Topic: T2.2 Construction, Operation and Management Reference number: 2041

Building information technologies and challenges in precast housing construction in Hong Kong

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Abstract: Prefabrication is generally regarded to have advantages over traditional construction methods; these advantages include reductions in time, defects, cost and safety risks and health, alleviation of adverse influence to the environment, and a consequent increase in productivity, whole-life performance, predictability, and profitability. Against the socioeconomic background for high housing demand and labor shortage, prefabricated construction, especially offshore prefabrication, is envisaged to gain momentum in the construction industry in Hong Kong. However, the applications of some innovative technologies in the Hong Kong construction industry are sporadic. Effective management is required to resolve the challenges in facilitating the housing production process. Through extensive contacts and preliminary studies with public bodies, such as Hong Kong Housing Authority, business associations, such as Hong Kong Construction Industry Council and Hong Kong Construction Association, and individual businesses and companies involved in the field, this study investigates current technologies adopted in precast housing construction and the challenges confronted in the process. The technological challenges mainly involve three aspects, namely, (a) information gaps, (b) real-time information visibility and traceability, and (c) information interoperability. This study provides in-depth understanding of current technologies and challenges confronted in the application of prefabrication in housing production in Hong Kong. A connected and dynamic building information modeling is proposed to be developed for reengineering offshore prefabricated construction processes.

Keywords: precast housing construction; construction management; building information technology; Hong Kong

1 Introduction

Every country in the world has its own housing problems, but probably none is comparable to Hong Kong, where housing has enduringly been a major concern to almost everybody over the past decades. The Policy Address 2013 reiterated an ambitious housing plan, that is, “approximately 75,000 new public

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rental housing flats over five years starting from 2012 to 2013 and approximately 17,000 home ownership scheme flats over four years starting from 2016 to 2017." With its potential benefits over traditional methods, such as better quality safer and cleaner working environment, and faster process,, prefabrication as a solution is gaining momentum in the face of the housing challenge. But, in order to cultivated the benefits of using prefabrication, its drawbacks, including poor interoperability, discontinuity, fragmentation, and lack of real-time information traceability and visibility, should be overcame, which are further exacerbated by movement of the entire sector to the offshore areas in the Pearl River Delta (PRD) region. The offshore prefabrication practices contribute to the complexity and difficulties in the prolonged production processes, including offshore prefabrication management, cross-border logistics, and on-site assembly. Stakeholders involved in housing production have developed various intelligent systems, such as the Housing Construction Management Enterprise System (HOMES) by Hong Kong Housing Authority (HKHA), enterprise resource planning (ERP), and building information modeling (BIM), which have significantly improved housing production. However, these systems are not connected, thereby making them new "information islands" to be bridged.

Through extensive contacts and preliminary studies with public bodies, such as HKHA, business associations, such as Hong Kong Construction Industry Council (HKCIC) and Hong Kong Construction Association (HKCA), and individual businesses and companies involved in the field, this study investigates current technologies adopted in precast housing construction and the challenges confronted in the process. This study has the following three specific objectives:

(1) Investigate major scenarios in the process of precast housing production
(2) Summarize technologies and challenges confronted in information technology application
(3) Proposed technical framework for solving the potential information island problem

2 Prefabrication and housing production processes in Hong Kong

2.1 Prefabrication technology

Prefabrication refers to the use of structures built in a different location than the location of use (Gibb and Isack, 2003). They occur in a manufacturing plant specifically designed for this type of process, which is typically in contrast to traditional on-site housing production. Some researchers have used modular buildings and modular housing to emphasize the products that consist of multiple sections called modules, which are prefabricated in a manufacturing plant(Aye et al., 2012). The individual modules of a building are constructed in a factory and then transported to the site through specially designed trailers. The advantages of prefabrication include reductions in time, defects, cost and safety risks and health, alleviation of adverse influence to the environment, and a consequent increase in productivity, whole-life performance, predictability, and profitability

Prefabricated construction processes can be summarized into five steps, namely, design, manufacturing, storage, transportation, and assembly on site. A client typically hires designers to perform architectural and engineering design, 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 help alleviate such problems as time overrun, poor quality, and harsh working environment in housing production. However, other problems that beset the construction industry remain unresolved. For example, the processes of design, manufacturing, storage, transportation, and assembly on site are largely fragmented. These processes are affected by the discontinuity of different parties, which are designated to perform different tasks. The fragmentation and discontinuity problems are not uncommon in prefabricated housing production in Hong Kong. Design information and orders for the prefabricated components should be passed to prefabrication plants without any ambiguity to allow effective manufacturing. Components should be manufactured and transported to sites to fit in with work crew scheduling. Among the many challenges for cultivating the benefits of using offshore prefabrication, a particularly difficult one is managing information, for example, improving real-time information visibility and traceability throughout the entire prefabrication processes (Lu et al., 2011). The problems could be further exacerbated by movement of the entire sector to the offshore areas in the PRD region.

2.2 Key scenarios in housing production

On the basis of the prototype of the offshore prefabricated housing processes and the pilot investigations conducted with individual businesses and companies involved in the field, this study summarizes three critical scenarios, namely, prefabricated construction, cross-border logistics, and on-site assembly. In each of the scenarios, three aspects, namely, labor, safety, and time, are highlighted as the problematic areas that deserve further improvement.

Prefab production

Instead of managing all raw materials and installing them on sites, prefabricated housing enables manufacturers to prefabricate some construction components offsite in the yards in the offshore PRD region. However, new challenges emerge from the processes. How the features of prefabrication (e.g., suitable for mass production) have been considered in the BIM process and how to pass the design information to the manufacturers without any ambiguity are not clear. Ideally, the drawings of construction components (e.g., slabs, partitioning walls, and staircases) should be directly generated from the BIM model for the manufacturers to produce accordingly. This process, which is called "holistic BIM" by some practitioners, is yet to be realized. The entire decision making in prefabrication manufacturing is based on untimed and inaccurate data and the rule of thumb. Communication is conducted through traditional approaches, such as phone calls, which are characterized by low efficiency.

Cross-border logistics

The finished prefabricated components are delivered by logistics companies, typically classified under third-party services, from the PRD region to construction sites in Hong Kong. This process is called cross-border logistics. Although Hong Kong has developed a capable logistic sector, the offshore prefabrication practice adds to the complexity of cross-border logistics. On the basis of our pilot studies, the cost of cross-border logistics could account for 15%–20% of the total prefabrication production cost.Prefab production and logistics companies do not share their information, so that they have to spend additional time on negotiating, discussing, and making decisions in a back-and-forth manner. In this case, logistic efficiency is largely affected. No common information platform is available to coordinate various stakeholders in cross-border logistics control for prefabricated housing construction. The research team is highly motivated to develop such a platform that can facilitate cross-border logistics in delivering prefabricated components effectively and efficiently.

On-site assembly

The third motivating scenario is for the on-site assembly of prefabricated components after they are delivered through cross-border logistics. BIM and its time-series construction simulation (e.g., a 4D model) have been advocated similar to IKEA's "assembly instructions" to guide and monitor the on-site assembly of prefabricated housing. However, improved on-site assembly management is required. No platform similar to the "assembly instructions" of IKEA has been developed to guide on-site assembly and make it highly efficient. This study proposes a technical framework through which an integrated framework can be developed to facilitate inheriting information from prefabricated production and cross-border logistics and can be used to facilitate the on-site assembly process.

3 Information technologies and challenges

3.1 Information technologies in prefabrication

Building information modeling

BIM is "a digital representation of the building process to facilitate exchange and interoperability of information in digital format"(Eastman, 1999). This digital representation is probably the most heatedly discussed technical advancement in the construction industry in Hong Kong and around the world. BIM can be an ideal backbone of the proposed platform if several key technological challenges can be addressed. Despite a wide range of BIM definitions, consensus is reached that BIM is not a simple 3D model but a process to improve the performance through the entire life cycle of buildings.BIM can be used for a wide range of purposes, for example, design and construction integration, project management, facility management (Jeong et al., 2009; Davies and Harty, 2011). BIM is argued to be a useful tool for reducing the problems in the construction industry, such as fragmentation, improving efficiency or effectiveness, and lowering the high costs of inadequate interoperability. BIM is also recognized as a virtual design and construction environment, a vehicle that facilitates communication among stakeholders, an information model that can be used throughout the project life cycle, or an education platform that can be used in universities or colleges As a digital platform, BIM can retain information such as design rationale to reduce improper discontinuity. Integration and collaboration are also highly encouraged in BIM, particularly when it works with the integrated project delivery model.

Furthermore, BIM is a significant development that is expected to lead to a paradigm shift in the construction industry.

HOMES

HOMES was developed by HKHA to enhance information flows and project logistic management in housing production (Fung, 2006). This system is a large-scale platform that integrating entire construction development and cycle, including initial project planning and management plan to on-site management, budgeting, contract, and payment settlement. HOMES facilitates communication with various internal and external contractors; assists middle management, project teams and back-office in their daily work; and provides a consolidated up-to-date picture for top management for facilitating future planning. This system provides remote access to help various professionals in different working locations to monitor ongoing housing programs and in-time project progress in terms of schedule, budget, expenditure, and payment. Also, this system keeps 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 involved within public housing projects (Lam et al., 2009). A restricted module open to senior management exists in HOMES, such as up-to-date key performance indicators, business plans, public housing program reports, and overall financial status for strategic management purpose (Lam et al., 2009). HOMES received a Hong Kong Information and Communications Technology Awarding 2006.

RFID technology

Few people in Hong Kong are knowledgeable in RFID technologies although almost everyone currently has at least one item with RFID in their wallet (e.g., Octopus cards or Hong Kong ID cards). RFID technology has been widely used in the manufacturing, logistics, and retail sectors because of its automatic ID solution that can streamline ID and data acquisition. This technology has been used in various applications, such as tracking railroad cars and intermodal freight containers, preventing theft of store merchandise, reading meters, collecting toll fees, and conducting agricultural and animal research; this technology is also considered as having potential in the construction industry. However, the use of RFID in the Hong Kong construction industry is sporadic. HKHA has explored the practice of attaching trees using RFID technology. HKHA and Mass Transit Railway Corporation (MTRC) have explored using RFID to tag their construction components, which are manufactured offshore in the PRD region. Pilot studies with our collaborators have shown that reading accuracy is a problem. Practitioners may use a technology only when it is 100% accurate. Cost is also an issue. The cost of some tags could be as high as HK$10; therefore, tagging less valuable but indispensable components with RFID tags is a less affordable practice. For the same reason, MTRC has discarded RFID and now uses quick-response code instead. Auto-ID technologies, such as RFID, are observed, but they are probably for window-dressing. Some valuable components, such as precast facades, are implanted with RFID, but they are used for quality control only. RFID is used in a piecemeal fashion in the prefabricated housing sector without an integrated approach in place. In the following section, this problem is explored in detail by placing the RFID technology in the context of BIM and offshore prefabricated housing processes.

3.2 Technical challenges

Information gaps

Stakeholders in housing production may include clients (both public developers, e.g., HKHA, and private developers), designers, consultants, contractors, suppliers, subcontractors, end users, and facility managers. Under the typical design, bid, and build housing delivery model, stakeholders have a hub-and-spoke representation, where a project occupies a central position and has direct connections with the related stakeholders. They are not necessarily involved in the entire project lifecycle. As the existence of competing interests, they do not always work together efficiently. This condition is often referred to as the discontinuity and fragmentation that exist in the construction industry. With these structural problems, issues, such as risk-aversion, short-termism, silo thinking, lost information, and ineffective communication, are commonly encountered. Prefabrication, as an innovative project delivery model, cannot fully solve the problems as these integrated procurement models do. On the contrary, prefabrication increases the problems because new stakeholders, such as offshore manufacturers, transporters, and host local authorities, are involved. BIM, as a common information platform contributed and shared by stakeholders, can facilitate information and communication, although it is not the solution to structural problems.

Lack of real-time information visibility and traceability

As described in the three motivating scenarios to enhance prefabricated housing production in Hong Kong, components are stored and transported across the border to construction sites for assembly. Ideally, the entire process should be closely traced and monitored not only to improve productivity but also to reduce nuisance throughout the logistics and supply chain. Prefabricated components are mostly transported to Hong Kong by lorries. Logistics companies are responsible for loading, fastening, and unloading of the prefabricated building components, as well as custom clearance. Real-time information visibility and traceability are lacking in these offshore prefabricated housing production processes. BIM has yet to be used as a platform from which real-time information visibility and traceability of the prefabricated components can be obtained. At its current stage, the BIM system cannot synchronize the location information of the on-delivering components through technologies, such as RFID, geographic information system, and global positioning system. Therefore, this system is a "blind BIM." The incomplete, inaccurate, and untimely data from previous processes may be re-entered into various isolated systems, such as BIM, supply chain management (SCM), and ERP, which cannot optimize the logistics and SCM. The unique and myriad prefabricated components require right items at the right time in the right place. This requirement is hardly executed in current prefabrication logistic management in Hong Kong, particularly given such challenges as limited resources, space, and time. The solution to such a problem remains a void to be filled.

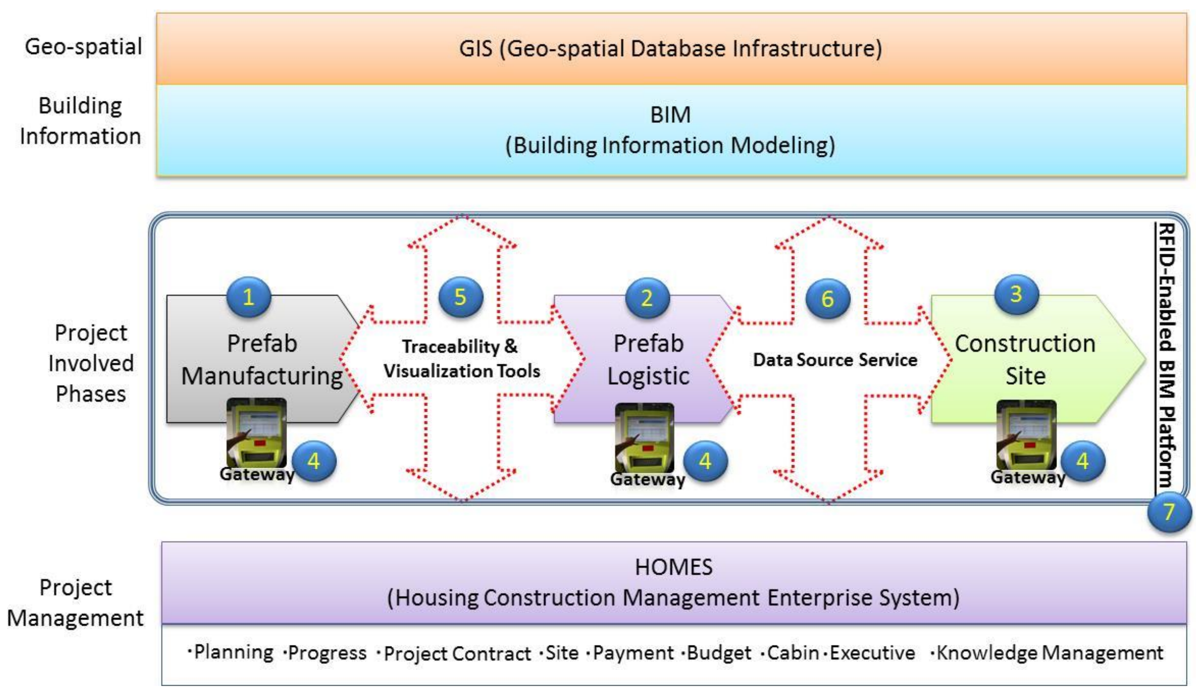
Lack of interoperability

On the basis of their information needs, different stakeholders have developed their own enterprise information systems (EISs), such as HOMES. Different companies have made their own ERP systems or purchased standard ERP packages. Communications between various stakeholders may have been greatly facilitated through managing the captured information in these systems. However, due to some many reasons, such as different functions, operating systems, and databases, these heterogeneous systems can hardly be effectively connected. Another obstacle is the adversarial culture in this sector. Stakeholders are basically self-guarded interest centers; sharing information among them is not an industry-wide culture. This condition has been called "information islands," which can be considered as bodies of information that need to be shared but there is no appropriate network to connect them. Information interoperability between the EISs of different stakeholders is fairly low. In addition, BIM may create new "information islands" in the construction industry. Different software vendors tend to promote their own commercial software packages, although they are all under the same umbrella of "BIM." Different BIM systems cannot communicate with one another. The recommendation of the Industry Foundation Classes is supposed to increase interoperability with an aim to bridge all new information islands, but achieving this goal remains a technical challenge.

4 Proposed technical framework

A specific technical framework, as shown in Figure 1, is proposed to play a systematic role in addressing the aforementioned challenges. Focus is placed on seven innovative technical components that have the most potential capability to solve the problems. The seven technical solutions are categorized using the convention in the service science literature as follows.

Figure 1: Technical framework for solving the challenges in building information technologies



Platform as a Service (Number 7): This aspect is the service-oriented open architecture platform called RFID-enabled BIM Platform (RBIMP) that incorporates key hardware and software settings for other technical solutions.

Software as a Service (Numbers 1–3): These aspects represent three sets of service-oriented decision support (software) systems, which are particularly developed as plug-ins for the three important phases, namely, prefab production, prefab logistics, and construction assembly on-site throughout the project lifecycle.

Infrastructure as a Service (Numbers 4–6): These aspects represent three sets of service-oriented facilities that combine hardware and software components for building up the infrastructure to create an intelligent construction environment. They include the following: (1) Smart objects[shareable content objects (SCOs)] and gateway technology: RBIMP Gateway works as a host to connect all SCOs and provides a suite of services to manage their operations and construction logics. This technology collects real-time information on prefabricated production, logistics and supply chain, and on-site assembly, as well as sends the information to upper-level decision makers according to the predefined workflows. (2) Traceability and visibility tools: these tools use real-time RFID-enabled construction data for precise decision making, such as prefabrication production planning and scheduling, logistic optimization, real-time visualability and traceability, JIT delivery, and smooth on-site assembly. These tools provide a rich set of sub-services to facilitate the operations of various end-users in prefabricated production, logistics, and on-site assembly. (3) Data source interoperability service: This service is designed to integrate different EISs so that data sharing, system interconnection, and interoperability could be improved significantly. This service uses agent-based technology that is capable of accomplishing construction tasks in an autonomous way with minimal human intervention. Various data sources with high heterogeneities, such as communication protocols, information presentations, and unformatted EDIs, should be standardized.

5 Conclusion

As a technical solution, prefabrication is gaining momentum in the face of the housing challenge in Hong Kong. But, in order to cultivated the benefits of using prefabrication, its drawbacks, including poor interoperability, discontinuity, fragmentation, and lack of real-time information traceability and visibility, should be overcame. These drawbacks are further exacerbated by the fact that the movement of entire sector to the offshore areas in the PRD region. Through extensive contacts and preliminary studies with public bodies, such as HKHA, business associations, such as HKCIC and HKCA, and individual businesses and companies involved in the field, this study investigates current technologies adopted in precast housing construction and the challenges confronted in the process. The technological challenges mainly involve three aspects, namely, (a) information gaps, (b) real-time information visibility and traceability, and (c) information interoperability. This study provides in-depth understanding of current technologies and challenges in the application of prefabrication in housing production in Hong Kong. A connected and dynamic BIM is suggested to be developed for reengineering offshore prefabricated construction processes.

ACKOWLEDGEMENTS

The Research Team (which consists of the Department of Industrial and Manufacturing Systems Engineering, Department of Civil Engineering and Department of Real Estate and Construction, The University of Hong Kong as well as the Department of Building and Real Estate, The Hong Kong Polytechnic University) would like to thank the HKSAR ITC/LSCM R&D Centre for partially funding this research through the Innovation and Technology Support Programme (Project Reference.: ITP/045/13LP). The Research Team is grateful to the Hong Kong Housing Authority and its contractors for supporting and participating in this research through a real project application.

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