BIM-based Onsite Location-dynamic Information Integration and Management

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Abstract
Existing methods for onsite safety and quality management mainly focus on particular purposes such as risk detection, accident warning and quality monitoring, and are limited in construction phase. In order to control the quality and safety on the construction site, inspections with location information are applied to the management process. Existing methods to integrate location information to a reliable data source according to Building information modeling (BIM) technology is to manually input information delivered by hardcopies. However, the unreliable operation process limits the result validity and the efficiency of subsequent management. In this study, a concept called Onsite Inspection BIM is proposed for construction onsite information integration. Then a location-dynamic data collection approach and a location-dynamic onsite management framework are presented. Finally, a prototype system is developed and implemented in the construction of a metro station, demonstrating the feasibility and effects of the proposed solution.

Keywords: onsite localization; BIM; information integration; construction management

1 Introduction

Onsite safety and quality management is significant during construction. For safety control, existing technical researches mainly focus on the methods or algorithms for risk detection and prevention. Among them, safety-relevant data collection is one hot topic because of the lacking of the tools for real-time behavior monitoring (Li & Chan et al 2015). Therefore, several techniques including Global Place System (GPS), Ultra Wideband (UWB) and Radio Frequency Identification (RFID) are applied for positioning and behavior-related data collection (Zhou et al 2015). A real-time location system based on wireless local area network (WLAN) and Time of Arrival (ToA) is considered more suitable for onsite localization (Li & Lu et al 2015). Meanwhile, the combination of image process and fuzzy logic is also regarded as an effective approach (Kim et al 2014). Based on the data collection techniques, efforts are put into data handling, safety analysis and accident warning. As a result, various construction safety management systems were developed and applied to construction projects (Hu & Zhang 2011, Yau et al 2014).

In order to control the onsite construction quality, inspection methods are applied to monitor the basic information of the quality condition. The traditional way to collect such information is to manually input information delivered by hardcopies. However, the unreliable operation process limits the result validity and the efficiency of subsequent management. Techniques such as RFID (Wang 2008), satellite positioning and sensor (Liu et al 2015) contribute to automatic construction quality inspection and management. Besides, Telepresence is used for monitoring the construction operation (Jaselskis et al 2014). Concerning the objective of management, not only the quality of construction results, but the quality of the whole construction phase is as well taken into account (Ko & Li 2014).

Building Information Modeling (BIM) technology is introduced as the ideal data source for onsite safety and quality management. For instance, wireless sensors are used to integrate the onsite location data and the BIM data to discover and display predefined safety problems (Riaz et al 2014). Nevertheless, most researches are limited in construction planning (Ganah & John 2015; Collins et al 2014; Chen & Luo 2014; Tsai et al 2014; Lee et al 2014; Davis & Harty 2013;) and few concentrates on directly integrating the onsite information into BIM to enrich the project information.

In this study, the Industry Foundation Classes (IFC)-based "Onsite Inspection BIM" is proposed for onsite information integration during construction. It aims at maintaining the information growth and delivery in the whole building lifecycle. On this basis, a location-dynamic onsite management framework which can be generally used to handle unknown onsite problems in safety and quality management is presented. As the core technique, a location-dynamic data collection approach which is based on Augmented Reality (AR), Received Signal Strength Indication (RSSI), Machine Learning (ML) and BIM is detailed described.

2 Onsite Inspection BIM

2.1 Location-dynamic Onsite Data

Construction sites are inundated with multifarious information. Onsite management systems obtain the useful information data, and provide services and functions based on these data. The collected data can be classified into three categories: location-permanent data (such as the sensor data and surveillance video), location-dynamic data (real-time localization method should be applied) and location-irrelevant data (such as data in process of schedule management and cost management).

In most studies, the collected data for safety management and quality management belong to location-permanent data, are mainly gathered by immobile instruments. In such manner, it can hardly describe unknown mistakes, violations or emergency or present entire on-site status. Nevertheless, location-dynamic data which are mainly created in onsite inspection process are able to offset these weaknesses.

In the past, people use paper to record any safety or quality issues. PDA or other mobile devices are gradually used as convenience recording tools in recent years. Within this process, the location related to such issues should be marked to ensure the value of inspection results. Some results may not link to location directly, but be associated with the building elements or spatial elements.

2.2 BIM

BIM is a concept built upon building lifecycle, which means BIM data should be able to be delivered from the prior phase to the next phase within building lifecycle (Zhang et al 2014). It can benefit the project by providing data basis for schedule preparation, estimation and other automatable requirements, and by offering uniform and coordinating information storage for information creation, modification and sharing (Chen & Luo 2014).

A BIM application should base on a special model which accepts necessary information from the general BIM data format and extends the original information model for next construction phase. Therefore, BIM should also be a shared information assembly in every phase (Zhang et al 2015), a data exchange standard is necessary. Among all those data standards, IFC is the most authoritative one. In this study, IFC is selected as the format of the original information model.

2.3 Definition of the Onsite Inspection BIM

The Onsite Inspection BIM is a sub Building Information Model attached with location-dynamic onsite data. IFC2X4 is regarded as the basic framework of the model.

An entity with location-dynamic data here is considered as *Thumbtack*, which can be classified with *IfcProduct* in IFC standard. It is possible to create a new child class of *IfcProduct* for *Thumbtack*, but a more practical approach is to adopt the existing *IfcProduct*, such as *IfcAnnotation*. *IfcAnnotation* is designed as an additional note or meaning of an object, and presented as a graphic within the geometric context of a project (Kim & Seo 2008). Actually, the concept of *Thumbtack* is similar to *IfcAnnotation*, and can be considered as a special type of *IfcAnnotation* without graphic presentation. The definition of *Thumbtack* based on *IfcAnnotation* is shown in Figure 1.

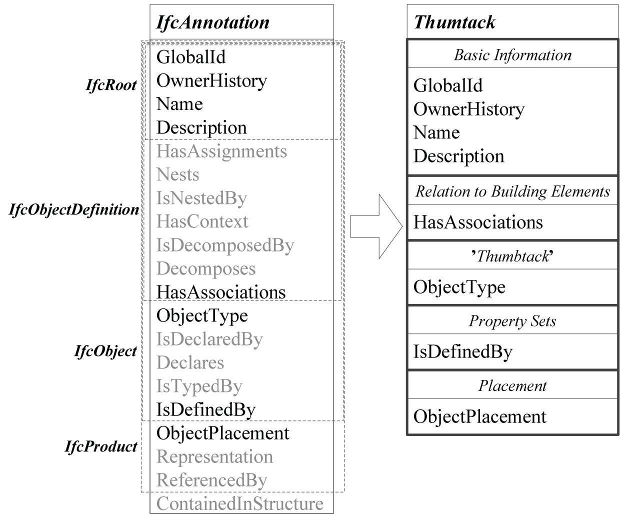

Figure 1 Definition of *thumbtack* based on *IfcAnnotation*

Four components are required in a *Thumbtack*: the basic information, the related building elements, the content and the placement. The attributes inherited from *IfcRoot* are the basic information and the type of the attribute *HasAssociations* inherited from *IfcObjectDefinition* is *IfcRelAssociates*, which contains the attribute *RelatedObjects* to indicate the related building elements. With regard to the content, the attribute *IsDefinedBy* inherited from *IfcObject* is required. Sets of *IfcPropertySet* are associated to the *Thumbtack* based on this attribute. The placement could be defined by using the attribute *ObjectPlacement* inherited from *IfcProduct*. Besides, to distinguish the *Thumbtack* and basic *IfcAnnotation*, the value of the attribute *ObjectType* should be 'Thumbtack'.

3 Location-dynamic Data Collection

3.1 Augmented Reality (AR)

AR, a concept involved with series of technologies including data storage and service environment, localization technologies, portable and mobile devices, and natural user interface, can help visualizing and comprehending the virtual concepts in 3D environment based on direct comparison between the virtual and the reality (Chi et al 2013). AR has been widely adopted in the architecture, engineering, and construction (AEC) industry. Some related studies include construction inspection (Dunston 2010), monitoring and documentation (Zollmann 2014), construction activity assistance (Hou 2013) and defect management (Kwon 2014; Park 2013), and most of them required unique AR devices.

The combination of BIM and AR shows great potentials in improving the activities in AEC industry (Wang 2013). For one reason is that BIM provides virtual data storage and services for AR. In the framework for integrating BIM with AR, even regular mobile devices can afford the natural user interface with most computation in a BIM server (Meža et al 2014). However, the limitation existed in wireless information transmission would make the AR results unsatisfactory.

3.2 Indoor Localization Technology

WLAN, UWB, Bluetooth, field strength systems and RFID (Deak et al 2012, Yang & Shao 2015) are adopted for indoor localization. Some obvious differences between WLAN and other localization technologies are the adaption to the existing wireless network and the difficulty of being referenced by applications on mobile platform.

Localization approaches for indoor environment usually are implemented by either ToA, Angle of Arrival (AoA) or received signal strength indication (RSSI) (Yang & Shao 2015). Both ToA and AoA require specific hardware for localization, while the RSS-based approaches use the common sensor techniques in mobile devices such as WLAN or Bluetooth. Two categories of methods based on RSSI have been developed: path-loss model-based method and RSSI map-based methods (Luo 2011). The path-loss model-based method estimates the distance from access points (APs) to users, and locates users based on several known-position APs by using the existing range-based locating algorithms (Yan et al 2013). It requires the locations of APs and experiments to determine the path-loss function. On the contrary, the distances from APs to users are not request in RSSI map-based methods because this method relies on radio map of RSSI which consists of known mappings from RSSI values to positions (Honkavirta et al 2009).

3.3 RSSI-based Interactive Localization Method

The scope of location-dynamic data collection for *Onsite Inspection BIM* should be as wide as possible to keep the model information up-to-date, so that managers can response quickly after understanding the accurate problem condition. Therefore, common mobile devices are more fitness than special devices for data collection. Hence, we choose RSSI-based localization approaches for location within the whole building. However, construction site changes every day, and a whole building is always too large and complex. These would reduce the accuracy of RSSI-based locating and could result in significant demand of the preparatory works. Thus, a new localization method is proposed to overcome these weaknesses. A *RSSI-based interactive localization method* based on BIM, AR and ML is described in Figure 2.

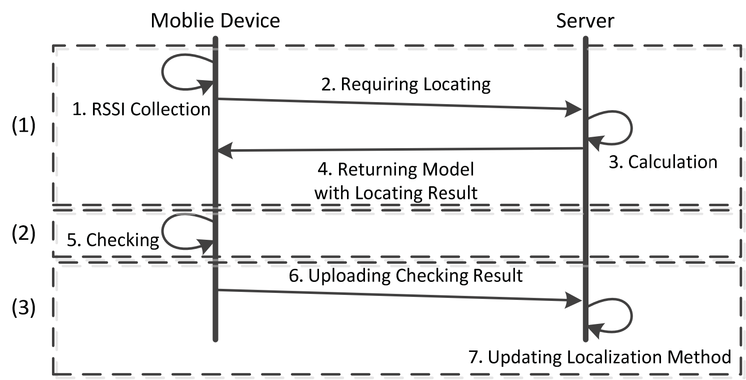

Figure 2 RSSI-based Interactive Localization Method Sequence Diagram

The proposed method consists of three steps:

(1) Rough Locating. In this step, a basic localization approach that should be optimized is applied to obtain a rough locating result. Afterwards, the corresponding virtual 3D data will be provided by BIM data server, and presented on a mobile AR device.

(2) Checking. After receiving the AR results, the user should check whether the result is acceptable and then correct the localization result in the mobile AR environment.

(3) Updating. The learning process in ML methods is carried out according to the corrected localization result so that the basic localization approach can be optimized.

Both the two classes (path-loss model-based method and RSSI map-based method) of RSSI-based localization approaches can implement in the rough locating step. By using the path-loss model-based method, the path-loss function is the optimizing target. And in case of using RSSI map-based methods, the optimizing target is the RSSI map. Considering the complexity of the construction site, the appropriate path-loss function could be dynamic and can hardly approach. Hence, the RSSI map-based method is suggested.

The necessary initialization, named as the training phase, of the RSSI map-based method is generating calibration points (CPs) which contain the map from radio strengths to position in virtual environment. The follow-up locating result is estimated by using closeness between the target node and CPs. Traditionally, this step should be finished manually, and the accuracy of the result is restricted to the amount and the distribution of CPs. But according to ML, CPs could be increased in the learning process by checking the position manually. This is considered as an open training, indicating that all users can contribute in the step.

4 Location-dynamic Onsite Management

4.1 Technical Framework

Considering the demand of the onsite inspection in safety and quality management, a location-dynamic onsite management prototype system is designed based on the above techniques. The technical framework of the prototype system is shown in **Error! Reference source not found.**.

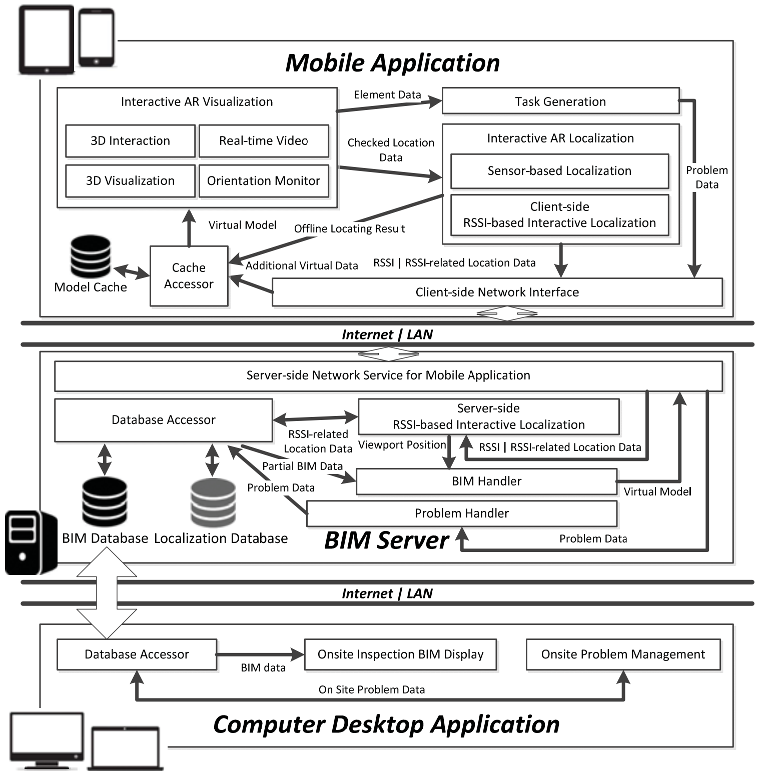

Figure 3 Technical Framework of Location-dynamic Onsite Management Prototype System

Based on Client/Server framework, the clients of the prototype system consist of a mobile application and a desktop application, realizing information delivery to the BIM server. The mobile application includes two main modules: interactive AR visualization and interactive AR localization.

The former one provides functions for the comparison between the reality and the virtual. In order to obtain and present the virtual model, the 3D visualization and interaction is necessary. And for reality displaying, the real-time video is required. To assure the synergy between the reality and the virtual when the mobile device moves, orientation monitor based on the basic sensors, such as gravity sensors, electronic compasses and gyroscopes should be included. Additionally, the existing AR visualization libraries, which are capable for 3D interaction and customized extension, should be implemented.

The interactive AR localization module provides both the localization methods whether online or not. The sensor-based localization should firstly determine the basis position of the mobile device according to a mark with known position by using QR code or Bluetooth. And remaining work is to calculate the placement of the mobile device based on the data from various kinds of sensors. This function provides offline locating or the rough locating step in *RSSI-based Interactive Localization*. The client-side *RSSI-based Interactive Localization* enables RSSI collection and processing the checked location data generated by the interactive AR visualization module. It is possible to apply Wi-Fi APs or Bluetooth APs, but Wi-Fi APs are suggested because Wi-Fi has broader coverage and is able to support wireless networks for data transmission.

The BIM server receives the RSSI or checked position data, and provides the virtual model, which consists of 3D representation data, building element attached data and the viewpoint position, required by the mobile application. The 3D representation data and building element attached data are obtained from a BIM database, and the viewpoint position is calculated in serverside *RSSI-based Interactive Localization*. Limited by the capability of wireless networks, the transmitted virtual model is only a partial one. Only the nearby building elements are taken into account. Relying on the mobile-side cache of model data, only new data needs to be transferred.

The BIM server also accepts the problem-related data generated by users, and store these data into the BIM database. The desktop application is capable to display onsite inspection BIM and to solve the discovered onsite problems.

4.2 Management Process

The objective of location-dynamic onsite management, called the open inspection, is to discover the potential problems which have not been considered in construction. The person who finds out the problem could be anyone on the construction site and with the mobile application. The management process of Location-dynamic Onsite Management is shown in **Error! Reference source not found.**.

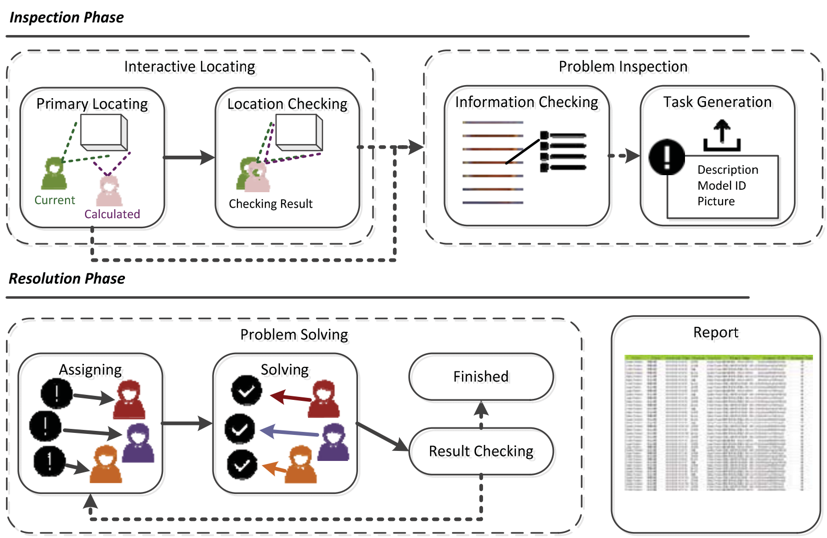

Figure 4 Management Process of Location-dynamic Onsite Management

The process is started when anyone onsite feels something abnormal or incorrect. A procedure of interactive locating, in which the user needs to correct the primary locating result, should be carried out to get the coincidence between virtual view and reality view in mobile application. Besides, the user can still use the basic localization function for a quick view. Afterwards, the user can check the information of the virtual building element. If it is considered a real problem needed to be solved, the user can create a task. After creating the task, the issue will be marked in the BIM display platform so that the manager can assign it to someone appropriate to solve the problem. The assigned person needs to sign when the problem is solved. Finally, inspectors are response to check the result and then the process will be closed when the problem is confirmed being solved. Additionally, periodical report is necessary to review and analysis the problem data.

5 Implementation and Results

5.1 Validation of RSSI-based Interactive Localization Method

An experiment was designed to verify the localization accuracy by introducing *RSSI-based Interactive Localization Method*. 10 Wi-Fi APs were set separated in several rooms, and 31 CPs with the minimum separation of 600 mm were designed. A simple K-nearest neighbor method (KNN) (Bahl & Padmanabhan 2000) and a radio map-based localization method were adopted as the basic localization approach. After the collection of CPs location data, 5 rounds of checking sequence were arranged. In each round, the location of every CP was calculated and the actual RSSIs and location of the CP were added into the RSSI map for further localization. The test result is shown in **Error! Reference source not found.**.

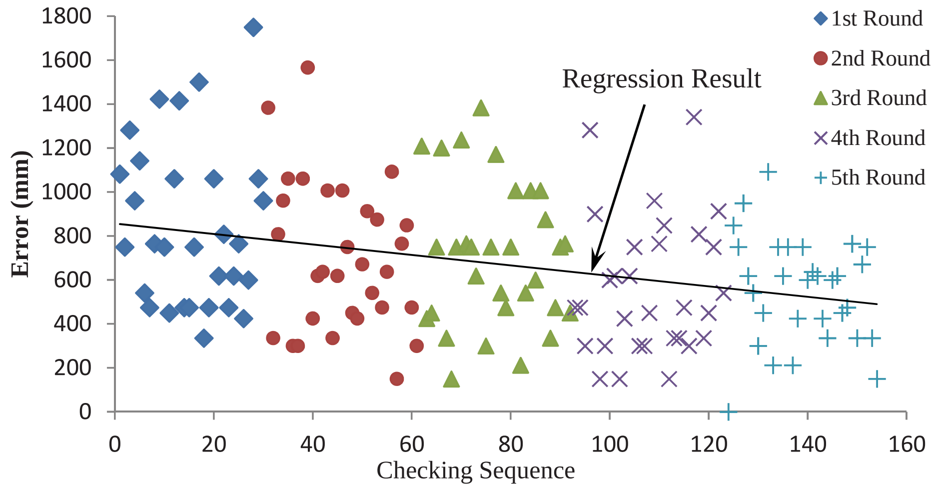

Figure 5 Localization Error Influenced by Checking Sequence

According to **Error! Reference source not found.**, a negative correlation was found between the checking sequence and the localization error, which meant that the checking process did improve the localization accuracy. The dispersion of the CP localization errors in each round reduced when checking process continued. This proves that the checking process can improve the reliability of the localization result.

5.2 Development of Prototype System

According to the technical Framework, a Location-dynamic Onsite Management Prototype System was developed. The mobile application was developed on Android platform. For interactive AR visualization, the DroidAR, an open source project, was applied. The model cache in mobile device was implemented by using SQLite. The BIM server was running on the Windows environment. The network service on the server was an ASP.NET web service. Besides, the desktop application was developed based on the 4D-BIM platform (Hu & Zhang 2011).

The system was tested in the construction of Hedong Station in Guangzhou Metro Project, including the construction of several subway stations and railroad sections. Figure 6 presents the system implementation.

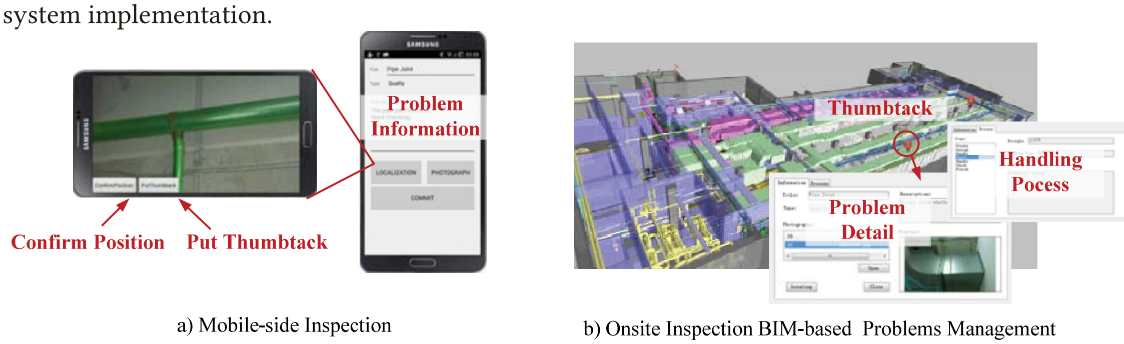

Figure 6 Implementation in Guangzhou Metro Project

5.3 Discussion and Future Works

The application results coincide with the expectation. However, some problems should draw attention in the *RSSI-based Interactive Localization Method*. Firstly, error is generated because of the instability of RSSI. A possible solution is to calculate the weight that indicates the reliability of the checking results according to the historical RSSI map data. Another problem is the accuracy of the rough locating phase. This accuracy is not limited strictly, but should be acceptable to ensure the condition that the user is able to match the virtual model with reality. This will be improved when the basic localization approach is sufficiently optimized. In the early stage, other non-radio-based localization method is in demand, such as the sensor-based localization method. The automatic training process based on the non-radio-based localization method is worthy considering in future work.

When in checking phase, users need to match the virtual model and reality by some operations on mobile devices. This could bring inconvenience to users. A proper consideration in technical way is to use image recognition to assist the relocation. To create an effective encouragement mode is also an acceptable way to this point.

The *RSSI-based Interactive Localization Method* is designed for large, complex and dynamic onsite environment. Additionally, two basic factors that cause the dynamism of the localization environment could be analyzed further. The first one is the change of the AP, and the other one is the change of the onsite elements. The basic localization approach validated in this study is kNN, and other optimizable localization approaches are all available, the validation work for these approaches can be considered in future.

The management process in this study is designed for open inspection in safety and quality management, without considering the professional assistance for targeted inspection. Although the process is suitable for targeted inspection, other works such as the navigation to targeted inspection should be studied in future. Besides, based on the open inspection, more information could be referenced. BIM could be substituted by 4D-BIM, which is a mature concept at present and is able to integrate all the construction-related information. Thus, some other management requirements can also benefit from the process.

The APs bring limitations to implement *RSSI-based Interactive Localization Method* and *Location-dynamic Onsite Management*. The Wi-Fi APs suggested in this study may be hardly deployed in early construction phase nowadays. In this consideration, the methods using Wi-Fi APs are more suitable for later construction phase such as MEP installation or even maintenance phase in building lifecycle.

6 Conclusion

In order to achieve the open inspection on the construction site, and a *Location-dynamic Onsite Management* mode is presented in this paper. Specifically, as the technical basis, an IFC-based *Onsite Inspection Model* is proposed to integrate the onsite problems into a building information model, and a *RSSI-based Interactive Localization Method* is designed for high accuracy indoor localization. Furthermore, a prototype system is developed and tested in a construction project of a metro station, proving that the proposed concepts are effective, even though further researches are necessary for existing problems and limits.

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