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# Towards Physical Internet-enabled Prefabricated Housing Construction in Hong Kong

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**Abstract:** Prefabrication could provide various benefits for housing production, including lower the cost, improve the management efficiency and quality, ensure the safety, and realize sustainability. However, to fully acquire these benefits in real world construction process, challenges still exist on real-time tracing and tracking of the prefabrication components, and getting real-time interactions among all the stockholders. Physical Internet (PI), as has been well adopted in logistics, could be an effective solution for real-time visibility. Based on the prefabrication practice in Hong Kong, this paper proposes the architecture of an PI-enabled prefabricated housing construction which upgrades and transforms the prefabrication construction so that the logistics echelons could be seamlessly integrated and synchronized, together with a PI-enabled decision support system (DSS) which uses Internet of Things (IoT) and cloud techniques for designing the architecture and a rich set of services and tools to assist different decision makers.. Firstly, three stages of prefabrication construction have been analyzed in detail to point out current challenges. Secondly, the technical framework of PI-enabled Building Information Modelling (BIM) Platform (PIBIMP) is developed. Finally, a case study is given to demonstrate the working process of our proposed solution, and the effectiveness of it has also been verified.



*Keywords:* Physical Internet (PI); Prefabricated Housing Construction; RFID; Smart Construction Objects (SCOs); Logistics and Supply Chain Management (LSCM).

## 1. INTRODUCTION

Prefabrication refers to a practice of assembling structure components in a manufacturing site and transporting complete or semis assemblies to the construction sites, where the structure is to be located (Tam, Tam et al. 2007). Currently, Hong Kong public housing has adopted prefabrication construction to build the buildings (Jaillon, Poon et al. 2009). Due to the limited space in Hong Kong public housing sites, the prefabricated components are manufactured in Pearl River Delta (PRD) such as Huizhou, Shenzhen, and Dongguan (Lu and Yuan 2013). The finished components are then delivered by trucks. Logistics plays an important role in the prefabricated housing construction in Hong Kong because construction sites require specific components at designated times. There is limited buffer in construction sites for keeping the large components. Due to the large volume of prefabricated components, the finished components in manufacturers should be shipped as fast as possible so that the inventory in warehouse could be minimized. Thus, the logistics synchronization between prefabrication manufacturing and construction site becomes significant.

Physical Internet (PI) refers to an open global logistics system based on physical, digital, and operational interconnectivity by making full use of encapsulation, interfaces, and protocols to replace current logistics models (Montreuil 2011). The initial manifesto of PI is to transform the way physical objects are handled, delivered, stored, realized, supplied and utilized so as to achieve global


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logistics efficiency and sustainability (Montreuil 2010). Current year, great attentions have been paid upon the Physical Internet due to the innovative and advanced concept of encapsulating goods into smart objects, sharing data in the Digital Internet, and shipping adaptively and efficiently. In the United States, National Science Foundation (NSF) has funded a research project conducted by Center for Excellence in Logistics and Distribution (CELDi), aiming at establishing a logistics system to gain efficiency of the Physical Internet. Physical Internet has been widely used for upgrading the logistics and supply chain management integrating the Internet of Things technologies (Zhong, Dai et al. 2013, Qiu, Luo et al. 2014, Zhong, Huang et al. 2014).

In order to make full use of the advantages of PI, several cutting-edge technologies like RFID have been used for facilitating the data capture and collection in construction process. Despite all the efforts, some gaps are still needed to study. These gaps are converted to several research questions which are focused on in this paper and corresponding solutions are provided as follows:

- How to integrate the PI concept into the construction logic within the echelons of prefabrication manufacturing, prefabrication transportation, and on-site assembly? This paper introduces a scheme for using PI to upgrade and transform the prefabrication construction so that the logistics echelons could be seamlessly integrated and synchronized.

- How to establish a system that is able to use the concept of PI for facilitating different decision-making parties so that information and sharing collaboration could be enhanced? This paper introduces a PI-enabled decision support system (DSS) which uses Internet of Things (IoT) and cloud techniques for designing the architecture and a rich set of services and tools to assist different decision makers.

A case from a real-life Hong Kong prefabrication housing construction is presented for demonstrating the adoption of PI concepts with advanced technologies like RFID and cloud in Hong Kong Housing Authority (HKHA) to upgrade the construction industry. The proposed system is implemented in the pilot companies to help different decision makers to facilitate their daily operations.

The rest of this paper is organized as follows. Section 2 illustrates the motivation scenario from a real-life construction project carried out by HKHA. Section 3 introduces the PI-enabled DSS in terms of PI concept for prefabrication construction and system architectures. In section 4, a case study is demonstrated on how the system could facilitate the data collection, information sharing, and decision-making. Section 5 concludes this paper by giving our lessons and insights from implementing the PI-enabled application as well as several future perspectives are proposed.

## 2. MOTIVATION SCENARIOS

In spite of its significant contribution to building environment development, construction is perceived as a contributor to degradation of the natural environment (Bossink and Brouwers 1996, Poon, Yu et al. 2004). The implementation of the ambitious housing plan in Hong Kong may further impact the environment, together with other issues including severe labor shortage and safety problem (Rowlinson 2004). In order to ease the above impacts, prefabrication has been widely adopted in housing projects in Hong Kong due to its more efficient, cleaner and safer working environment, as well as better quality (Jaillon and Poon 2014). Other useful tools being applied include Building Information Modelling (BIM), aimed to address issues such as fragmentation, efficiency/effectiveness, and inadequate interoperability (Succar 2009, Lu and Yuan 2013) and Enterprise Information Systems (EISs) such as Housing Construction Management Enterprise System (HOMES), designated to enhance information flows and project logistics management in housing production (Fung 2006).

The motivating scenarios come from current movement of Hong Kong Housing Authority in response to the changing socio-economic constraints in Hong Kong and the Pearl River Delta (PRD). The whole prefabrication sector serving Hong Kong is primarily located in offshore areas in the PRD such as Shenzhen, Dongguan, Huizhou, Zhongshan, and Shunde. Offshore prefabrication makes it possible to lower cost of materials and labour.

The motivating scenarios focus on three specific phases, namely, prefabrication production, cross-border logistics, and on-site assembly:

- Prefabrication production involves the production and timely delivery of quality prefabricated construction components. The key users are the project client and its collaborative prefabrication producers.
- The cross-border logistics is the linkage between the production and on-site construction phases, which involves the transportation of the manufactured prefabricated components from production plants to construction sites for assembly. Real-time visibility of logistics status and just-in-time (JIT) logistics operations can provide seamless linkage and delivery tracking between prefabrication factories and the construction sites.
- On-site assembly of the prefabrication components is the last phase covered in prefabricated housing construction. It occurs after the prefabrication components are delivered through the cross-border logistics to the construction site.

As the above three scenarios involve many stakeholders, such as client, consultant, main contractor, prefabrication factory, transporter, and etc., it is significant to the whole offshore prefabrication housing production processes that need to be reengineered. In each scenario, three aspects including