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Use of a Mobile BIM Application Integrated with Asset Tracking Technology over a Cloud

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Abstract: Over the last decade, BIM and tracking have been explored by many researchers. Despite the extensive efforts in these domains, they have been mostly individually studied, and limited effort was made to fully integrate them into a single system. This study proposes a new development of a virtual mobile BIM platform for an on-site application by integrating the three systems: Building information modeling (BIM), Bluetooth Low Energy (BLE), and inertial measurement units (IMU). The proposed system is created by 1) developing a low-cost tracking system using BLE and IMU, 2) developing a mobile BIM platform, and 3) integrating the developed components over a cloud. The tracking system is comprised of BLE-sensors, IMU sensors, and map knowledge. The mobile BIM platform is developed through data extraction from BIM and then integration into the tracking system. The study conducts a field experiment to demonstrate the capability of the system with respect to the real-time tracking information, the corresponding virtual BIM view, and communication. The test results show that the integration of the system is successful between the tracking system and the mobile BIM system, and that a new on-site communication tool using BIM and tracking is successfully implemented. In conclusion, the study advances the use of BIM and tracking with system integration that can improve the overall project management and coordination.

Keywords: Building Information Modeling; BIM; Bluetooth Low Energy; BLE; Cloud; IMU; Tracking;

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1 Introduction

With the advancement of mobile communication technology, construction management has become busier, complex and dynamic. These trends demand that construction professionals be more effective and organized to handle the demands of modern operations. Over the last decade, Building Information Modeling (BIM) has become an essential tool that provides an intelligent platform to efficiently plan, design, construct, simulate, and manage buildings and relevant information in a digital form [1]. This digital form of data allows sharing and managing of project plans and information among stakeholders much more effectively than the conventional paper-based methods. A rapid adoption of BIM followed this technological advancement by the industry. The evolution of BIM in the AEC industry brought a paradigm shift from the traditional project delivery process.

Despite the advancement, the construction sector still struggles due to the lack of effective construction management methods in various aspects of construction operations: safety management [2,3], assess control [4], quality inspection and control [5,6], and progress of as-built environment [7,8]. For instance, project inspectors/managers spend a considerable amount of time on-site for 1) looking up information, such as plans and specifications, 2) manually taking notes in the field and logging in such information in the office. Existing methods of tracking and managing defect detection and material inspection still rely on a labor-intensive, unreliable manual recording on paper-based documents [5]. Furthermore, other common on-site problems include time and space discrepancies between a construction-site and a remote office, insufficient number of on-site managers, and inefficient communication among project stakeholders [6,9]. Cho et al. (2015) proposed a cloud-based energy management system and showed its efficacy as a decision support tool. In construction, use of such cloud-based communication can help to better address the mentioned on-site issues, but such a tool is missing in state of the art construction management tools. In addition, the digital data representing a building model often fails to provide construction-specific information and therefore requires extra effort in analyzing the model and then developing detailed project-specific construction plans [11].

Recent advancements in mobile technology enabled commercial development of mobile BIM. These are, however, still in the beginning stage of development and use in construction. Our recent in-person interviews with construction companies indicate many issues with such technologies to be practically used on-site. The users are required to be familiar with them for operation. This, in turn, necessitates extra costs in training and educating crews on regular basis. In addition, due to the lack of location awareness within a current mobile BIM system, the users need to manually navigate through the virtual BIM environment to find their locations. Also, due to the same reason, the system does not have the interactive ability to visualize near-by context information and provide object data relevant to the users.

As discussed above, the benefits of BIM are evident for use in office, but when it comes to construction in field, there exist challenges and issues that limit the effective use of BIM in certain aspects. Thus, this research presents a new approach to provide a more effective tool for on-site use. The approach combines a tracking system with a mobile BIM. The research uses sensing and mobile technologies to explore the integrated system. This system has potential to realize Internet of Things (IoT) through the use of a cloud, which can offer an increased connectivity to the world and a transformative, revolutionary impact on the construction domain. In the remaining sections, this paper will introduce an initiating effort by realizing a Bluetooth Low Energy (BLE) indoor tracking system on a mobile BIM environment that provides a cloud communication tool.

2 Literature Review

Positioning technology has gained rapid attention and has in fact been used in our lives for decades. With the introduction of Global Positioning System (GPS) technology, it has already been rooted in many forms of outdoor applications including navigating, tracking and monitoring. Available position information can be extended to location-based applications. Over the last decade, many researchers have investigated various topics of the indoor positioning field with different sensing protocols, including UWB [12,13], RFID [14,15], and Wi-Fi [16], with different tracking algorithms including fingerprinting, lateration, and proximity. Despite these efforts, there still exist many technical and practical challenges that prevent widespread use of indoor tracking applications [17]. To overcome the challenges, this study uses a relatively new technology, BLE, that offers special features over other sensing technologies, including low cost, small form factor, and low energy researchers [18–20].

In another aspect of effort to overcome the drawbacks, a few researchers have explored BIM in the development of a tracking/monitoring system. Shen and Marks (2016) introduced a framework to visualize near-miss data, manually collected by construction-site personnel, in a BIM platform. Fang et al. (2016) proposed an integrated BIM-RFID tracking system for construction management applications. This study, however, presents several drawbacks as for real-time application yet: 1) BIM was used only for visualization purposes, 2) the used approach, proximity cell-based localization, was unable to perform continuous tracking of a target, and 3) the system required complex installation of sensors with wired power sources. Li et al. (2014) conducted a study to develop a positioning algorithm that takes into account the signal attenuation from walls. This study made an initiating effort to utilize a BIM model to iteratively recognize nearby walls and consider a certain signal loss from each of detected walls nearby the target. To fully consider the signal attenuation occurring in Radio Signal Strength Indication (RSSI)-based technology, there exist more factors, such as ceiling, floor, human, and existing radio signals that can negatively impact the signal quality. In addition, although BIM was integrated as part of the system, the role of BIM was limited to iteratively detecting walls, and the walls were assumed to offer a constant factor of signal reduction. A more recent study conducted by Park et al. (2016) presented an effective use of BIM in conjunction with tracking for a safety application. Their developed system extracted BIM’s object data and used it to serve as geometric boundaries to assist tracking and to visualize the tracking results with respect to the safety hazard conditions used in their study. Although these efforts are found within the BIM and tracking domain, limited research work is done that utilizes a 3D BIM model to create a virtual environment presenting a construction site and that utilizes building elements as a base of communication tool for construction applications.

3 Objective

The objective of this study was to develop a cloud-based on-site construction management tool that utilizes BIM and tracking technologies. This system should provide 1) location information of the user within a mobile BIM environment; 2) rich project information from BIM; and 3) a communication platform to store and share information collected at the site with other associated stakeholders.

4 Methodology

To meet the requirements defined by the objective, three entities, namely a BIM model, a tracking system and a cloud server, are integrated into a single system. Through this integration, information sharing takes place between components. Figure 1 shows a flowchart of the integrated system. The following subsections will discuss each of the components in detail.

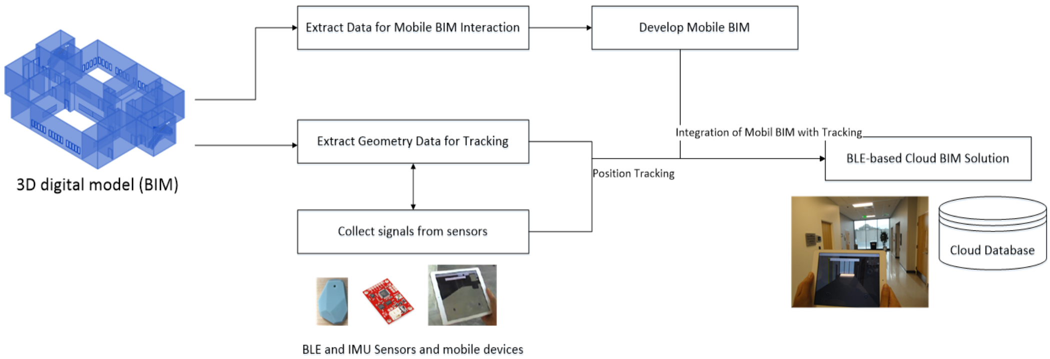

Figure 1: Flowchart of the mobile BIM system

4.1 BIM component

BIM plays three important roles in the integrated system: 1) visualization, 2) geometric constraints for tracking, and 3) object information for on-site communication. Figures 2 and 3 show examples of object information property and geometric constraint property information, respectively. Information of any object that is modeled within a BIM model can be extracted. Such accurate BIM object information can be combined with visualization of the site to form a virtual BIM model for on-site use. Also, the geometric properties of elements including walls and doors can be extracted from BIM and imported into the tracking component of the integrated system. These elements construct boundaries and prevent a target from moving across the boundary by serving as geometric constraints. The exchange of the geometric constraint information can enhance the quality of tracking and thereby provide more reliable visualization to the end user.

4.2 Sensor component

The tracking component is one of the most critical components of the integrated system as it provides the location information of the target, on which the visualization and data communication are based. Our system uses the BLE-based technology to realize a low-cost and reliable tracking system. Figure 4 shows the interaction of the tracking system with the BIM component. The BLE sensors communicate with the mobile device, and this communication provides absolute position reference estimation. At the same time, the inertial measurement unit

(IMU) component, which broadcasts the data over a BLE package, provides relative position estimation with respect to the previously known location. This estimation of relative movement also minimizes the fluctuation in the position estimation provided by the BLE sensors. Furthermore, the orientation data from the IMU sensor is interpreted as the heading direction of the target and used to visualize the scene of the site.

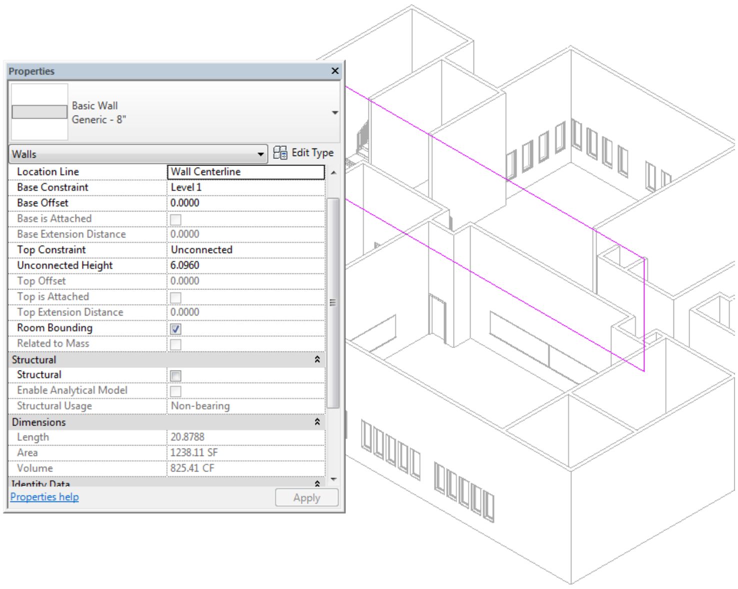

Figure 2: Example of object information from BIM

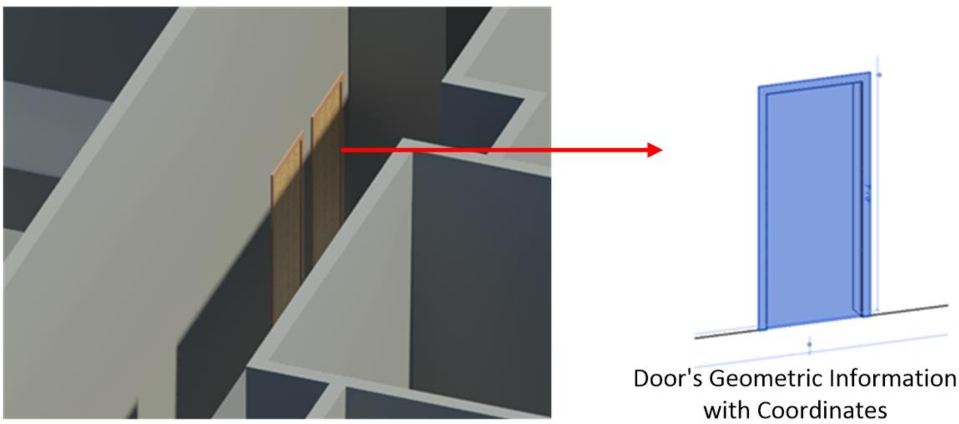

Figure 3: Example of geometric constraint property information from BIM

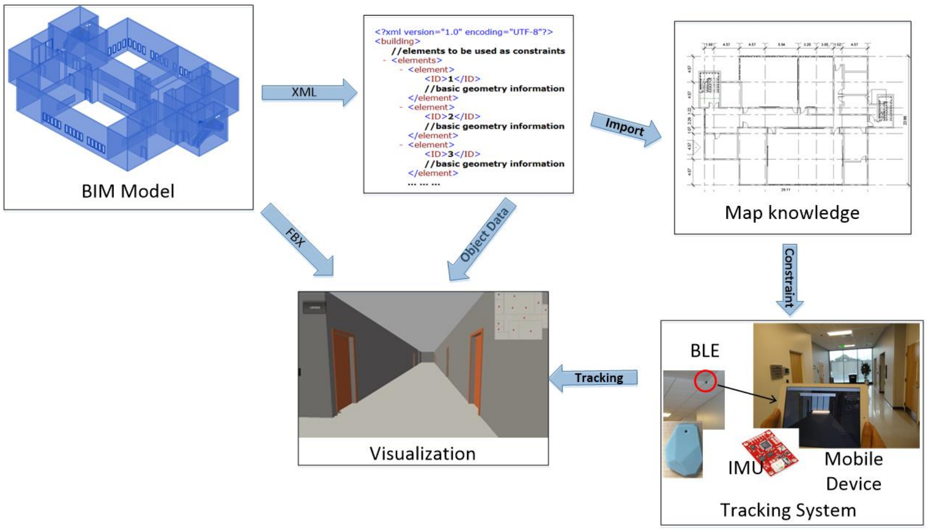

Figure 4: Tracking part of the integrated system

4.3 Cloud component

The developed system utilizes a cloud server to provide a platform for data storage and exchange. The use of a cloud server offers the capability of storing information at a more global level, where such information can be instantly shared with other relevant stakeholders and modified with on-going processes. For example, any issues found on-site, which require immediate attention of relevant parties, can be directly reported to the cloud and shared with the relevant parties.

Figure 5 shows examples of a few on-site issues that need attention from workers: a) an unsafe scaffold without bottom plates, b) hazardous materials on the ground, and c) inappropriate sharp metal piece on a thin rubber mat. The last example with a sharp metal piece on a rubber mat seems trivial, but can have a considerably negative quality impact on the building. If not properly treated or the end-tip of the metal piece rips the rubber mat, water can flow through below the roof and may cause damage to concrete or cause leakage somewhere inside the building. With the cloud components these issues can be immediately reported to the associated workers, and preventive actions can be taken in a timely manner. Therefore, the cloud component is essential in developing an integrated mobile BIM construction application.

Figure 5: On-site issues requiring preventive actions

5 Experimentation

A field experiment was designed with consideration of two aspects. First, to prove the capability of the tracking component of the integrated system, the test was designed with different spaces and complex movements. Second, BIM information including the model view as well as property information was verified though the provided mobile BIM user interface which communicates over a cloud.

The entire third floor of the Mason building at Georgia Institute of Technology was selected as a testbed. This testbed presented complexity with respect to space configuration and existing infrastructure. Such complexity is one of the most critical components that a tracking system should overcome as discussed in the literature review section. Figure 6 shows the layout of the system set-up for the experiment. A total of 18 BLE beacons were installed on the ceiling area over the testbed. The test subject was asked to move in and out of different spaces (e.g., Corridor, Room 1 and Room 2) and make multiple turns while walking.

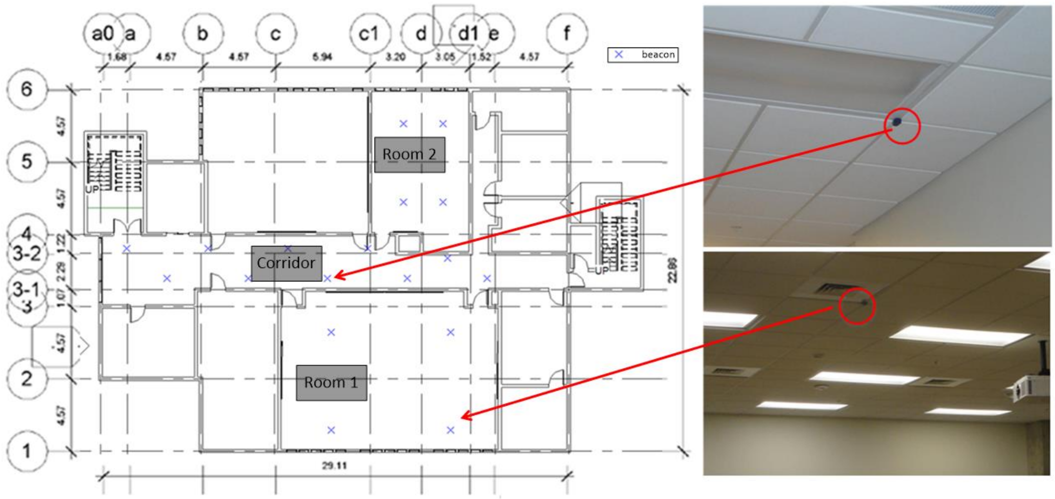

Figure 6: Testbed and system installation.

Figure 7 shows the tracking results of the test showing the estimated location information at the top-right corner in each of the sub-figures (a, b, c and d) as well as the corresponding virtual BIM views. Figures 7 a, b, c and d are the representations of the sequential movements in space. These results demonstrate that the mobile BIM application was successfully integrated with the BLE-based tracking system, and provided virtual mobile BIM views together with location estimation in real time.

Figure 7: Tracking test result and virtual BIM view

Figure 8 shows interactions that the mobile BIM application can create over the pre-configured cloud; Figure 8a shows the developed application that can be used by a site manager. BIM objects that are extracted shown as an example in Figures 2 and 3 can be inspected by the site manager. The pre-configured cloud stores real-time site information collected by individual personnel; Figure 8 presents real-time location information of the personnel (Figure 8b) as well as data collected through the on-site communication (Figure 8c).

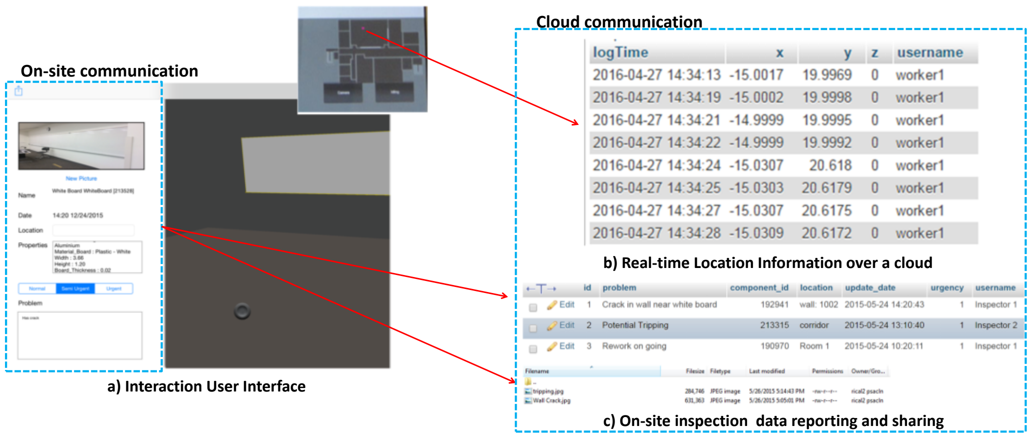

Figure 8: On-site and cloud communication

5 Conclusion

Over the last decade, BIM and tracking have been explored by many researchers. Despite the extensive efforts in these domains, they have been mostly individually studied, and limited efforts were made to fully integrate them into a single system. This study proposed a new development of a virtual mobile BIM platform for an on-site application by integrating the two systems. The proposed system was created by 1) developing a low-cost BLE-based tracking system, 2) developing a mobile BIM platform, and 3) integrating the developed components over a cloud. The tracking system was comprised of BLE-sensors, IMU sensors, and map knowledge. The mobile BIM platform was developed through data extraction from BIM and then integration into the tracking system. A field experiment was conducted to demonstrate the capability of the system with respect to the real-time tracking information, the corresponding virtual BIM view, and communication. The test results showed that the successful integration of the system was made between the tracking system and the mobile BIM system, and that a new on-site communication tool using BIM and tracking was successfully implemented. In conclusion, the study advanced the use of BIM and tracking with system integration that can improve the overall project management and coordination.

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