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SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong

Clyde Zhengdao Li [a], Jingke Hong [a, *], Fan Xue [a], Geoffrey Qiping Shen [a, **], Xiaoxiao Xu [b, ***], Lizi Luo [a]

[a] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong [b] College of Civil Engineering, Shenzhen University, Nanshan, Shenzhen, China

Abstract

Housing has been a major concern in Hong Kong for the past several decades, increasing pressure on the Hong Kong Housing Authority to pursue ambitious housing plans. As a sustainable construction technology, prefabrication has been increasingly adopted in the delivery of housing plans to alleviate various constraints, such as labor shortage, time, safety, and environmental protection. However, few studies have conducted a strategic analysis of the current situation and planning management of prefabrication housing production (MPHP) in Hong Kong. By performing a strengths, weaknesses, opportunities, and threats (SWOT) analysis, the current study attempts to facilitate a more in-depth understanding of the MPHP development status in housing production in Hong Kong. Data underpinning the SWOT analysis are collected from various channels, including literature review, prefabrication-related regulations, interviews with experts, and government reports. This study provides an opportunity for major stakeholders to perceive the external and internal conditions of prefabrication development in Hong Kong. Internet of Things (IoT)-enabled platform deploying BIM to re-engineer offshore prefabricated construction processes, which are proposed based on the identified SWOTs for solving weaknesses and dealing with threats, are significant for improving MPHP in Hong Kong.

1. Introduction

The balance of housing supply and demand is one of the most crucial concerns in Hong Kong, which is one of the most densely populous areas in the world. Hong Kong has an area of 1104 sq. km. and an average population density of 6420 persons per sq. km (Jaillon & Poon, 2008). Limited availability of land and expensive land prices have resulted in the prevalence of high-rise building construction in Hong Kong. However, only a small percentage of the people can afford the high prices of dwellings in private housing, with about 50% of the population residing in public housing. More than 100,000 applicants are on the waiting list of the Housing Authority for public rental housing (PRH), with a possibility of having to wait at least seven years to move into a rental place considering PRH demand and supply (Chua, Wong & Shek, 2010). Housing issues in Hong Kong have resulted in widespread discontent. The Hong Kong construction industry has also witnessed a series of dilemmas and constraints, including safety, labor shortages, time, and environmental protection. Under this socioeconomic background and as a solution to housing problems, prefabricated construction is envisioned to gain momentum in Hong Kong.

Prefabrication is a manufacturing process that generally occurs in a specialized facility where various materials are combined to form the component parts of the final installation (Gibb, 1999). Prefabricated construction has long been recognized internationally to have numerous advantages that benefit the majority of participating parties in the construction process. Prefabrication is also recommended as a key vehicle in alleviating the adverse environmental impact of conventional cast in-situ construction, as well as in emphasizing efficient construction within developed construction industries (Li, Shen & Alshawi, 2014a; Mao, Shen, Pan, & Ye, 2013a). However, compared to other developed countries, such as Germany and Japan, the application of prefabrication technologies and practices of management of prefabrication housing production (MPHC) in Hong Kong remain at a low level. Possible reasons for this low level issues, such as the lack of accurate information on precast element management, poor information sharing among various enterprise systems, and fragmentation and discontinuity of the entire prefabrication supply chain, that confront the prefabrication housing production process. For instance, the processes of design, manufacturing, storage, transportation, and assembly on site are fundamentally fragmented. These processes are subjected to discontinuity of different parties designated to perform different tasks. Design information and orders for prefabricated components should be transmitted to prefabrication plants without any ambiguity to allow for effective manufacturing. MPHC practices should also have definite norms to regulate the precast concrete construction market. In general, industry stakeholders also lack awareness on the actual costs and underestimate potential savings in raw materials consumption when adopting prefabrication technologies. Most construction projects adopting prefabricated components do not conduct a comprehensive evaluation of the potential effects of prefabrication application. These problems illustrate the pressing need to enhance current MPHC practices to raise productivity in the Hong Kong construction industry.

In general, a strengths, weaknesses, opportunities, and threats (SWOT) analysis and the Internet of Things (IoT)-enabled strategic development of MPHC can contribute to the development of MPHC practices of a particular region from several perspectives. First, the analysis can assist both construction industry stakeholders and the government in developing an in-depth understanding of MPHC status quo in the studied region. Second, SWOT analysis and MPHC facilitate identification of the main problems confronted by the construction industry when adopting prefabrication technologies, thereby allowing for corresponding actions to be introduced for enhancement. Third, the analytic results can provide valuable reference in the formulation of related platform to help improve both short- and long-term MPHC developments in the region. To solve weaknesses and deal with threats identified in SWOTs analysis, critical Internet of Things (IoT)-enabled platform are proposed for the development and promotion of prefabricated construction at the strategic level of housing production in Hong Kong. The specific objectives of the current study are as follows: (1) review the current MPHC practices in Hong Kong and develop major questions for interviews; (2) perform a SWOT analysis on MPHC based on survey results; and (3) propose the corresponding IoTenabled platform and policy recommendations for MPHC development.

2. Prefabrication housing production in Hong Kong

Prefabricated construction refers to structures built at a location different from their location of use. Prefabrication occurs in a manufacturing plant designed specifically for this type of process and is typically in contrast with traditional on-site housing production. Several studies tend to use the terms modular buildings and modular housing to emphasize products composed of multiple sections called modules, which are prefabricated in a manufacturing plant. Individual building modules are constructed in the factory and then transported to the site via specially designed trailers. Therefore, the generally agreed upon benefits of using prefabrication include reductions in cost, time, defects, health and safety risks, and environmental impact, as well as a consequent increase in predictability, whole-life performance, and profitability (Li, Shen, & Xue, 2014b; Long, Zou, & Liu, 2009; Mao, Shen, Shen, & Tang, 2013b; Pons & Wadel, 2011).

Prefabricated construction technology has been applied in many countries, including Singapore, Japan, the US, and the UK; the use of said technology is also no longer new in the construction industry in Hong Kong (Jaillon & Poon, 2009). Fig. 1 illustrates the prefabricated housing construction process. Often, a client will hire designers to develop architectural and engineering designs, with special considerations given to the adoption of modules and their structural safety, buildability, and transportation convenience. Unlike the processes embedded in conventional cast in-situ construction, prefabricated housing is considered a significant process innovation that can alleviate problems in housing production, including time overrun, poor quality, and harsh working environment (Wang, Li & Tam, 2014). However, other problems besetting the construction industry remain unchanged. For example, the processes of design, manufacturing, storage, transportation, and assembly on site are fundamentally fragmented. These processes are subjected to discontinuity of different parties designated to perform different tasks. The problems of fragmentation and discontinuity are common in prefabrication housing production in Hong Kong. Design information and orders for prefabricated components need to be transmitted to prefabrication plants without any ambiguity to allow for effective manufacturing. Components should be manufactured and transported to sites to synchronize with the schedules of the work crew. Managing information (e.g., improving real-time information visibility and traceability throughout the entire prefabrication process) is a particularly notable challenge among the many challenges in cultivating the benefits of using offshore prefabrication (Lu, Huang, & Li, 2011). These problems could be exacerbated further because the entire prefabrication sector has been transferred to offshore areas in the Pearl River Delta (PRD) region. With the above mentioned issues, conducting a SWOT analysis is necessary to gain in-depth understanding on MPHC in the Hong Kong construction industry.

3. Methodology

3.1. Research framework

The most crucial tool adopted for the strategic analyses of MPHC in Hong Kong is the SWOT analysis approach, which is a useful tool for the strategic planning process. SWOT analysis is recognized extensively and constitutes an important means for learning about a situation and designing future procedures that can be considered necessary to enable strategic thinking. The SWOT analysis approach has been broadly applied in a variety of disciplines for investigating problems from a strategic perspective. For instance, in the research field of waste management, an investigation into the development of construction waste management in Shenzhen, Mainland China, is conducted and a set of concrete strategic action plans are subsequently proposed to improve the management in that region (Yuan, 2013), while the similar analyses are also witnessed in the research filed in construction industry (Lu, Li, Shen & Huang, 2009), and urban planning (Zuxin, Xinran & Zhenliang, 2009). The general process of SWOT can be divided into four main parts: (1) investigating current development of housing production, (2) forming research question for SWOT, (3) conducting SWOT analysis, and (4) proposing corresponding platform.

Fig. 2 shows the methodology adopted for the analysis in this study. In the first step, the current housing challenges confronted by the Hong Kong government are presented in detail through an analysis of collected materials. These materials are collected from two channels:

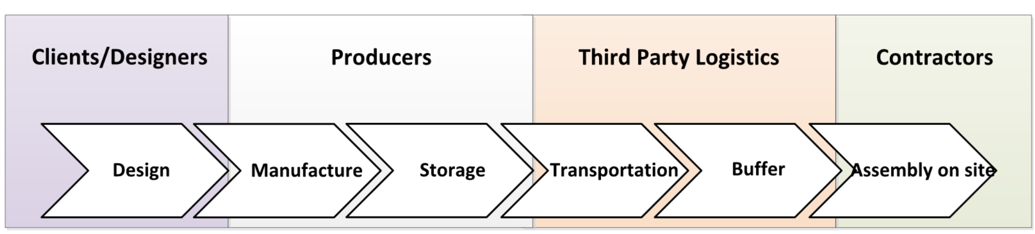


Fig. 1. Prefabricated housing construction process.

through an investigation of the relevant government guidelines and reports and by consulting stakeholders involved in housing production, such as manufacturers, logistics personnel, and contractors. Second, research questions are designed to investigate the SWOT of prefabrication housing production in Hong Kong. Third, a comprehensive SWOT analysis is performed based on the developed research questions. The answers to the research questions are formulated based on the results of the analyses of information obtained from a series of semi-structured interviews with concerned major stakeholders, including HKHA (Hong Kong Housing Authority) staff members responsible for housing production in the region, managers from precast manufacturers and logistics companies, engineers, and on-site managers of contractors. A series of semi-structured interviews were conducted in 2014, with each semi-structured interviews lasting between 50 and 60 min in task 1 and 2. Focus group meeting involving various stakeholders was organized to analyze the strengths, weaknesses, opportunities and threats encountered in the PHP industry. A profile of interviewees and stakeholders from different parties is shown in Table 1. The main cause for including these stakeholders

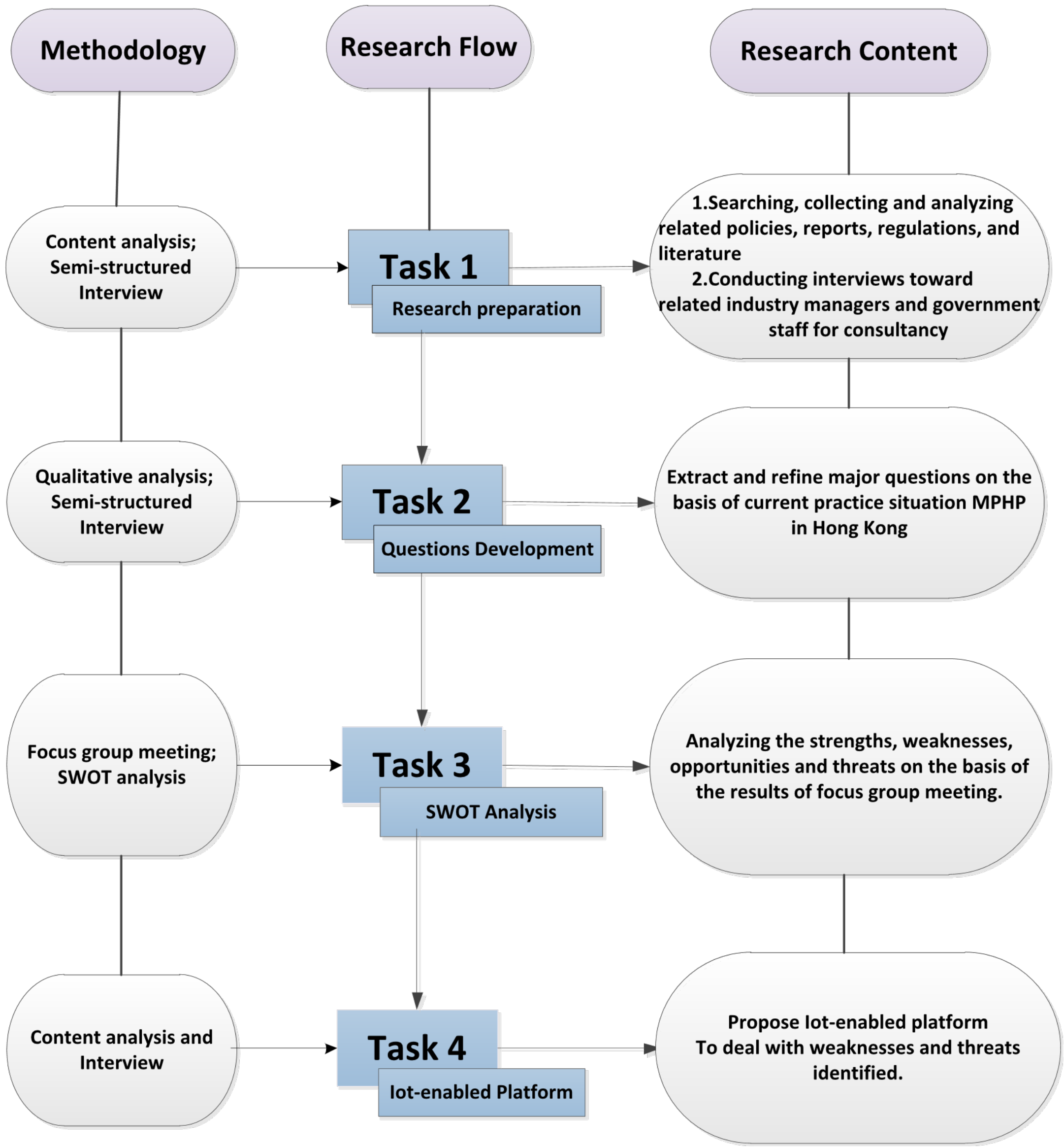


Fig. 2. Research flow.

Table 1

Profile of interviewees and stakeholders from different parties.

N.	Position	Company	N.	Position	Company
1	Structural Engineer	Hong Kong Housing Authority	6	Assistant Engineer	Main Contractor

2	Architect	Hong Kong Housing Authority	7	Site Agent	Main Contractor
3	Contract Manager	Main Contractor	8	BIM Manager	Main Contractor
4	Senior Engineer	Main Contractor	9	Factory Manager	Production Company
5	Project Manager	Main Contractor	10	Business Manager	Logistics Company

in semi-structured interviews and focus group meeting is their extensive experience in every process of offshore prefabrication housing production in Hong Kong. These stakeholders are well informed on the current practices of prefabrication housing production in Hong Kong. Although the opinions of other stakeholders, such as construction workers, may also be beneficial in the understanding of practical construction issues in the precast housing production process, their viewpoints could reflect precast housing production issues from a project-level rather than from a regional perspective. Hence, considering that the key objective of this research is to examine the Hong Kong precast housing production industry practices from a strategic perspective, precast housing production-related issues from a broader perspective should be placed to the pivot. Fourth, based on the identified SWOTs, suggestions to improve the prefabrication housing production are proposed in accordance with the principle of “transforming weaknesses to strengths, and minimizing threats.”

3.2. Questions formulation

The primary research questions developed for the semistructured interviews are explained and presented as follows.

Question 1: What are the strengths of Hong Kong when implementing prefabricated construction management practices?

The first question aims to determine both internal and external strengths of Hong Kong in implementing prefabricated construction management practices. For example, this question may deal with the benefits that Hong Kong contractors may gain from the use of prefabricated components when the Buildings Department implemented the incentive schemes through JPNs 1 and 2. The interviewees may also be asked the following specific questions:

What policy advantages may Hong Kong have when promoting the application of prefabrication technology?

What factors caused Hong Kong to act as a pioneer in the use of prefabricated construction method in China? Question 2: What are the weaknesses of implementing MPHP in Hong Kong?

The second question examines the possible weaknesses of the Hong Kong construction industry when developing MPHP. For example, this question may explore the obstacles (e.g., relatively high construction cost and difficult vertical transportation) that contractors face in adopting prefabrication technology. During the interview, the professionals were asked to give their views on the following questions.

In what aspects should improvements be made to promote the use of precast units in housing production?

What are the disadvantages of implementing MPHP practices in Hong Kong?

What obstacles hinder the application of prefabrication technology in Hong Kong?

Upon which aspects does MPHP need to be enhanced?

Question 3: What opportunities can Hong Kong explore to develop MPHP?

The third question is designed to examine future possible opportunities of the Hong Kong construction industry when developing MPHP practices. This question requires information on the benefits that result from MPHP development, including improved quality, shorter construction period, and better construction environment. The third question can also be expounded further in the following questions.

What opportunities can the Hong Kong construction industry utilize to promote the use of prefabrication technologies? What types of benefits will ensure the future improvement of MPHP in Hong Kong?

Question 4: What threats could the Hong Kong construction industry face when improving MPHP practices?

The last question intends to examine the threats that could prevent promotion of the use of precast units and improvement of MPHP in the Hong Kong construction industry. The interviewees were also asked the following questions.

What internal and external obstacles could the Hong Kong construction industry encounter in developing MPHP practices?

Is the environment of the Hong Kong construction industry suitable for a more extensive use of prefabrication technologies?

4. SWOT analysis of MPHP in Hong Kong

SWOT analysis enables the identification of the main problems confronting the construction industry when adopting prefabrication technologies and contributing to the formation of a better understanding of both the internal and external situation of MPHP practice. The external conditions are related to the threats and opportunities, whereas the internal conditions refer to the weaknesses and strengths. A specific account of SWOTs as a result of a series of interviews is as shown as Table 2, and the discussion on strengths/weaknesses/opportunities/threats are based on both of interviewer results and literature review.

4.1. Strengths

4.1.1. Extensive experience in prefabricated construction

Prefabricated construction has long been adopted in Hong Kong. Along with public housing programs in Hong Kong, prefabricated buildings were first developed (e.g., home ownership scheme or HOS) in the mid-1980s; prefabrication and standard modular designs, were introduced in public housing projects (Jaillon & Poon, 2009). The most frequently adopted precast elements include parapets, precast facades, partition walls, semi-precast slabs, staircases, and in more recent times, kitchens and volumetric precast bathrooms (Tam, Tam, Zeng, & Ng, 2007). Prefabricated components took up to approximately 17% of the total concrete volume consumed in projects of public housing in 2002 (Chiang, Chan, & Lok, 2006), whereas a pilot project stretched the application of precast components to 65% in 2005, and included the use of structural walls and precast kitchen (Jaillon & Poon, 2008).

More recently, prefabricated components in Hong Kong have evolved from simple partition walls (dry walls) to highly complex pre-installed components. Fig. 3 shows the typical prefabricated components in the housing sector in Hong Kong. In general, the early adoption of prefabricated units in public housing projects and

Table 2

SWOT analysis results.

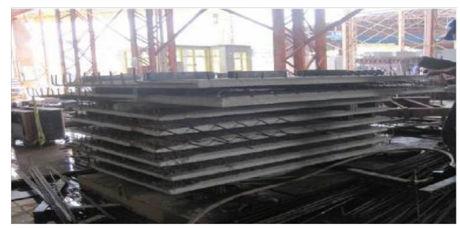
	Strengths	Weaknesses
Internal conditions	Extensive experience in prefabricated construction	Inefficient information transmission between the design and prefabrication stages
	Pioneer in promoting information technology (IT)in MPHP	Lack of real-time information visibility and traceability
	Consensus of building authorities regarding the promotion of prefabrication technology	Information gaps among stakeholders, technologies, and processes
	Leading role in promulgating MPHP-related regulations	Lack of interoperability between various stakeholders and their heterogeneous enterprise information systems (EIS)
	Opportunities	**Threats**
External conditions	Appeal to alleviate conflict between high housing demand and labor shortage	Inefficient installation management because of compact space
	Appeal to reduce construction waste	Inefficiency in transportation and high cost of cross-border logistics

	Appeal to alleviate construction safety hazards	Insufficient information storage method of precast elements

Precast Tie Beam

Precast Facade

Precast Volumetric Bathroom



Precast Slab

Precast Staircase

Precast Partition Wall

Precast Landing

Precast Refuse Chute

Fig. 3. Typical precast elements.

the HKHA's extensive experience in applying prefabrication technology have significant influence, and subsequently inspired prefabrication innovations in the private sector, including the use of precast staircases, façades, beams, slabs, and volumetric bathrooms. Innovations in the private sector have also affected those in the public sector with the use of precast structural walls and lost form panels (permanent formwork). Extensive experience has enabled innovations in the Hong Kong prefabrication sector to continue to thrive and be rewarding.

4.1.2. Pioneer in promoting information technology in MPHP

HKHA pioneered the use of information technology (IT), such as the Housing Construction Management Enterprise System (HOMES) and radio-frequency identification (RFID), in housing production. HOMES was developed by HKHA to enhance the flow of information and project logistics management in housing production. This system is "a large-scale integrated platform for the entire development and construction cycle, from project planning and project management to site management, budgeting, contract, and payment settlement. It eases communication and collaboration with external contractors, and assists back-office, middle management and project teams in their daily work, as well as giving top management a consolidated up-to-date picture for future planning." HOMES provides remote access to assist professionals in different working locations to monitor current housing programs and in-time project progress in terms of schedule, budget, expenditures, and payment. This system also maintains the records of previous housing projects and serves as a collaboration and knowledge-sharing platform to facilitate information and experience sharing among internal and external working parties within public housing projects. HOMES also has a restricted module available to senior management, which provides up-to-date key performance indicators, business plans, public housing program reports, and overall financial status for strategic management purposes (Lam, Wong & Kenny, 2009). In 2006, HOMES was recognized for its contribution to the housing sector by the Hong Kong Information and Communications Technology Awards.

Initially, RFID was introduced as an alternative technology to replace the barcode system for identifying items. Compared with both the barcode and magnetic strip systems, RFID can store a relatively larger amount of data. These data can be encrypted to increase data security. Using RFID enables simultaneous reading of data from multiple tags, thereby enhancing data processing efficiency. Unlike both barcode and magnetic strip systems, direct contact between an RFID reader and tagged items is no longer necessary because RFID uses radio waves for data transmission. Writing data back to the RFID tag is also possible, significantly increasing the interaction between items, system, and users. In recent years, RFID has been used extensively in the manufacturing, logistics, and retailing sectors because of the technology's automatic identification solution that can streamline identification and data acquisition. RFID has also been used in various applications, such as reading meters, preventing theft of store merchandise, tracking railroad cars and intermodal freight containers, collecting tolls, and conducting agricultural and animal research; this system also has potential in the construction industry. HKHA and Hong Kong MTR Corporation have explored RFID use to tag construction components manufactured offshore in the PRD region.

4.1.3. Consensus of building authorities regarding the promotion of prefabrication technology

Housing production in Hong Kong mainly adopted conventional construction technologies characterized by fixed jobsites, labor intensive, formwork and falsework, cast in-situ, wet trades, and bamboo scaffolding. Although this cast in-situ construction technology has its own strengths (e.g., highly flexible to design change), the technology has also received widespread criticisms. In April 2000, Tung Chee Hwa, then Hong Kong Special Administrative Region (HKSAR) chief executive, appointed the Construction Industry Review Committee (CIRC) chaired by Henry Tang to conduct a comprehensive review of the state of the construction industry and recommend improvement measures to uplift its quality and performance. The report, entitled “Construct for Excellence,” critically identified the problems besetting the industry. Among the relevant ones are as follows:

Poor site safety record;

Inadequately trained workforce;

Unsatisfactory environmental performance;

Extensive use of traditional and labor-intensive construction methods; and

Declining productivity growth and high building cost.

In the report, the extensive use of both prefabrication and standardized and modular components received consensus and was proposed as the primary strategy for improving the Hong Kong construction industry (Committee, 2001).

4.1.4. Leading role in promulgating MPHP-related regulations

Fig. 4 shows that since 2000, the Hong Kong government has issued a series of policies to encourage sustainable construction to adopt prefabricated building components in construction projects. HKHA was also recommended to assume the lead role in promoting the extensive use of prefabrication in Hong Kong, while the private sector's capacity for applying prefabrication should be enhanced through training, promulgation of related guidelines and codes, and research and development. Typically, following the government directive, the Hong Kong Buildings Department, Lands Department, and Planning Department jointly issued JPNs 1 and

2. The two JPNs stipulated that when green building technologies, including prefabrication, were adopted, building developers could receive GFA exemptions. A series of follow-up regulations have also been formulated to reinforce incentives of the use of prefabrication, including waste disposal charging scheme and waste disposal regulation notice that aims at reducing construction waste largely generated from conventional cast in-situ construction, forcing developers to shift from conventional construction method to more sustainable prefabrication method.

4.2. Weaknesses

4.2.1. Inefficient information transmission between the design and prefabrication stages

Prefabricated housing enables manufacturers to prefabricate several construction components offsite in the offshore yards in the PRD region instead of managing all raw materials and installing them on site. However, this process has several weaknesses. First, both the method of considering the prefabrication features (e.g., suitability for mass production) in the building information modeling (BIM) process and transmission of the design information to the manufacturers are unclear. Ideally, technical drawings of the construction components (e.g., slabs, partitioning walls, staircases, etc.) should be generated directly from the BIM model to the manufacturers who will produce them accordingly. However, the idea of a "holistic BIM" has yet to be realized. Manual handling of ordering information is extremely difficult, if not completely impossible for both clients and suppliers/manufacturers. Similar to a garments or electronics company, a manufacturer commonly supplies various prefabrication

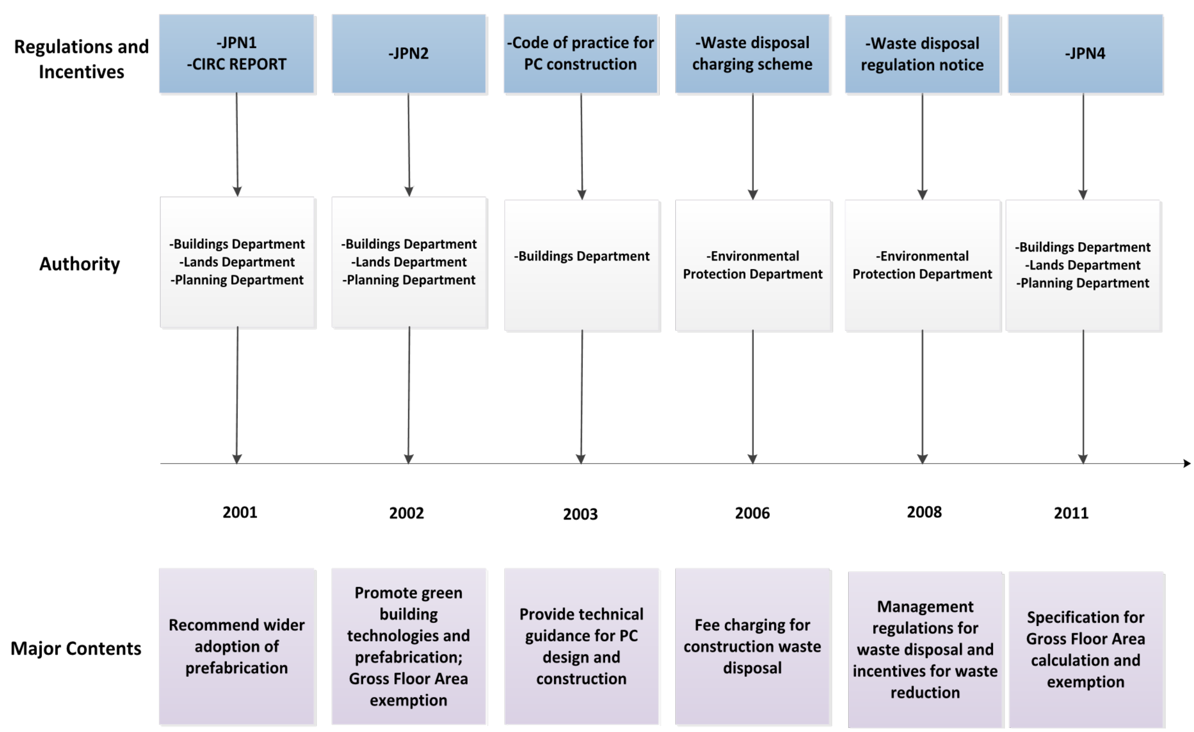


Fig. 4. Regulations and policies development.

components to different clients/ contractors and their construction sites. Receiving orders and changes from the clients/contractors would cause the production to become prone to errors. Currently, companies have to allot extra labor costs on checking, counting, and sorting their raw materials, including semi-finished and finished prefabricated components, through a highly inefficient process. Information is also labeled using paper cards or painted labels without using new Auto-ID technologies (e.g., RFID). This approach results in difficulties in efficient retrieval of data for other purposes, such as production management, inventory management, and transportation. Consequently, components may be delivered by mistake to other construction sites, causing possible serious project delays. In general, the entire decision-making process in prefabrication manufacturing is based on outdated and inaccurate data, as well as the "rule of thumb." Communication is also conducted through traditional and inefficient means, such as phone calls.

4.2.2. Lack of real-time information visibility and traceability

Production, transportation, and assembly are the three major scenarios of off-shore prefabrication in Hong Kong. Thus, to enhance productivity, components will be stored and transported across the border to construction sites in Hong Kong for assembly. Ideally, the entire process should be traced and monitored closely to improve productivity and reduce problems through the logistic and supply chain. The prefabricated components are transported to Hong Kong mostly using lorries. Logistics companies are responsible for loading, fastening, and unloading the prefabricated building components, as well as for customs clearance. Consequently, these offshore prefabrication housing production processes lack real-time information visibility and traceability.

Logistics and supply chain management (LSCM) originated from the manufacturing industry, and is defined as a network of organizations involved through upstream and downstream linkages to minimize time spent on each activity and maximize value on each echelon (Cooper, Lambert, & Pagh, 1997). LSCM plays a critical role in prefabrication logistics management in Hong Kong because most prefabricated components are generated in offshore sites in the PRD region. Prefabrication logistics management in construction can improve information flow, save costs, and support revenueenhancing business strategies. One of the most significant approaches to LSCM is the just-in-time (JIT) delivery system that originated from the Toyota production management (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). In prefabricated construction projects, LSCM relies heavily on accurate and timely information sharing among different stakeholders. However, current logistics information is based mainly on paper, phone, and manual entry approaches, resulting in the prevalence of human error and data inconsistency.

4.2.3. Information gaps among stakeholders, technologies, and processes

Stakeholder is a word increasingly used and abused in Hong Kong society and in the construction industry. Stakeholders are persons, groups, organizations, members, or systems that affect or can be affected by the actions of an organization. Stakeholders have different interests and would have different positive or negative influences on a system. Stakeholders in housing production may include clients (both public developers, such as HKHA and the Urban Renewal Authority and private developers), designers, consultants, contractors, suppliers, sub-contractors, end users, and facilities managers. Based on the current and typical design, bid, and build (DBB) housing delivery model, stakeholders have a hubandspokes representation. In the DBB model, the project occupies a central position and has direct connections with related stakeholders. These stakeholders are not necessarily involved in the entire project lifecycle and thus, may not always work together efficiently, and can also have competing interests. This situation is often referred to as the fragmentation and discontinuity that exist in the construction industry. With these structural problems, various issues are common, including risk aversion, short-termism, silo thinking, lost information, and ineffective communication.

Despite BIM being a common information platform where information and communication contributed and shared by stakeholders can be facilitated, addressing several weaknesses in this platform are necessary. First, the actual nature of the information is unclear. Uncertainties on how design information is received by production lines or how assembly information is embedded in prefabricated components and deciphered by workers on site still exist. Our observations indicated that workers were marking information, such as YL-HC/KT1B/8/39/PH, on prefabricated components using marking pens yet were unaware of the purpose of their actions. Product information is generally disconnected with the design information stored in a building information model. Although information is obtained using advanced RFID subsystems, making them "talk to" BIM remains a problem. Although ideally, BIM is a real-time information representation of an "as-built" project, this platform cannot synchronize with a project. Software vendors have developed several plug-ins for BIM to perform popular functionalities, such as clash dictation and bills of quantity (BQ) generation. However, the interface between a BIM system and an RFID subsystem or other peripheral devices (e.g., Webcam and laser scanner) has yet to be developed.

4.2.4. Lack of interoperability between various stakeholders and their heterogeneous enterprise information systems

For the past several years, various stakeholders have developed their respective enterprise information systems (EIS), such as HOMES, based on their information requirements.

Different companies have also customized their respective enterprise resource planning (ERP) systems or purchasing standard ERP packages. As stated by the interviewees, these systems have considerably facilitated the operations undertaken by different stakeholders by pushing precise information for decisions making. Nevertheless, these heterogeneous systems cannot "talk" to one another because of various reasons, including varying databases, functions, and operating systems. Another obstacle is the adversarial culture prevalent in the EIS sector. Stakeholders are self-guarded interest centers and thus, sharing information among them is not an industry-wide culture. This situation has been referred to as "information islands," which can be considered bodies of information that need to be shared but have no network connection. Therefore, information interoperability among EIS of various stakeholders is extensively recognized to be fairly low.

4.3. Opportunities

4.3.1. Appeal to alleviate conflict between high housing demand and labor shortage

Every country faces its own housing problems; however, no other housing problem is probably comparable to Hong Kong, where housing has been a major concern for the past several decades. At present, housing supply in Hong Kong is primarily through three channels, namely, private housing, PRH, and subsidized housing under HOS. HKHA records show that a total of 2,599,000 permanent residential apartments were in stock by the end of March 2012, among which, private apartments accounted for 56% (1,447,000), PRH accounted for 29% (761,000), with subsidized housing reaching 15% (391,000). These housing supplies are positioned in an increasingly decaying urban setting. The Housing, Planning, and Lands Bureau in 2005 reported that Hong Kong has approximately 39,000 private buildings, with approximately 13,000 of these buildings being over 30 years old. In ten years, this number will increase to 22,000. In terms of demand, 48,841 marriages were recorded in Hong Kong between the periods from 2004 to 2011; however, only 13,609 new private apartments were completed within the period, resulting in an average of 3.6 couples competing for one private apartment (Census and Statistics Department, 2007). The upsurge in prices of private housing has made this option affordable for only a very small percentage of people, with about 50% population having to reside in public houses (Census and Statistics Department, 2007). More than 100,000 applicants were on the wait list for vacant PRH (Census and Statistics Department, 2007). Given the PRH demand and supply, these applicants have to wait an average of seven years to move into PRH. Consequently, the housing issues have resulted in widespread discontent in Hong Kong. In July 2012, the new administration initiated a series of policies and regulations (e.g., "Ten measures by Leung," "Hong Kong Land for Hong Kong Residents," and the Special Stamp Duty) to address these issues. Producing more public apartments is one of the long-term strategies on the agenda of the government. Table 3 shows the public housing production forecasts, which was reiterated by HKSAR chief executive C.Y. Leung during the Policy Address where, through a large number of pages, an attempt to discuss the housing issues in Hong Kong was made.

On the production sphere, even if the government can secure land supply, whether the existing industry capability is sufficient to deliver the ambitious housing plan within such a short period remains questionable. First, the construction industry has a severe labor shortage with only 294,400 employees, which takes up about 8% of the total Hong Kong labor force. From this total, approximately 50,000 are at the worker level. The construction industry is also losing its appeal because of various reasons, such as aging population (Census & Department, 2012), the boom of the local construction market such as the 10 mega-infrastructure projects, and the poor image of the industry. Labor cost is also surging to increasing heights. The average daily wages of a bamboo scaffolder, mason, and bar bender and fixer reached HK$1147.0, HK$1247.5, and HK$1295.5, respectively (Census & Department, 2012). Despite the high wages, finding sufficient workers to produce houses remains a challenge.

4.3.2. Appeal to reduce construction waste

The fulfillment of such an ambitious housing plan in Hong Kong have further environmental effects because of the dust, greenhouse gas emissions, noise pollution, consumption of non-renewable natural resources, and construction waste. The construction industry is generally regarded to be a significant contributor to the deprivation of natural resources and environment despite the significant contribution of this industry to built environment development. In 2011, solid waste transported to landfills reached a record high of 13,458 tons per day (tpd), of which construction waste accounted for 25% (Department, 2012a). Waste dumping in landfills will cause extensive soil, water, and air pollution as the anaerobic degradation of the waste will generate CO_2 and methane. Construction waste also places enormous pressure on landfills as land resources are highly valuable in this compact city. Construction waste takes up landfill space at a rate of approximately 3,500 m^3 per day and costs the Hong Kong government more than HK$200 million annually for landfill disposal (Poon, Yu, Wong & Cheung, 2004). The Hong Kong Environmental Protection Department predicts that landfill facilities will reach their maximum capacity in the next 10 years, with an estimated 24% annual increase in construction waste for disposal (Department, 2007).

4.3.3. Appeal to alleviate construction safety hazards

Another problem faced by the housing plan of Hong Kong is safety, because the region is infamous for its high construction accident rates. According to the statistics from the Hong Kong Labor Department, the industrial accident rate in Hong Kong remains high at approximately 50% in 2011, although the number of industrial accidents has decreased steadily from 6239 in 2002 to 3112 in 2011 (Department, 2012b). A high number of industrial fatalities

Table 3

Public housing production forecasts.

Year	Public rental housing	Subsidized sale apartments	Total
2012e2013	13,100	0	13,100
2013e2014	14,100	0	14,100
2014e2015	12,700	0	12,700
2015e2016	20,400	0	20,400
2016e2017	15,300	2200	17,500
Grand Total			77,800

Source: Hong Kong Housing Authority

were recorded in this sector, with fatalities totaling 23 and fatality rate at nearly 0.367 in 2011 (Department, 2012b). The construction industry accounted for approximately 20% of all industrial accidents, a considerable percentage among all industrial fatalities in Hong Kong (Department, 2012b). The accident and fatality rates in the construction industry are significantly higher than the average rate of all industries. Therefore, the implementation of such an ambitious housing plan will possibly result in more constructionrelated accidents if no action is taken. Among the various construction-related safety hazards, include falling from high places, motor vehicle crashes, excavation accidents, electrocution, and machines, asbestos, solvents, noise, and manual handling activities.

4.4. Threats

4.4.1. Inefficient installation management because of compact space

Construction sites in Hong Kong are often compacted, with limited spaces for storing large and heavy components. Therefore, site management is often on the critical path for the success or failure of a construction project. Under these circumstances, JIT delivery and assembly model would be desirable. However, a site manager in Hong Kong will normally have to reserve components/ materials of 1.5 stores on site as buffer. The limited space results in more time for vertical transportation of precast units from the ground level to the designated floors. One interviewed manager stated that if an effective schedule for prefabrication assembly is lacking, then adoption of prefabrication may extend the floor construction cycle of cast in-situ floor from the usual five to seven days. Verification of the components is also inefficient primarily because of the extensive use of paper or paint labels. Workers have to pay attention to the verification process sequentially, leading to extra labor and time costs. Despite the focus of workers, accuracy of the verification process is not guaranteed because paper-based documents, or even the handwriting and modified labels, are frequently unclear. Current practice may also cause safety issues. Construction workers on the sites are often preoccupied with their responsibilities, several of which require space (e.g., for crane towers to hoist various components to proper positions). If the required spaces are occupied, then serious safety issues may occur.

4.4.2. Inefficiency in transportation and high cost of cross-border logistics

As mentioned, the entire sector of the production of precast elements in Hong Kong has been transferred to the PRD region, such as Shunde, Dongguan, Huizhou, Zhongshan and Shenzhen. The transfer is a natural response to the changing socio-economic landscape in the region. Hong Kong imports all the construction materials from Mainland China, which is one of the major materials suppliers. China can offer a full spectrum of raw materials because of the availability of resources and strong manufacturing capability. Offshore prefabrication enables purchase of cheap materials from Mainland China, while enabling Hong Kong to take advantage of the cheap and abundant labor force in the PRD region. Once the precast elements are manufactured, only a few pieces of these typically large and heavy components can be delivered at a time using a heavy truck. Therefore, the progress, timing, and cost of the construction generally depend on the logistics of the prefabricated module delivery. Based on our pilot studies, the cost of cross-border logistics could take up to 15%e20% of the total prefabrication production cost. The low efficiency of customs control also forces logistics companies to invest additional funds in leasing storage spaces near Lo Wu or Lok Ma Chau to store prefabricated components temporarily. This issue also has a negative effect on logistics efficiency and effectiveness.

4.4.3. Insufficient information storage method of precast elements

One of the managers interviewed stated that it would be extremely difficult if not completely impossible for both clients and suppliers/manufacturers to handle ordering information manually. Similar to a garment or an electronics company, it is not uncommon for a manufacturer to supply various prefabrication components to different clients/contractors and their construction sites. Taking orders and changes from clients/contractors makes the process susceptible to errors. Currently, companies have to allot extra labor cost on checking, counting, and sorting their raw materials as well as semi and finished prefabricated components. However, efficiency to achieve this goal remains lacking.

Another challenge is determining how to embed the design information in the prefabrication components for further use. Currently, information is labeled through paper cards or painted labels without using new auto-ID technologies. This approach causes difficulties in the efficient retrieval of data for other uses, such as production management, inventory management, and transportation. As such, components may be delivered to other construction sites by mistake, which may cause serious project delay.

5. IoT-enabled platform to improve MPHP in Hong Kong

Fig. 5 shows that based on the identified weaknesses and threats in SWOTs analysis, an innovative IoT-enabled platform deploying BIM to re-engineer offshore prefabricated construction processes for improving MPHP development can be proposed solving weaknesses and dealing with threats. 'Transforming weaknesses to strengths, and minimizing threats' is the basic principle of proposing the platform. The IoT-enabled platform deploying BIM to reengineer offshore prefabricated construction processes will be developed through the following steps: Step 1- map the offshore prefabrication processes in the HK-PRD setting; Step 2- obtain information flow throughout the offshore prefabricated construction processes; Step 3- develop a Web portal based on service-oriented architecture; Step 4- Integrate Auto-ID technologies to improve information interoperability as well as real-time information visibility and traceability of offshore prefabrication construction; and Step 5- Integrate people, offshore prefabrication processes, information flow, and technologies in a BIM-centered system. Detailed explanations on the development of the proposed IoT-enabled platform to solve the potential weaknesses and threats in SWOTs analysis are provided below as shown in Table 4. Take the weaknesses "Inefficient installation management because of compact space" for example, it normally leads to practical problems in the prefabrication industry, such as delay of the delivery of precast element to site and installation error of precast elements in construction site. The required function to handle this kind of weaknesses is Just-In-Time (JIT) delivery and assembly in compact site area, which will be developed in the IoT-enabled platform.

An innovative platform should be developed by deploying BIM as the basic infrastructure underlying the system structure to deal with weaknesses and threats identified in the SWOTs.

The platform may position Hong Kong as the leading region in the use of BIM to re-engineer architecture, engineering, and construction processes, particularly for offshore prefabricated construction processes. The platform emphasizes the integration of stakeholders to encourage communication and coordination based on BIM. An innovation on the structural design of the proposed platform is the use of BIM as an information hub to connect smart construction objects (SCOs) and create an intelligent construction environment. BIM currently deposits a hub of information received from designers and engineers. RFID systems will be connected to BIM models by developing further existing application program interface (API). This process may lead to a popular plug-in to

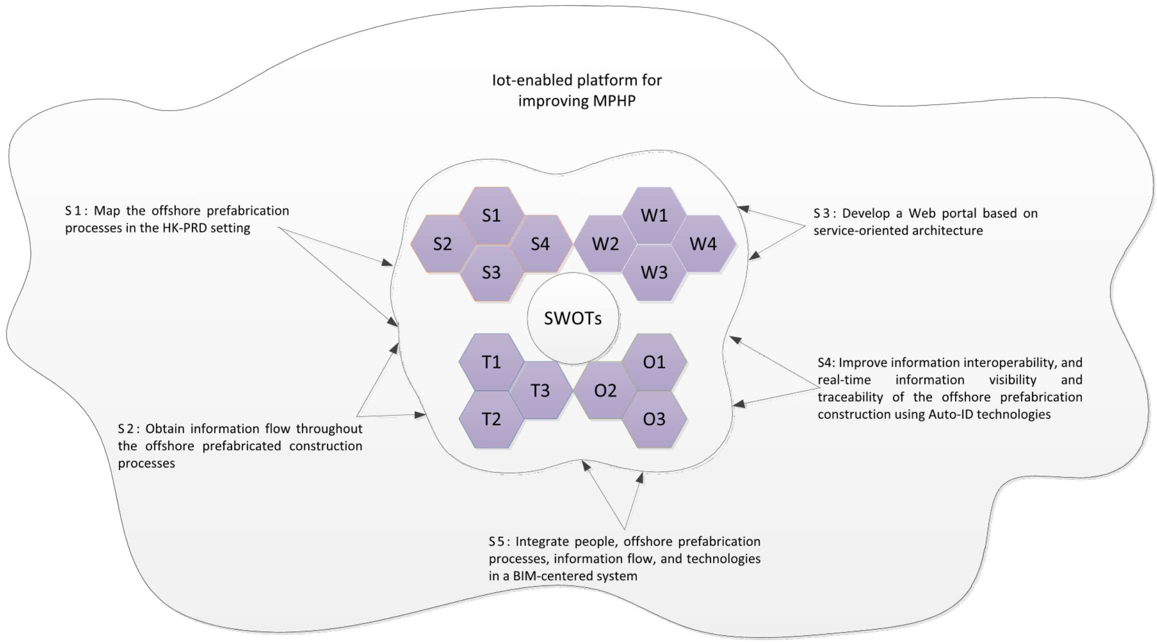


Fig. 5. IoT-enabled platform for MPHP.

Table 4

IoT-enabled platform and corresponding weaknesses and threats to be handled.

Development of IoT-enabled platform	Required functions to weaknesses and threats in PHP	Weaknesses and threats in PHP	Description of potential practical problems
IoT-enabled platform deploying BIM to re-engineer offshore prefabricated construction processes:	Just-In-Time (JIT) delivery and assembly in compact site area	Inefficient installation management because of compact space	Delay of the delivery of precast element to site Installation error of precast elements

Step 1 e map the offshore prefabrication processes in the HK-PRD setting;	Production information sharing between Prefabrication manufacturer and logistics and assembly companies that lead to extra negotiation time	Inefficiency in transportation and high cost of cross-border logistics	Logistics information inconsistency because of human errors Low information interoperability between different enterprise resource planning systems
Step 2 e obtain information flow throughout the offshore prefabricated construction processes;	Embedding the design information in the prefabrication components for further use	Lack of interoperability between various stakeholders and their heterogeneous enterprise information systems (EIS)	Tower crane breakdown and maintenance Slow quality inspection procedures
Step 3 e develop a Web portal based on service-oriented architecture;	Efficient communication among stakeholders and managers	Inefficient information transmission between the design and prefabrication stages	Design change Inefficiency of design approval
Step 4 e integrate Auto-ID technologies to improve	Passing the design information to the	Information gaps among stakeholders,	Inefficient design data transition Design information gap

information interoperability as well as real-time information visibility and traceability of offshore prefabrication construction;	manufacturers without any ambiguity	technologies, and processes	between designer and manufacturer
Step 5 e integrate people, offshore prefabrication processes, information flow, and technologies in a BIM-centered system.	Efficient identification and verification of proper precast components	Insufficient information storage method of precast elements Lack of real-time information visibility and traceability	Inefficient verification of precast components because of ambiguous labels Misplacement on the storage site because of carelessness

integrate RFID technologies with BIM. Currently, only few plug-ins, such as clash detection and BQ generation, have been observed in the industry, while the investigations the methods to link RFID and BIM are few and far between. These limitations may also provide an opportunity to connect BIM and IoT given that materials based on BIM can be easily purchased, and other resources are available around the world. Besides, using the graphic information generated from the RFID-enabled BIM platform to instruct the entire offshore prefabrication housing production is considered an innovation. For example, one may perceive IKEA furniture and its "assembly instruction" as a highly innovative approach. Currently, 2D tools, such as Gantt chart, are adopted to indicate progress in processes. BIM is used only in conducting construction rehearsals for a standard floor to optimize the configuration of construction resources. This platform should be able to generate innovative visual "instructions" to configure resources, trace and track prefabrication components alongside the logistics and supply chain, and to assemble them on site, such that the weaknesses and threats identified in the SWOTs can be solved. Detailed development function and development processes can be divided into 5 steps as follow.

Step 1: Map the offshore prefabrication processes in the HK-PRD setting

Effort should be exerted in understanding the processes and relevant constraints to enable the separation of design, manufacturing, storage, transportation, and assembly from one another. Previous studies have explored the processes in construction project management to plan resource allocation. However, the management skills and relevant information required by prefabrication construction differ significantly from what on-site projects often encounter in the construction industry. Therefore, mapping offshore prefabrication processes for further analysis, which is mainly the concern of HKHA (particularly in the HK-PRD setting), is necessary.

The aforementioned innovative platform serves as a framework for mapping the offshore prefabrication processes; however, more effort should be focused on developing a more detailed description of these processes. For this purpose, case studies should be conducted in three types of offshore prefabrication plants, namely manufacturing, logistics, and on site assembly. A case study research of three companies should be conducted to allow the exploration and understanding of complex issues based on collected primary data. This method can be considered as robust, particularly when a holistic, in-depth investigation is required. A combination of qualitative methods (e.g., semi-structured interviews, focus group meetings, non-participant observation, field notes, and analysis of documents and materials) should be used to investigate information flow throughout the processes.

Step 2: Obtain information flow throughout the offshore prefabricated construction processes

Achieving the objective of enhancing housing production by reengineering the offshore prefabrication processes requires that all involved parties, particularly HKHA and its associated entities, align the processes based on available information to form better decisions. Information is recognized as a core element for successful management. Mapping the offshore prefabrication processes eases obtaining the information flow throughout these processes.

The data flow diagram (DFD) originally developed by IBM will be adopted. DFD is a significant modeling technique used in analyzing and constructing information processes. DFD refers to an illustration that explains the course or movement of information in a process. Fisher and Shen (1992) utilized this tool to map the flow of data within a construction company to facilitate better information management.

The current study will focus on the use of DFD on three specific and critical scenarios, including prefabricated construction, crossborder logistics, and on-site assembly, which are mostly HKHA concerns. The first focus is on how design information is composed and decomposed by designers and passed on to the precast component plants. Analysis of the drawings will identify such information as design drawing and rationales created by using ArchiCAD or other BIM software. Parallel to this analysis is the information of the client's order sent to the plant. Formal and informal communications (e.g., drawings, briefings, and emails) among the different parties (e.g., clients, designers, and manufacturers) involved in offshore prefabricated construction processes will be obtained, analyzed, and mapped using DFD. The interoperability of information flow will be of particular interest in aligning the processes.

The second focus is on information flow from storage and transportation to sites. Transporting prefabricated building components to HKHA construction sites, such as Tung Tau Cottage Area East, is often outsourced to professional logistics companies. Professional logistics companies are responsible not only for loading, fastening, and unloading prefabricated building components but also for customs clearance. The information flow can be obtained by analyzing the contracts between the plant and logistic companies, as well as their working files for custom clearance. Therefore, maintaining real-time information visibility and traceability of the precreation components is critical to ensuring the smooth delivery of logistics and supplies to the sites.

The third focus is on the information flow from factory to on-site assembly. Compact sites in Hong Kong necessitate that prefabricated components must reach construction sites efficiently to fit into the on-going job on site. Therefore, not only is real-time information visibility and traceability critical but the sequence and positions of the prefabricated components should also be well organized. This part of information flow can be obtained by analyzing the working files, drawings, and field notes, as well as through non-participant observation and semi-structured interviews with site managers. The information obtained will be significant HKHA in formulating high-level decision-making after providing feedback to BIM or HOMES.

Step 3: Develop a Web portal based on service-oriented architecture

A Web portal should be developed and operated following a standard service-oriented architecture to enhance information interoperability among EIS of various stakeholders. A complete service-oriented architecture process involves three main phases, namely, publish, search, and invoke. Service providers/developers set up Web services at sites of selected servers and publish the particulars, including but not limited to interfacial description capability and location. The required Web services can be searched and selected by service consumers from the published database. Prior to the solicitation of services, values must be defined clearly and delivered over a detailed application process.

The three typical phases involve three fundamental Web services tools, including universal description, discovery and integration (UDDI); Web services description language (WSDL); and simple object access protocol (SOAP). UDDI is a platformindependent, XML-based registry for distributed services to list themselves on the Internet. The WSDL standard provides a uniform method for describing the abstract interface and protocol bindings of these services. This tool further describes what a Web service can do, where it resides, and how to invoke it. SOAP is a platformindependent protocol for invoking the distributed Web services through the exchange of XML-based messages. (Pang et al., 2014).

The concept of service in service-oriented architecture (SOA) is extended in the proposed platform. Various related application systems or information sources are defined as services, which can be classified into three categories. The first category includes standard optimization software where scheduling and planning algorithms are devised and deployed. Under the cloud computing concept, this category belongs to software as a service. The second category includes third-party native enterprise information/application platform. Examples of this platform include various BIM and HOMES modules. This category considers platform as a service. The third category includes data sources obtained directly from different types of native database systems. Adaptation is provided to convert information sources into standard Web services with standard output. This category presents the database concept as a service in cloud computing.

The proposed Web portal is a hybrid service-oriented architecture where software, platform, and database as services are combined innovatively to ensure the efficient working of different functions required by various stakeholders engaged in prefabrication construction.

Step 4: Integrate Auto-ID technologies to improve information interoperability as well as real-time information visibility and traceability of the offshore prefabrication construction

The objective of enhancing housing production through reengineering of offshore prefabrication processes requires all parties, particularly HKHA and its associated entities, to align the processes based on available information to form better decisions. Information is recognized as a core element of successful management and mapping the offshore prefabrication processes enables the information flow to be obtained throughout these processes. DFD should be adopted to ensure ease in obtaining the information flow. DFD refers to an illustration that explains the course or movement of information in a process. The information identified in DFD will be structured, stored, retrieved, visualized, and traced in real-time to support various decision-making processes within HKHA. This process will be accomplished by adopting Auto-ID technologies, such as barcode, quick response code, RFID, and magnetic strip. Among these Auto-ID technologies, RFID is the most promising in terms of obtaining real-time information among prefabrication manufacturing, logistics, and on-site constructions. RFID tags can be used to store information, while RFID writers with USB connection to computers can assist in encoding information into the tags. Previous studies have suggested that as a rule of thumb, the information in the tags should be brief. For example, a serial code, with its complex structure as stated in the data flow diagram, should be placed in a backend system; the rationale for this step is for security reasons and to use the processing power provided by the backend system. RFID readers (e.g., handshaking devices) will be used to retrieve information from both the tags and the backend system. Programming based on the APIs of RFID will be necessary to complete the functions.

Step 5: Integrate people, offshore prefabrication processes, information flow, and technologies in a BIM-centered system

The task of integrating people, offshore prefabrication processes, information flow, and technologies in a BIM-centered system can be understood as an actual example of the IoT. Fig. 6 shows the BIM-centered system prototype. In the prototype, a gateway will be developed to connect the RFID subsystem with the BIM subsystem. Graphically, this connection can be considered as a gateway between BIM and the backend system. A data exchange protocol will be developed at a lower level and an API at a higher level; these two elements will enable information synchronization between the two subsystems. One proposal suggested that the data exchange protocol be based on the Industry Foundation Classes (IFC) standards because of the interoperability of the gateway subsystem. IFC is published by the International Alliance for Interoperability and as a major data standard for BIM, IFC plays an important role in the process because IFC is a standard for globally sharing data throughout the project life cycle across disciplines and technical applications in the construction industry. The information collected and mapped in DFD will be incorporated into the BIM subsystem. Various APIs have been developed to facilitate further developments on the BIM software (e.g., ArchiCAD, AutoCAD, Revit, and NavisWork) and enable users to connect to the Auto-ID subsystem. Of particular interest in this case is enabling the BIM subsystem to "talk" to the building components through Auto-ID technologies and respond to the intervention of users when necessary. Microsoft Visual Studio is the ideal programming environment for developing gateway.

Once the Auto-ID subsystem and gateway are developed, the next step is to encapsulate their functionalities for industrial users. Computer technologies, such as Google Sketch Up and Microsoft Visual Studio, will be used to develop the operable system. All these technologies, including SCOs, RFID, wireless, and BIM, have been discussed and tested considerably in the construction industry. Hence, in this case, the innovative action is to organize these technologies cohesively to improve current offshore prefabricated construction processes. Not all of the aforementioned technologies are completely available and are still subject to further development. The integration will transfer and upgrade the managerial level of HKHA and the construction industry in both Hong Kong and PRD in a real-time, interoperable, and closed-loop manner.

Fig. 7 shows that the BIM-centered system can be developed further into four key components, namely, the SCOs, gateway, decision support service, and data source interoperability service.

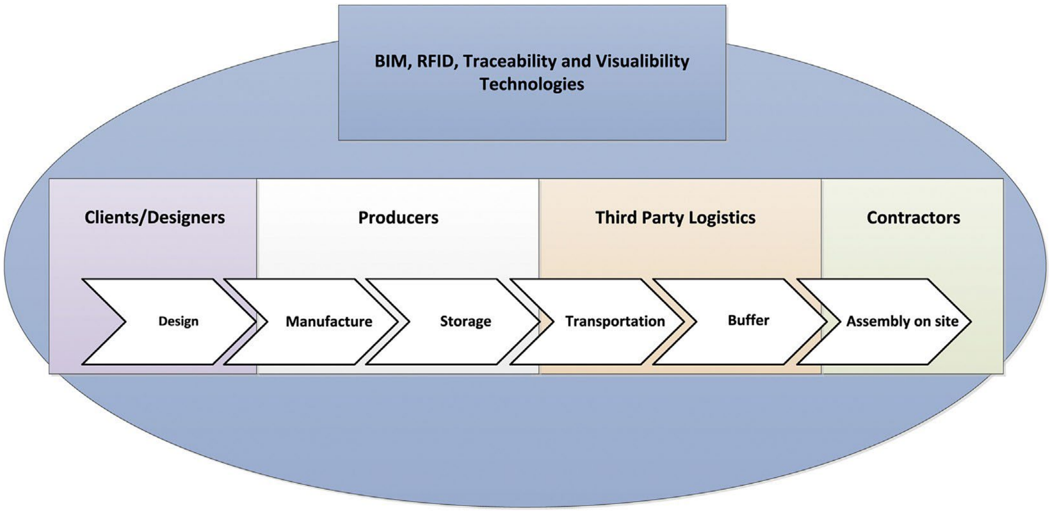


Fig. 6. Prototype of the proposed RFID-enabled BIM platform for offshore prefabrication housing production.

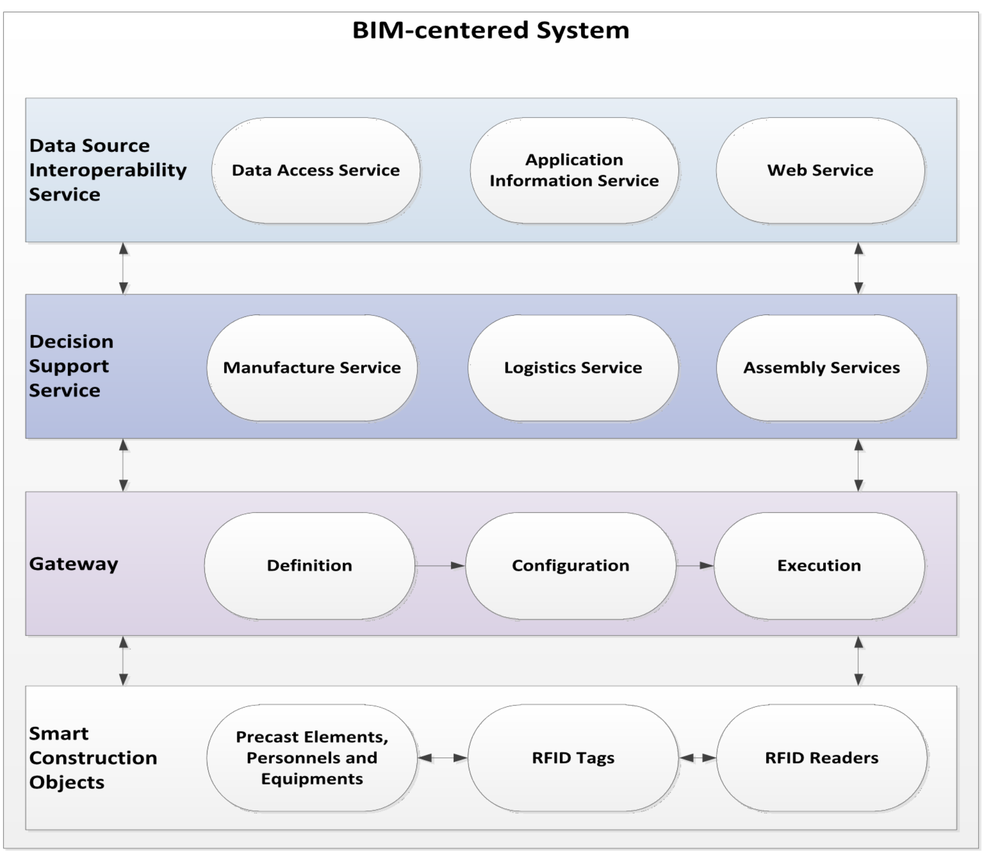


Fig. 7. Overview of the BIM-centered system.

Through the development of the Iot-enabled platform, the identified weaknesses and threats would be minimized and the MPHP level would be generally enhanced. The platform can successfully address the weaknesses and threats identified in the SWOTs analysis. The abundant paper-based records can be subsequently freed for many processes and only reserved for verification in key processes, which will help enhance efficiency of installation management, information storage and transportation (Threats 1, 2 and 3). The usage of BIM technique can also be henceforth extended to construction phase. If the histories of building components and the project progress are kept for future operation and maintenance phase, the BIM of built works can also be utilized, which will help fill the information gaps among stakeholders, technologies, and processes and enhance interoperability between various stakeholders and their heterogeneous (Weaknesses 3 and 4). It should be noticed that the platform is in fact not changing the core processes of the current business processes. Instead, some real-time data gathering is attached to the processes in convenient ways for the operators. For example, an inspector in the production factory can scan the component object for a confirmation of original design (Weaknesses 1). The disseminations of the real-time data and the status of the virtual models are also suggested in multiple ways, while App and SMS notification can be used to guide the relevant workers, greatly improving real-time information visibility and traceability (Weaknesses 2).

6. Conclusion

Insights into the external and internal situations of MPHP in the Hong Kong construction industry have been obtained through the SWOT analysis. The results indicate that further development of MPHP requires Hong Kong to build on its strengths, including its ample experience in prefabricated construction, pioneering work in promoting IT in MPHP, and consensus building among authorities regarding the promotion of prefabrication technology. The Hong Kong government should also take the lead in implementing MPHP-related regulations in cities worldwide. However, several weaknesses are observed in the MPHP practices in Hong Kong. These weaknesses include inefficient information transmission between the design and prefabrication stages, lack of real-time information visibility and traceability, and lack of interoperability among different stakeholders and their respective heterogeneous EIS. These weaknesses have hampered the further development of MPHP in Hong Kong.

The findings of this study also provide insights into the opportunities that Hong Kong can leverage and threats that it needs to address. In general, Hong Kong faces a severe labor shortage and extreme high labor cost in the construction industry, thereby necessitating the formulation of incentives to promote its MPHP practice. The strong appeal to alleviate the adverse environmental effects of construction waste provides another opportunity to promote the practices of MPHP in the construction industry in Hong Kong. The wide-ranging support of industry associations and local government serve as a concrete underpinning to uphold MPHP. Nonetheless, threats to a successful MPHP are also significant, and involve primarily inefficient installation management because of compact space, inefficiency in transportation, and high cost of cross-border logistics.

IoT-enabled platform for enhancing MPHP in the Hong Kong construction industry are proposed based on the SWOTs identified. The IoT-enabled platform that deploys BIM to re-engineer offshore prefabricated construction processes can be developed through 5 steps: (1) map offshore prefabrication processes in the Hong KongePRD setting; (2) maintain the flow of information throughout the offshore prefabricated construction processes; (3) explore the Web portal based on service-oriented architecture; (4) improve information interoperability and real-time information visibility and traceability of offshore prefabrication construction using Auto-ID technologies; and (5) integrate people, offshore prefabrication processes, information flow, and technologies in a BIM-centered system. The identified SWOTs are crucial to the success of MPHP in the Hong Kong construction industry, and will serve as useful references for other countries/cities worldwide with similar building environment of labor shortage, high labor cost and high housing demand, facilitating them to achieve an improved MPHP level. The proposed platform emphasizes the integration of stakeholders to encourage communication and coordination based on a BIM, so as to reduce fragmentation and discontinuity in MPHP. The innovativeness of the platform, by looking at the offshore prefabrication housing processes, is not only to alleviate the inherent structural problems of project delivery organizations, but also to increase their connectedness by using state of the art information communication technologies (ICT) in BIM. The proposed IoT-enabled platform are expected to be utilized by housing production related departments to improve the MPHP level in the prefabrication housing production industry.

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