Smart Facility Management Systems Utilizing Open BIM and Augmented/Virtual Reality

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Abstract

Building Information Modeling (BIM) is a technique in which a three-dimensional (3D) building model is constructed and designed in a computer. In recent years, BIM has been widely used in design and construction phases, but it has not been widely used in operation and maintenance phases, which account for the largest part of the building life cycle. The information required in BIM is different in each of the phases of design, construction, operation, and maintenance, and there are many pieces of reproduced information, making it difficult for managers to utilize the information. Although a number of studies have been conducted on combination of BIM with various technologies such as Internet of Things (IoT) and advanced sensing equipment in operation and maintenance, and interlinking of the obtained information with BIM information, there have been difficulties in commercialization and field application. This study aims to determine the problems found in previous studies and propose a fusion process in which new technologies adopt and utilize virtual reality techniques such as augmented reality (AR), mixed reality (MR), and head-mounted displays (HMDs) in existing maintenance work, thereby increasing maintenance work efficiency and further improving the utilization of BIM.

Keywords –
OpenBIM; Facility Management; Augmented reality; Virtual reality; Maintenance; Process Innovation

1 Introduction

1.1 Research Background and Purpose

The fourth industrial revolution (Industry 4.0) will bring about various technological changes in a variety of industries including the building industry, which has been affected by Industry 4.0 in many areas. According to ‘IoT Analytics’, seven main technologies that will lead Industry 4.0 are cyber physical systems, cloud computing, big data, system security, 3D printing, augmented reality (AR), and humanoid robots. The number of patent registrations for these technologies has increased by approximately 12 times between 2010 and 2015 [1]. The Gartner Hype Cycle for Emerging Technologies in 2017(Figure 1) reported that AR technology has already passed through ‘the peak of inflated expectations’ where excessive interests are concentrated and has entered the ‘trough of disillusionment’ where investments occur in corporations that own actual technologies, and it forecasts that virtual reality (VR) and AR will grow explosively until 2021 [2].

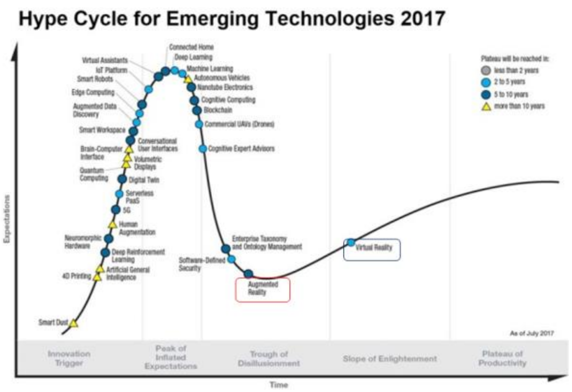


Figure 1. Augmented Reality / Virtual Reality in Hype Cycle (Panetta, 2018)

With the advancement of these technologies, a variety of new technologies have been combined in the building industry as well. Through the utilization of Building Information Modeling (BIM), information in the life cycle of building projects from design, construction, operation and maintenance, demolition, and remodeling can now be managed. To utilize this informatization model, requirements of BIM attribute information for each phase need to be specified and development and promotion of BIM libraries and standard formats are required. In addition, a process improvement for efficient BIM technology application is needed. In this regard, related studies have also been conducted actively. It is now time to consider how BIM information is efficiently created and fused with other new technologies (IoT, 3D printing, AR/VR) and utilized. Facility management (FM) accounts for 85% of the building life cycle cost (LCC) [3]. On-site facility data visualization and real-time collaboration function utilizing AR technology will change the maintenance work process and significantly benefit economy in terms of LCC viewpoints. Nonetheless, compared to the design and construction phases, few studies have been conducted on the applications of state-of-the-art technologies such as AR and VR to the maintenance work process.

Thus, this study identifies a trend of BIM and AR/VR technologies and determines an information linking method as one of the studies on smart FM for automation management and efficient execution of maintenance on facilities. It also proposes a smart maintenance work process that is applicable to smart FM systems by deriving user tasks where BIM and AR/VR technologies need to be applied in existing maintenance work.

1.2 Study method and procedure

This study adopts the following methods to enable smart FM work execution with applications of BIM and AR/VR technologies in FM of the building sector of public facilities. First, the existing maintenance work process is analyzed through a literature review. Through this analysis, the problems of existing processes are derived, and technical solution methods are searched. Second, component technologies of open BIM and AR/VR and Head Mounted Display (HMD) devices for visualization implementation are analyzed to derive applicable technologies and devices for smart FM. Third, a new work process for smart FM is proposed and detailed use cases for workers to execute the process are divided. Finally, the applicability of the technologies is determined through simple prototype implementation for each phase in the processes.

2 Research Trends

2.1 Building maintenance using BIM

The advantage of applying BIM to the maintenance phase is that it can utilize analysis data for purchase procurement of machine equipment, control systems, and other products and it can check whether all systems are correctly operating after buildings have been completed. It can also play a role as an interface for sensors and remote operation management of facilities, and real-time monitoring on control systems through providing accurate information about space and systems [4]. The BIM for FM is a sole information basis that provides a manual for building users. This can help the location of models such as facilities, attachments, and furniture to be recognized visually and can support contingency planning, security management, and scenario planning [5]. As described above, several studies have been conducted actively to draw out the advantages of BIM application to FM as much as possible.

A study by Yu et al. developed a data model, FMC, that can extract the required information from Industry Foundation Classes (IFC) for information compatibility of BIM data with FM [6]. A study by Mendez proposed functions that can be utilized by BIM in the maintenance phase and developed a web-based prototype to improve utilization of BIM data [7]. East and Brodt developed a spreadsheet-based data exchange format, COBie, to solve inefficiencies due to unnecessary information in maintenance among information sets created during design and construction phases [8]. A study by Burcin et al. defined a level of BIM recognition in the maintenance phase through expert interviews, applicable areas, required data and processes for successful implementation of BIM [9]. Lee et al. attempted to improve a facility maintenance system through benchmarking of the COBie system [10] and Choi et al. conducted a study to implement a FM system for sewage treatment based on COBie [11].

Most of the previous studies on FM utilizing BIM are focused on interoperability with FM systems and a measure to link data that are produced during design and construction phases, as well as being directed toward application of BIM to FM systems and commercialization.

2.2 Utilization of AR/VR technologies in the building industry

The trend of utilizing AR/VR technology in the building industry is reflected in the focus of most studies being on analysis of applicability of virtualization technology in the early days. Hammad presented the applicability of AR technology to field tasks of infrastructure [12] and Kwon analyzed considerations in the development of wireless technology-based AR-applied systems in terms of display, tracking, and servers. Afterward, a study on presentation of AR system prototype for inspection of steel column construction was conducted [13][14].

A variety of studies have also been conducted in relation to VR technology. For example, decision-making support through virtualization and simulation has been studied. Kim utilized VR technology in a system that evaluated a road scenery design and selected the final alternative based on superior scenery, technicality, and environmental criteria [15]. A study by Choi implemented a cloud-based BIM platform by which construction site environments could be experienced indirectly through simulations [16].

For studies on AR authoring tools, AR modeling through capturing and rendering of exterior structures in real time and a 3D modeling tool called 'Tinmith', which was manufactured to provide interaction between user and AR directly, can be found [17]. More recently, prototypes that can be applicable to real construction sites have been developed. For example, Dunston used a head mounted display (HMD) to represent a 3D computer-aided design (CAD) model on an actual real background, thereby conducting a study on AR-CAD that found a spatial interference on the drawings in the design phase [18]. Moon et al. implemented an AR prototype that can select the position of a tower crane appropriately in a high-rise building construction site and conducted a verification procedure through actual building drawings [19].

The analysis results in previous studies showed that the utilization of AR/VR technology in the building industry has enabled efficient construction management by recognizing design drawings intuitively by users. Four-dimensional (4D) BIM based on existing virtual environments has lacked reflection of actual construction site conditions. Thus, if AR technology that reduces a cognitive resistance is applied to maintenance sites, its value and utility would be significant in terms of productivity improvements.

3 Theoretical Discussion

3.1 Open BIM and IFC standards

In terms of commercial CAD systems, BIM technology has been advancing continuously. However, the most difficult limitation in BIM application is data compatibility. BIM platforms can share all information throughout the building life cycle in their unique data formats. However, the absence of standard formats and data access methods can create a problem in BIM data exchange between CAD systems. To overcome this problem, the Industry Foundation Classes (IFC) have been applied as a standard data format to exchange and share BIM data.

The IFC are a neutral data model rather than a proprietary model of a specific software vendor. They have been developed by the International Alliance for Interoperability (IAI), buildingSMART, to facilitate data compatibility for information sharing and exchange between application tools used in the building industries. They have been developed as standardized data sets for data compatibility between application tools. OpenBIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model [20]. Based on openBIM, several public project order issuing institutions in the USA and Europe require openBIM-standard-based delivery. The BIM-based public project orders in North America and Europe have been expanding throughout the world.

The AR/VR-based smart maintenance process proposed in this study utilizes openBIM for data interoperability.

3.2 AR/VR technology

The component technologies of AR applied to building industries that were analyzed in the previous studies can be summarized as follows.

- GPS-based technology: user location is recognized using GPS technology and registration to real environment can be done by projecting a 3D model to a pre-calculated location through the display.
- Vision-based technology: feature points are recognized based on images inputted to the camera and camera position is calculated to register a 3D model with a real environment.
- Real-time 3D recognition technology: real spaces are recognized and interpreted to align virtual objects in real spaces.
- Positional tracking technology: accurate tracking data values of user's position are reflected in the display in real time.
- Head tracking technology: can make a virtual object transit not only by position detection of the user according to movement in the real space but also by detection of head movements even when staying in the same position.
- Gaze (pupil) tracking technology: tracks the focal points of the pupils of eyes in real time using image processing, or can be implemented by a specific transmitter.
- High transparency technology: it overlays the view in the real space and the virtual object image naturally to project the light reflected in the real space to the retina.

The features, advantages, and disadvantages of AR/VR as virtualization technologies utilized in the building industries in construction sites are as follows.

- HMD hardware is needed to block the field of view in the real space as a technology that uses a 100% virtual image rather than a real image.

- It can provide various angles and stereoscopic effects through computer graphics, but it lacks site reality compared to AR.
- It is a technology that overlays 3D virtual images to real images. It requires a coordinate recognition technology of device medium or a rotation sensor to accurately overlay virtual images to positions in the real space.
- It has the advantage of delivering site-based selected information realistically, but has a limitation in recognition accuracy due to various site obstacles.
- It can be superior in providing indoor information of a completed building where the surrounding environment is stable.

This study aims to improve efficiency and productivity of maintenance work. To achieve this, it utilizes basic components and element technologies of AR/VR technologies.

4 OpenBIM-Based Smart FM

4.1 Overview of smart FM

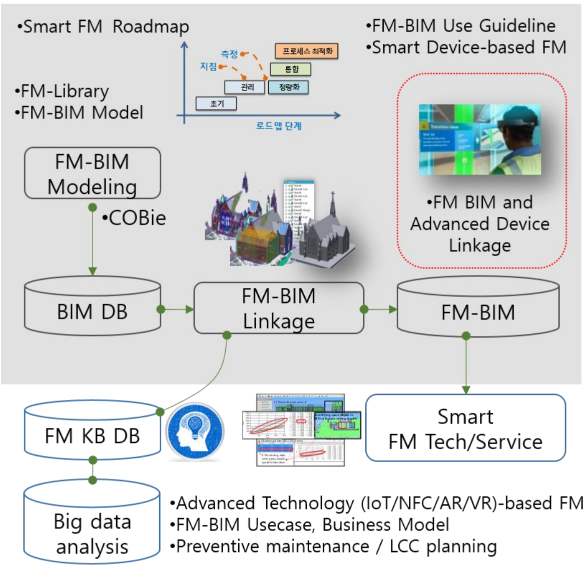


Figure 2. Smart FM technology development for advanced device and data analysis

The smart FM proposed in this study is a platform that employs the IoT, cloud, big data, and mobile (ICBM) basis technologies. It has the following major technologies.

- Scan/reverse design technology (SCAN-BIM, BIM model reverse design technology)
- Intelligent FM BIM technology (cloud/big data/intelligent model/BIM data analysis technology)
- Smart field FM BIM technology (IoT/VR/AR-based BIM FM)

The smart maintenance process proposed in this study is based on smart field FM BIM technology. It aims mainly to support site work. Figure 3 shows a diagram of the improved maintenance work flow.

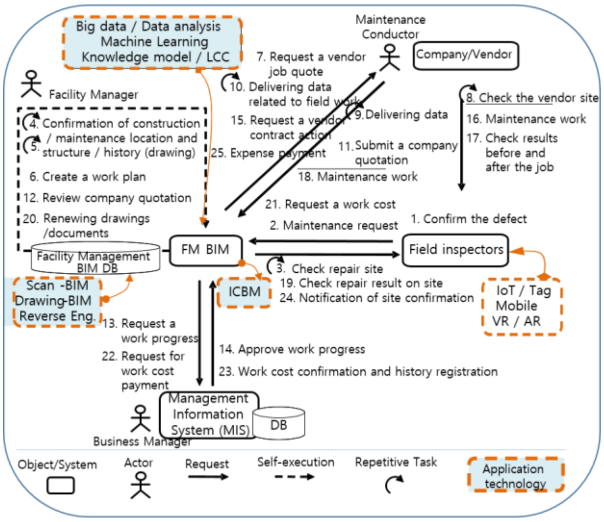


Figure 3. Maintenance work flow diagram in Smart FM

Through the ICBM platform-based FM BIM system that manages the facility management database in the center, variably distributed data can be gathered and processed as a hub for each request.

4.2 Existing maintenance work process

The routine maintenance inspection work processes of various facilities are investigated through a literature review and worker interviews. The maintenance work process differs depending on facility uses and sizes. Thus, this study limited the use and size to public facilities of less than five stories. The general maintenance work process is:

1. Establishment of inspection plan
2. Discovery/investigation of abnormality and defects
3. Determination of maintenance work schedule through safety diagnosis; and then if required
4. Repair work.

When utilizing BIM, histories of facility maintenance can be included and utilized in the BIM data. It is also differentiated from existing maintenance work processes by its process of automatic extraction of various statistical data and establishment of preventive repair plans as well as its conducting visualization simulations after repair work is complete. The as-is process of various maintenance works is divided into tasks for each user and is represented in Figure 4.

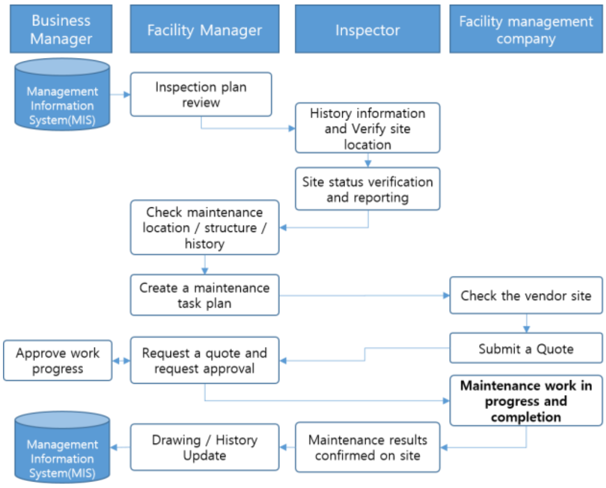


Figure 4. As-is process flow diagram of maintenance work

The facility manager then reviews the inspection plan and the inspector conducts inspection at the site based on the plan. Afterward, facility manager checks the history of maintenance and conducts maintenance, and the facility management company rechecks the site. When the facility management company submits a quote, the facility manager checks the quote. Once the executive manager approves the work, the facility management company can start the maintenance work.

4.3 Improvements in the AR/VR technology application process

Previously, data such as drawings, history information, and related documents were distributed and stored during facilities maintenance work. In addition, when facility defects occurred, it took a lot of time to search history information, drawings, company information, site location, and MIS history information. This was one of the main factors hindering work efficiency. The inefficient process with iterative tasks and sequential progress is improved through AR/VR technologies to produce an improved to-be process as shown in Figure 5.

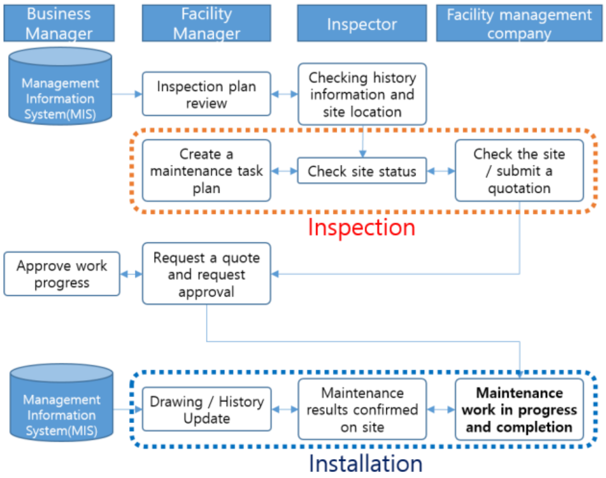


Figure 5. To-be process flow diagram of maintenance work

If VR virtualization technology utilizing BIM model spatial information is applied to review the work of the facility manager inspection plan, the inspector's history information and site position verification work can be done simultaneously. If AR technology is applied to a process when an inspector verifies a facility status at the site, the facility manager and facility management company can share the site conditions in real time and collaboration work for maintenance can be achieved. If AR technology is applied even when the facility management company does maintenance work, follow-up work of the inspector and facility manager can be done simultaneously. The utilization scenarios of the proposed system are shown in Figure 6 for different technical areas.

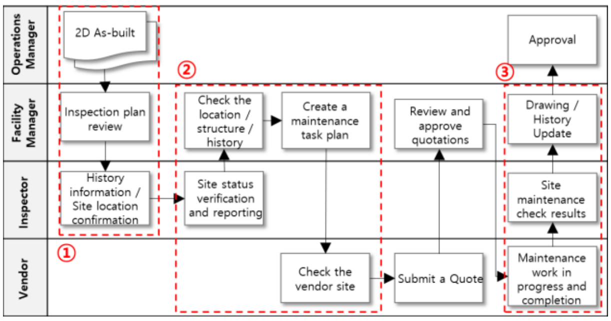


Figure 6. Utilization scenarios of the proposed system

The core technologies in the visualization process for each space through VR are as follows.

- Reference information system by phase
- Information division and information sharing process
- Indoor positioning technology

- Marker-indoor positioning integration technology

The core technology in the real-time collaboration process through AR visualization are as follows.

- VR/AR-based surveillance construction support technology
- 3D information + AR overlaying technology
- 3D data conversion technology for AR/VR

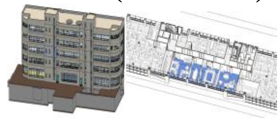
Table 1 Key issues and core technologies in the proposed maintenance work

① Space-specific visualization through VR	
Key issues	• Mapping of attribute information and mapping of necessary information to shape information • The user/manager side information process must be established & information control • Real-time management technology through history management based on current location information
Core technology	• Step-by-step reference information system • Information Segmentation and Information Sharing Process • Indoor Positioning Technology • Marker - Indoor positioning integrated technology
② Real-time collaboration through AR visualization	
Key issues	• The Inspector provides real-time information on the target location and history for checking the status of the object, • Real-time sharing of real-time information through 3D visualization
Core technology	• Surveillance-based support technology based on virtual / augmented reality • 3D Information + AR Overlaying Technology • 3D data conversion technology for AR / VR
③ Site-based update of historical information	
Key issues	• Check the real-time field status, upload and save the inspection contents, update historical information by each type of work • As-built model update through on-site information update
Core technology	• Data lightening support technology • 3D contents update process and technology based on reverse design • IoT information-based control technology for managers

4.4 Implementation of the improved process

An openBIM dataset of public facilities of five or fewer stories was utilized to implement the proposed AR/VR-based smart maintenance process. Table 2 shows the data and programs used to verify the applicability.

Table 2 Data and tools used for validation

Data and Tools	Programs and contents
BIM Dataset	Autodesk Revit(rvt), LOD500(BIM for FM)
Geometry models converted to IFC standards	
VR development tool	Unity
VR HMD	Microsoft Hololens
AR development tool	ARtoolkit, Android studio
AR HMD	Vuzix M100

To implement a VR virtualization prototype for prior inspection planning review and site location verification work (Figure 7), a model library for each maintenance target object should first be extracted from BIM information, and converted into model data for each space. The above process is required to use the 'Unity' VR implementation authoring tool. Any openBIM dataset can be acceptable. A VR prototype is complete for maintenance area visualization if spatial and object data are combined in Unity and camera and moving travel paths are set up followed by building into a preferred platform. To demonstrate this, Microsoft's 'Hololens' was used as an HMD.

For the implementation of AR technology-applied process, a maintenance history information overlay function and a real-time communication function were implemented through the open source programs 'ARtoolkit' and 'Vuzix M100', and Android SDK.

Figure 7. Validation of AR/VR based maintenance task through simple test

5 Conclusion

This paper proposed a process to apply AR/VR technologies to site maintenance work in the openBIM-based smart FM system. A survey analysis was conducted regarding existing BIM-based maintenance and AR/VR research in building industries. Along with surveys on openBIM and AR/VR technologies, a method to utilize them in maintenance work was derived. Finally, a process by workers and technology systems was proposed for AR/VR-applied maintenance work, and this was implemented as a prototype.

As a result, the utilization of AR/VR technologies in the maintenance work enabled fast and accurate decision making. With BIM data that can replace existing two-dimensional drawings and AR technology that can visualize information through overlay, inefficient re-work elements can be removed. In addition, since openBIM datasets created in the construction phase are utilized, it has the advantage of requireing little resource input for technical application. It can also improve accuracy and reliability of maintenance work results by minimizing interventions based on individual subjective judgments through real-time site circumstance sharing and collaboration functions via HMDs.

However, since the scope of this study was limited to the maintenance of public facilities of five or fewer stories in the building sector, the study results cannot be applied to other purposes and larger facilities. If maintenance work is extended to mechanical, electrical, and plumbing (MEP) facilities, the required BIM information can be extensive, and lightweight data are therefore needed. Thus, for future study, the following topics can be selected: definition of classes for attribute information visualization and BIM models for each facility of various sizes and uses, measures to link HMD and IoT sensing data, ensuring connectivity with actuators, and technical advancement of marker recognition with regard to maintenance targets.

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