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Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore

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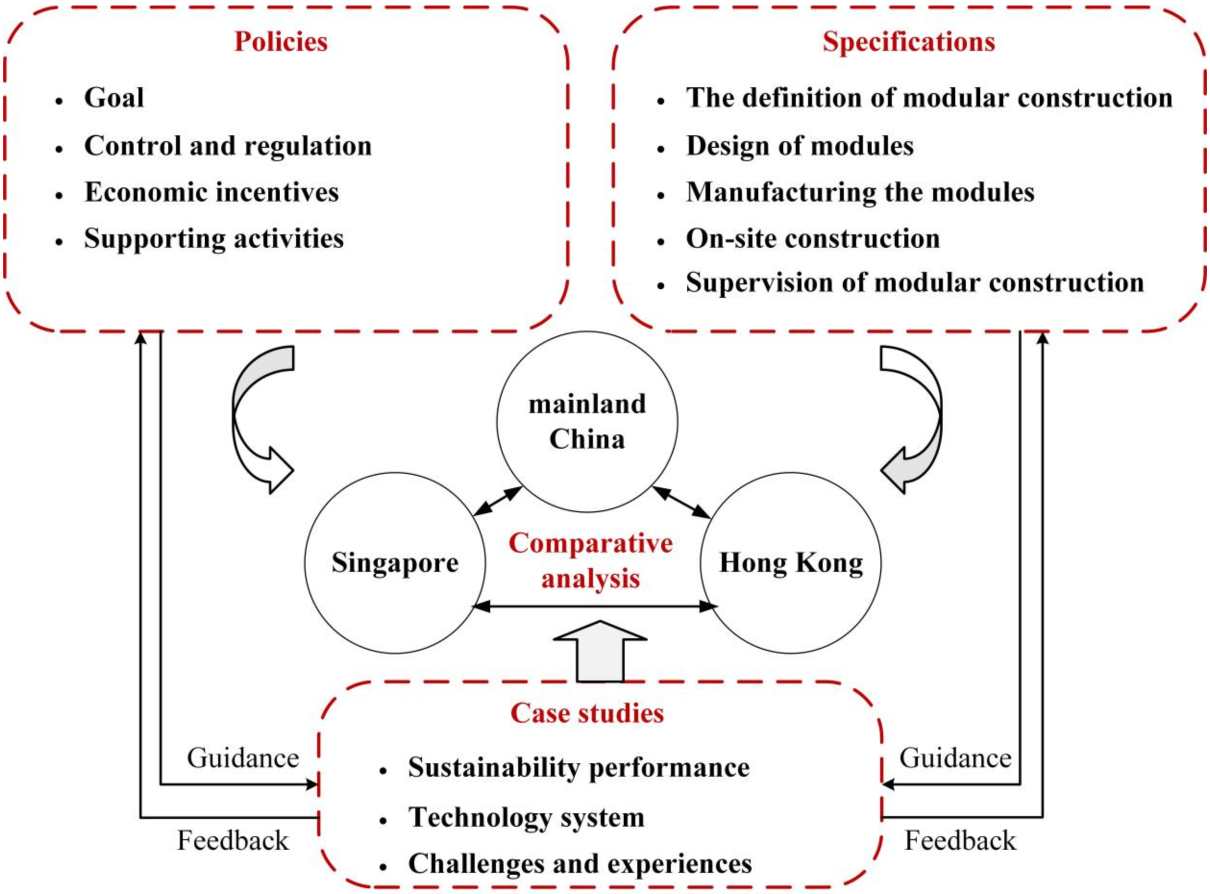
Graphical Abstract



ABSTRACT:

Modular construction is considered as the future of the construction industry. While the sector is growing rapidly in some areas, there are still barriers to overcome. For more than two decades, several regions and countries, such as mainland China, Hong Kong, and Singapore, were using prefabricated / precast components to construct high-rise buildings in both private and public sectors. Such practices suffered from several limitations, which warrant the need for modular construction. Modular construction method needs to evolve so as to meet different regional requirements and restrictions, namely regulations, economy, market and building types. But the regional requirements and constraints on adopting modular construction remain unexplored. These differences are not widely appreciated. Hence, this research aims to perform comparative analysis of modular construction practices in terms of policies, specifications, and real projects in Hong Kong, Singapore, and mainland China. The results of the comparative analysis indicate that Singapore has developed a relatively effective policy system to help the construction industry embrace modular construction, while the three regions have not issued authoritative specifications. In general, modular construction still needs more support from the government, especially in terms of technical guidance and innovation. Cases studies show that the sustainability performance of modular construction is not balanced in terms of the economic, social and environmental dimensions. The lessons and challenges of modular construction drawn from the cases are also summarized. The construction industry should work closely with the government to achieve sustainable construction of modular building. The developed research on modular construction will increase the understanding of common practices in close

countries where the industry in each can benefit from such practices to advance the domain.

Key words: comparative analysis; modular construction; case studies; policies; specifications

1 INTRODUCTION

For more than two decades, several countries and regions, such as Hong Kong, Singapore, and mainland China, were using prefabricated / precast components to construct high rise buildings in both private and public sectors (Jaillon and Poon, 2009; Xu et al., 2015). The prefabricated / precast components improve the quality and reduce waste and construction duration when compared to traditional construction techniques (Jaillon and Poon ,2009 & 2014; Li et al., 2014; Abdul Rahim and Qureshi, 2018; Lu et al., 2018).

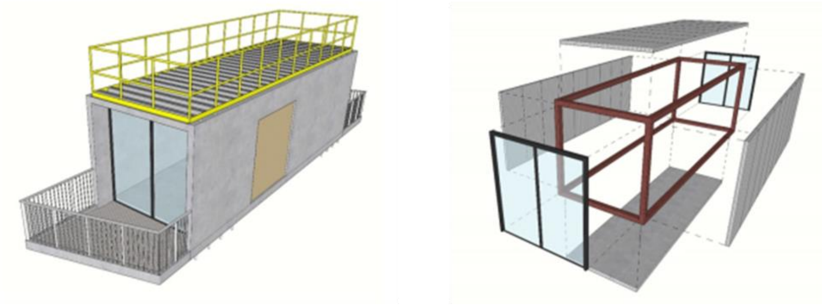
However, prefabricated / precast components face ineffective assembly management due to limited site conditions, poor communication among project stakeholders, and technical issues. These technical issues include water seepage from widows and bathrooms, improper connection and fittings between prefabricated / precast components, inaccuracy of manufactured component sizes, and incompatibility of design and the actual manufactured components (Li et al., 2016a&b; Tam et al., 2015; Abdul Rahim and Qureshi, 2018).

Therefore, due to the above-mentioned limitations of the prefabricated / precast components, the government and industry of Hong Kong and Singapore are lenient towards complete building modules or elements, which are called MiC in Hong Kong or Prefabricated Prefinished Volumetric Construction (PPVC) in Singapore. Modular construction can reduce the construction time and labor-intensive activities, minimize disruption to the adjacent services, improve the quality and increase the productivity as well as sustainability. Modular construction is gradually adopted as one of the significant means to embrace productivity. At least 15 projects adopted PPVC in Singapore (Ho et al., 2019). Three large-scale projects of modular construction have been completed and two projects are under construction in mainland China. In Hong Kong, no modular building has not yet completed, but two public projects have decided to pilot the MiC technology in response to the Policy Agenda.

Although some projects have already constructed by modular construction technology, modular construction is still not the mainstream. On one hand, the popularity of modular construction is related to the performance in real projects, and on the other hand, it depends on the government's implementation. The practices of government provide greatest impetus for the adoption of modular construction. However, little literature attempted to explore practices covering both the government and the construction industry. As a result, this research aims to perform comparative and content analyses of modular construction in terms of practices, policies, developments, specifications, and real case study projects in Hong Kong, Singapore, and mainland China. The government practices focus on policies and specifications. Meanwhile, case studies analyze sustainability performance, technology system, and challenges. Besides, this paper conducts a comparative study among Singapore, Hong Kong and mainland China to explore regional requirements and challenges. Hence, this research can contribute to improve the understating of practices in each country and advance the learning process. Meanwhile, the lessons deprived from the practices of three regions can provide insightful recommendation to close countries on the implementation of modular construction.

2 LITERATURE REVIEW

Modular construction comprises prefabricated room-sized volumetric units that are normally fully fitted out in manufacture and are installed on site as load-bearing ‘building blocks’ (Lawson, 2009). The modules can broadly be classified into reinforced concrete, steel and wooden modules. The typical reinforced concrete and steel modules are shown in Figure 1(a) and 1(b).



(a) (b)

Figure 1:(a) concrete module, (b) steel module (image via the BCA, 2019)

Recently the modular construction has aroused wide attention from various countries. This widespread interest could be categorized into four topics, namely, (1) Performance evaluation, (2) Technology system, (3) Challenges and recommendations, and (4) Practices of government and construction industry.

2.1 Performance evaluation

The lack of understanding of the benefits of off- site construction contributes to the low market share. Therefore, some studies made efforts on quantitatively evaluating the performance of modular buildings and comparing it with traditional buildings. Literature on the first theme, “Performance of evaluation”, mainly focuses on the time, economic, social and environmental performance.

Although the degree of time reduction varies depending on the type, size, and complexity of the project, the time-reduction benefits of the modular construction have been amply demonstrated in multiple cases. For example, Ho et al. (2019) and Rahman and Sobuz (2018) argued that PPVC projects are anticipated to reduce construction duration by 2– 6 months. Hammad et al. (2019) indicated that modular construction can cut down the construction duration by about 40% compared with conventional construction.

The economic factor remains a major concern for the practitioners of construction industry (Hong, 2018). Lopeza & Froese (2016) showed modular construction method is more cost-effective than panel prefabrication. However, Ho et al. (2019) argued that the modular construction might increase the cost by the ranges of 10% - 20% and 15% - 25% for concrete and steel PPVC, respectively. Ho et al. (2019) also reported that the saving in costs due to reduction in construction time might be counterbalanced by the cost of large variation in modules sizes, transportation, special crane that carry 25 – 30 tons, factory and holding yards, site supervision and quality control to assure compliance with industry codes.

Social performance evaluation of buildings, especially modular buildings, are still lacking. Liu & Qian (2019) indicated that the social sustainability of modular building is superior to that of semi-prefabrication building. The modular construction has obvious advantages on the worker’s health and safety, but the advantages are not significant in most indicators.

Environment is one of the most important dimensions in the assessment of sustainable construction. Tavares et al. (2019) investigated the energy consumption and greenhouse gas emissions of a modular home by a “cradle-to-site” analysis, as well emphasized the transport-related impacts that may jeopardize the potential benefits for overseas locations. Quale et al. (2012) figured out that the impacts of modular construction were lower on average than that of conventional construction, but the gaps were varied within each. Compared with conventional housing, modular home reduced energy consumption by 4.6% and greenhouse gas emissions by 3% over a 50-year life cycle that excludes replacement and the end-of-life phases (Kim, 2008)

Sustainability construction performance is indispensable for achieving sustainable development (Shen et al., 2007). The Triple Bottom Line (TBL) model, including social, environmental and economic dimensions, is widely accepted to assess the sustainability performance (Berardi, 2013). Kamali and Hewage (2016) revealed that the researches concerning the life cycle performance of modular construction mainly focused on the environmental performance of modular construction. There were gaps in the literature covering all the dimensions of sustainable construction (i.e., economic, environmental, and social) in modular construction environment. The absence of a generalized framework made it difficult to decide the appropriate construction method among different methods (Kamali & Hewage, 2017). Hence, researches on the triple bottom line of sustainability performance of modular construction have become an increasing trend. For example, Kamali & Hewage (2017) established the sustainability evaluation indicators which is composed of economic indicators, social indicators and environmental indicators. Hammad (2019) proposed a building information modelling-based decision support tool to compare modular and conventional construction through quantifying certain economic, social and environmental factors.

2.2 Technology system

Researchers have made extensive efforts in connection system (Chen et al., 2017, Sanches et al., 2018), lateral force-resisting system (Hong, 2011) and seismic design (Annan et al., 2009; Gunawardena et al., 2016; Fathieh and Mercan, 2016), to develop a more reliable high-rise modular system. There is pressure to apply exclusively modular structures to high-rise buildings due to poor wind-resisting system. Therefore, hybrid structures are common in high-rise modular buildings, such as, a platform or skeletal structure, or a concrete core (Lawson et al., 2012; Lacey et al., 2018). However, a new system presented by Gunawardena et al. (2016) was strategically placed stiff modules to replace the conventional core. Besides, installation and manufacturing tolerance is an urgent problem in the design of modular buildings (Lawson and Richards, 2010).

2.3 Challenges and recommendations

Despite the inherent superiority of modular construction, the implementation of modular construction faces many challenges, from planning and design to transportation, and assembly. Ho et al. (2019) and Abdul Rahim and Qureshi (2018) explored the defects in using modular construction technology, which can generally be categorized into the following seven perspectives, (1) lack of experience in how to design and install, (2) extensive coordination and organization from design to construction (e.g. complex procurement and contracting issues),

(3) additional transportation and logistics considerations, (4) higher construction costs, (5) complex inspection and code compliance, (6) massive design work and minimal changes, and (7) lack of understanding of modular construction's benefits among developers. Besides, few other management issues are arising from the usage of modules, such as progress payment framework, new procurement and business model, coordination among stakeholders, oversize heavy truck transportation, and intellectual property of PPVC modules (Rahman and Sobuz, 2018; Ho et al., 2019).

In addition to the challenges mentioned above, each region faces respective challenges due to different environments when adopting modular construction.

In Hong Kong, the harsh weather conditions and environment make design and construction more complicated. The module connections should be able to carry the strong wind loads due to Typhoons and heavy rains. Singapore is a country with limited land resource and industrial capacity, so most modules are produced overseas and then imported into Singapore, which significantly increases the transportation cost (Hwang et al., 2018a). Moreover, Singapore strictly controls the movement of heavyweight vehicles (Land Transport Authority, 2016).

2.4 Practices of government and construction industry

In Singapore and Hong Kong, due to the local authority realizes the potential of modular construction, the practices mainly come from the public sector, while the implementation of modular construction in the private sector lags behind. Whereas, the corporations of mainland China are more motivated to promote modular construction. Consequently, existing modular construction practices of mainland China were found to be mainly confined to the private sector.

2.4.1 Modular construction in mainland China

In mainland China, Hua and Wang (2017) indicated that the application of modular building is gradually moving to multi-storey and high-rise buildings. Since 2007, enterprises began to introduce advanced modular construction techniques actively. Furthermore, the enterprises and scholars are working together to make the technological systems to fulfill statutory requirement of mainland China. Meanwhile related practice had been carried out since 2014 (Ren and Chen, 2018; Wang et al., 2014). The first project of modular buildings is composed of ten 18-storey public rental buildings in Zhenjiang, Jiangsu, whose gross floor area up to 134500 m^2. Nevertheless, as the modular construction is in the exploration stage in mainland China, the government has not proposed a specific term to describe the modular construction.

2.4.2 MiC in Hong Kong

In the mid-1980s, prefabrication along with standard modular designs were introduced into the public sector (Mak, 1998; Zhang, 2018). Recently, the HKSAR Government has been promoting MiC actively. As stated in the Policy Agenda, the HKSAR Government is determined to promote and lead the adoption of MiC. The Government injected $1 billion to set up Construction Innovation and Technology Fund (CITF) to encourage innovation in the construction industry. The adoption of modular construction in within the scope of the funding (Tam, 2018). Meanwhile, the Housing Authority is planning to adopt a modular construction approach in an elderly home project (Financial Secretary, 2019).

The MiC Display Centre firstly using MiC in Hong Kong demonstrates that modules' performances can comply with the relevant standards and regulations. Besides, two pilot projects are already in statutory process in response to the Policy Agenda (Financial Secretary, 2019).

2.4.3 PPVC in Singapore

At the outset, the construction industry in Singapore started using the prefabricated components since the 1980s (Ting and Jin, 2019). After long time using prefabricated components, the Singapore government represented by the Building and Construction Authority (BCA) decided to promote full fabrication module technology, which is called Prefabricated Prefinished Volumetric Construction (PPVC). The PPVC is the synonym terminology of modular construction that is used in other places, such as North America.

Since November 2014, using PPVC method is one of the land sales conditions in some selected land parcels (BCA, 2017b). The first PPVC project was constructed at the Nanyang Technological University (NTU). This project assembled 1,200 steel PPVC modules with a rate of 6 – 8 modules per day (Chain, 2018; Hwang et al., 2018; Ho et al., 2019). Private sector is also participating in the development and usage of PPVC. One example is the Changi Crowne Plaza Hotel extension project, which shortened the construction duration by 17% and labor by 40%; however, the cost was increased by 10-15% (Ho et al., 2019).

Generally, in Singapore, an increasing number of apartments, hotels, residential buildings, office buildings and industrial buildings are adopting PPVC method to build under the enthusiasm of local governments. In contrast, the development of modular construction in Hong Kong and mainland China lag behind Singapore in terms of both the number of project and the range of applications.

Most of the literature focused on performance evaluation, technology system, and identifying barriers and developing strategies. Less literature studied the practices of government and construction industry, especially policies and specifications which play an indispensable role in encouraging the construction industry to use innovative technologies. For example, prefabricated technologies were not popular in the private sector until the HKSAR Government encouraged the adoption of prefabricated materials by introducing gross floor area recessions (Tam et al., 2015). Therefore, it is imperative to examine the modular construction practices.

Nevertheless, these studies related to performance, technology system and challenges of modular construction provide a good reference to conduct case studies. Specifically, to make the case studies valuable, it should cover performance, technology system, challenges and lessons. According to the perspective of Kamali & Hewage (2016&2017), the dimensions of sustainable construction (i.e. economic, environmental, and social) must be considered during performance evaluation in order to fully reflect the performance of modular buildings. Besides, the results of the case studies can be compared with existing research and then further improve people's understanding of modular construction.

3 RESEARCH METHODOLOGY

Based on the above comprehensive literature review, it was further found that the practices of modular construction was kept unexplored particularly in Hong Kong and mainland China. This research intends to explore modular construction practices including policies, specifications and case study projects. This will enhance the understanding of modular construction practices and policies and assist in drawing lessons from the international practices. The qualitative Content Analysis method, which is used in an inductive way to provide knowledge and new insights, is suitable to analyze policies and specifications. However, the research will only be limited to describe how policies and/or standards are developed and implemented within a selected nation. Thus, in order to provide an informative study, the comparative analysis especially the gap analysis is employed to explore the practices among mainland China, Hong Kong, and Singapore. Comparative analysis is a common method used to holistically analyze the differences and similarities in policies (Ronchi et al., 2019; Rodrigues et al., 2017) and standards (Zhang et al., 2017) between different countries or regions. It is possible to improve the understanding of reality while maintaining the nature of practices (Seny Kan et al., 2015). It should be mentioned that the ultimate goal is not to identify an ideal system through the comparison, but to establish a broad framework that distinguishes the key policies and specifications concerning modular construction. It can also be used to clarify the similarity and differences between regional practices, which are valuable references for further research.

The utilized steps of content analysis include identification, description of content, and discussion (Elo and Kyngas, 2008). The overall research methodology is presented in Figure 2 as follows:

(1) In the data collection phase, policies and specifications related to modular construction were identified, deprived and coded. Relevant policies and specifications comprised the bases of

qualitative content analysis and comparative study.

(2) After identifying a total of 12 key policies, the policies were classified into goal, control and regulation, economic incentives, and supporting activities in order to describe the content. Comparative analysis is integrated into qualitative content analysis to further identify the gap, overlap or inconsistency between the three regions.

(3) Similarly, six specifications, which were highly related to modular construction, were analyzed and compared according to the construction process of modular buildings.

(4) The comparative analysis of real projects were conducted in the case studies, providing valuable experience to the construction industry. To be more specific and focused, this study only focused on high-rise building projects.

(5) According to the results of comparative analysis, the discussion explored the sustainability performance of modular buildings, the common and regional challenges, the effectiveness of policy system and the guidance of specifications.

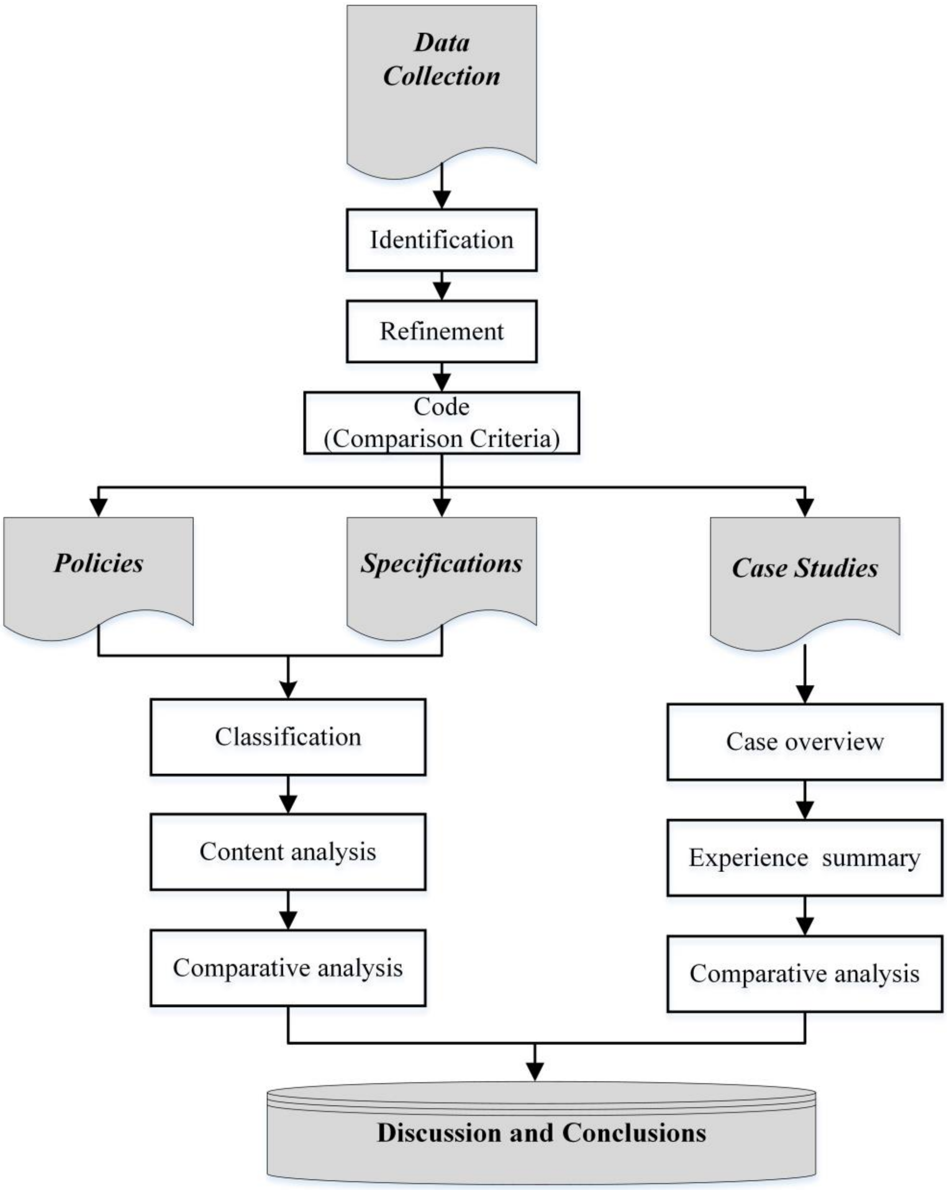


Figure 2: Overall Research Methodology

4 DATA COLLECTION

In order to discover how the government promotes the construction industry adopt modular construction and further explore their similarity and differences among three regions, a data collection on policies and specifications related to modular construction is developed.

4.1 Policies

It is noted that no policy confines the modular construction is released in mainland China.

However, there are many policies on generic off-site construction, which are also applicable to modular construction to a certain extent. To facilitate the analysis, Nanjing, where a demonstration modular building project is located, is chosen as the sample. The policies concerning modular construction to be further distilled are coded and listed in the Table 1.

Table 1: Summary of policies concerning modular construction

	Item	Source
Mainland China	1. Opinions on Further Promoting the Development of Assembled Buildings	Document
	2. Implementation Opinions on Accelerating the Modernization of the Construction Industry and Promoting the Upgrade of the Construction Industry	Document
Hong Kong	1. 2018 Policy Address and Policy Agenda	Document
	2. 2017 Policy Address and Policy Agenda	Document
	3. Construction Innovation and Technology Fund (CITF)	Website
Singapore	1. Building Control (Buildability and Productivity) Regulations 2011	Document
	2. 1st Construction Productivity Roadmap	Document
	3. 2nd Construction Productivity Roadmap	Document
	4. Integrated Construction and Prefabrication Hub (ICPH)	Website
	5. Prefabricated Prefinished Volumetric Construction (PPVC)	Website
	6. Construction Productivity and Capability Fund	Website
	7. Building Innovation Panel (BIP)	Website

4.2 Specifications

The specifications for modular construction are summarized in Table 2. Although these three specifications have known issues of inconsistent hierarchy and classification. On the basis of frank recognition of these limitations, the comparisons remain valuable for understanding the modular construction.

Table 2: Summary of specifications concerning modular construction

	Item	Hierarchy
Mainland China	1. Specification for design of prefabricated monolithic modular building (Exposure Draft) (abbreviated as Specification for design) 2. Specification for construction and acceptance of prefabricated monolithic modular building (Exposure Draft) (abbreviated as Specification for construction and acceptance) 3. Specification for isolation technology of prefabricated monolithic modular building (Exposure Draft) (abbreviated as Specification for isolation technology)	Association's standards
Hong Kong	1. PNAP ADV-36 Appendix A: Design Requirements for Modular Integrated Construction 2. PNAP ADV-36 Appendix B: Quality Control and Supervision of MiC	Regulations
Singapore	1. Design for Manufacturing and Assembly-Prefabricated Prefinished Volumetric Construction (Guidebook)	Technical specifications

5 ANALYSIS OF GOVERNMENT PRACTICES

5.1 Policies

The policies of modular construction implementation are categorized into goal, control and regulation. After identifying the related policies, economic incentives and support activities are described in detail. Under each category, comparative analysis is conducted to identify gaps, overlaps or inconformity among the three regions. The framework of this section is presented in Figure 3 in which the economic incentives discuss the subsidy, tax breaks, and award regulations. However, land supply and approval regulations as well as logistic support and coordination with the government are discussed for the categories of control/regulations and supporting activities, respectively.

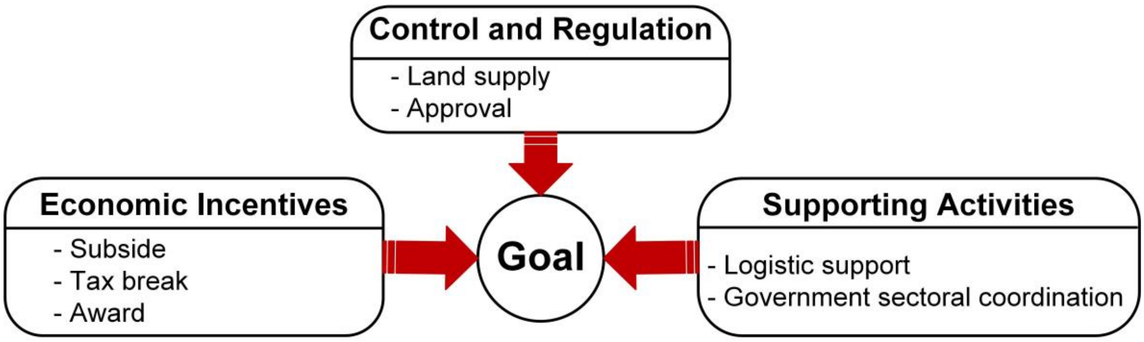


Figure 3： The analysis framework of policies

5.1.1 Goal

There are two policies, which are identified as goal, providing overall guidance to construction industry. Other policies, namely control and regulation, economic incentives and supporting activities, are formulated to achieve goals. The government aimed to increase productivity in the construction industry by an average of 2-3 percent per annum between 2010 and 2020 (BCA, 2010). From 2014 to 2018, the goal has been achieved for five consecutive years (BCA, 2019d). However, the Nanjing government formulated the development goal of assembled buildings, namely the prefabricated buildings would account for more than 30% of new buildings, and the residential buildings delivered with finished products would account for more than 50% by 2020.

5.1.2 Control and regulation

The control and regulation instrument regarded as the traditional but the most efficient policy, which can regulate the behavior of practitioners and the construction industry (Spence and Mulligan, 1995; Huang et al., 2016; Chang et al., 2016). The function of this type of policy is to promote the adoption of modular construction and to ensure that the performance of modular building meets mandatory requirements. At present, the control instruments are mainly land supply and approval.

(i) Land supply

The Nanjing government divided the whole city into the categorized areas: propulsion, active promotion and encouraged promotion. Hence, stipulated the prefabrication ratio not less than 50% and 40% in a residential and public building, respectively if the project is located in the propulsion area and single building area more than 5000 m^2. Similarly, in Singapore, the Building Control (Buildability and Productivity) Regulations 2011 stipulated that the area of using PPVC shall account for more than 65% of the gross floor area when the building is used for residential purposes. (BCA, 2011). Because land is so scarce in Singapore, this mandatory measure is a strong incentive for the construction sector to adopt modular construction method.

(ii) Approval

It should be mentioned that the administrative procedures of modular buildings still refer to administrative procedures of prefabricated components in mainland China. For example, the government cannot issue construction permits until the design documents project meet mandatory standards. The main body and the decoration need to be checked and accepted separately. However, partial decoration has been carried out in the factory, which brings some obstacles to the acceptance of modular building.

In addition to project approval, in Hong Kong, the supervision is not limited to project assembly, but also includes module suppliers. MiC systems must be approved in principle under the pre-acceptance mechanism before they are manufactured and used. The pre-acceptance mechanism aims to ensure that the materials and designs should comply with Buildings Ordinance (BO).

In addition, it can share the information on MiC with users and increase the public's access to information. In Singapore, the acceptance framework was established by BCA to ensure that reliability and durability of proposed PPVC systems can meet the minimum standards.

5.1.3 Economic incentives

Apart from control and regulation, economic incentives can also change the behavior to achieve specific objectives; therefore, it is widely used by the government to encourage the construction industry to adopt modular construction technology. Three kinds of economic incentives are provided to help the construction sector offset the cost premium of adopting modular construction, i.e. subsidy, tax break, and award.

(i) Subsidy

The HKSAR Government is committed to lead the adoption of MiC, which is supported by a $1 billion Construction Innovation and Technology Fund (CITF). Contractors and consultants can apply to CITF for subsidy when hiring professional consultants, purchasing or renting construction-related equipment, or even purchasing MiC modules if the project adopting innovative technology (Financial Secretary, 2019).

In Singapore, small and medium-sized firms can use Construction Productivity and Capability Fund (CPCF) to purchase equipment. To further promote the implementation of innovative and productive technologies in the public sector, a S$150 million Public Sector Construction Productivity Fund (PSCPF) was introduced since 2017. In mainland China, from 2016 to 2020, 10 million yuan was arranged from the city's urban construction funds for the modernization of the construction industry each year.

(ii) Tax break

In Singapore, BCA (2015b) is extending the Land Intensification Allowance (LIA) scheme to provide tax break on capital expenditure, which is required for the construction of ICPHs. In mainland China, the research and development expenses incurred in the development of new technologies can be deducted before the enterprise pay the income tax.

(iii) Award

To complement incentive system, the "Opinions" also provided a series of award measures. For example, if prefabrication ratio is more than 50% and the buildings are decorated when delivering, the Pre-sale Permit certificate can be issued in advance, which is a great incentive for developers to use off-site construction method. In addition, if developers take the initiative to adopt the off-site construction technology, meanwhile the prefabrication ratio is up to 40%, the government will provide incentives in the form of a gross floor area recessions.

5.1.4 Supporting activities

The policies mentioned above are a strong impetus for the construction industry to adopt modular architecture, but some obstacles remain unresolved, such as immature technology, low awareness of benefits of modular construction, and complex administrative approval. Hence, the government carried out a number of supporting activities to address these barriers.

(i) Logistics support

To build native off-site manufacturing capacity, the Singaporean BCA formulated a masterplan for the development of Integrated Construction and Prefabrication Hubs (ICPHs), which are multi-storey advanced factories for manufacturing prefabricated elements (BCA, 2015). BCA has awarded five tenders of ICPH, site area up to 119680.5 m^2 before 31 August, 2018.

(ii) Government coordination

In Singapore, after the BCA realized the difficulties encountered by the company in the process of obtaining approval, three committees were established to assist enterprises to develop research, obtain regulatory licenses, and resolve regulatory conflicts since 2019. These committees included: (1) Research & Innovation Committee, (2) Technology Assessment Committee and (3) Inter-Agency Coordinating Committee, In particular, the Technology Assessment Committee will facilitate early resolution of outstanding issues between the applicant that require multi-agency regulatory assistance and respective authorities and agencies if the innovation can lead to at least 20% improvement in productivity or sustainability or the innovations are potential to significantly improve the built environment (BCA, 2019c).

The policies mentioned above are divided into sub-categories and list in Figure 4. It clearly presents the existence of some gaps which could be considered in future policy initiatives. Besides, through horizontal and vertical comparison.

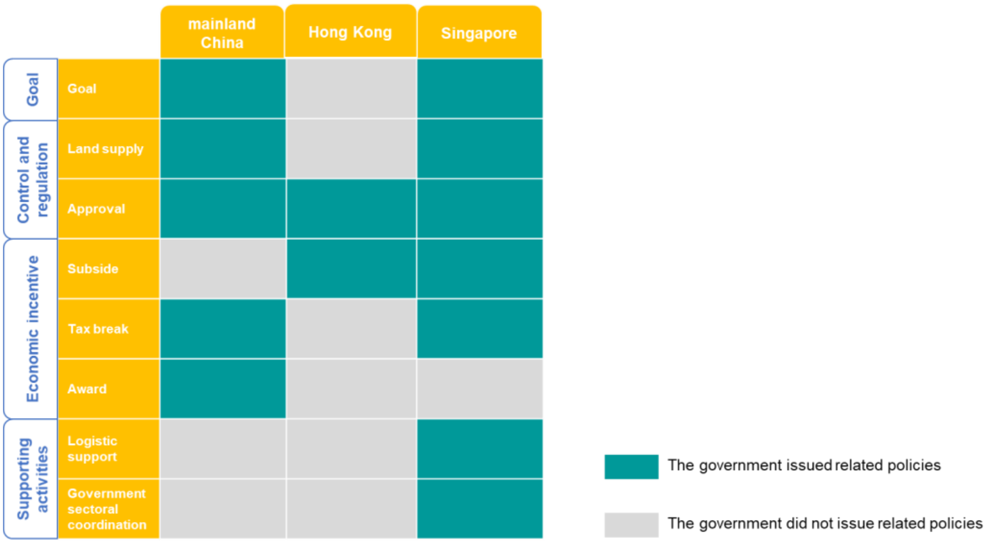


Figure 4: Policies comparison among mainland China, Hong Kong, Singapore

(1) All policies mentioned above aim to directly increase the supply of modular buildings in the market, or to provide a lenient environment for the development of modular buildings, which then indirectly increase the supply. However, the policy to stimulate the demand for MiC is ignored.

(2) The HKSAR Government has not formulated a distinct plan to implement MiC. In addition, the lack of mandatory policy and incentive measures lead to low MiC adoption in the private sector.

(3) In general, Singapore had issued considerable policies and even set up new organizations to bolster its plan. Mandatory land supply, economic incentives and supporting activities are implemented jointly, which is instrumental to form a virtuous circle and speeds up the application of PPVC method.

(4) The mainland China has issued a series of policies on off-site construction methods without being specific to modular construction. In this context, it is inevitable that certain current policies do not apply to modular construction and even exert negative influence on

implementing this method. If mainland China is to vigorously promote modular construction, it is essential to recognize the differences between modular construction and prefabricated component construction, and then revise items that is not applicable for modular construction.

(5) It is worthwhile to refer the pre-acceptance mechanism which had been set up in Hong Kong and Singapore in the context of lacking authoritative technical standards or regulations.

5.2 Specifications

The main specifications concerning modular construction in three regions have been identified. This section will elaborate on a comparative study from definition, design, manufacture, on-site construction and supervision.

5.2.1 The definition of modular construction

The definition of modular construction, namely "a construction method whereby free-standing volumetric modules (with finishes, fixtures, fittings, etc.) are manufactured off-site and then transported for constructing buildings" (Building Department, 2017), is almost the same in Hong Kong and Singapore. In Singapore, it is further emphasized that modules are manufactured in an approved manufacturing facility using an approved manufacturing method. However, the definition of module is "single room or a 3D unit with certain functions prefabricated in a factory" in the "Specification for design". It does not highlight that the module units are integrated with structure system, envelope system, MEP system and interior decoration system.

5.2.2 Design of modules

Specifications on design of module have been issued in all three regions. As shown in Figure 5, there are great similarities in design considerations among three regions, they all emphasize modules connection, consideration of construction, structural design of modules and fire safety. Moreover, three specifications can complement each other. For example, the "Specification for design" provided two requirements for modularization, however it did not stipulate when to operate it. In the "Guidebook", it emphasized the modularization must be conducted simultaneously with the unit layout design.

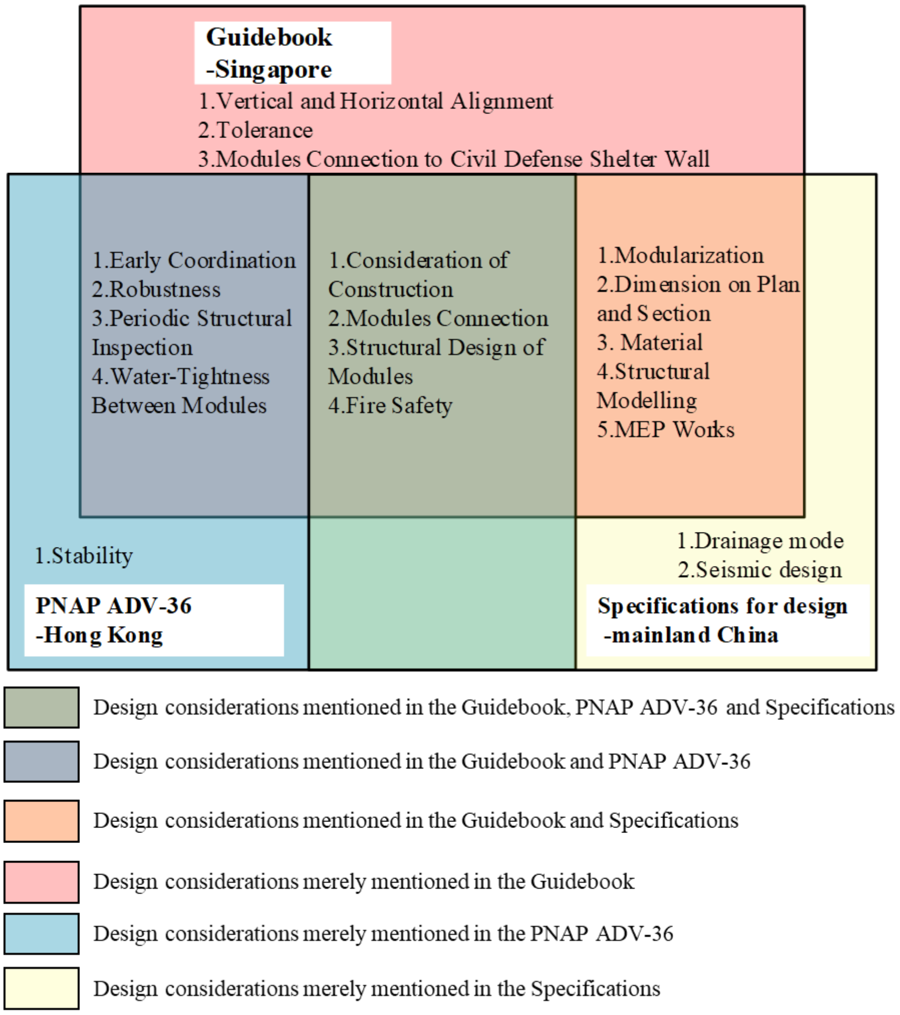


Figure 5: Comparison of design considerations in three specifications

Different specifications also or proposed their own design considerations as different natural environment. For instance, seismic design was not highlighted in the “Guidebook” and PNAP ADV-36. On the contrary, the “Specification for isolation” is specially compiled to provide provisions for seismic design of modular buildings because the Code of Seismic Design is stringent. In mainland China, most cities and regions are located in the areas where earthquakes are a common occurrence, thus module connections should be able to resist the force of the earthquake.

5.2.3 Manufacturing the modules

The production process of reinforced concrete PPVC and steel PPVC was introduced in the “Guidebook” respectively. Each step is equipped with a corresponding picture, allowing practitioners to understand the module production process intuitively. Except the “Guidebook”, no excellent specification for module production has been issued in mainland China and Hong Kong.

5.2.4 On-site construction

The “Specification for construction and acceptance” focuses on the specific operations, such as the requirements of materials, transportation, hoisting and assembling. While, the “Guidebook” focuses on the critical points of project management on construction site, the main concerns are as follows: (1) access and traffic management, (2) Just-In-Time operation, (3) types of cranes, (4) safety. The weight of the module can reach 30 tons or more, the type of cranes is closely related to the time, cost and safety. Therefore, construction management personnel need to pay attention to the tower crane. The Just-In-Time operation is also popular in Hong Kong as the construction sites generally are not available to unload and storage massive modules.

5.2.5 Supervision of modular construction

In Hong Kong, Quality Assurance Scheme and Quality and Qualified Supervision had been carried out to guarantee that the quality of module can satisfy the requirement of ordinances. Under the Quality Assurance Scheme, prefabricated factories are required to possess quality assurance certificates. Quality and Qualified Supervision made three main requirements, including the content, frequency and supervisor.

In Singapore, the inspection and quality check are divided four aspects, namely (1) quality checks; (2) structural works inspection, (3) MEP works inspection and (4) architectural works inspection. There is massive inspection work during the architectural works, among which water tightness inspection is a critical point.

In mainland China, the supervision is mainly carried out in the hoisting and assembling process. It is found that the "Specification for construction and acceptance" is still based on certain preceding standards and codes, and some previous items are emphasized or adjusted to fit the modular construction.

The comparison of the supervision of module construction among three regions is shown in Table 3, and the differences are list as follows:

(1) Phrase: the inspection and supervision in the "Guidebook" and PNAP ADV-36 are merely limited to the production phrase, while the supervision in the Specification has an orientation towards on-site supervision.

(2) Content: both “Guidebook” and “Specification for construction and acceptance” do not state the inspectors’ appointees and the frequency of inspections clearly as those of Hong Kong.

(3) Hierarchy: most of the supervision requirements in the PNAP ADV-36 and “Specifications for construction and acceptance” are mandatory, while the supervision in the “Guidebook” are almost optional.

(4) Inspector / supervisor: The “Specification for construction and acceptance” mainly provides reference for the contractors. While the “Guidebook” provides workers in prefabricated factories with how to inspect modules. PNAP ADV-36 Appendix B proposes supervision requirements for AP, RSE and the Registered Contractor (RC).

Table 3: Comparison of the supervision of module construction

	Mainland China	Hong Kong	Singapore
Phase	Manufacture and on-site construction	Manufacture	Manufacture
Supervision content	(i) Production Testing; (ii) Entry Detection; (iii) Connection Detection; (iv) Structure Detection.	(i) Quality Assurance Scheme; (ii) Quality and Qualified Supervision.	(i) Quality Checks; (ii) Structural Works Inspection; (iii) MEP Works Inspection; (iv) Architectural Works Inspection.
Hierarchy	Mandatory	Mandatory	Optional
Inspector / Supervisor	Contractors	AP, RSE and the Registered Contractor (RC)	Workers in prefabricated factories

6 ANALYSIS OF CASE STUDIES

The selected case studies include the fire services accommodation, student residences, and residential building. The general information about 4 cases is presented in the Table 4. Based on the results of the literature review, the case studies will provide a comparative analysis focusing on the sustainable construction, including economic, environmental and social dimensions. In addition, the technology system and challenges will be analyzed and compared. Thus, some valuable lessons will be learned and summarized in this section.

Table 4: Completed and on-going modular construction project overview

	Project overview
	**1. Disciplined Services Quarters for the Fire Services Department** ● **Address**: Pak Shing Kok, Tseung Kwan O, Hong Kong ● **Number of floors**: 16 to 17 floors ● **Number of Quarters**: 5 quarters blocks, 648 units ● **Commencement Date**: September, 2018 ● **Expected Completion Date**:2021
 (image via the University of Hong Kong)	**2. Student Residence at Wong Chuk Hang Site for the University of Hong Kong** ● **Address**: Wong Chuk Hang, Hong Kong ● **Number of floors**: 20 floors ● **Number of rooms**: 1,224 hostel rooms ● **Commencement Date**: 1st Quarter, 2019 ● **Expected Completion Date**: before 4th Quarter, 2023

	**3. Residential building in Nanjing** ● **Address**: Jingtian Road, Nanjing, mainland China ● **Number of blocks and floors**: 3 blocks, 11 floors ● **Number of Modules**: 1285 modules ● **System**: light concrete modules with conventional core ● **Duration**: April,2015- April,2018
 (image via the BCA)	**4. Residential Halls at Nanyang Crescent** ● **Address**: Nanyang University, Singapore ● **Number of blocks and floors**: 4 blocks, one 11-storey and three 13-storey 16 floors ● **Number of Modules**: 676 modules ● **System**: steel modules with conventional core and podium floors ● **Duration**: December, 2014 – June, 2017 ● **Performance**: 25% manpower reduction; 40% improvement in productivity; the total cost was $132.003 million, equivalent to $2,719 per square meter.

6.1 The on-going modular construction projects

Case 1: The Disciplined Services Quarters for the Fire Services Departmental at Pak Shing Kok, Tseung Kwan O, is the first pilot project using MiC in Hong Kong. This project turns a new page in the construction industry of Hong Kong.

Case 2: The Student Residence at Wong Chuk Hang Site for the University of Hong Kong, has been selected by the Development Bureau as a pilot MiC project. Funding for this project has been approved by the Finance Committee of the Legislative Council.

These two pilot projects from Hong Kong's public sectors are expected to demonstrate the feasibility of modular construction method in tall buildings in local environment.

A large number of workers can move away from risky site activities, bringing about better safety, productivity, and quality. Modular construction is expected to achieve green construction because of reduced waste and site nuisance.

6.2 The completed modular construction projects

Case 3: Lan Mountain residential building in Nanjing: The case of residential building in Nanjing firstly applied modular construction technology to the high-rise residential building in mainland China. The walls of the modules were the steel frame filled with lightweight concrete. Only trusses were set at the top of the module to facilitate the placement of pipelines and equipment. The schematic diagram of module system is given in Figure 6(a). Each apartment was composed of five kinds of modular units, as shown in Figure 6(b). The size of module was: from 2.78m up to 5.51m width (3.79m on average), from 2.34 m up to 9.36m length (5.36m on average), 2.9 m height. The living room (36.18m^2) was the largest module.

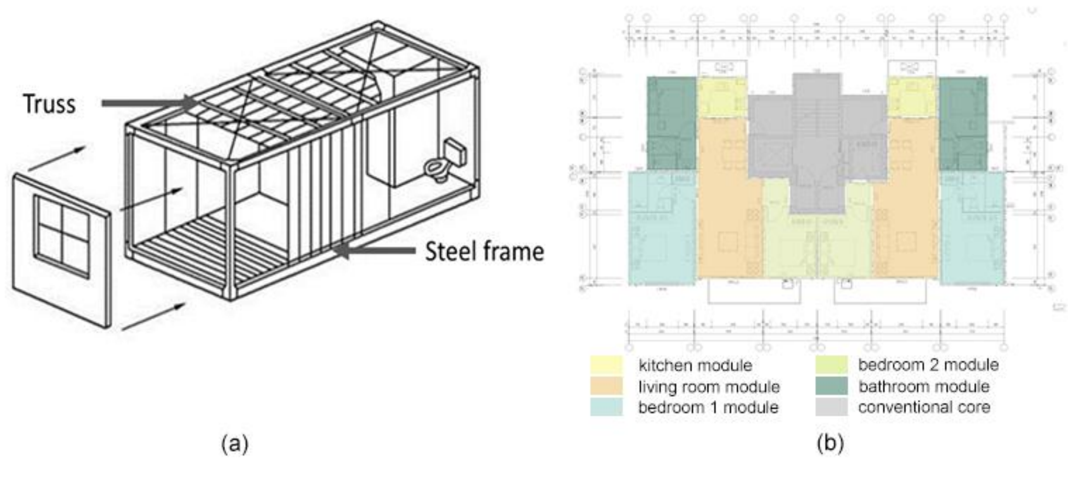


Figure 6: (a) Module system, (b) Typical plan layout

Currently, in mainland China, due to lack of experiences in modular construction, the modular construction project is regulated strictly by the local government departments, which brought some difficulty to the approval of this project. Therefore, a lot of time and efforts are devoted to the design phase to ensure the feasibility of the drawing. The owner, architects, module suppliers jointly participated in the drawing deepening process, which contributes to the successful delivery of the project. The participants focused on the following critical points in the design phase:

(1) Story height

At first the floor to ceiling height less than 2700 mm. Due to story height has a significant impact on the living comfort, project team carried out two optimizations to solve the problem. On one hand, the trusses in the middle of the modules were canceled to ensure the net height up to 2700 mm. On the other hand, the elevation of the surrounding trusses around the module was increased by 15mm. The module units are integrated with structure system, envelope system, MEP system and interior decoration system. Hence, the installation and usage of central air conditioning were greatly affected by this change. The technical personnel had to recalculate the bearing capacity of the trusses.

(2) Waterproof

Compared with the traditional cast-in-place building, prefabricated building is prone to water seepage. Hence the balcony, toilet and kitchen were well designed to tackle this problem. For instance, the floor elevation of the balcony was lower than that of the living room, as shown in Figure 7(a). Additionally, in order to avoid water seepage between modules, the root of the wall also took waterproof measures. Moreover, ceramic plates were laid on the façade of the buildings so that the water seepage was solved effectively, but the ceramic plate is expensive.

(3) Arrangement of pipeline

The position of the pipe was accurate to the millimeter and was fully compound with the module structure to avoid conflicts. In addition, the pipelines were orderly arranged for ease of maintenance, as shown in Figure 7(b). The pipeline between modules did not go through the wall, and its connecting hinge is located above the door. As shown in Figure 7(c), a hole was reserved above the door to provide operating space for the secondary connection of the pipe at site.

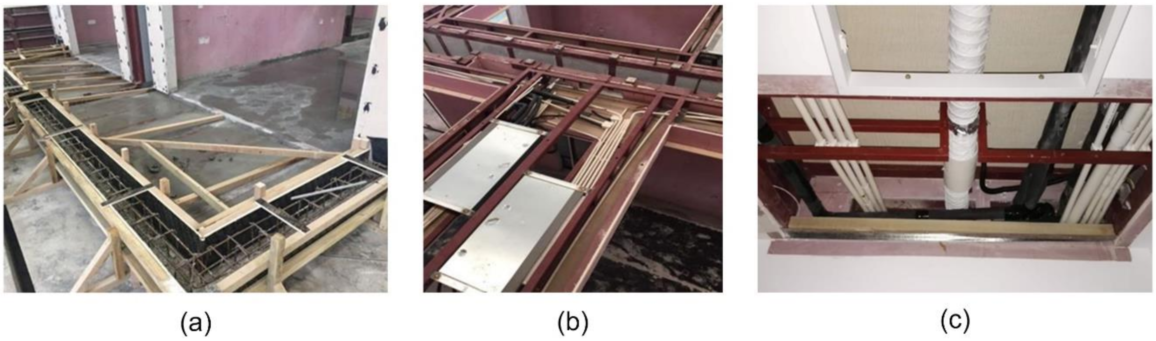


Figure 7: (a) Balcony manufacture in the factory, (b) Pipeline arrangement, (c) Pipeline connecting hinge

<u>(4) Elevation</u>

Designers fully recognized that the thickness of materials, even construction methods will affect the elevation of the ground. Thus, the floor elevation, thickness of materials, as well as construction methods were confirmed before modules were manufactured to ensure that the height difference between rooms (e.g., the core floor and the indoor floor) is reasonable.

Modules were manufactured and prefabricated in Zhenjiang, approximately 100 km from the construction site. In order to discover problems promptly, two mock-up modular apartments were produced before the manufacture of modules. The interviewee also highlighted that the inspection carried out by the owner at the manufacturing factories was a crucial factor in ensuring that the completed modules meet the requirements of the contract.

Module manufacture and the on-site construction were carried out simultaneously. The modules were assembled after installing foundation beam. Figure 8 describes how the modules were hoisted and assembled in the Lan Mountain residential buildings. It took 187 days to install 1,285 modules. The entire construction duration lasted 665 days. Compared with the traditional construction, using modular construction did not save time in this project. The benefit of reduction in time did not be materialized in this project for two reasons. First, it can be derived from Figure 9(a) that more than 50% of the time was spent in the wet trade, i.e. the construction of the core and the façade. In order to construct a reliable anti- lateral system, the core is complicated with high the content of the steel bar. At the same time, the construction is not easy to operate due to the narrow working space. Second, a large number of finished products were reworked and repaired due to the poor protection and the unreasonable decoration processes, which somewhat affected the schedule.

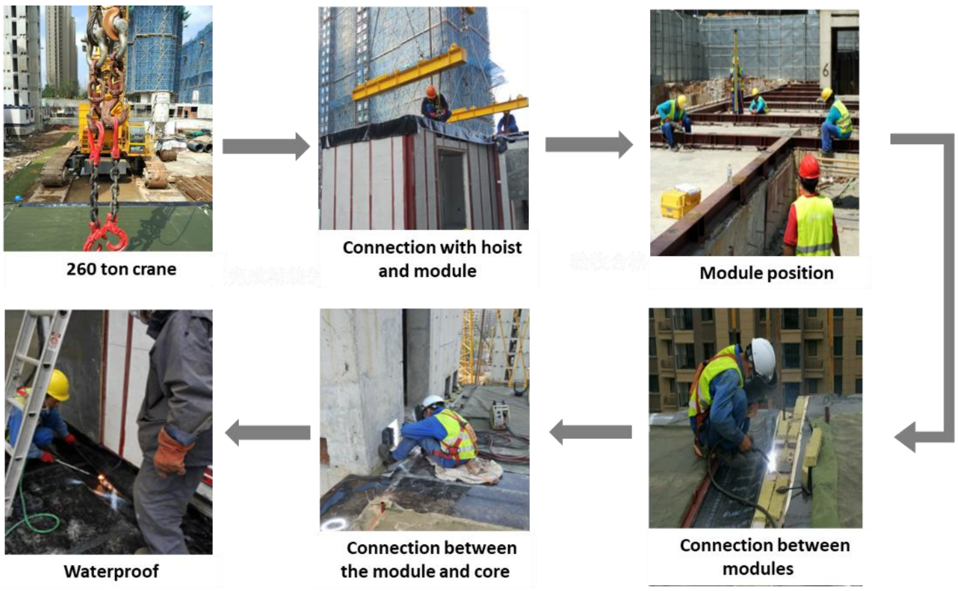
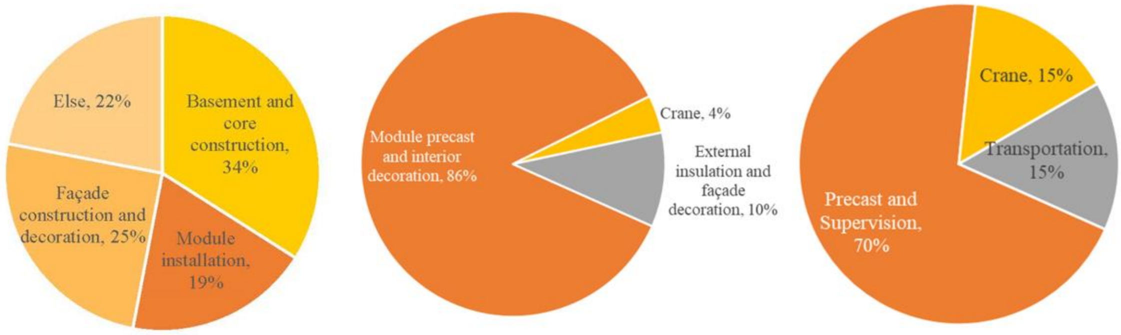


Figure 8: The steps of module installation in Residential buildings (Nanjing, China)



a : Each process duration in Residential buildings (Nanjing, China)

b: Concrete module cost drive in Residential buildings (Nanjing, China)

c:Steel module cost drive in the Residential Halls at Nanyang Crescent

Figure 9: Related statistics on modular construction

The cost of each module consists of three parts: module production and interior decoration, lifting and external insulation, and façade decoration. Module cost drivers are presented in the Figure 9(b). The façade of the module adopted ceramic plate for reliable waterproof with high price. Hence, it is necessary to study a more economical facade method, such as paint and integrated board.

Sustainable construction was achieved using modular construction technology with less construction material wastage and carbon emission in Lan Mountain residential buildings. Construction material wastage is reduced by 85%, carbon emission reduced by 51.7kg / m^2, which is equivalent to saving 19.88kg of standard coal. At the same time, the improvement in the airtightness of the window modified the thermal insulation performance of the enclosure structure and reduced the expenditure of using air conditioning.

Due to the lack familiar projects for reference, this project encountered many challenges. The first challenge is difficult approval, from drawing approval to acceptance. Secondly, there is massive coordination work for more than 4 design teams. Intellectual property is also a serious issue. The module supplier provided the module's drawings as their own intellectual property, which affected the communication between participants. Another challenge is the layout of pipes, lines and equipment, which is caused by reduced floor-to-floor height. In addition, a high proportion of factory decoration led to an increase in the cost of finished product protection and secondary maintenance. Finally, economy of scale has failed to materialize. The gross floor area of the in-site work is only about 10,000 m^2. On one hand, the owner cannot find a strong contractor and on the other hand, it is impossible to organize the flow construction similar to the traditional construction mode.

Case 4: The Residential Halls at Nanyang Crescent: Nanyang Technological University took the challenge to be the first institution to use PPVC in 2013 in Residential Halls at Nanyang Avenue. Subsequently, Residential Halls at Nanyang Crescent continued to adopt PPVC in 2015. PPVC construction method has been implemented successfully in the Residential Halls at Nanyang Crescent with higher quality finishes, less labor-intensive activities on site, better housekeeping and reduction of wastage. The C has won the Construction Productivity Awards (CPA) for its outstanding performance in improving productivity.

The modules were modularity with high repetition and low variation in types to reap the full benefits of DfMA. However, the facade was customized with a view of designing a unique and non-monotonous facade design. The connections between modules no longer required welding, but only a bolt and tie plate assembly.

As shown in Figure 10, the conventional podium floors were constructed to handle sloping terrain; the transfer slab was constructed to connect conventional podium floors and steel-type modules; the lateral stability was offered by centralized conventional core.

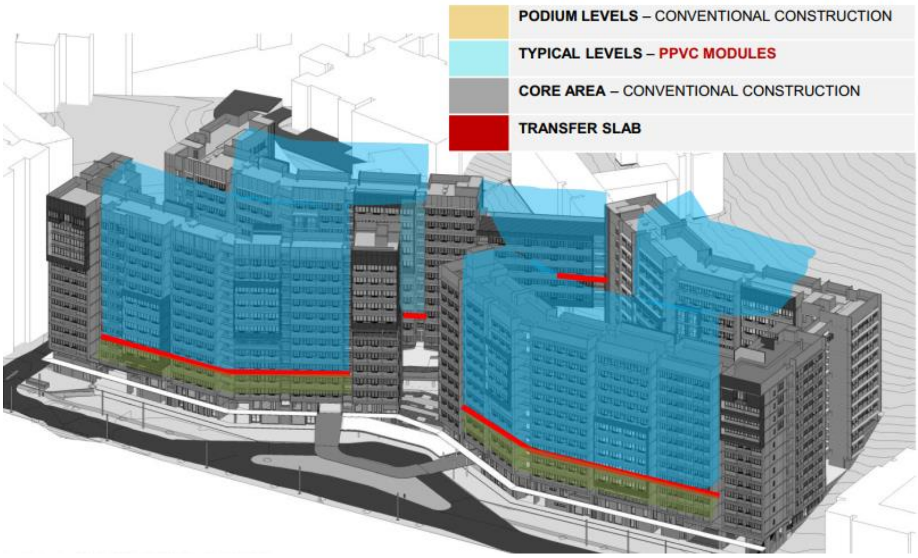


Figure 10: 3D View of the Residential Halls at Nanyang Crescent (image via Chain)

The construction duration was only 6 months with the floor cycle shortened to approximately 4 days. It is estimated that only 7 workers were required to install a module in 30 minutes.

The steel chassis of modules were manufactured in Zhangjiagang, China. After the modules were imported into Singapore, the rest of external and internal finishes such as lighting, windows and fans were carried out in fit-out factory. Hence, inspections carried out periodically at the local and overseas manufacturing factories to guarantee that the quality of modules could satisfy the requirement of the contract. Meanwhile, transnational transport and quality inspection dramatically increased the project's construction cost. The transportation, prefabrication and supervision account for 15% and 70% of module costs, respectively, as shown in Figure 9(c).

The modules were massive with maximum dimensions of 3.25m width, 10.76m length, and 3.14m height. The largest modules weighed 17.6 tons, and the mean steel tonnage of each module was 4.8 tons. Therefore, the contractor selected the crane with high bearing capacity, which take up 15% of PPVC cost as shown in Figure 9(c).

Noise and pollution are significantly reduced at the construction site. Due to less need for on-site workers and short construction time, a corresponding reduction in the likelihood of injury is realized. At the same time, less work-at-height also reduces fall accidents. Although there is no precedent for the removal and recycling of modular buildings, the potential for steel reuse is still exists because the modules can be easily detached.

The reduced floor-to-floor height, intellectual property, and massive coordination work issues are also existed in the case of Residential Halls at Nanyang Crescent. In addition, design and submission needs to be completed within a tight 20-month period. Another challenge is the high transportation and supervision costs. Besides, PPVC modules needed to be stored elsewhere due to Fitting-up Yard with limited storage space. The increase in crane capacity is accompanied by a significant increase in operation costs. The comparison of the two cases is captured in Table 5.

Table 5：the comparison between Residential buildings in Nanjing and Residential Halls at Nanyang Crescent

Item	Case 3: Residential buildings in Nanjing, China	Case 4: Residential Halls at Nanyang Crescent, Singapore
Gross Floor Area and Percentage GFA		
Gross Floor Area (entire development)	38695 m^2	48550 m^2
Gross Floor Area (using PPVC)	28401 m^2	20600 m^2
Percentage GFA (entire development)	73%	42%
Percentage GFA (floor areas above podium levels)	81%	53%
Technology system		
Technology system	Conventional core + module	Conventional core + module
Module		
Material	Steel modules with light weight concrete floors and walls	Steel module

Dimension	W: 3.79m on average L: 5.36m on average H: 2.9 m	W: 2.97m on average L: 8.1m on average H: 3.14m
Total number of modules	1285	676
Total type of typical modules	10	8
Production processes	Factory 1 (production and internal decoration)→delivery	Factory 1 (production of the steel chassis)→Factory 2 (fit-out of external and internal finishes)→Delivery
Decoration ratio (factory/on-site)	60% / 40%	70% / 30%
Time		
Duration	37 months	31 months
Hoist speed	4-8 modules a day	6-8 modules a day
Floor cycle construction	3.5 days	4 days
Cost		
Construction Cost	$ 865.11 /m^2	$ 2548 /m^2
Cost premium	16%~18% cost premium	15~20% cost premium
Manpower		
Manpower	9-10 workers were required to install a module (20% saving)	7 workers were required to install a module (40% saving)
Challenges		
Common challenges	1. Floor-to-floor height 2. Intellectual property and 3. Massive coordination work	
Regional challenges	1.. Difficult approval 2. Finished product protection cost 3. Lack of economy of scale	1. Tight timeline of design and submission 2. Expensive transportation costs and supervision costs 3. Limited storage space 4. Initial crane cost

7 DISCUSSION

7.1 Sustainable construction performance

The economic dimension of sustainable construction is primarily concerned with construction time and cost (Kamali and Hewage, 2017). According to the case studies, the hoist speed was undoubtedly rapid. However, modular construction needed longer preparation before construction. Additionally, the results of the case studies reveal that the cost premium ranges from 15%-20%. From economic perspective, modular construction did not perform well as traditional construction method.

However, the merits of modular construction in the environmental and social dimensions cannot be ignored. The environmental advantages of modular construction are clear, which include the reduction in wastage, greenhouse gas emissions, noise and dust. It is estimated that material wastage was reduced by 85%, greenhouse gas emissions reduced by 51.7kg / m^2.

While there are different perspectives on the criteria of the social dimension (Zuo et al., 2012; Goel and Ganesh, 2019), workforce health and safety is one of the main principles (Hill and Bowen, 1997; Kamali and Hewage, 2017). Adopting modular construction can improve workers' health and safety because of less work-at-heights. The construction industry is unattractive among young people because the construction industry is perceived as boring and dangerous. This phenomenon is expected to change when the construction industry is actively embracing innovative technologies like module construction.

Economic sustainability is intricately linked to the social and environmental dimensions (Chang,2016). According to Hill and Bowen (1997), despite the initial cost premium, the two cases can be economically sustainable, as environmental and social sustainability can bring long-term benefits for stakeholders. In the future, the construction industry should work with the government to further pursue the balance of sustainability construction.

7.2 Challenges of adopting modular construction

The three challenges identified in the case study, namely intellectual property, reduced floor height and finished product protection, are not mentioned in previous literature reviews, which should be considered in future studies. Besides, the challenges vary from region to region. There are still lots of barriers exist, which need champions of the industry to lead with innovative, economic, sustainable, and clean production solutions.

7.3 Effectiveness of policy system

Currently, in mainland China and Hong Kong, the authorities do not have mandatory regulations and sufficient incentive measures, which are specific to modular construction, to encourage practitioners to embrace modular construction method. In contrast, the Singaporean government has issued obligatory regulations that PPVC should be adopted in the selected areas and launched ambitious package of measures to fully implement PPVC. What’s more, Singapore’s policy system is more effective. In the case 4, the three challenges, namely tight timeline for design and submission, transportation and supervision costs, and crane, can be addressed to some extent through corresponding economic incentives and supporting activities, such as subside, Inter-Agency Coordinating Committee and ICPH masterplan.

The Singapore sets a model for other countries to establish their own policy system for implementing modular construction. Nevertheless, modular construction is not yet mature and require strong support from governments, including Singapore, to promote greater progress and breakthroughs in critical technologies.

7.4 Guidance of specifications

The “Guidebook” provides the elaborate but optional practical tips. On the contrary, the PNAP ADV-36 only imposes mandatory requirements on quality control and supervision. Though mainland China has released association's standards in January 2018, the certain content of specifications does not conform to the characteristics of modular construction. It indicates that the modular construction is still in its infancy, and the mature and instructive standards or specifications are vacant.

8 CONCLUSIONS

Modular construction has been improving constantly to make the modules better meet the specific requirements of each project and region. This paper aims to conduct a comparative analysis focusing on modular construction practices among three regions, Hong Kong, Singapore and main land China.

The policies related to modular construction are further divided into four categories, namely goal, control and regulation, economic incentives and supporting activities. Combined with the challenges identified in the case studies, it shows that Singapore has established a fairly comprehensive policy system to encourage the construction industry adopt modular construction, albeit less support for technical innovation. Additionally, it reveals that no mature and authoritative standards and specifications, which can guide the practitioner to use modular construction method. The case studies provided a comprehensive analysis focusing on sustainable performance, technology system, challenges and lessons. It indicates that the merits in economic dimension is not significant as those of social and environmental dimensions due to cost premium and slight time advantage. The construction industry should work with the government to further pursue the balance of sustainable construction.

The research has several implications for the research community. Firstly, it shows that the implementation of modular construction needs lots of support from governments. Meanwhile, practitioners still need to heightened awareness of modular construction especially module production and supervision. Secondly, many barriers are distinguished through the comparative analysis of practices, which need researchers make efforts to tackle.

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REFERENCES

Annan C D, Youssef M A, El Naggar M H. Seismic overstrength in braced frames of modular steel buildings[J]. Journal of Earthquake Engineering, 2009,13(1):1-21.

Arif M, Egbu C. Making a case for offsite construction in China. Engineering[J]. Construction and Architectural Management, 2010(6):536.

BCA. 1st Construction Productivity Roadmap, 2010. https://www.bca.gov.sg/newsroom/others/pr03032011_CPA.pdf, surfed at July. 30, (2019).

BCA. 2nd Construction Productivity Roadmap, 2015. http://www.nas.gov.sg/archivesonline/data/pdfdoc/20170307002/Annex%20A%20-%202nd%20Construction%20Productivity%20Roadmap.pdf, surfed at July. 30, (2019).

BCA. Integrated Construction and Prefabrication Hub (ICPH), 2018.

https://www.bca.gov.sg/buildabledesign/tender_precast_hub.html, surfed at Mar. 22.

BCA. Prefabricated Prefinished Volumetric Construction (PPVC),2019a. https://www.bca.gov.sg/BuildableDesign/ppvc.html, surfed at Mar. 22, (2019).

BCA. Construction Productivity and Capability Fund, 2019b. https://www.bca.gov.sg/CPCF/cpcf.html, surfed at Mar. 22, (2019).

BCA. Building Innovation Panel (BIP), 2019c. https://www.bca.gov.sg/cpc/BIP.html, surfed at Mar. 22, (2019).

BCA, Project Productivity,2019d. https://www.bca.gov.sg/productivity/site_productivity_statistics.html, surfed at July. 30, (2019).

BCA. The Building Control (Buildability and Productivity) Regulations 2011[S], 2011.

Berardi U. Clarifying the new interpretations of the concept of sustainable building[J]. Sustainable Cities and Society, 2013, 8:72-78.

Building Department. PNAP ADV-36, 2017. https://www.gov.hk/en/theme/bf/pdf/PNAPADM-19.pdf

Chain P. Prefabricated Prefinished Volumetric Construction (PPVC) in Singapore: NTU case studies[C]//International Conference on Modular Integrated Construction, Kowloon, Hong Kong, 2018.

Chang R, Soebarto V, Zhao Z, Zillante G. Facilitating the transition to sustainable construction: China's policies[J]. Journal of Cleaner Production. 2016,131:534-544.

Chen Z, Liu J, Yu Y, Zhou C, Yan R. Experimental study of an innovative modular steel building connection[J]. Journal of Constructional Steel Research, 2017,139:69-82.

Chen Z, Zhong X, Yu Y, Liu Y, Han J. Key technologies and application in multi-storey modular steel residential building (in Chinese) [J]. Architecture Technology, 2018,49(04):372-376.

Elo S, Kyngas H. The qualitative content analysis process[J]. Journal of Advanced Nursing, 2008, 26(1):107-115.

Fathieh A, Mercan O. Seismic evaluation of modular steel buildings[J]. Engineering Structures, 2016,122:83-92.

Financial Secretary. Modular Integrated Construction, 2019. https://www.fso.gov.hk/eng/blog/blog130119.htm, surfed at Mar. 22, (2019).

Goel A, Ganesh LS, Kaur A. Deductive content analysis of research on sustainable construction in India: current progress and future directions[J]. Journal of cleaner production, 2019, Vol. 226: 142-158.

Gunawardena T, Tuan Ngo, Mendis P, Alfano J. Innovative Flexible Structural System Using Prefabricated Modules[J]. Journal of Architectural Engineering, 2016,22(4):1-7.

Hammad A W, Akbarnezhad A, Wu P, Wang X, Haddad A. Building information modelling-based framework to contrast conventional and modular construction methods through selected sustainability factors[J]. Journal of Cleaner Production, 2019,228:1264-1281.

Hill R C, Bowen P. Sustainable construction: principles and a framework for attainment[J]. Construction Management and Economics, 1997(3):223.

Ho K M, Lam J P, Max S. Pre-Fabricated Pre-Finished Volumetric Construction (PPVC) for residential projects[R]. Threesixty Cost Management Pte Ltd, 2019. Web:https://surbanajurong.com/wp-content/uploads/2018/08/1.-PPVC-Final-.pdf. surfed at Jan. 28(2019).

Hong S-G, Cho B-H, Chung K-S, Moon, J. Behavior of framed modular building system with double skin steel panels[J]. Journal of Constructional Steel Research, 2011,67:936-946.

Hong J, Shen G Q, Li Z, Zhang B, Zhang W. Barriers to promoting prefabricated construction in China: A cost–benefit analysis[J]. Journal of Cleaner Production, 2018,172:649-660.

Hua K, Wang Z. Research and application of structural system in high-rise modular building (in Chinese) [J]. Low Temperature Architecture Technology, 2017,39(05):31-33.

Huang B, Mauerhofer V, Geng Y. Analysis of Existing Building Energy Saving Policies in Japan and China[J]. Journal of Cleaner Production, 2015, 112:1510-1518.

Hwang B-G, Shan M, Looi K-Y. Key constraints and mitigation strategies for prefabricated prefinished volumetric construction[J]. Cleaner Production, 2018,183:183-193.

Jaillon L, Poon C S. The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector[J]. Automation in Construction, 2009,18(3):239-248.

Jaillon L, Poon C S. Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong[J]. Automation in Construction, 2014,39:195-202.

Kamali M, Hewage K. Life cycle performance of modular buildings: A critical review[J]. Renewable and Sustainable Energy Reviews, 2016(62):1171-1183.

Kamali M, Hewage K. Development of performance criteria for sustainability evaluation of modular versus conventional construction methods[J]. Journal of Cleaner Production, 2017,142(Part 4):3592-3606.

Kim D. Preliminary Life Cycle Analysis of Modular and Conventional Housing in Benton Harbor, Michigan[D]. University of Michigan: Ann Arbor, MI, USA, 2008.

Lacey A W, Chen W, Hao H, Bi K. Structural response of modular buildings – An overview[J]. Journal of Building Engineering, 2018,16:45-56.

Land Transport Authority. Administration of Oversized Heavy Vehicle movement[S]. 2016.

Lawson R M, Ogden R G, Bergin R. Application of modular construction in high-rise buildings[J]. Journal of Architectural Engineering, 2012(2):148.

Lawson R M, Richards J. Modular design for high-rise buildings[J], Procedings of The Institution of Civil Engineers-Strucures and Buildings, 2010,163(3):151~164.

Li C Z, Hong J, Xue F, Shen G Q, Xu X, Luo L. SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong[J]. Habitat International, 2016,57:74-87.

Li C Z, Hong J, Xue F, Shen G Q, Xu X, Mok M K. Schedule risks in prefabrication housing production in Hong Kong: a social network analysis[J]. Journal of Cleaner Production, 2016,134(15):482-494.

Li Z, Shen G Q, Xue X. Critical review of the research on the management of prefabricated construction (in Chinese) [J]. Habitat International, 2014,43:240-249.

Liu S, Qian S. Evaluation of social life-cycle performance of buildings: Theoretical framework and impact assessment approach[J]. Journal of Cleaner Production, 2019,213:792-807.

Lopez D, Froese T M. Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes[J]. Procedia Engineering, 2016,145:1291-1297.

Lu W, Chen K, Xue F, Pan W. Searching for an optimal level of prefabrication in construction: An analytical framework[J]. Journal of Cleaner Production, 2018,201(10):236-245.

Mao C, Xie F, Hou L, Wu P, Wang J, Wang X. Cost analysis for sustainable off-site construction based on a multiple-case study in China[J]. Habitat International, 2016,57:215-222.

Mak Y. Prefabrication and industrialization of housing in Hong Kong[D], The Hong Kong Polvtechnic University, Hong Kong, 1998.

Nanjing People's Government. Implementation Opinions on Accelerating the Modernization of the Construction Industry and Promoting the Upgrade of the Construction Industry[D], 2015. http://www.nanjing.gov.cn/zdgk/201605/t20160510_1056988.html

Quale J, Eckelman M J, Williams K W, Sloditskie G, Zimmerman J B. Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States[J]. Journal of Industrial Ecology, 2012, 16(2):243-253.

Abdul Rahim A, Qureshi S L. A review of IBS implementation in Malaysia and Singapore[J]. Planning Malaysia, 2019,16(2):323-333.

Rahman M, Sobuz B H. Comparative Study of IPS & PPVC Precast System- A Case Study of Public Housing Buildings Project in Singapore[C]// Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD), KUET, Khulna,

Bangladesh, 2018.
Ren Z, Chen M. A new exploration of construction method on the design of the temporary office area for enterprises at Xiong'an civic service center[J]. Architectural Journal, 2018(08):10-13. (In Chinese)
Ronchi S, Salata S, Arcidiacono A, Piroli E, Montanarella L. Policy instruments for soil protection among the EU member states: A comparative analysis[J]. Land Use Policy, 2019,82:763-780.
Rodrigues E E C, Rodrigues J P C, da Silva Filho L C P. Comparative study of building fire safety regulations in different Brazilian states[J]. Journal of Building Engineering, 2017,10:102-108.
Sanches R, Mercan O, Roberts B. Experimental investigations of vertical post-tensioned connection for modular steel structures[J]. Engineering Structures, 2018,175:776-789.
Seny Kan A K, Adegbite E, El Omari S, Abdellatif M. On the use of qualitative comparative analysis in management[J]. Journal of Business Research, 2016,69(4):1458-1463.
Shen L, Hao J L, Tam W Y, Yao H. A checklist for assessing sustainability performance of construction projects[J]. Journal of Civil Engineering and Management, 2007, 13(4): 273-281.
Spence R, Mulligan H. Sustainable development and the construction industry[J]. Habitat International, 1995, 19(3):279-292.
Tam V W Y, Fung IWH, Sing M C P, Ogunlana S O. Best practice of prefabrication implementation in the Hong Kong public and private sectors[J]. Journal of Cleaner Production, 2015,109:216-231.
Tam, K. L. Are We Ready? Pilot Modular Integrated Construction (MiC) Project of Student Residence at Wong Chuk Hang Site for the University of Hong Kong[C]//International Conference on Modular Integrated Construction, Kowloon, Hong Kong, 2018.
Tavares V, Lacerda N, Freire F. Embodied energy and greenhouse gas emissions analysis of a prefabricated modular house: The "Moby" case study[J]. Journal of Cleaner Production, 2019,212:1044-1053
Ting S K, Jin H F. Prefabrication in The Singapore Construction Industry[C]. White paper, https://pdfs.semanticscholar.org/9450/18d67bc8865b855f081d10435a5e5bf37cd2.pdf, surfed at Mar. 22, (2019).
Xu G, Zhong R Y, Yang H, Huang G Q. Cloud Asset-enabled Prefabrication Transportation Service for public housing production in Hong Kong[C]// IEEE International Conference on Automation Science & Engineering. IEEE, 2015.
Zhang W, Lee M W, Jaillon L, Poon C S. The hindrance to using prefabrication in Hong Kong's

building industry[J]. Journal of Cleaner Production, 2018,204:70-81.

Zhang Y, Wang J, Hu F, Wang Y. Comparison of evaluation standards for green building in China, Britain, United States[J]. Renewable and Sustainable Energy Reviews, 2017,68(Part 1):262-271.

Zhong R Y, Peng Y, Fang J, et al. Towards physical internet-enabled prefabricated housing construction in Hong Kong[J]. IFAC-PapersOnLine, 2015,48(3):1079–1086.

Zuo J, Zillante G, Wilson L, Davidson K, Pullen S. Sustainability policy of construction contractors: A review[J]. Renewable and Sustainable Energy Reviews, 2012,16(6):3910-3916.