BIM-BASED AUGMENTED REALITY INSPECTION OF FACILITY MAINTENANCE MANAGEMENT

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ABSTRACT

More than 65% of the total cost in buildings comes from Facility Maintenance Management (FFM). Despite that, facility managers have still relied on the traditional method. Building Information Modeling (BIM) based on Augment Reality (AR) can enhance the activity of FFM. In this study, a framework was developed for end-users and facility managers where end-users report maintenance requests, while facility management (FM) department are responsible to manage them. This will help FM team to optimize building maintenance strategies and decision-making and finally reduce the costs associated with the maintenance activities in the buildings.

INTRODUCTION

In the life cycle of a project, the operation and maintenance (O&M) phases are just as important as the planning and construction of the project itself. Compared with other phases, the highest costs occur during the O&M phase since some reports show that more than 60 percent of a total project cost is related to this phase (Akcamete, Akinci, and Garrett 2010; Teicholz 2013). Beside, Lee et al. (2012) indicate that American building industry wastes approximately 67 percent annually in O&M phase, emphasizing the importance of Facilities Management (FM) tasks.

FM tasks are fragmented and require gathering and sharing large amounts of information related to facilities spaces and components, and covering historical inspection data and operation information (El Ammari and Hammad 2019). More than 65% of the total cost in FM comes from facility maintenance management (FMM) (Chen et al. 2018). Despite that, facility managers have still relied on the traditional computer-aided-design (CAD) systems to create the necessary information (e.g. the location of building elements, dimension, material and specifications) to operate and maintain their assets in buildings (Volk, Stengel, and Schultmann 2014a). Furthermore, there is a lack of efficient maintenance strategies and right decision making approaches to reduce FMM costs (Chen et al. 2018).

Building Information Modeling (BIM) has been emerging as a potential solution for FMM to address the challenges of information reliability, interoperability (Cavka, Staub-French, and Poirier 2017) and guide decision-makers in addressing building maintenance problems. BIM constitutes an effective platform by which to depict high-quality information and integrate different platforms and sources. BIM utilizes 3D, parametric and object-based models to create, store and use coordinated and compatible data throughout the life cycle of a facility (B Becerik-Gerber et al. 2012). Researchers have focused on implementing BIM for different aspects of FM, especially for FMM (Arayici 2008; Singh, Gu, and Wang 2011). However, the BIM visualization potential for improving maintenance activities was not considered in their studies (Alavi et al. 2021). In order to improve the effectiveness of BIM applications, some studies have shown that incorporation of the augmented reality (AR) technology would be beneficial for improving the usability and accessibility of BIM information (Chen, Lai, and Lin 2020).

AR is an innovative technology that can enable digital information such as 3D models, images, and animations to be overlaid on the real world to facilitate natural contact between users and their surroundings (Cheng, Chen, and Chen 2017). For years, AR was applied to the Architecture, Engineering, Construction and Operation (AECO) industry (Dunston and Wang 2011). AR makes user information readable and manipulable surrounding facilities by mixing virtual and the real world. However, currently there are limited studies about implementing AR collaboration for FMM (Chen et al. 2019).

The aim of this research is to develop a framework for end-users and FM team by integrating BIM and AR to support FMM. Such incorporation will help FM team to optimize building maintenance strategies and decision-making.

LITERATURE REVIEW

FM staff are required to collect high-quality information to achieve corrective maintenance actions (Shalabi and Turkan 2017a). To further improve FMM tasks, it is necessary to implement BIM and AR jointly to access high-quality information and visualize the required information. BIM can support FM tasks by acting as a data repository, locating equipment within a facility, and coordinating information from multiple systems (Burcin

Becerik-Gerber et al. 2012). Researchers focus on implementing BIM for different aspects of FM, such as: maintenance of warranty and service information (Arayici 2008; Singh et al. 2011); quality control (Boukamp and Akinci 2007); asset management and monitoring (Alavi and Forcada 2019; Arayici 2008; B Becerik-Gerber et al. 2012); energy management (Dave et al. 2018; Wang, Pan, and Luo 2019); sustainability (Arayici et al. 2011; Barnes and Castro-Lacouture 2009; Sacks, Treckmann, and Rozenfeld 2009); space management (Alavi and Forcada 2019; B Becerik-Gerber et al. 2012; Cho, Alaskar, and Bode 2010); emergency management (Alavi and Forcada 2019; Wetzel and Thabet 2015); and retrofit planning (Mill, Alt, and Liias 2013). BIM implementation can be further extended to: preventive maintenance planning (Burcin Becerik-Gerber et al. 2012; Chen et al. 2018); building systems analysis (Burcin Becerik-Gerber et al. 2012; Weygant 2011); commissioning processes (Burcin Becerik-Gerber et al. 2012; Jiao et al. 2013); and strategy planning (Burcin Becerik-Gerber et al. 2012; Zou and Wang 2009). Some early BIM-based FMM studies have shown how BIM can improve FMM activities (Cavka et al. 2017; Chen et al. 2019, 2020; Volk, Stengel, and Schultmann 2014b). Hassanain et al. (2003) introduced a general object-oriented schema for FMM that supports information exchange from the construction phase to the O&M phase. Liu et al. (2012) investigated how to use Geographic Information System (GIS) and BIM to obtain FMM information. Some researchers (Golabchi, Akula, and Kamat 2016; Motawa and Almarshad 2013; Shen, Hao, and Xue 2012) provided different decision support tools for FMM. However, no visualization function was considered in these studies. On the other hand, other studies (Chen et al. 2018; Shalabi and Turkan 2017b; Yang and Ergan 2016) have used BIM visualization for facilitating FMM. For instance, Chen et al. (2018) presented an FMM framework for automatic scheduling of facility maintenance work orders. Such studies have utilized BIM visualization to assist FMM to identify failure components in buildings and have access to FMM information. Since BIM has its inherent trait of having geometric data in 3D, the vast majority of the researchers tend to use BIM visualization as the interface to show FMM information with a constrained investigation of the other potential approaches to show the high-quality information such as AR visualization.

AR provides a suitable interface for FMM fieldwork support (Koch et al. 2014; Lee and Akin 2011) by providing the superimposed geometric representation on the physical space along with the relevant BIM-based FMM information (Gao and Pishdad-Bozorgi 2019). Researches have been used AR to facilitate FM tasks. For example, Irizarry et al. (2014) proposed an AR system for facility managers to provide FMM information, proved to be able to improve efficiency during FMM. Lee et al. (2011) presented a system of an AR-based equipment O&M fieldwork support application to improve efficiency in FMM. Hou et al. (2014) presented a framework in which AR combined with photogrammetry to manage information for FMM. Ting et al. (2019) developed a facility risk assessment and maintenance system prototype enabling facility managers to select the maintenance policy for a single piece of equipment. Chen et al. (2020) integrated AR with BIM to improve safety and reduce error for FMM activities. FMM tasks frequently require multiple users to communicate and interact with each another. For instance, when occupants report a problem, the facility manager comes to the office of the employee and inspects the problem on site. After identifying the problem, the facility manager makes decision and calls the administrative affairs manager, reports the problem and requests a work order. To deal with this issue, AR can give a UI to FM staff and occupants to straightforwardly communicate with surrounding facilities (Chen et al. 2019). Despite this, the vast majority of the current collaborative AR applications are for FM staff or technicians which restricts the correspondence and collaboration among FM staff and occupants.

THE DEVELOPED FRAMEWORK

According to the PAS-1192:2013 standard (BSI 2013), an asset information model ought to incorporate a graphical model, non-graphical information, and documentation. The graphical model shown in AR mode was obtained from the BIM model and model was placed into the real world through mobile devices. The non-graphical information is obtained from either the BIM model or other documentation (e.g. maintenance information) stored in Computerized Maintenance Management System (CMMS). The developed framework is shown in Figure 1. The graphical model was exported from the BIM model as .FBX file prior to import the model into AR project in Unity engine. Unity (Unity Technologies 2020) is a cross-platform game engine which can be used to create three-dimensional, two-dimensional, virtual reality, and augmented reality games, as well as simulations and other experiences. Unity supports multi-platforms development which can be used to develop desktop computer application in operation system like Windows, MacOS, Linux or mobile application in iOS/Android platforms. A part of the non-graphical information was extracted from the BIM model using a visual programming extension for Autodesk Revit, Dynamo while the other part of the non-graphical information was obtained from CMMS software. Then, the non-graphical data were stored in SQL server database. Microsoft SQL Server (Oracle Corporation 2016) is a relational database management system developed by Microsoft. As a database server, it is a software product with the primary function of storing and retrieving data as requested by other software applications

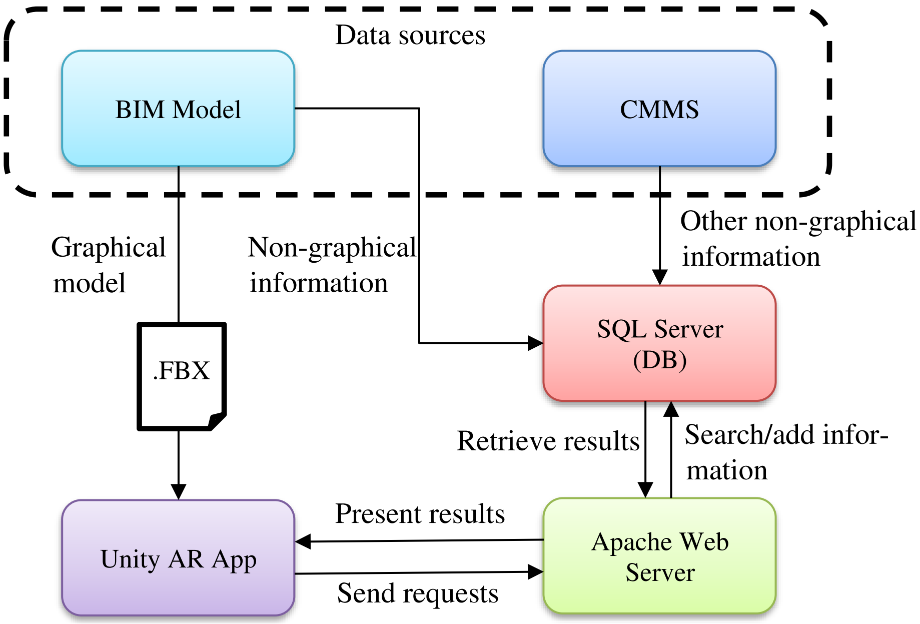

Figure 1: The developed framework

which may run either on the same computer or on another computer across a network (including the Internet). Moreover, Apache HTTP Server and PHP with SQL query commands were used to link database to the Unity AR app, based on which multiple users can read and update information in the database. The Apache HTTP Server (Robert McCool 2018) is a free and open-source cross-platform web server software, released under the terms of Apache License 2.0. Apache is developed and maintained by an open community of developers under the auspices of the Apache Software Foundation. PHP (PHP 2013) is a popular general-purpose scripting language that is especially suited to web development. PHP code is usually processed on a web server by a PHP interpreter implemented as a module, a daemon or as a Common Gateway Interface (CGI) executable. On a web server, the result of the interpreted and executed PHP code – which may be any type of data, such as generated HTML or binary image data would form the whole or part of a HTTP response. Finally, the Unity AR App for mobile devices was created to support FMM tasks.

BIM model preparation for FMM

Even though the non-graphical information was extracted from BIM and CMMS into the SQL server, it still cannot represent complete information on maintenance activities. Therefore, shared parameter was utilized to allow BIM models to contain facility maintenance information. Shared parameter is a Revit term that can be added to the Revit family for custom data fields. It can also be accessible for any project due to holding parameters in a separate file. In this study, room and system information were defined and assigned to rooms in BIM, while others (i.e. information related to the components) were assigned to their corresponding family (e.g. mechanical family). Table 1 shows the information requirement for rooms and system included into the BIM model. The non-graphical information for each component in a building is different; thus, it was crucial to assign the shared parameters into their relevant families in BIM. For instance, considering 'Ventilation control' as a shared parameter, it should be assigned to mechanical family but not wall family.

Table 1: Room and System information

Required information	
Room information	• Thermal satisfaction (Obtained from the satisfaction survey) • Current Temperature • Current Humidity • Average temperature in this month • Average humidity in this month • Individual thermostat control (yes/no)
System information	• Type of heating (Radiators / Air water / Splits / VRV) • Type of cooling (Air-water / Fan coils and AHU / Splits / VRV) • Type of ventilation (Natural / Forced independent / Forced integrated in the heating and cooling)

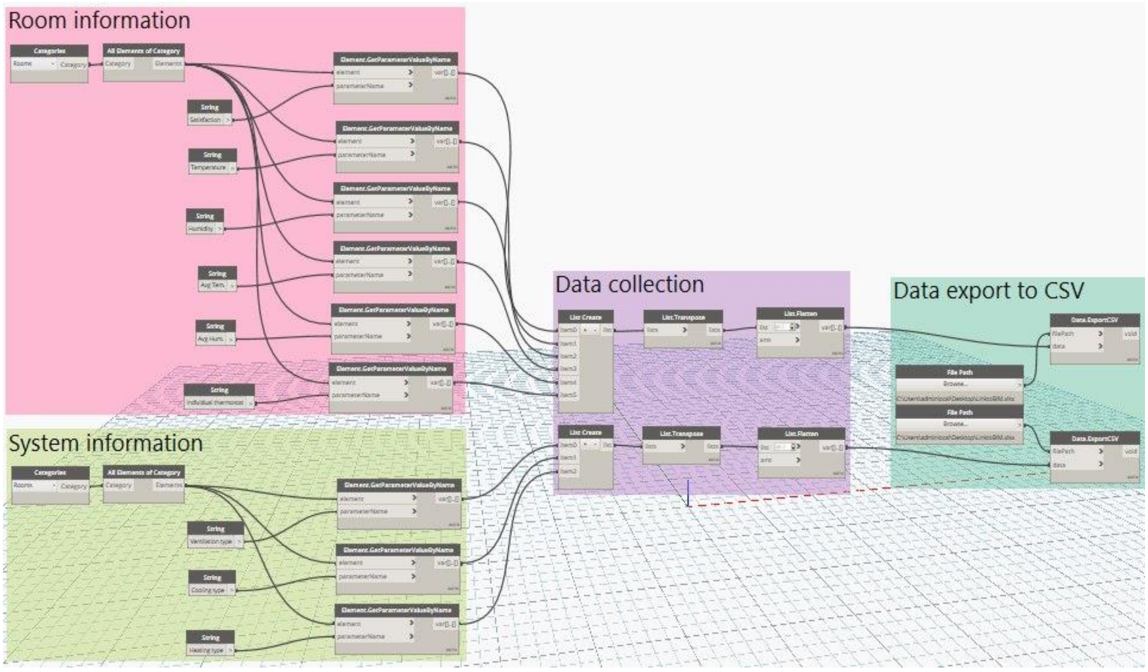

Figure 2: Dynamo script used for data extraction

Then, this kind of information was exported to CSV format and then into the SQL server. The Dynamo script supported this functionality and are presented in Figure 2.

AR preparation for FMM

To create AR and visualize the causal factors of a problem, Google ARCore and Unity were used. ARCore (Google 2018) is Google's platform for building augmented reality experiences. Using different APIs, ARCore enables phones to sense its environment, understand the world and interact with information. Some of the APIs are available across Android and iOS to enable shared AR experiences.

RESULTS AND DISCUSSION

AR provides a UI to FM department and end-users (i.e. occupants) to communicate with each other. In this user interface, there are two modes for end-users and FM department where end-users report maintenance requests, while FM department are responsible to manage them. End-users can open the app installed on their smartphone and report a problem to the FM staff to solve it. Based on the deploying physical marker for each room captured by

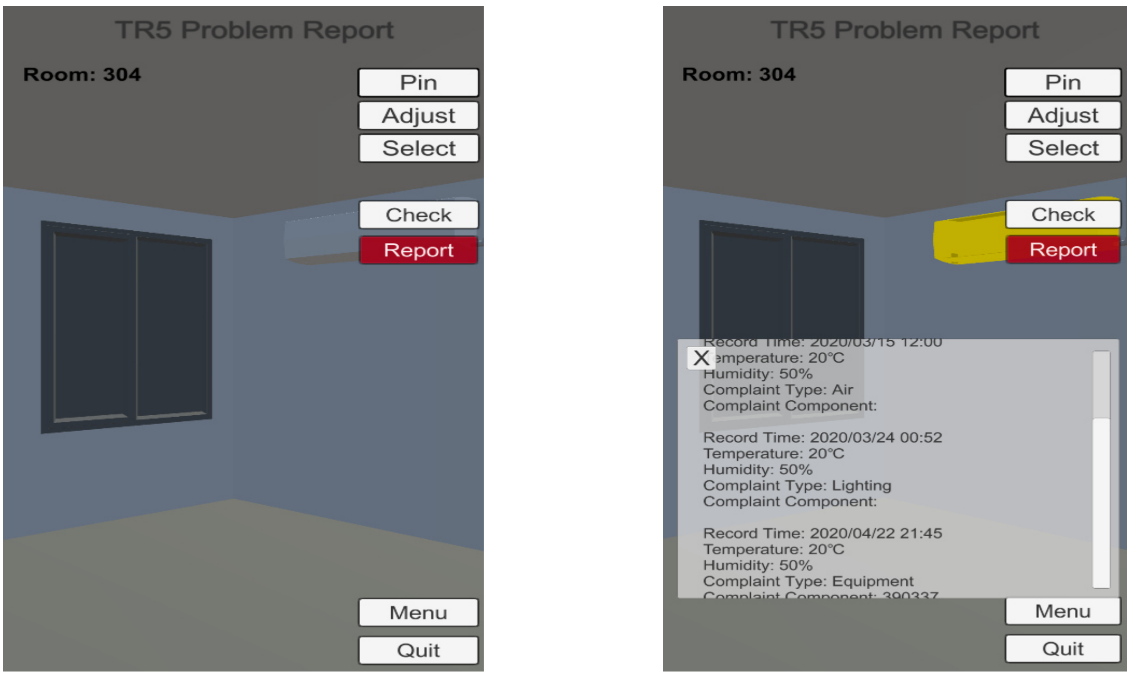

Figure 3: AR-based FMM for end-users (User Complaint Mode)

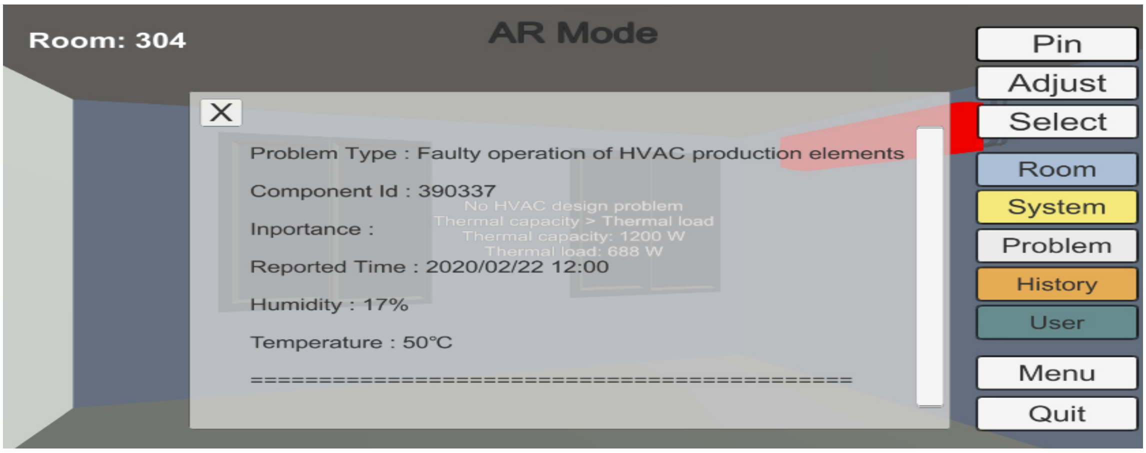

Figure 4: Information related to the reported component (FM mode)

AR app using the cameras, the corresponding facilities and information were displayed on the device with the correct position. When end-users detect a problem, they can select the equipment (e.g. split) which is not functioning properly and the equipment will be highlighted automatically so that FM staff will know which equipment is being reported by a user. End-users will also be able to check complaint progress through the app. Figure 3 shows the screen shots of the mobile application of user complaint mode.

FM staff inspects the condition of reported components. If components are being reported as failed, the FM staff will move to the location of reported components. Then, FM staff can directly check the condition of the reported component in the AR by clicking on the component. The corresponding information is shown in their device, including problem type, component ID, date and hour of reported problem, temperature and humidity on the moment of reporting the problem, impotency of the problem, and maintenance history of the equipment as illustrated in Figure 4.

FM staff can also access to the information related to the space by clicking on the corresponding bottom in their device while they enter a room. For example, by clicking on "System" bottom, the system information related to the space such as type of heating, cooling and ventilation is shown up in AR app. BIM-based AR system enables app to provide room and system information automatically for each room by entering into the room. Figure 5 shows the screen shots of room and system information when FM

(a)

(b)

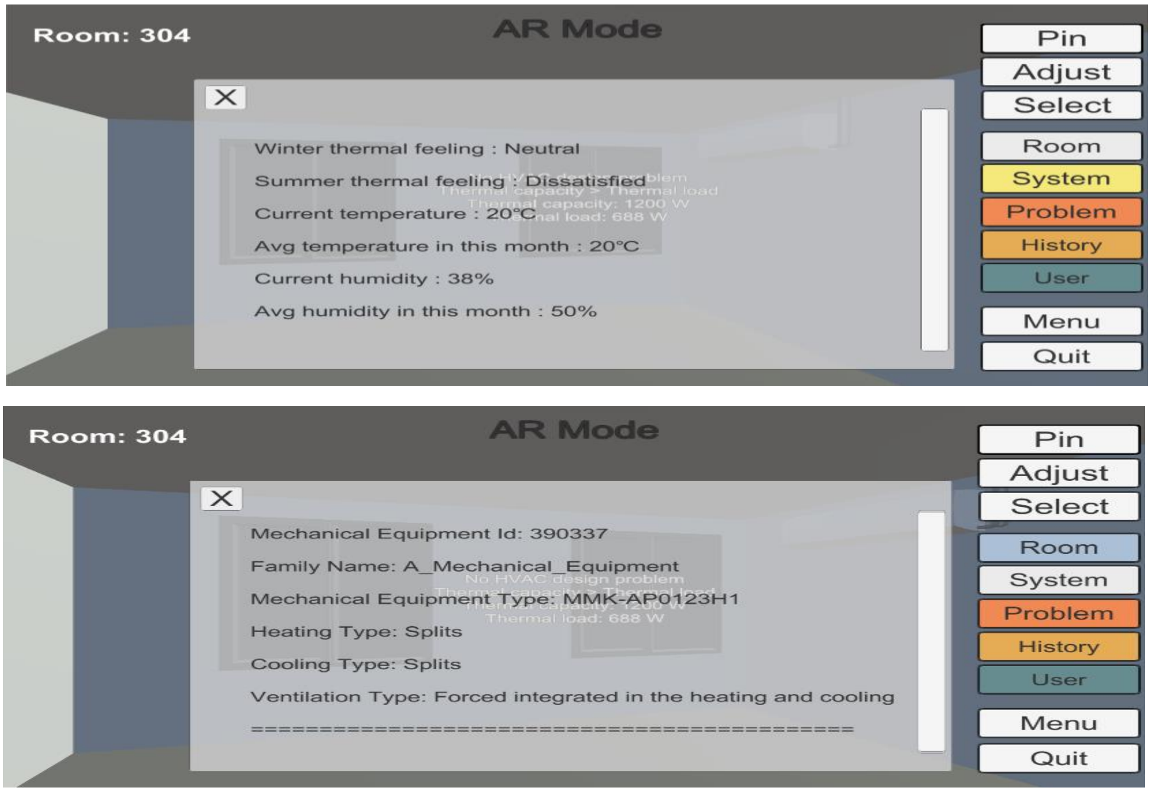

Figure 5: (a) Room information and (b) system information related to the space (FM mode)

staff entered the space where the failure component is located (FM mode). Such information help FM staff to make decision on tackling the problem. Considering this kind of information and checking the component in present, FM staff will be able to find out the problem (either repair or replace the component) and report its status to the technician by filling out maintenance request form in their device. When inspection has been completed, the technician team are responsible to fix the component. Then, the information related to both the failure component reported by a user and the status of the component reported by FM staff is stored in SQL database and accessible by clicking on "History" bottom in AR app (FM mode) to supports decision-making on FM activities. In other words, FM staff can make quick inquiries of FMM information and know each component's status in the AR app.

CONCLUSIONS

It is absolutely crucial for facility managers to access appropriate and reliable information along with friendly visualization to operate and maintain equipment and systems efficiently in buildings to extend the lifespan of equipment and support decision making. To access high-quality information and visualize the required information, it is essential to implement BIM and AR jointly. In this study, a framework was developed to integrate BIM and AR for FMM activities including end-users and FM modes. The proposed framework for end-users, it is anticipated that it can enhance users' satisfaction by simply reporting the problem. For FM, on the other hand, improves maintenance activities and minimize labor time and equipment downtime by providing the location of malfunction equipment along with appropriate and reliable information. Such incorporation will help FM team to optimize building maintenance strategies and decision-making. The proposed framework is likely to be valuable to facility managers who will be able to make a more precise analysis of building performance. Future research will develop a direct link and app for facility managers to find an optimum path according to the emergency level of each problem reported by end-users. The mobile application will also help to generate maintenance paths for FM staff to guide them into the places where problems locate.

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