to understand each phase's (initiation, planning and design, and construction phase) significance towards promoting the MiC uptake:

$$R_{X_i} = \frac{w_{X_i}}{\sum_{j=1}^{n} w_{X_i}} \tag{6.3}$$

where w_{X_i} is the absolute weight of latent variable derived from the PLS-SEM model, $\sum_{j=1}^{n} w_{X_i}$ denotes the sum of absolute weights for all latent variables, R_{X_i} represents the significance index of latent variable X_i, implying the contribution of X_i to the overall MiC uptake.

IV. Compute the combined impacts of initiation, planning and design, and construction

Correspondingly, the impacts of all three stages were calculated through the impact levels as well as the relevant significance index of their contributing factors. This computation was done via Equation 6.4:

$$CioA = IL(Ini) \times R(Ini) + IL(P\&D) \times R(P\&D) + IL(Con) \times R(Con) \tag{6.4}$$

where $CioA$ denotes the combined impact of all phases strategies, and relevant IL and R values were calculated using Equation 6.2 and Equation 6.3.

All necessarily related values were entered into the model, denoting the unit as 'Dmnl' as the inputs are measured in percentage or scale. Prior to the base simulation runs, all the tests mentioned above are performed on the model to ensure its accuracy. The comparison of the base run simulation results between Case A and Case B is illustrated in Figure 6.5.

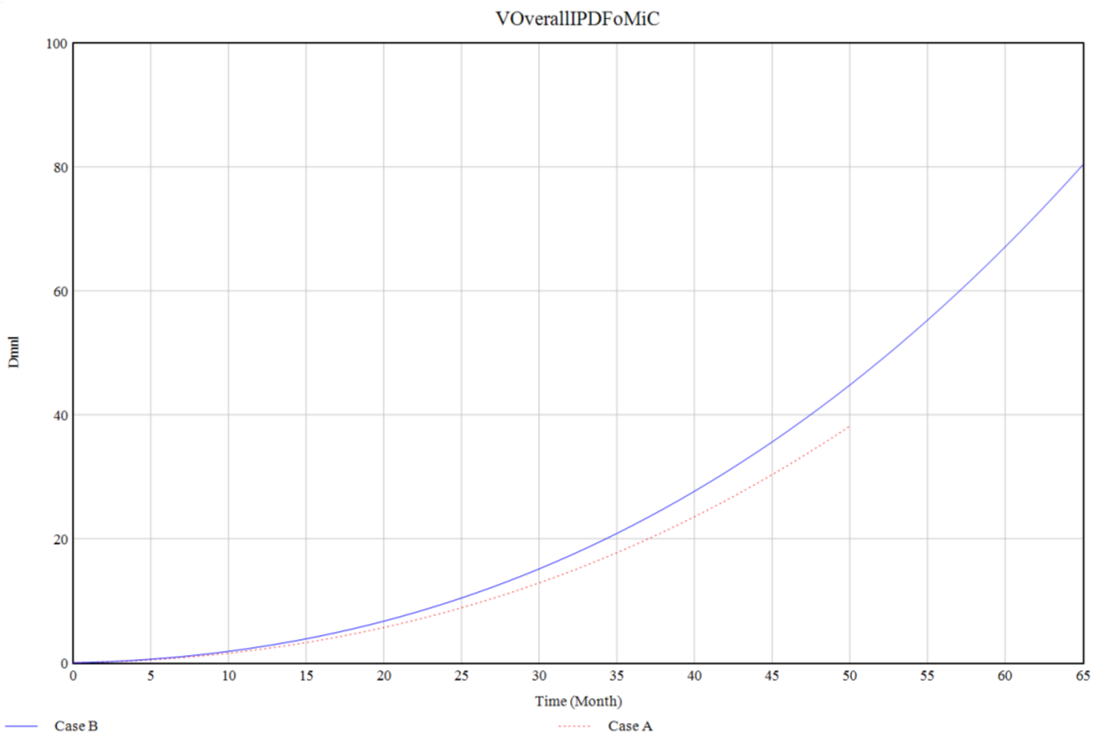

Figure 6.5 Base Run Simulation Comparison Between Case A & B

Figure 6.5 shows that all the critical PDFs influence both newly-built public MiC housings, with an impact efficiency of approximately 38% for Case A and about 80% for Case B when the projects are delivered successfully. Considering that the construction scope of Case B is much larger than that of Case A, and the expected overall three phases of MiC projects (including initiation, planning and design, and construction) is longer than Case A, the impact of critical PDFs on large-scale buildings will be greater and longer-lasting.

6.6.2 Policy scenarios analysis

In order to comprehend the optimal way for increasing the uptake of MiC in Hong Kong, various scenarios were modelled and evaluated in two categories. Scenarios in the first category assessed the impacts of the initiation, planning and design, and construction phases on the overall MiC uptake. Scenarios in the second category evaluated the influence of various components and critical PDFs on the overall MiC uptake.

6.6.2.1 Dynamic impacts of the three Stages

In this model, scenario modelling was executed using the Simulate and Synthesim function within the *Vensim PLE* software to explore the overall influences of each initiation, planning and design, and construction phase. For each stage, while keeping all other strategies in the case baseline adoption, the corresponding internal implementation level was increased to 100% to assess its overall impact on the MiC uptake, as displayed in Figure 6.6. The 'baseline implementation of all current strategies' yielded an adoption efficiency of approximately 38%, and the detailed comparison results of scenario modelling are demonstrated in Figure 6.6. The results reveal that the initiation phase has the most significant impact on the overall uptake of MiC. The diagram suggests that at 100% implementation of the preferential interest of the MiC project, taxation reduction, investment to MiC projects, environmental protection, the publicity of MiC, macro housing policy and COVID-19 pandemic crisis confrontation in the initiation phase, the overall adoption efficiency of MiC would hopefully reach about 80%. It is worth noting that this is not only the result of initiation from a separate perspective, partly because these adjustments were able to drive implementation and generate positive reactions during the planning, design, and construction phases.

The construction phase has the second-largest impact on the overall uptake of MiC, second only to the initiation phase. This influence was driven by 100% implementation of the relevant PDFs within the model, which includes the customs clearance facilitation in the Greater Bay Area (e.g. facilitate personnel exchange and enhancing the flow of goods), the transportation and logistics in the Greater Bay Area (e.g. expedite cross-boundary infrastructural connectivity), a globally competitive modern industrial system and jointly cooperation platforms establishment in Greater Bay Area (e.g. accelerate the flow of data and information), the authoritatively designed standards, codes and guidelines for MiC, expanded scope/type of the prefabricated elements and components, MiC technological support and innovation, COVID-19 pandemic crisis confrontation, finance support, quality acceptance standard for project completion, and boost to the sale of the MiC buildings. The results indicate that the overall adoption efficiency of about 56% for MiC will be expected to be achieved when the policies mentioned above are at 100% promotion.

The dynamic scenario simulations revealed that increasing adoption of strategies at the planning and design phase is capable of promoting the MiC uptake, although its effect is not as dramatic as during the construction and initiation phases. As shown in Figure 6.6, the results imply that when the measures in the planning and design phase are 100% implemented, around 50% of the overall MiC adoption efficiency would be achieved. The related drivers involve these aspects, including construction waste disposal charging scheme, micro-housing policy (the restriction on the type and size of property development), environmental protection, the proportion of prefabrication in public housing projects, COVID-19 pandemic crisis confrontation, and the procurement system. In summary, with the case baseline adoption efficiency of all strategies being around 38%, in scenario models, the overall adoption efficiency of MiC can be improved by about 12% in the planning and design phase, while the initiation and construction phases can be increased by 42% and 18%, respectively. This further proves that the initiation phase is the most crucial process for the MiC uptake, which echoes the insights proposed by Wuni and Shen (2020).

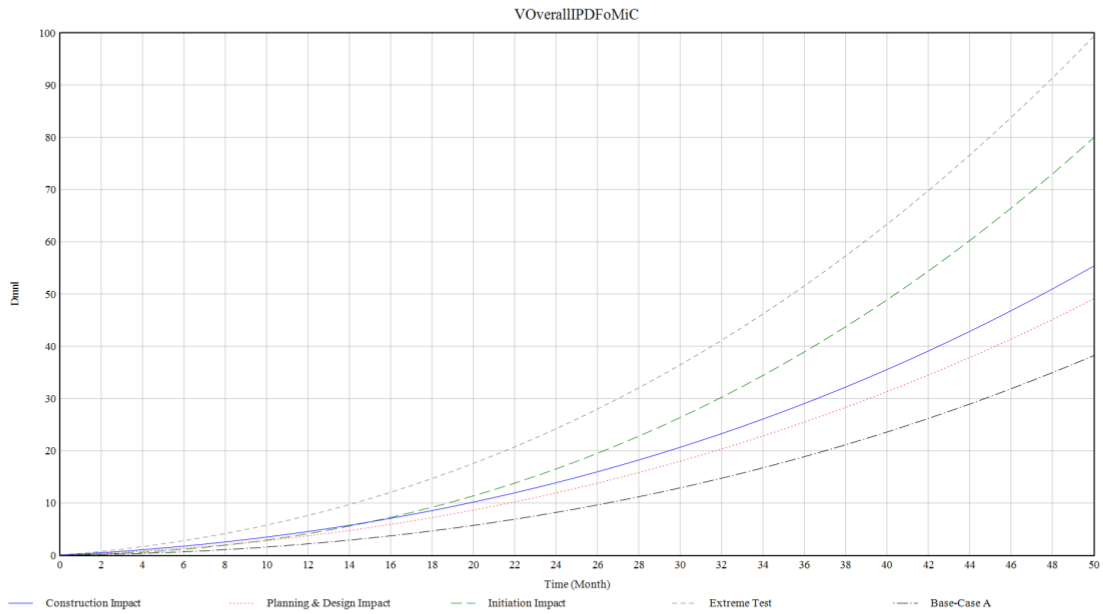

Figure 6.6 Dynamic Impacts of Different Stages on MiC Uptake

6.6.2.2 Key dynamic PDFs of the overall MiC uptake

The dynamic scenario simulations on the impacts of implementing an individual strategy on the overall MiC uptake were performed by leaving other strategies at the case baseline implementation level. The outcomes go beyond the single impact of strategies since they reveal the dynamic impacts of each critical PDF or related PDF component adopted during initiation, planning and design, and construction phases. The initiation strategies for MiC uptake were simulated to explore how these seven critical PDFs influence the overall adoption efficiency of the modular building method. In order to comprehensively reflect the effects of different components extracted via factor analysis in Chapter 4, the dynamic influence of the two components (PSPDF and RPDF) in the initiation phase is further simulated and analysed. Figure 6.7 illustrates the simulated varying trends of component I-1 (Promotional & Sustainable PDF) and I-2 (Regulative PDF). The result showed that Regulative PDFs have a higher impact on the MiC uptake than Promotional & Sustainable PDF. Additionally, this extended dynamic simulation result is consistent with the previous static factor analysis result. For further detailed analysis on the seven critical PDFs, as presented in Figure 6.8, adjustment of the government policy related to macro housing policy has the highest impacts on the overall MiC uptake. Given that the Hong Kong government has provided more public rental housing units and revised the public-private split of new housing supply, coupled with the widespread mandatory adoption of modular construction in public housing, this result makes sense. This is closely followed by the COVID-19 pandemic crisis confrontation, as MiC prides itself on building high-quality and safe isolation houses within a short schedule (Abdelmageed & Zayed, 2020; Luo et al., 2015; Wuni & Shen, 2019), so the impact of this PDF during the epidemic will be particularly prominent. Other prioritised strategies are the preferential interest of the MiC project, the publicity of MiC, taxation reduction, investment to the MiC project, environmental protection, based on their significance. These are all policy drivers related to promotion and sustainability, while their influence will be slightly lower than regulations.

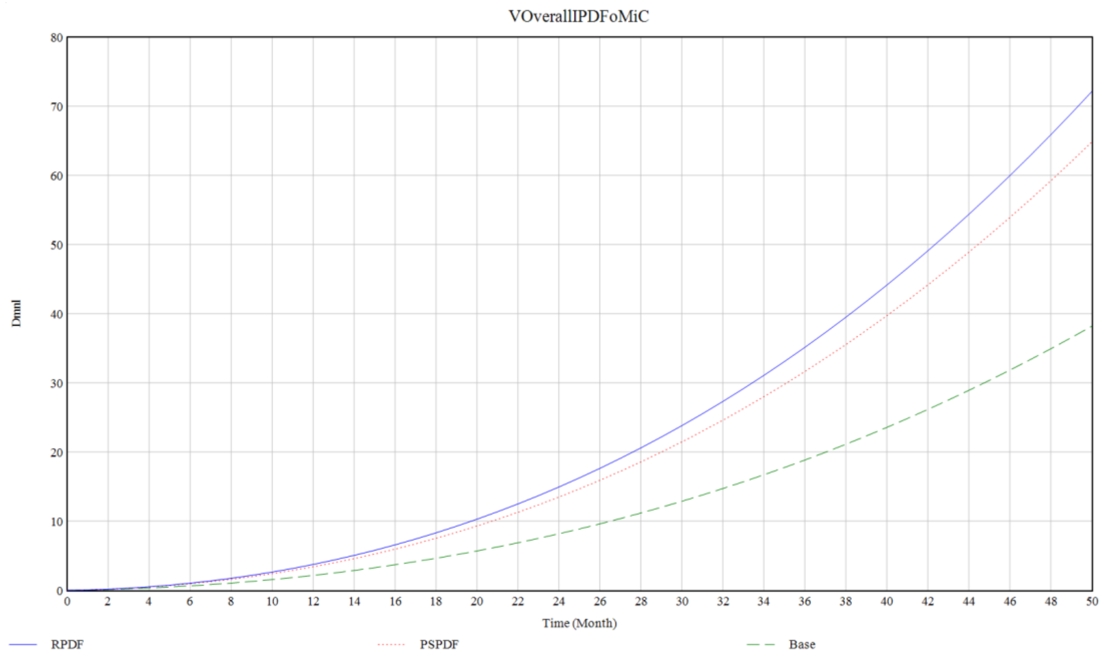

Figure 6.7 Dynamic Impacts of Different Components on MiC Uptake at Initiation Phase

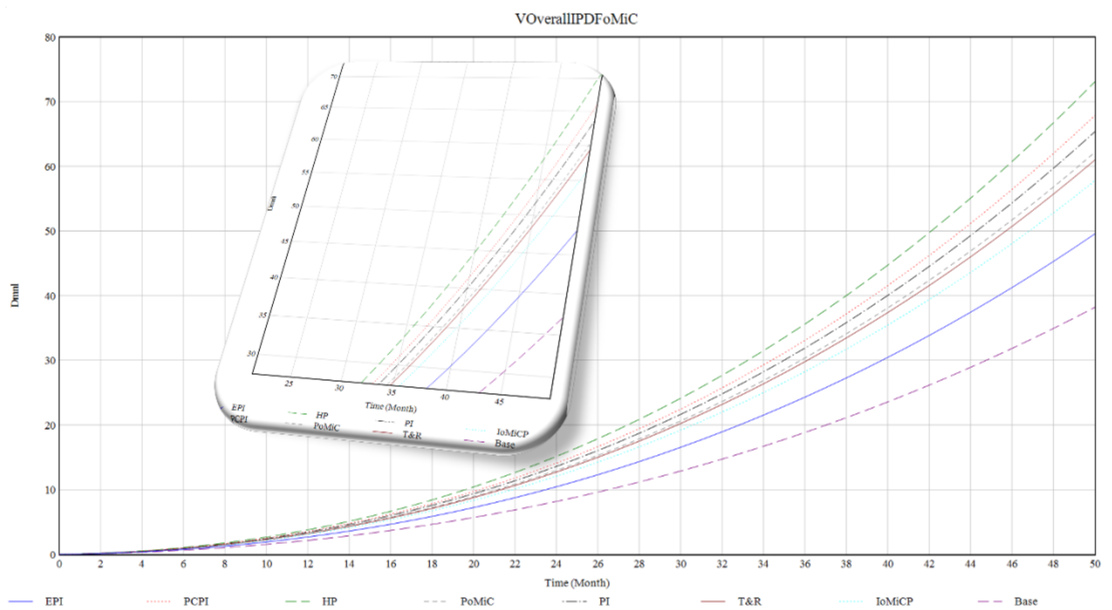

Figure 6.8 Dynamic Impacts of Different PDFs on MiC Uptake at Initiation Phase

Relative impacts of different planning and design strategies were also simulated to understand the comparison of trends in the influence of six critical PDFs on MiC uptake.

There are two components, SPDF and RPDF, each containing three different PDFs. Figure 6.9 shows the simulated varying tendency of components II-1 (Sustainable PDF) and II-2 (Regulative PDF). The result presented that Regulative PDFs have a greater impact on the MiC uptake than Sustainable PDFs. Similarly, the dynamic simulation result of this SD model is consistent with that of the earlier static factor analysis. The differences are quite subtle when examining the effects of six different PDFs on overall MiC uptake closely, as illustrated in Figure 6.10. The COVID-19 pandemic crisis confrontation has the highest impacts on the overall MiC uptake during the planning and design phase, while the proportion of prefabrication in public housing projects takes the second place to exert an influence on MiC uptake. Excellent flexibility in the design phase of MiC is in line with the requirements of the current epidemic (Tayo et al., 2020; Yatmo et al., 2021). The offsite and modular solutions for the construction industry can well respond to emergencies (Gbadamosi et al., 2020). With the announcement that further MiC applications will raise the utilisation rate of prefabricated concrete components from 70% to approximately 90% on plan (Hong Kong Housing Authority, 2019), the improvement of MiC housing in Hong Kong will be deepened. According to their importance, other impact factors include the procurement system, construction waste disposal charging scheme, environmental protection, and micro-housing policy (the restriction on the type and size of property development).

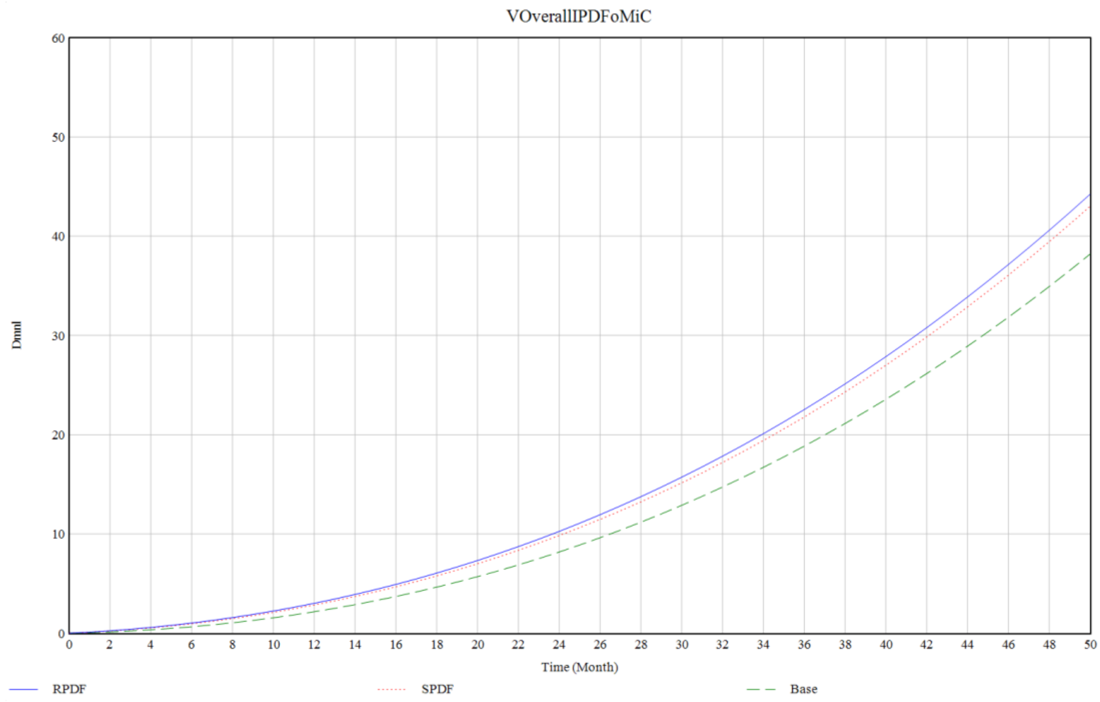

Figure 6.9 Dynamic Impacts of Different Components on MiC Uptake at Planning & Design Phase

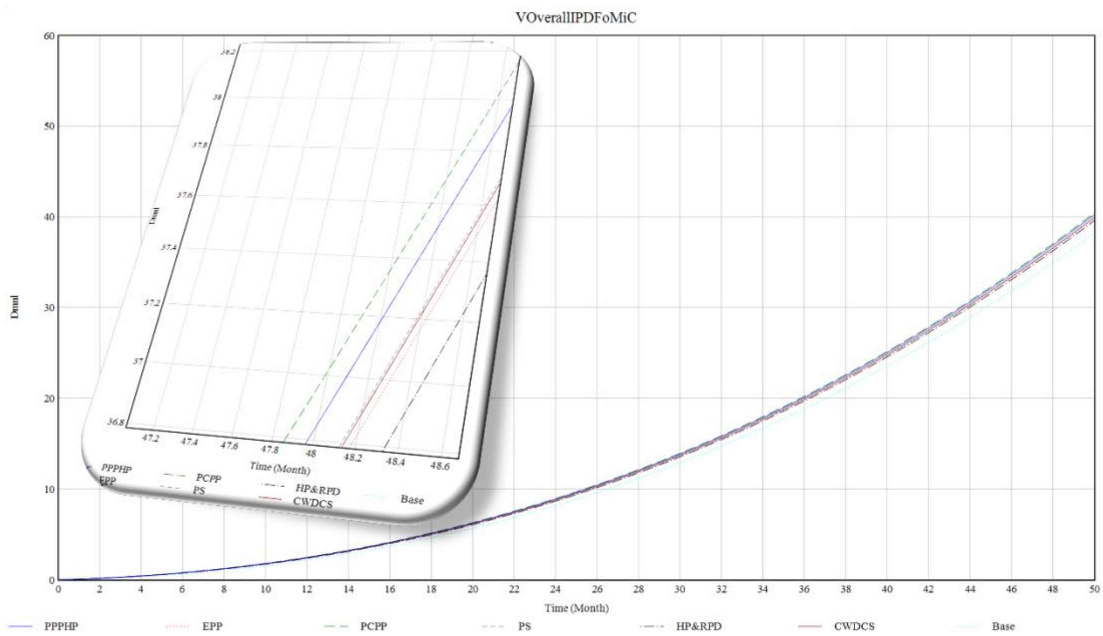

Figure 6.10 Dynamic Impacts of Different PDFs on MiC Uptake at Planning & Design Phase

Similarly, the construction strategies for MiC uptake were simulated to examine how the effective implementation of these ten critical PDFs individually affects the efficiency of MiC adoption. There are three components in the construction phase, GBADPDF, TRPDF and PPDF, containing three, four, and three different PDFs, respectively, as detailed in Chapter 4. Figure 6.11 demonstrates the simulated changing trends of component III-1 (Greater Bay Area development PDF), III-2 (Technical & Regulative PDF) and III-3 (Promotional PDF), and the result revealed that Technical and Regulative PDFs has a more significant impact on the MiC uptake than Greater Bay Area development PDF and Promotional PDF. It can be clearly observed from Figure 6.11 that the influence curves of GBADPDF and PPDF are very close and almost coincide. However, this dynamic simulation result does not correspond to the previous static factor analysis, where the Greater Bay Area development PDF is identified as the most influential component. This may be because in factor analysis (a static analysis), on the one hand, there is a slight bias in sample size; on the other hand, most professionals are highly inclined to attach importance to the adjustments related to the Greater Bay Area policies, as they significantly affect the efficient transportation of modules in MiC and timely communication between stakeholders (Li et al., 2016; Luo et al., 2019). While many practitioners neglected to assess the long-term dynamic impacts of factors from a holistic perspective. Under objective dynamic simulations of this SD model, technological and regulative policies will occupy the dominant role. Technological innovation and progress have always been emphasised by many scholars and construction practitioners (Ahmad et al., 1995; Arayici et al., 2011).

Moreover, the impact efficiency of regulative PDFs has been the highest all the time, from the initiation phase to the planning and design phase. Among detailed individual strategies related to the ten critical PDFs, as depicted in Figure 6.12, the policy-related COVID-19 pandemic crisis confrontation has the most remarkable tendency of improving the overall MiC uptake during the construction phase. The authoritatively designed standards, codes and guidelines for MiC has the second-highest possibility to affect the overall MiC uptake, while the influence of MiC technological support and innovation on MiC uptake ranks third. Similar to the first two stages, the COVID-19 pandemic crisis confrontation policy requires temporary isolation buildings to be completed rapidly and with high quality (WHO, 2021), and MiC is the best option (Yatmo et al., 2021). Numerous studies have shown that the inappropriate or even absence of design codes and standards for prefabricated components in MiC buildings is identified to be a critical political factor related to inefficient adoption and poor performance of MiC (Han & Wang, 2018; Mao et al., 2015; Zhang et al., 2014), so its improvement can well promote the MiC uptake. Technological Innovation and production would bring about the supremacy of modernism in architecture (Lobsinger, 2011). Many researchers attempted to integrate the use of technology into the business processes of MiC from the perspective of technological innovation, such as VP-based IKEA model (Li et al., 2011), Internet of Things-enabled BIM platform (IBIMP) for the MiC projects (Zhai et al., 2019), and real-time information sharing to support the adoption of offsite technology (Pan et al., 2012). All of these have been verified through practice or case studies to promote the MiC uptake. Other seven strategies in order of their significance are the expanded scope/type of the prefabricated elements and components, a globally competitive modern industrial system and jointly cooperation platforms establishment in the Greater Bay Area (e.g. accelerate the flow of data and information), quality acceptance standard for project completion, finance support, boost to the sale of the MiC buildings, the customs clearance facilitation in Greater Bay Area (e.g. facilitate personnel exchange and enhancing the flow of goods), and the transportation and logistics in Greater Bay Area (e.g. expedite cross-boundary infrastructural connectivity) respectively.

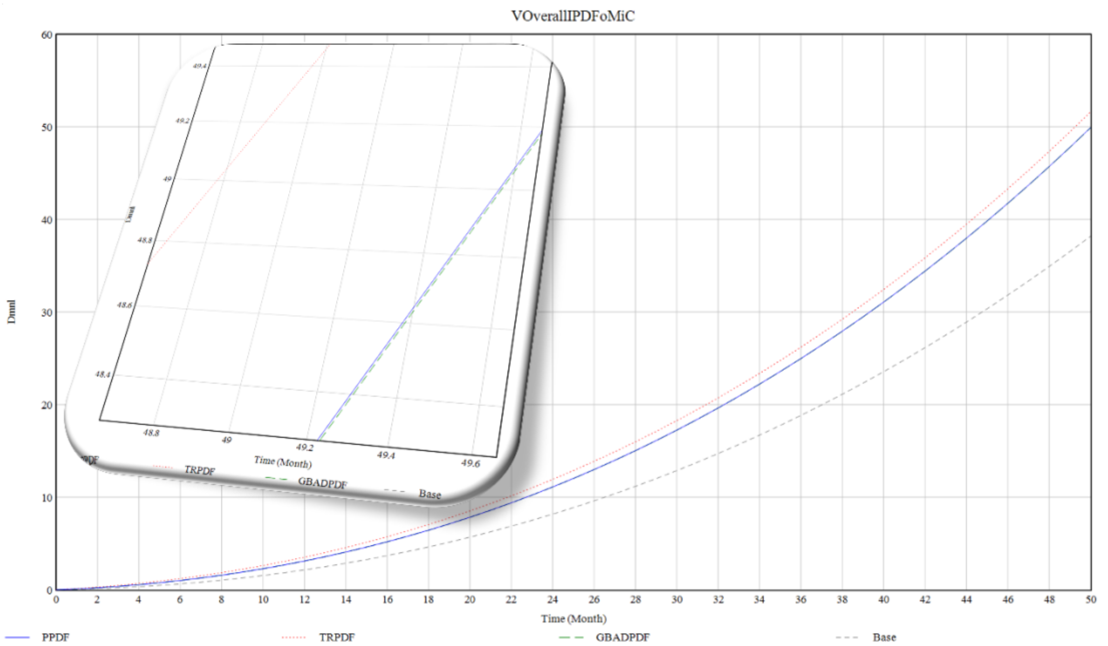

Figure 6.11 Dynamic Impacts of Different Components on MiC Uptake at Construction Phase

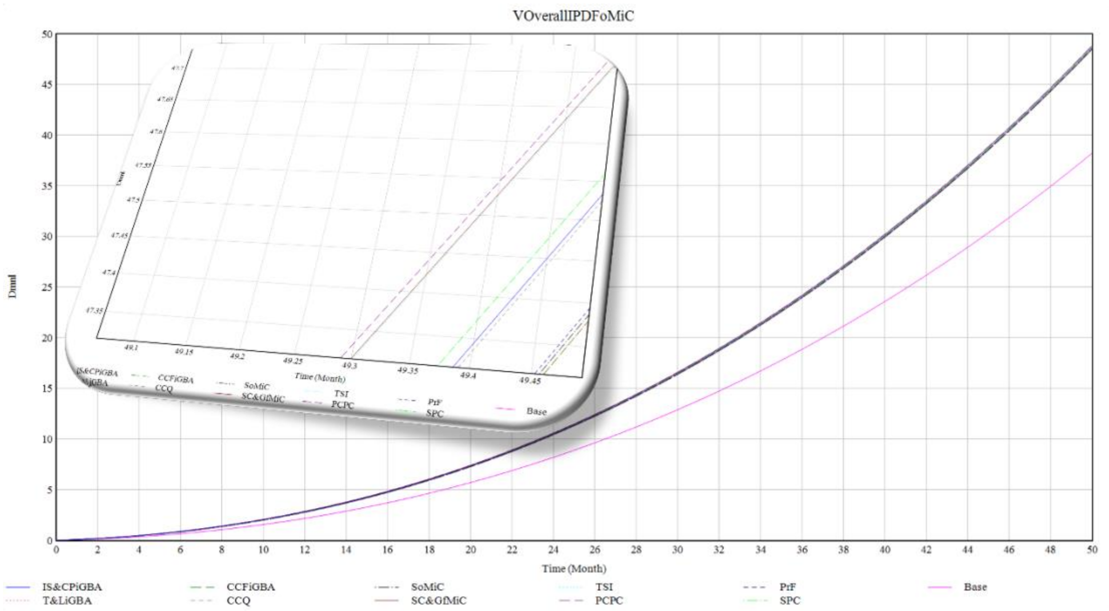

Figure 6.12 Dynamic Impacts of Different PDFs on MiC Uptake at Construction Phase

In order to fathom the top strategies for improving the MiC uptake, the scenario simulation results of different components for initiation, planning and design, and construction strategies are combined regardless of their implementation stage. Figure 6.13 demonstrates the varying curves of dynamic impacts of all the seven components on MiC uptake and the order of their importance. The result implies that Regulative PDF has the highest tendency to enhance the MiC uptake. Remarkably, the influence of Regulative PDF is always the strongest at each phase. Promotional PDF also attracts attention, second only to Regulative PDF. Other strategies are Sustainable PDF, Technical PDF, and Greater Bay Area development PDF.

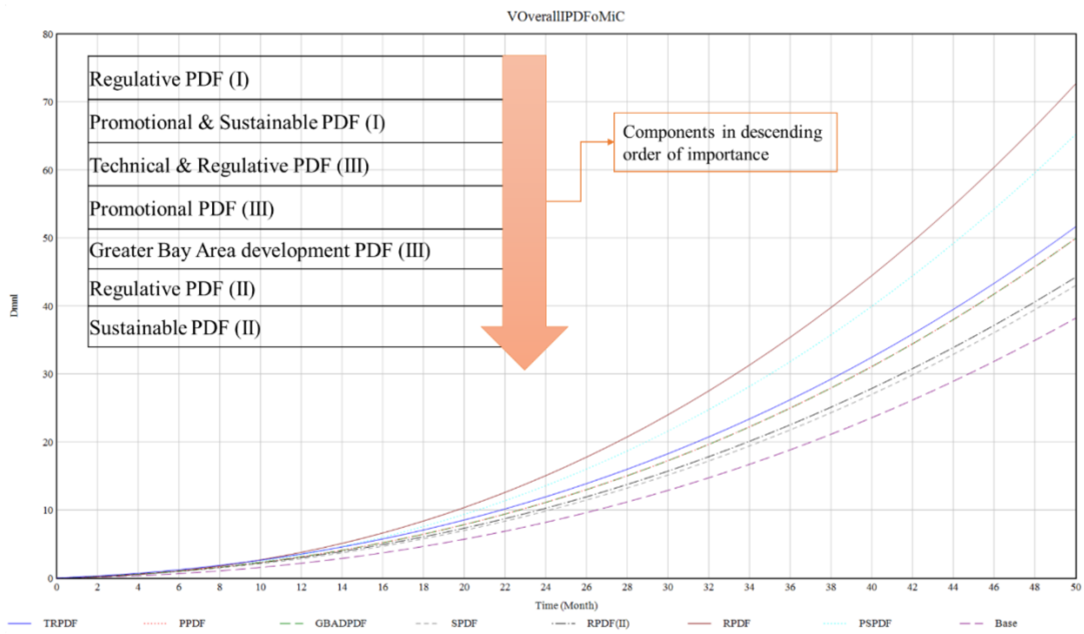

Figure 6.13 Dynamic Impacts of Different Components on MiC Uptake

6.6.2.3 Underlying strategies for MiC uptake

Based on the results of case simulations and the above-mentioned policy scenarios analysis, combined with the expert opinions derived from interviews, this study provides the following strategies to improve the uptake of MiC practices in Hong Kong.

Boost MiC adoption in buildings under emergencies

From the results of policy scenarios analysis, the policy to deal with the COVID-19 pandemic crisis confrontation shows its highest impact on the MiC uptake during all three phases (initiation, planning and design, and construction). The significant benefits of MiC lie in its rapid construction speed and controllable high quality (Gao & Tian, 2020; Jiang et al., 2018), which significantly contributes to the creation of isolation space for patients during the COVID-19 epidemic and the need for temporary hospitals. Standard quarantine space creation measures used to contain the COVID-19 epidemic include the construction of temporary mobile cabins, temporary tent-based structures, newly constructed temporary hospitals, and retrofitted buildings for an emergency, all of which are offsite and modular solutions (Gbadamosi et al., 2020). Emergency engineering projects such as Lei Yue Mun quarantine camp in Hong Kong, Huoshenshan Hospital in Wuhan, Wuhan Thunder God Mountain, are good MiC practices. This motivates the government and construction industry practitioners to respond to emergencies by means of boosting the adoption of MiC in temporary buildings, which can not only promote the overall uptake of MiC but also effectively meet the demands of some temporary constructions, making it possible for temporary buildings to have better performance. In addition, the detachability of MiC buildings is further conducive to sustainable recycling development, reducing consumables and construction waste.

Expand MiC adoption in public housing and encourage its application in private buildings

The Hong Kong government has promulgated the Long Term Housing Strategy (LTHS), which listed the provision of more public rental housing (PRH) units and subsidised sale flats (SSTs) and the stabilisation of the residential property market as three major strategic directions (Long Term Housing Strategy Annual Progress Report 2020, 2021; Transport and Housing Bureau in Hong Kong, 2020). Additionally, in 2019, the Legislative Council Panel on Housing adjusted the public-private allocation of new housing supply over the 10-year period from 60:40 in 2019-20 to 70:30 in 2028-29.

These macro housing policies will have an impact on the MiC adoption since prefabricated components are mandatory to be used in public housing. To achieve the housing policy requirements mentioned above, it is strongly recommended to further adopt MiC in public housing rather than just prefabricated components because of its unique advantages in accelerating the construction cycle (Chen et al., 2017; Xie et al., 2020). Meanwhile, when interviewing practitioners in this industry, some experts also mentioned that actively encouraging private buildings to adopt MiC to build good looking and diversified houses is also an optional measure to promote the application of MiC.

Provide more GFA exemption for MiC projects

The Hong Kong Buildings Department has launched a series of preferential interest incentive policies to promote prefabricated development. Among them, the GFA-compensate introduced in 2002 is the most attractive to real estate companies (Zhou et al., 2019). More than a few professionals mentioned that increasing the GFA relaxation percentage for MiC development could remarkably promote the uptake of MiC in Hong Kong, as the exemption percentage of GFA has not adjusted for nearly 20 years. The most effective way to enhance the enthusiasm of real estate enterprises to implement MiC is to strengthen government financial incentives (Jiang et al., 2018), which the interviewees have unanimously agreed on in this study.

Enhance information technology support across the supply chain

The core of improving the construction industry's productivity lies in technological innovations (Slaughter, 2000). The effectiveness of promoting the adoption of MiC largely depends on solving technical issues; therefore, the government has always attached great importance to promoting the implementation of innovative building technologies (Zhou et al., 2021). Nowadays, the application of emerging information and communication technologies such as Radio-frequency identification (RFID)/ Near Field Communication (NFC)/ Quick Response (QR) code tags can facilitate services, tools and mechanisms for different stakeholders involved in the construction phase, increasing the accomplishment of daily operations and decision-making across MiC housing project management to ensure timely project delivery (Li et al., 2017). This viewpoint was also supported by the project managers and professionals who participated in this study. They explained that these information tracking technologies and communication platforms could well be assisted the timely information sharing throughout the supply chain, facilitated the orderly installation of the modules in the MiC project, contributing to the smooth progress of the overall project schedule. Moreover, an efficient supervision system could be vigorously promoted to record all processes of modules effectively and improve punctuality and productivity by maintaining better control over the construction quality, thereby contributing to better performance and further adoption of MiC. It is believed that with the technological advancement supported by the policy, MiC will have a promising prospect.

Formulate explicit standards and guidelines for MiC

To date, there are still no authoritative and mature standards and specifications that can guide practitioners to become proficient at using the modular construction approach (Xu et al., 2020). Inappropriate design codes and standards for MiC buildings were even listed by Luo et al. (2015) as one of the top five risk factors affecting practitioners' attitudes toward MiC implementation. In practice, many practitioners also expressed their opinions in this regard during the interview; that is, the standards and procedures of the MiC project urgently need clear rules and regulations to provide guidance, among which the review of statutory submissions related to MiC is also mentioned in addition. In this regard, Hong Kong should actively learn from Singapore, which has established a relatively comprehensive policy system to promote the adoption of MiC in the construction industry (Xu et al., 2020). In addition, while requiring buildings to use prefabricated components to achieve buildability, Singapore has closely integrated this requirement with its promulgated series of policies, standards and regulations (Chiang et al., 2006; Mao et al., 2018). In general, it is necessary to define clear standards and guidelines for MiC.

Promote further implementation of relevant policies in the Great Bay Area

A complex cross-border transportation process is a unique feature of MiC in Hong Kong that is different from other places. Land resources available in Hong Kong are limited. The suppliers have established manufacturing plants within the Great Bay Area as it is economical due to the lower cost of labour and land (Luo et al., 2019). From the results of factor analysis in Chapter 4, the relevant Great Bay Area policies are of great significance to the uptake of MiC, while their influence is not so considerable in the policy scenarios analysis of the SD model. Comprehensive analysis of the reasons: First, due to the difference in sample size, this SD model was established based on existing project data, while the previous factor analysis was to integrate the insights of experts and scholars in a large scope; Second, the project model is based on the status quo and is a short-term reflection, while the large-scale questionnaire survey and interviews represent long-term effects. It can also be seen that, at the present stage, the relevant Greater Bay Area policies have not been fully put into practice, leading to a lack of in-depth perception of them by many practitioners. However, in reality, from the perspective of long-term development, they will have a great impact on the uptake of MiC, so the government should make efforts to accelerate their implementation.

6.7 Summary of the Chapter

This chapter describes a step-by-step process in the development of the SD model to simulate the dynamic impacts of the initiation, planning and design and construction phases, as well as their associated PDFs, on the overall MiC uptake in Hong Kong. The model was established with the help of Vensim PLE software, including a causal loop diagram and a stock-flow diagram, in which the latter is converted from the former by means of mathematical equations. Five model testing and validation were conducted to ensure that the constructed model can substantially reflect the accuracy of the actual conditions in a reasonable mode. Two case studies of MiC buildings under construction in Hong Kong are applied to perform base run simulation, from which the newly built public MiC housings can be concluded to be influenced by all critical PDFs. Various scenarios are simulated to evaluate the impact of each PDF on the overall MiC uptake. The results imply that the PDFs in the initiation phase have the greatest impact on the overall uptake of MiC, followed by the construction phase. The PDFs in the planning and design phase have the least impact. The impact of all critical PDFs during the initiation, planning and design and construction phases are evaluated separately. The analysis suggests that Regulative PDF has the highest tendency to enhance MiC uptake in each phase. PDFs related to the COVID-19 pandemic crisis confrontation, macro housing policy, the preferential interest of MiC project, MiC technological support and innovation, authoritatively designed standards, codes and guidelines for MiC and Greater Bay Area development policies have higher significance in promoting MiC uptake compared with other PDFs. In response to the preceding points, and based on the outcomes of case simulation combined with the expert opinions from interviews, this study proposes six specific recommendations for improving MiC uptake: (1) boost MiC adoption in buildings under emergencies (e.g. COVID-19 pandemic), (2) expand MiC adoption in public housing and encourage its application in private buildings, (3) provide additional GFA exemption for MiC projects, (4) enhance information technology support across the supply chain, (5) formulate explicit standards and guidelines for MiC and (6) promote further implementation of relevant policies in the Greater Bay Area.

Chapter 7 Conclusions

7.1 Introduction

This chapter summarises the main information of the entire research and draws conclusions. Firstly, the research aim and three objectives presented at the beginning are revisited to assess whether they have been fully realised. Thereafter, the key findings obtained from this study are summarised, accompanied by an emphasis on the research implications and its contributions towards the existing body of knowledge and the construction industry. Finally, based on the research limitations faced, further research directions are revealed and discussed.

7.2 Review of Research Objectives

The principal aim of this study is to understand the complexity of policy-driving forces and their impacts on MiC uptake and to formulate appropriate measures for improving the MiC policy-making in Hong Kong. To realise this aim, this research progressively pursues three specific objectives as follows:

(1) To identify and examine critical PDFs across major MiC project phases: initiation, planning and design, and construction;

(2) To investigate the interactions between critical PDFs and stakeholders at different MiC project phases in Hong Kong and

(3) To propose appropriate measures to improve policy-making for the overall MiC uptake via developing a system dynamics model to simulate and assess the

potential impact of critical PDFs.

Chapter 2 scrutinises the industry development situation of MiC in Hong Kong and reviews all relevant studies published in peer-reviewed journals, thereby providing the necessary theoretical basis for the determination of the research problem and its solutions. Chapter 3 details the theories and application of research methods and data analytical tools, which are utilised to accomplish the research objectives. These two chapters lay a solid foundation for further investigation.

To realise the first objective, critical PDFs associated with MiC projects in Hong Kong from the perspective of industry experts are identified and examined in Chapter 4. Extensive relevant literature reviews, a pilot study and an expert opinion survey were conducted to gather the necessary data for this study. Meanwhile, correlation significance analysis and factor analysis are adopted for data analysis, which is conducive to understanding critical PDFs with their appropriate groupings in the three phases of the MiC process.

To achieve the second objective, the interrelationships between relevant stakeholders and identified critical PDFs in each of the three phases (i.e. initiation, planning and design, construction) are carefully explored in Chapter 5. Expert interviews are conducted to quantify the relationships. Meanwhile, SNA is applied to visualise two-mode networks and perform quantitative analysis, which is beneficial for understanding interactions within the networks by prioritising the prominent positions of stakeholders and relevant PDFs associated with each phase from a network perspective.

To accomplish the third objective, a system dynamics model incorporating critical PDFs is proposed to simulate and assess their impact on the overall MiC uptake in Hong Kong in Chapter 6. Questionnaire survey, expert interviews and case studies are conducted to determine the fundamental variables and their relationships within the model. Meanwhile, system dynamics is adopted for model development, base run simulation and policy scenarios analysis, thereby facilitating the formulation of specific recommendations to improve MiC uptake in Hong Kong. On the one hand, the SD model reflects the complexity of its associated PDFs in all phases (initiation, planning and design, construction) of MiC. On the other hand, the dynamic model depicts how the overall MiC uptake is affected by dynamically critical PDFs in each phase.

7.3 Summary of Research Findings

By accomplishing the three objectives, the key research findings scattered throughout this study are summarised as follows.

Firstly, Stages I (initiation phase), II (planning and design phase), and III (construction phase) have 12, 12 and 23 optional PDFs, respectively, generated from comprehensive literature review and professional interviews. A total of 85 questionnaire responses from industry experts in MiC projects in Hong Kong are collected, and the results enable the ranking of critical PDFs for the success of MiC projects in Hong Kong in terms of their importance. In Stages I, II and III of the MiC processes, 7, 6 and 10 critical PDFs, respectively, are identified during the data analysis through data normalisation and factor analysis. Thereafter, identified critical PDFs are grouped into seven components in three stages through factor analysis. Stage I includes two components, namely, Promotional and Sustainable PDFs (i.e. preferential interest of the MiC project, taxation reduction, investment to MiC projects, environmental protection and publicity of MiC) and Regulative PDFs (macro housing policy and COVID-19 pandemic crisis confrontation). Stage II includes Sustainable PDFs (construction waste disposal charging scheme, micro-housing policy (restriction on the type and size of property development), environmental protection) and Regulative PDFs (proportion of prefabrication in public housing projects, COVID-19 pandemic crisis confrontation and procurement system). Stage III has three components, namely, Greater Bay Area development PDFs (customs clearance facilitation in GBA (e.g. facilitate personnel exchange and enhance the flow of goods), transportation and logistics in GBA (e.g. expedite cross-boundary infrastructural connectivity) and globally competitive modern industrial system and jointly cooperation platforms establishment in GBA (e.g. accelerate the flow of data and information), Technical and Regulative PDFs (authoritatively designed standards, codes and guidelines for MiC, expanded scope/type of the prefabricated elements and components, MiC technological support and innovation, COVID-19 pandemic crisis confrontation) and Promotional PDFs (finance support, quality acceptance standard for project completion, and boost to the sale of the MiC buildings).

Secondly, relevant stakeholders involved in the three phases of MiC projects in Hong Kong are identified based on literature review and real case studies, amongst 10, 14 and

31 stakeholders are included in Stages I, II and III, respectively. Three two-mode networks at different stages are established after assessing the interactions between critical PDFs and relevant stakeholders through interviews with professionals. The visualisation of PDF-stakeholder networks is displayed via *NetMiner 4.4.3.g*. Moreover, six indicators (degree, degree centrality, node betweenness centrality, link betweenness centrality, closeness centrality and eigenvector centrality) are measured in the two-mode network quantitative analysis, from which critical stakeholders and their relations with critical PDFs could be derived. The results of the two-mode SNA reveal the most important PDFs in each stage and the key stakeholders associated with them. The environmental protection policy (A12), COVID-19 pandemic (B1) and construction waste disposal charging scheme (B6) and quality acceptance standard for project completion (C22) are considered the most important PDFs in Stages I, II and III, respectively. The government of the Hong Kong SAR (S1) and developers/clients (S3) are highlighted, and have the greatest influence on the implementation of policies and play the most important role in the development of stakeholder collaboration in the three stages. The dynamic changes and impact of stakeholders under the influence of critical PDFs at different stages of MiC are discussed. Particularly, as the MiC project progresses, the interrelationships between designers/architects/urban planners (S4), consultants (S5) and NGOs/local communities (S11) and relevant critical PDFs are strengthened. Interaction and connection between the general public (S7), media (S8) and industry institutions (S10) and related critical PDFs are diminished. The influence

of research institutions (S9) remains relatively steady. In the construction phase, manufacturer (S18), main contractors (S15), sub-contractors (S16) and the Guangdong Province government (S2) are added to form the core authority. From the perspectives of different stakeholders, valuable recommendations are also proposed on improving the application and practicality of modular buildings in Hong Kong in terms of policies. The government is optimistic that under leadership, industry institutions are willing to respond, and developers, contractors and suppliers are willing to take the initiative to participate and jointly promote MiC immediately. For developers/clients, particularly private developers, their consideration of cost and profit, in addition to some mandatory policy requirements, leads them to expect to be given continuous preferential policies or financial support to the units applying MiC technology. Additionally, they look forward to the designated policies tailored to local conditions in the Greater Bay Area. Manufacturers, main contractors, and sub-contractors, in addition to financial support and policy incentives, are also optimistic about having a sound reputation incentive mechanism to help them with their considerable long-term development.

Thirdly, the SD model is established with the help of *Vensim PLE* software, including causal loop and stock-flow diagrams. Two case studies of MiC buildings under construction in Hong Kong are applied to perform base run simulation, from which the newly built public MiC housings can be concluded to be influenced by all critical PDFs. Moreover, the impact on large-scale buildings will be substantial and long term. Various scenarios are simulated to evaluate the impact of each PDF on the overall MiC uptake.

The results imply that the PDFs in the initiation phase have the greatest impact on the overall uptake of MiC, followed by the construction phase. The PDFs in the planning and design phase have the least impact. The impact of all critical PDFs during the initiation, planning and design and construction phases are evaluated separately. The analysis suggests that Regulative PDF has the highest tendency to enhance MiC uptake in each phase. PDFs related to the COVID-19 pandemic crisis confrontation, macro housing policy, the preferential interest of MiC project, MiC technological support and innovation, authoritatively designed standards, codes and guidelines for MiC and Greater Bay Area development policies have higher significance in promoting MiC uptake compared with other PDFs. In response to the preceding points, this study proposes six specific recommendations for improving MiC uptake: (1) boost MiC adoption in buildings under emergencies (e.g. COVID-19 pandemic), (2) expand MiC adoption in public housing and encourage its application in private buildings, (3) provide additional GFA exemption for MiC projects, (4) enhance information technology support across the supply chain, (5) formulate explicit standards and guidelines for MiC and (6) promote further implementation of relevant policies in the Greater Bay Area.

7.4 Contributions of the Research

The theoretical and practical contributions of this research to the body of knowledge and the construction industry are reflected in the following aspects.

7.4.1 Theoretical contributions to knowledge

Firstly, this research identifies and examines critical PDFs associated with MiC projects during their relevant phases (initiation, planning and design, construction) in Hong Kong from the perspective of industry experts. After conducting relevant significance and factor analyses of the collected data from the questionnaire survey, this study fills in the current research gap that lacks a systematic quantitative analysis method for investigating policy-driving forces in MiC through the major MiC project phases. A total of seven components, including 23 critical PDFs in the three phases of the MiC process, are explained in detail, providing a more comprehensive implication compared with other studies that have analysed individual construction phases. The current study reveals the pattern of a series of policy drivers for MiC uptake in the Hong Kong market, thereby laying a solid foundation for MiC policy-oriented research and contributing to the current body of knowledge through an in-depth understanding of MiC from the perception of industry specialists.

Secondly, this study investigates the interrelationships between critical PDFs and their associated stakeholders in MiC projects in each of the three phases, revealing the dynamic fluctuations of these interactions across the major project phases- initiation, planning and design, and construction. Given that multiple stakeholders involved in construction projects are closely related to the successful implementation of specific policies and regulations, the underlying relationships between stakeholders and detailed PDFs, particularly in MiC projects, should be further explored. By adopting the SNA approach on the empirical information from interviews with professionals, this study addresses the limitations of previous research, namely, analysing the priority of stakeholders and critical factors through a direct ranking method or directly linking stakeholders with risks/key success factors. Moreover, the most prominent PDFs and stakeholders in each phase are indicated, and the core stakeholder structure in the construction phase is discussed. This study shows the structure and pattern of the complex network interrelations between stakeholders and critical PDFs in different stages. Additionally, this research contributes to the body of knowledge by providing an in-depth insight into stakeholder management and network analysis in the MiC domain.

Thirdly, this research applies the SD technique to comprehensively assess the dynamic impacts of critical PDFs on the overall MiC uptake in Hong Kong in various phases. An SD model is established to portray various critical PDFs and their relationships, along with simulating how they influence the MiC uptake in Hong Kong individually and partly combined. Prior to this study, predicting from a dynamic point of view how policy drivers would affect the overall MiC uptake was difficult. Therefore, this dynamic model can serve as an innovative tool for understanding the dynamic impacts of critical PDFs. The policy scenario analysis suggests that the initiation phase has the greatest impact on the overall uptake of MiC, followed by the construction phase. The planning and design phase has the least impact. Regulative PDF has the highest tendency to enhance the MiC uptake in each phase, with Promotional PDF and

Technical PDF also attracting attention. This study proposes six recommendations for high-impact PDFs to enhance the MiC uptake in Hong Kong, thereby deepening the comprehension of policy implementation from an objective perspective.

7.4.2 Practical contributions to the construction industry

Firstly, the identified critical PDFs under seven appropriate components for MiC uptake throughout all project phases would enable decision-makers to grasp key policy drivers in the context of Hong Kong, thereby furthering the development of MiC from a policy perspective. These findings also provide evidence-based pointers for policymakers and researchers to better understand and initiate promotional policies for the adoption of MiC practice in Hong Kong as policy support becomes mandatory, contributing the applicable knowledge of MiC to the industry.

Secondly, this research assists the involved practitioners in MiC to gain insight into the interrelationships between critical PDFs and relevant stakeholders, leading to an improved understanding of the impacts of policy drivers on stakeholders and how stakeholders adopt policies. Valuable recommendations are proposed for improving the application and practicality of modular buildings in Hong Kong in terms of policies from the perspectives of different stakeholders, such as the government, developers/clients, industry institutions, manufacturers, main contractors, sub-contractors and the general public.

Thirdly, the proposed SD model provides a practical tool for policymakers to identify, simulate, analyse and evaluate critical PDFs that have a high significance in promoting

MiC uptake in each phase. Additionally, this model is beneficial for the government to test the effectiveness of MiC promotion strategies prior to implementing them. By applying the developed model, various policy scenarios can be simulated, thereby enabling the proposal of specific recommendations to enhance the uptake of MiC in a scientific manner.

7.5 Research Limitations

Although this study provides theoretical and practical contributions to the field of MiC knowledge by filling in some research gaps, some perceptible limitations of this research should be noted to promote the further development and wide application of MiC.

Firstly, the major limitation of this study is the small sample size used for the survey. Only 85 valid sets of feedback were collected from the questionnaire survey, for a 40% valid return rate. The author has exerted extensive effort to distribute questionnaires and tried various methods to collect professional feedback from different organisations and backgrounds familiar with and involved in MiC in Hong Kong. Compared with other similar studies, the current sample size is not unduly small, given the relatively small population of MiC experts in Hong Kong, and the empirical data obtained are sufficient to support the developed outcomes. However, an improved response rate could facilitate improved generalisation of the results. Moreover, collecting additional empirical data can further enhance the interpretation and reliability of the conclusions, as well as strengthen the justifications for model verification in this study.

Secondly, the scope of this study is limited in terms of regions; therefore, the results would not be necessarily generalised for all the country contexts. Further, these policy drivers and implications are jurisdiction-specific, their levels of criticality would necessarily differ, but some interesting core commonalities may emerge. The proposed model is most suitable for Hong Kong and some developed countries with similar MiC development trajectories, such as Singapore, Japan and other regions. However, owing to the nature of policies and their dynamics varying across dissimilar industrial contexts and jurisdictions, additional scenario simulations and case studies should be widely applied in various regions to generate superior, applicable, compatible and robust results.

Thirdly, one source of weakness in this study that could have affected the measurements of PDFs is that data collection was performed during the COVID-19 pandemic. Additionally, the policy environment is changeable, indicating that the developed SD model should be improved through periodic review and monitoring of its dynamics to make appropriate adjustments in different periods. Therefore, similar SD modelling can be performed to determine the impact of policy-driving forces on MiC in Hong Kong after the COVID-19 pandemic (normal customs clearance and exchanges between Hong Kong and the Mainland). Note that the uptake of MiC may be correspondingly enhanced with improved conditions.

7.6 Further Research Directions

Despite the aforementioned limitations, valuable insights gained from this study may assist in the improvement of MiC uptake from a new perspective. Broadly, the present study lays a solid groundwork for future research as follows.

Firstly, PDFs studied in this research may not be the only PDFs that exist. Hence, the developed model should also be tested and verified using actual case studies to avoid unobserved biases. Given that modular buildings have recently received heightened global attention and interest, similar studies can be conducted in various countries and regions, such as Mainland China, to promote the vigorous development of the local modular construction industry.

Secondly, further research in this field could effectively explore in detail how policy-driving forces influence different processes in the construction phase, such as module production, transportation and on-site assembly. The reason is that this study examines PDFs of the project phases- initiation, planning and design, and construction from a holistic perspective, whilst the details of the construction phase remain worthy of further investigation.

Thirdly, given that the SD model in this study treats the MiC uptake as a system whilst disregarding the stakeholders involved in the entire process, future research can consider developing a hybrid dynamic model that combines SD and agent-based modelling to simulate PDFs in MiC. In this hybrid dynamic model, SD can be applied to model PDFs, whilst agent-based models can be used to model the stakeholders involved.

Lastly, post-COVID19 industrial regulations and policy interventions under a ‘new normal’ should be explored in future research to offer timely recommendations.

Appendix A: Questionnaire

A survey on policy-driving forces for the Uptake of Modular integrated Construction in Hong Kong

Letter to Participants

Invitation to participate in the research on ‘Modelling Policy-Driving Forces for the Uptake of Modular integrated Construction in Hong Kong’

To whom it may concern

Dear Sir/Madam

I would like to wish you a very Happy Day!

As a respected practitioner with extensive knowledge of policy management and **Modular integrated Construction (MiC)** in Hong Kong, you are cordially invited to share your expertise to complete a questionnaire survey which is part of a Ph.D. research entitled ‘**Modelling Policy-Driving Forces for the Uptake of Modular integrated Construction in Hong Kong.**’ This study aims to examine the impact of the dynamic and interactive policy-driving forces (PDFs) on the different MiC phases in Hong Kong, and formulate appropriate measures thereafter to improve policy-making.

The Ph.D. research is sponsored by **The Hong Kong Polytechnic University’s Postgraduate Studentship** Scholarship and supervised by **Prof. Geoffrey Qiping Shen**.

I will be extremely grateful if you could spare around **15 minutes** of your time to complete this **online questionnaire**. Your much-needed opinions will be treated with strict confidentiality and used only for academic purposes.

Many thanks for your kind support. **Your views are valuable to the success of this Ph.D. research and the development of MiC policies in Hong Kong.** After the survey, we are willing to share a summary of the outcomes with you if you are interested.

I would be grateful if you could complete it within **one week**. Thank you again for your generosity in assisting my Ph.D. study. Please feel free to contact me if you have any inquiries.

Online Survey Link: https://forms.gle/TJdSDffXqsrpmw9h7

Warm Regards,

……………………………………

JIN Xin, Verna, Ph.D. Candidate
Department of Building and Real Estate
Faculty of Construction and Environment
The Hong Kong Polytechnic University, Hong Kong

Tel: 3400 8138

Policy-Driving Forces for MiC Uptake in Hong Kong – Questionnaire Survey

Please tick ("x") to indicate your opinions.

<u>Information of Participants (Subject matter experts)</u>

1. Your current professional affiliation:

☐ Public sector ☐ Private sector ☐ Both

2. Working organisation:

☐ Government ☐ Client ☐ Main Contractor ☐ Manufacturer
☐ Transporter ☐ Designer ☐ Consultant ☐ Related Researcher
☐ Supplier of materials/equipment ☐ Others, please specify:____________

3. Your working/research experience in the construction industry in Hong Kong:

☐ 5 years or less ☐ 6-10 years ☐ 11-15 years
☐ 16-20 years ☐ 21 years or more

4. Education background:

☐ Doctoral ☐ Master's ☐ Bachelor's ☐ Other

5. Current position in the organisation:

☐ Director ☐ Senior Manager ☐ Manager ☐ Other Staff

Question:

Part I: **Occurrence Possibility of PDFs**. What is the degree of probability of a specific policy-driving force occurring during the relevant MiC project phases?
Number 1= not possible at all; 2= impossible; 3= neither possible nor impossible; 4= possible; 5=highly possible.

Part II: **Impact Degree of PDFs**. When the policy-driving force occurs, to what extent is the specific MiC-related policy-driving force affect the successful implementation of MiC projects in the relevant phase.
Number 1= not influential at all; 2= uninfluential; 3= neither influential nor uninfluential; 4= influential; 5=highly influential.

Stage I: Initiation Phase (including potential prefabricated project identifying, financial analysis, feasibility study report preparing and decision-making)

	Policy-Driving Forces	**Occurrence Frequency and Impact**									
A-		***Occurrence Possibility*** 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2	Change of the Government policy related to economic factors, such as the realisation of Micro-control, etc	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3	Change of the Government policy related to finance, such as interest rate and the extended repayment period	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4	Change of the Government taxation and revenue policy related to modular integrated construction, e.g. increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5	Change of the Government policy related to the preferential interest of the modular integrated construction project, such as it increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6	Change of the Government policy related to investment of the modular integrated construction project, e.g. investment increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7	Change of the Government policy related to the restriction of the property market, stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Adjustment of the Government policy related to housing policy, such as supportive	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9	Change of the Government policy related to land supply and usage, e.g. restriction or relaxation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10	Change of the Government policy related to the urban plan	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11	Change of the Government policy related to the publicity of modular integrated construction, e.g. increased promotion	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12	Change of the Government policy related to environment protection, more friendly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Stage II: Planning & Design Phase (including the acquisition of land use rights, project design and planning approval)

Policy-Driving Forces		**Occurrence Frequency and Impact**									
B-		***Occurrence Possibility*** 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2	Change of the Government policy related to the proportion of prefabrication in public housing projects, e.g. the proportion increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3	Change of the Government policy related to finance, such as influence to market increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4	Change of the Government policy related to taxation and revenue, such as them increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5	Change of the Government policy related to the preferential interest of the modular integrated construction project, such as it increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6	Change of the Government policy related to construction waste disposal charging scheme, e.g. stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7	Change of the Government policy related to site selection criteria for new precast manufacturing sites, such as stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Change of the Government policy related to housing policy, such as the restriction on the type and the size of property development	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9	Change of the Government policy related to land supply and usages, such as restriction or relaxation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10	Change of the Government policy related to urban planning policy, such as plot ratio, site coverage, height restriction and green ratio	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11	Change of the Government policy related to the procurement system, e.g. adding innovative	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12	Change of the Government policy related to environment protection, more friendly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Stage III: Construction Phase (including tendering of the project contractors, prefabricated modules design/manufacturing/transportation/on-site installation, other construction works, acceptance of the completed construction quality and project hand over)

	Policy-Driving Forces	**Occurrence Frequency and Impact**									
C-		***Occurrence Possibility*** 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2	Change of the Government policy related to prefabrication technological support and innovation, such as BIM, RFID	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3	Change of the Government policy related to finance, such as influence to the construction cost	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4	Change of the Government policy related to the construction material supply and price, e.g. them increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5	Change of the Government policy related to import of the construction material, such as importation increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6	Change of the Government policy related to construction waste disposal charging scheme, e.g. stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7	Change of the Government policy related to site selection criteria for new precast manufacturing sites, criteria are stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Change of the Government policy related to scope/type of the prefabricated elements and components, e.g. increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for modular integrated construction, more refined	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10	Change of the Government policy related to the multi-sector governance of modular integrated construction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11	Change of the Government policy related to the procurement system, adding innovative	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12	Change of the Government policy related to environment protection, more friendly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13	Change of the Government policy related to modular integrated construction tendering, e.g. the process is more open	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14	Change of the condition on modular integrated construction contracts, e.g. stricter requirement	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

15	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
16	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
17	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
18	Change of the Government policy related to the Mainland and Hong Kong Closer Economic Partnership Arrangement (CEPA) and Professional Services in Greater Bay Area, such as extending the scope of mutual recognition of qualifications for construction professionals	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
19	Change of the Government policy related to the restriction of the construction schedule	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
20	Change of the Government policy related to labour policy, protect labour interests	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
21	Change of the Government policy related to project/qualification supervision, e.g. stricter supervision	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
22	Change of the Government policy related to the standard of the acceptance of the completed construction quality, e.g. higher standard	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5
23	Change of the Government policy related to the sale of the modular integrated construction,e.g. more cost-effective trade	□ 1	□ 2	□ 3	□ 4	□ 5	□ 1	□ 2	□ 3	□ 4	□ 5

Would you have some suggestions/opinions related to the Policy aiming to promote the MiC in Hong Kong?

Please, if you would like to receive a summary of the research findings, kindly provide your NAME and the EMAIL address

Name:_________ **Email Address:__________**

-The end-

Please, thank you for your participation

Appendix B: Data Collection Guide for the Case Study

Case Study- HKU Student Residence Hall at Wong Chuk Hang/ BoxPod and OPod by James Law Cybertecture Architects

Invitation to participate in the research on 'Modelling Policy-Driving Forces for the Uptake of Modular integrated Construction in Hong Kong'

Dear xxx,

I would like to wish you a very Happy Day!

As a respected practitioner with extensive knowledge of policy management and **Modular integrated Construction (MiC)** in Hong Kong, you are cordially invited to share your expertise to complete a questionnaire survey which is part of a Ph.D. research entitled **"Modelling Policy-Driving Forces for the Uptake of Modular integrated Construction in Hong Kong.**" The study aims to examine the impacts of the policy-driving forces (PDFs) on MiC projects and to develop a dynamic model for simulating and assessing the potential impacts of the critical PDFs on the overall uptake of MiC in Hong Kong.

The Ph.D. research is sponsored by **The Hong Kong Polytechnic University's Postgraduate Studentship** Scholarship and supervised by **Prof. Geoffrey Qiping Shen**.

I would be extremely grateful if you could spare around **5 minutes** of your time to complete this **questionnaire**. Your much-needed opinions will be treated with strict confidentiality and used only for academic purposes.

Many thanks for your kind support. **Your views are valuable to the success of this Ph.D. research and the development of MiC policies in Hong Kong.** After the survey, we are willing to share a summary of the outcomes with you if you are interested.

Thank you again for your generosity in assisting my Ph.D. study. Please feel free to contact me if you have any inquiries.

Warm Regards,

…………………………………

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Faculty of Construction and Environment
The Hong Kong Polytechnic University, Hong Kong

Tel: 3400 8138

Modelling Policy-Driving Forces for MiC Uptake in Hong Kong

Please tick ("x") to indicate your opinions.

<u>Information of Participants (Subject matter experts)</u>

1. Your current professional affiliation:

☐ Public sector ☐ Private sector ☐ Both

2. Working organisation:

☐ Government ☐ Client ☐ Main Contractor ☐ Manufacturer
☐ Transporter ☐ Designer ☐ Consultant ☐ Related Researcher
☐ Supplier of materials/equipment ☐ Others, please specify:____________

3. Your working/research experience in the construction industry in Hong Kong:

☐ 5 years or less ☐ 6-10 years ☐ 11-15 years
☐ 16-20 years ☐ 21 years or more

4. Education background:

☐ Doctoral ☐ Master's ☐ Bachelor's ☐ Other

5. Current position in the organisation:

☐ Director ☐ Senior Manager ☐ Manager ☐ Other Staff

Question:

Part I: **Occurrence Possibility of PDFs**. What is the degree of probability of a specific policy-driving force occurring during the relevant MiC project phases?
Number 1= not possible at all; 2= impossible; 3= neither possible nor impossible; 4= possible; 5=highly possible.

Part II: **Impact Degree of PDFs**. When the policy-driving force occurs, to what extent is the specific MiC-related policy-driving force affect the successful implementation of MiC projects in the relevant phase.
Number 1= not influential at all; 2= uninfluential; 3= neither influential nor uninfluential; 4= influential; 5=highly influential.

Stage I: Initiation Phase (including potential prefabricated project identifying, financial analysis, feasibility study report preparing and decision-making)

	Policy-Driving Forces	**Occurrence Frequency and Impact**									
A-		***Occurrence Possibility*** 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4	Change of the Government taxation and revenue policy related to modular integrated construction, e.g. increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5	Change of the Government policy related to the preferential interest of the modular integrated construction project, such as it increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6	Change of the Government policy related to investment of the modular integrated construction project, e.g. investment increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Adjustment of the Government policy related to housing policy, such as supportive	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11	Change of the Government policy related to the publicity of modular integrated construction, e.g. increased promotion	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12	Change of the Government policy related to environment protection, more friendly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Stage II: Planning & Design Phase (including the acquisition of land use rights, project design and planning approval)

B-	**Policy-Driving Forces**	**Occurrence Frequency and Impact**									
		Occurrence Possibility 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2	Change of the Government policy related to the proportion of prefabrication in public housing projects, e.g. the proportion increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6	Change of the Government policy related to construction waste disposal charging scheme, e.g. stricter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Change of the Government policy related to housing policy, such as the restriction on the type and the size of property development	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11	Change of the Government policy related to the procurement system, e.g. adding innovative	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12	Change of the Government policy related to environment protection, more friendly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Stage III: Construction Phase (including tendering of the project contractors, prefabricated modules design/manufacturing/transportation/on-site installation, other construction works, acceptance of the completed construction quality and project hand over)

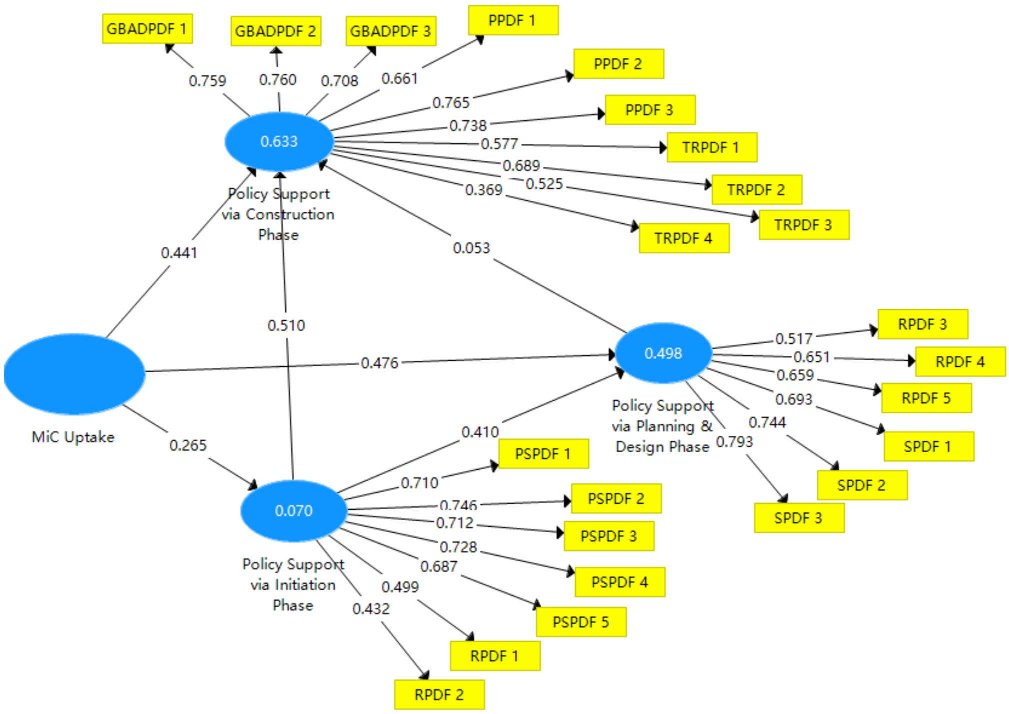
	Policy-Driving Forces	**Occurrence Frequency and Impact**									
C-		***Occurrence Possibility*** 1= not possible at all to 5= Highly possible					***Impact Degree*** 1= not influential at all to 5= Highly influential				
1	Change of the Government policy related to COVID-19 pandemic, the COVID-19 causes stricter policies	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2	Change of the Government policy related to prefabrication technological support and innovation, such as BIM, RFID	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3	Change of the Government policy related to finance, such as influence to the construction cost	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8	Change of the Government policy related to scope/type of the prefabricated elements and components, e.g. increased	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9	Change of the Government policy related to the authoritatively designed standards, codes and guidelines for modular integrated construction, more refined	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15	Change of the Government policy related to the customs clearance facilitation in Greater Bay Area, such as facilitating personnel exchange and enhancing the flow of goods	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16	Change of the Government policy related to the transportation and logistics in Greater Bay Area, such as expediting cross-boundary infrastructural connectivity	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
17	Change of the Government policy related to building a globally competitive modern industrial system and jointly cooperation platforms in Greater Bay Area, such as flow of data and information	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
22	Change of the Government policy related to the standard of the acceptance of the completed construction quality, e.g. higher standard	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
23	Change of the Government policy related to the sale of the modular integrated construction, e.g. more cost-effective trade	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Would you have some suggestions/opinions related to the Policy aiming to improve the success of this MiC project in Hong Kong?

-The end-

Please, thank you for your participation

Appendix C: PLS-SEM Model



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