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An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction

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ABSTRACT

Building Information Modelling (BIM) serves as a useful tool in facilitating the on-site assembly services (OAS) of prefabricated construction for its benefits of powerful management of physical and functional digital presentations. However, the benefits of using BIM in the OAS of prefabricated construction cannot be cultivated with an incomplete, inaccurate, and untimely data exchange and lack of real-time visibility and traceability. To deal with these challenges, an Internet of Things (IoT)-enabled platform is designed by integrating IoT and BIM for prefabricated public housing projects in Hong Kong. The demands of the stakeholders were analysed; then smart construction objects (SCOs) and smart gateway are defined and designed to collect real-time data throughout the working processes of on-site assembly of prefabricated construction using the radio frequency identification (RFID) technology. The captured data is uploaded to cloud in real-time to process and analyse for decision support purposes for the involved site managers and workers. Visibility and traceability functions are developed with BIM and virtual reality (VR) technologies, through which managers can supervise the construction progress and approximate cost information in a real-time manner. The IoT-enabled platform can provide various decision support tools and services to different stakeholders, for improving the efficiency and effectiveness of daily operations, decision making, collaboration, and supervision throughout on-site assembly processes of prefabricated construction.

1. Introduction

Prefabrication has been widely adopted by Hong Kong Housing Authority (HKHA), who is the main provider of public housing in Hong Kong, for its public housing projects, due to its more efficient, cleaner and safer working environment, and better quality [1–3]. For example, the public housing project at Tuen Mun Area 54 Site 2, Phases 1 & 2, makes use of 11 types of precast elements, including precast façade, semi-precast slab, volumetric precast bathroom, tie beam, staircase, parapet, refuse chute, half landing, water meter room, lift machine room and main roof slab. Some of them are proposed by the general contractor. As a 'sweet point' of balancing construction cost and labour requirement [4], contractors adopt a 6-day cycle for the typical floor (usually 20 to 30 units) on-site assembly in high-rise public housing projects since 1990s in Hong Kong. Among the processes of on-site assembly, BIM serves as a useful platform for facilitating the on-site assembly services (OAS) of prefabricated construction for its benefits of providing collaborative working teams and decision makers with the physical and functional representations of prefabricated components [5]. For example, the status of prefabrication components could be traced and visualized in BIM platform for supporting the progress control [6, 7].

However, the well-formatted information of prefabricated component at the right time in the right location is still insufficient to further raise the efficiency of collaborative working and decision making in on-site assembly services when adopting BIM in prefabricated construction projects [8]. For example, the location information of both outdoor and indoor resources through positioning technologies such as RFID (radio frequency identification), UWB (ultra-wideband), and GPS (global positioning systems) have been synchronized in BIM for safety management [9], while few studies integrate the accurate location information of on-delivering prefabricated components into BIM platform for

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monitoring the right components to be assembled in the correct position in a safer manner [10]. Additionally, the information of changes, cost and schedule are delivered from previous processes (i.e., design, manufacturing, logistics) could be updated to a centralized BIM platform for sharing the information among different stakeholders [20]. However, this information is usually re-entered incompletely, inaccurately and untimely into various isolated systems (i.e., enterprise resource planning (ERP)) of the different stakeholders in most of the current project practices, which could not efficiently support the decision making in the OAS [11]. These problems can be further deteriorated in Hong Kong particularly due to the numerous constraints such as limited resources and space [12–14].The solution for such situation is still a void to be filled.

To handle these challenges, an Internet of Things (IoT) enabled platform is to be developed in this research by deploying BIM as the basic infrastructure underlying in its system structure. This research employed a typical design science research methodology [15], which consists of six steps of problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication, in the research and development. Section 2 is the literature review which also identified the need of BIM and IoT-based OAS management system. Section 3 describes the objectives of the BIM and IoT-based OAS regarding field interviews, the design of SCOs, and the development of the OAS decision support system. The demonstration of the system on a real project and the evaluation are given in Section 4. Conclusions appear in Section 5. The specific objectives of this research are: (1) to investigate and analyse business process and requirement of on-site assembly of prefabricated construction; (2) to propose the architecture design and develop the Internet of Things enabled platform; (3) to apply the developed platform to practical project to test its performance and effectiveness.

This centralized BIM platform not only integrates the information delivered from the previous stages but also synchronizes the location information of prefabricated components for facilitating the real-time communication and coordination among the different stakeholders for better decision making in the OAS. The innovativeness of this platform, by looking at whole processes of the on-site assembly of prefabricated construction, is to increase their connectedness by using BIM as an information hub to connect information and communication technology (ICT) enhanced SCOs. The architecture of the IoT-enabled platform has considered the business processes, the stakeholders, the information flow, the visibility and traceability of the real-time data. It uses the service-oriented open architecture as a key innovation to enable the platform as a service. Given its potential to manage building information throughout processes of OAS, the IoT-enabled platform is considered as a significant component of the HKHA's overall ICT architecture and systems, which aims to re-engineer the OAS of prefabricated construction in Hong Kong for a better support of decision making.

2. Literature review

The advanced OAS planning and control systems initiated from the Last Planner® System (LPS®) which is a production management system that applies pull and look-ahead planning to remove constraints and make downstream activities ready. Weekly work planning is adopted to reduce uncertainty and find relevant causes for variances. LPS also uses the percentage of the plan completed (PPC) to measure and monitor the process. However, LPS is difficult to visualize the flow of work process. Building Information Modelling (BIM) can be utilized to simulate and visualize the construction process with 3D geometric models and ample information to facilitate communication among stakeholders. In addition, LPS is the weekly work planning that may lead to a long response time to address daily constraints. Sacks et al. (2010) developed the KanBIM concept which can manage day-to-day status feedback and support human decision making or negotiation among stakeholders. As prefabricated construction contains multiple phases from manufacturing, logistics to site assembly, the direct use of LPS and BIM in prefabricated construction has an apparent gap related to the interoperability and real-time traceability of information. Dave et al. (2016) therefore developed a communication framework by adopting IoT (Internet of Things) to strengthen the use of Lean Construction management and tracking technologies such as RFID and GPS, which are critical components of IoT, to track the status of workers, materials, and equipment in the whole process. A conventional RFID system contains an antenna, a transceiver (RFID reader) and a transponder (Radio Frequency tag). The antenna sets up an electromagnetic area where the tag detects the activation signal and responds by transmitting the stored data from its memory through radio frequency waves. RFID can be applied to monitor unit status during manufacturing and site assembly stages while GPS can be adopted to locate the units during logistics phase and calculate the remaining time to site. One RFID-enabled BIM platform has been developed for prefabricated construction by researchers in Hong Kong [2, 7]. The platform's architecture has three dimensions: infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS). The IaaS level contains hardware and software layers. The hardware layer consists of the SCOs and the Gateway, while the software layer involves a Gateway Operating System (GOS) to manage the SCOs. SCOs with functional data and data collection devices are enabled by the RFID system and other innovative technologies. RFID was firstly introduced as a sister technology to replace barcode system for identifying items. By comparing it with barcode system and magnetic strip system, RFID can store a relatively large number of data. This data can be encrypted to increase data security. It is possible to read data from multiple tags in one time thus increase the efficiency of data processing. In comparison with barcode or magnetic system, no direct contact between a RFID reader and the tagged items is needed as it uses radio wave for data transmission. In addition to reading data, it is possible to write data back to the RFID tag, which greatly increases the interaction between items, systems, and people. The GOS is developed to aggregate and pre-process the massive real-time data such as Industry Foundation Classes (IFC) data converted from BIM software (e.g. Revit), GPS data, RFID data (e.g. schedule, cost, production attributions) and point cloud data. In addition, the PaaS level is related to the data source management services (DSMS) which facilitate the heterogeneous information and application systems by applying XML/JSON-based BIM model and connecting the backend RFID system with BIM model. This enhances the initial BIM platform to a multi-dimensional one. The SaaS level consists of three management services (manufacturing, logistics, and on-site assembly) to enhance the information sharing and communication for stakeholders' decision-making at different stages. This study details the deployment and application of the on-site assembly services to try to improve the dilemmas of current project practices in Hong Kong including: (1) construction sites in Hong Kong are often compacted, with only limited space for storing large and cumbersome components [16]. Thus, site management is often on the critical path for the success or failure of a construction project. Under this circumstance, a Just-In-Time (JIT) delivery and assembly are desired but currently in Hong Kong, normally a site manager should reserve components/materials of 1.5 stores on site as a buffer. The JIT delivery of prefabrication components is yet to be harvested; (2) verification of the components is inefficient [17], mainly due to the wide use of paper or paint labels. Workers should pay attention to the verification process sequentially, which will lead to extra labor and time cost. Yet, the accuracy of the verification process is not guaranteed since the paper-based documents, or even handwriting and modified labels are usually ambiguous; (3) current practice may cause safety issues. Construction workers on the sites are usually busying with their operations, some of which need enough space e.g. for crane towers to hoist various components to proper positions [18]. If the required spaces are occupied, serious safety issues may be occurred; (4) if too many components are placed on a construction site, workers