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Prefabricated construction enabled by the Internet-of-Things

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ABSTRACT

Prefabricated construction has been used for public rental housing in Hong Kong. In order to speed up housing delivery, Hong Kong Housing Authority (HKHA) have employed advanced technologies, including Building Information Modelling (BIM) and Radio Frequency Identification (RFID), in some of their pilot prefabrication-based construction projects. However, the information obtained from BIM and RFID is not well connected and shared among relevant stakeholders. This paper introduces a multi-dimensional Internet of Things (IoT)-enabled BIM platform (MITBIMP) to achieve real-time visibility and traceability in prefabricated construction. Design considerations of a RFID Gateway Operating System, visibility and traceability tools, Data Source Interoperability Services, and decision support services are specified for developing the MITBIMP. A case study from a real-life construction project in Hong Kong is used as a pilot project to demonstrate advanced decision-making by using cutting-edge concepts and technologies within the MITBIMP to providing a basis for real-time visibility and traceability of the whole processes of prefabrication-based construction.

1. Introduction

Prefabrication refers to the practice of manufacturing the components of a structure in a factory and transporting complete or semi-complete assemblies to the construction site where the structure is to be located [35]. Building Information Modelling (BIM) plays an important role in supporting prefabrication-based construction due to its powerful management of physical and functional digital presentations. BIM currently supports the planning, design, construction, operation, and maintenance of most physical infrastructures from apartment buildings to bridges [3]. Additionally, BIM has been adopted widely for prefabrication-based construction in the U.S., U.K., Japan, South Korean, and Singapore [27,35].

Hong Kong, an international city with over 7 million population, is suffering from a lack of housing. In order to address this issue, the Hong Kong Housing Authority (HKHA) devised a ten-year public housing program [12]. BIM-based prefabrication played a great part in this program with 17% of the total concrete volume used in public housing projects being precast components between 2002 and 2005, and with precast components making up 65% of a special pilot project during that time [9,16]. However, there are several challenges when using BIM in public housing projects based on prefabricated construction. Firstly, data collection from prefabrication manufacturing to on-site construction uses paper-based manual operations. Thus, the captured data are prone to be incomplete, inaccurate, and inadequate [40]. Secondly, information sharing among different parties is confined due to the adoption of traditional methods of communication such as e-mail, phone calls, and fax. Lost information, ineffective communication, and risk-aversion are common in a construction project. Thirdly, collaboration among prefabrication manufacturers, transportation parties, and on-site assemblers heavily relies on real-time information such as the status of precast components, delivery progress, and the location of components. Such information will be fed back to BIM with a certain delay due to manual input operations so that gaps among the involved

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parties exist, causing poor visibility and traceability of construction progress.

Several cutting-edge technologies have been used to facilitate information collection in construction projects. One of the core technologies is the Internet of Things (IoT), with RFID (Radio Frequency Identification) being one of its key technologies used to facilitate supply chain management, safety management, facility management, and activity monitoring [4,13,17,25,31,33,38]. An elementary application of IoT is the tracking of the materials for various precast components [41]. For a secondary use of the RFID technology, information lifecycle management (ILM) for material control on construction sites has been proposed [19]. In addition to IoT, laser scanning has been proposed for collecting geometric and spatial data for BIM [2,6,7,28,32,36]. Sensors for temperature, force, and positioning have also been used to collect real-time information for better construction [1,11,29].

These studies provide useful references when integrating BIM with other critical information for facilitating construction projects. Some researchers have even incorporated these advanced technologies into BIM with real physical buildings [8]. Along with other advanced technologies, it is possible to use IoT technology in the building industry through a context-aware scenario, although this is not the case with logistics and supply chain management (LSCM). For enhancing information sharing, a link between BIM and enterprise resource planning (ERP) was introduced for visualizing construction processes among different parties [5]. This linked information visibility is based on existing data from databases in BIM and ERP. Thus, it is not a real-time traceability and visualization tool. With the development of Cloud technology, a conceptual framework of prefabricated building construction management system (PBCMS) was proposed to enable access to knowledge [20]. Despite all these efforts, some knowledge gaps still exist, which for the purposes of this study have been converted to the following research questions and corresponding solutions:

- How to create smart construction objects (SCOs) that are able to sense, behave, and execute construction logic within the echelons of prefab manufacturing, prefab transportation, and on-site assembly? This paper introduces a scheme for creating typical construction objects into SCOs using IoT and cloud technology, as well as proposing a designed and developed MITBIMP Gateway for managing the SCOs.
- How to establish a system that is able to interact with BIM software and share the information among different parties so that collaborative decision making could be enhanced? This paper introduces a RFID-enabled BIM platform that uses IoT and cloud techniques for designing the architecture. The platform includes a rich set of services and tools to support collaborative decision making in construction projects.
- How to extend 3D design and modelling in BIM to a multi-dimensional application by making full use of collected real-time data so that decisions based on the solution could be more reasonable, precise, and scientific? This paper introduces a traceability and visibility service, which extends the construction business solution into a multi-dimensional level that includes other dimensions such as time (progress) and cost.

The remainder of this paper is organized as follows. Section 2 introduces the architecture of the MITBIMP and discusses design and development considerations to make the platform into a technical reality. In Section 3, a real-life public housing project from Hong Kong is used to demonstrate the necessity and usefulness of the MITBIMP. Section 4 concludes the paper by providing insights gained from implementation of the MITBIMP as well as discussing several aspects for improvement.

2. Multi-dimensional IoT-enabled BIM platform

2.1. Architecture

The proposed MITBIMP, as shown in Fig. 1, concerns production processes, stakeholders, information flow, and real-time information visibility and traceability. Whereas a conventional BIM system provides only 3D models, based on Auto-ID technology and Information technologies, the MITBIMP integrates additional dimensional information (e.g. project progress and cost) to extend the original 3-dimensional platform to a multi-dimensional one, which uses service-oriented architecture (SOA) as a key innovation to enable the platform as a service (PaaS). The MITBIMP contains three levels so as to seamlessly integrate into HKHA's current information architecture. At the bottom, IaaS (Infrastructure as a Service) level includes hardware and software layers. The hardware layer consists of the SCOs and the MITBIMP Gateway, and the software layer includes a Gateway Operating System (GOS) and management tools to manage the SCOs. The MITBIMP Data Source Management Service (MITBIMP-DSMS) level provides not only a self-service portal for managing platform infrastructure and service provision, but also services across the MITBIMP to support Software as a Service (SaaS) and to handle the IaaS. The MITBIMP Decision Support Service (MITBIMP-DSS) level contains three major management services for various stakeholders at different stages of the construction lifecycle.

From the bottom to the top in Fig. 1, SCOs are construction objects from HKHA construction sites, where typical construction resources are equipped by RFID devices and thereby converted into “smart” objects. The MITBIMP Gateway connects, manages, and controls the SCOs through defining, configuring, and executing the construction operations. The MITBIMP-DSS is designed to suit prefabrication housing construction in Hong Kong at three key phases: prefabrication production, prefabrication logistics, and on-site assembly. In order to enhance data sharing and interoperability among BIM, HOMES (an enterprise resource planning system used by HKHA for more than 10 years) and the MITBIMP, visibility and traceability tools and Data Source Interoperability Services (DSIS) are designed to use an XML-based data sharing mechanism to enable advanced decision making.

There are three sets of service-oriented facilities that are based on cutting-edge IoT technologies for building up the infrastructure to create an intelligent construction environment. The first set includes smart objects, the MITBIMP Gateway and GOS. Visibility and traceability tools and data source interoperability service are deployed in PaaS as the second set, and a prefabrication production management service, a cross-border logistics management service, and an on-site assembly management service are provided in SaaS as the third set of services.

2.2. SCO, MITBIMP and Gateway Operating System (GOS)

SCOs are typical construction resources such as tools, machines, and materials, which are converted into smart objects through binding them to different RFID devices. The purpose of SCOs is to create an intelligent construction environment within typical prefabrication production sites such as factories, warehouses, logistics and supply chains, and construction sites. SCOs are building blocks for such intelligent environments, within which they are able to sense and interact with each other. Typical construction resources are converted into SCOs through various tagging schemes. Firstly, critical prefabrication components such as volumetric kitchens, toilets, and precast facades, are tagged individually, which means that an item-level tagging scheme is adopted because they easily influence the progress in prefabrication-based construction. For non-critical materials such as dry walls and building blocks, tray-level or batch-based tagging scheme are adopted. That means tags are attached to the trays that carry multiple minor prefabrication components. Workers such as machine operators, vehicle drivers, logistics operators, and on-site assembly workers, are tagged with RFID-enabled staff cards. Such construction resources attached with tags are passive SCOs.

The deployment of RFID readers follows a systematic approach. In a typical prefabrication production factory, machines and buffers are equipped with RFID readers because they are value-adding points, whose working status must be real-time monitored. Buffers are