Information Exchange Process for AR based Smart Facility Maintenance System Using BIM Model

S.W. Chung[a], S.W. Kwon[b], D.Y. Moon[a], K.H. Lee[a], and J.H. Shin[a]

[a]Department of Convergence Engineering for Future City, SungKyunKwan University, Republic of Korea
[b]School of Civil, Architectural Engineering and Landscape Architecture, Sungkyunkwan University, Republic of Korea (corresponding author)
E-mail: suwanx@nate.com, swkwon@skku.edu, yoshy17@nate.com, kiwijoa@skku.edu, kyup@skku.edu

Abstract –

In this study, we propose information exchange process for the effective integration of building information modeling (BIM) into an augmented reality (AR)-based smart facilities maintenance (SFM) system. The proposed SFM system refers to a system that combines technologies such as AR and IoT sensors in the field maintenance work. This requires the acquisition of data from various sources followed by transformation of these data into an appropriate format. Construction operation building information exchange (COBie) is widely used as a means to effectively integrate and utilize information for maintenance. Therefore, SFM system has a requirement attribute information system with reference to COBie. But this information should be linked to the maintenance work procedures in the actual use case scenario and it is necessary to define the information exchange process. To solve this problem, we uses the following methods to enable SFM system development with applications for BIM and AR technologies in the FM of the building sector of public facilities. First, it analyzes the previous studies on BIM-based maintenance works and AR technology. Second, it divides the SFM work process utilizing the BIM-based COBie system, and it defines the COBie data required for each work phase. Third, it develops a scenario-based business process modeling notation (BPMN) for the SFM system prototype. Finally, it proposes an implementation method of SFM system architecture.

Keywords –

Building information model; Facility maintenance; Augmented reality; Business process modeling notation

1 Introduction

1.1 Background and Objectives of the Research

One of main purposes of facility management (FM) is to realize the expected asset value by maintaining or complementing qualities of facilities planned in the design phase and secured in the construction phase. FM phase accounts for the longest proportion in the building life cycle, and the cost consumed in this phase occupies 85% of the life cycle cost (LCC) [1]. Facility information generated in the design and construction phases is utilized as basic implementation data of the facility management system (FMS) for effective and systematic operation and maintenance, but it takes a considerable amount of time and money to implement basic data in the FMS through defining and verifying the required information in the operation and maintenance phases. To resolve difficulties in current FMS implementation process, building information modeling (BIM) technology has been introduced, which can act as an alternative system to systematically and efficiently operate and maintain the facilities. BIM is structured with objects, attributes, and relationships. Since all attributes and relationships are defined based on objects, BIM can manage the required information for operation and maintenance by function, space, and use purpose.

Building owners and facility maintenance mangers have an opportunity to reduce a large amount of cost during a much longer maintenance period than that of design or construction phase by utilizing BIM-based information. However, although utilization of BIM information in the facility maintenance phase has many advantages, BIM information has not yet been utilized in on-site maintenance work. This is because a variety of information required for facility maintenance has not been defined, and, in many cases, this information is not included in BIM-based design.

To solve this problem, a large number of studies have been conducted to develop a system to transfer BIM information generated over the design and construction phases into the facility maintenance phase. As a result, data exchange format called construction operation building information exchange (COBie) was developed by public institutions, which took project ordering tasks of major facilities in the USA.

Meanwhile, AR technology has been utilized in various areas, such as product review and production system design. More recently, with the advancement of smart devices, users can now employ AR more easily than ever before. The construction industry is also actively introducing on-site facility data visualization and real-time collaboration features by utilizing AR technology. However, few studies have been conducted on the utilization of AR technology in the maintenance phase as compared to the design and construction phases, even though economic benefits would be the largest in terms of LCC.

Thus, as one of the few studies on SFM for automation management and efficient execution of facility maintenance, this study aims to discuss the current trend of BIM and AR technology; it measures of how to link information and proposes an AR-based SFM system. In addition, this study sets the COBie system as a benchmarking target—which has been developed as a system prototype in the USA and is now widely recognized in the world—to define the required information exchange process for implementation.

1.2 Study Method and Procedure

This study uses the following methods to enable SFM system development with applications for BIM and AR technologies in the FM of the building sector of public facilities. First, it analyzes previous studies on BIM-based maintenance works and AR technology. Second, it divides maintenance work process utilizing a BIM-based COBie system, and it defines COBie data required for each work phase. Third, it develops a scenario-based business process modeling notation (BPMN) for the SFM system prototype. Finally, it proposes an implementation method of SFM system architecture.

2 Analysis of Previous Studies

2.1 Building Maintenance Using BIM

When BIM is applied in the maintenance phase, it can be utilized in analysis data for the purchase procurement of machine equipment, control systems, and other products; it can also check whether all systems are correctly operating after buildings are complete, which is the advantage of BIM to the maintenance phase. It can also act as an interface for sensors; it can remotely operate the management of facilities and provide real-time monitoring of control systems through providing accurate information about space and systems [2]. BIM for FM provides a manual for building users, which can help to locate models visually, such as facilities, attachments, and furniture. BIM also supports contingency plans, security management, and scenario planning [3]. As described above, several studies have been conducted actively to show the advantages of a BIM application to FM.

A study by Yu developed a data model, Facility Management Classes (FMC), which can extract required information from Industry Foundation Classes (IFC) for information compatibility of BIM data into FM [4]. A study by Mendez R. proposed functions that can be utilized by BIM in the maintenance phase; the study developed a web-based prototype to improve the utilization of BIM information [5]. East and Brodt developed a data exchange format called COBie based on a spreadsheet to solve inefficiencies due to unnecessary information in maintenance among information sets created during the design and construction phases [6]. A study by Burcin defined a level of BIM recognition in the maintenance phase through expert interviews, applicable areas, required data, and processes to implement BIM successfully [7]. Lee et al. attempted to improve a facility maintenance system through benchmarking the COBie system, and Choi et al. conducted a study to implement a FM system for sewage treatment based on the COBie [8][9].

One study proposed software architecture to integrate BIM with geographic information system (GIS)-based FMS effectively [10]. Another study proposed integrating BIM-based Mechanical, Electrical, and Plumbing (MEP) information in the operation and maintenance phases [11].

Most of the previous studies on FM utilizing BIM focus on the interoperability with FM system and a measure to link data produced during design and construction phases as well as a direction to application of BIM to FM systems and commercialization has been chosen.

2.2 Utilization of AR Technologies in Building Industry

The trend of utilizing AR technology in building industry has showed that earlier studies focused on the analysis of applicability of virtualization technology Hammad presented the applicability of AR technology to field works of infrastructure, and Koo considered the development of a wireless technology-based, AR-applied system in terms of display, tracking, and servers. Afterward, a study on the presentation of an AR system prototype for the inspection of steel column construction was conducted [12] [13].

For studies on AR authoring tools, AR modeling through capturing and rendering of exterior structures in real time and 3D modeling can be found. A tool called "Tinmith" was manufactured to interact between users and AR directly [14]. 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 [15].

More recently, studies on the application of AR to building maintenance have been conducted in various ways. A study by Bae et al. proposed a novel method that supported on-site construction and facility management works by documenting on-site problems and progress visually by on-site staff and by making recent project information accessible as a form of AR overlay [16]. Another study proposed a natural marker-based AR framework that can support facility managers digitally when they search FM items or perform maintenance and repair works [17]. Kwon et al. proposed a SFM system that improved existing maintenance work; thy studied a novel maintenance work process and an implementation method to apply AR technology [18].

The analysis results of previous studies have showed that the utilization of AR 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 about the 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 SFM and COBie System

3.1 Overview of SFM

A SFM system proposed in this study aims to support tasks of workers and managers by introducing Internet of things (IoT)/VR/AR technologies to existing on-site maintenance works. The base data to combine the new technologies are BIM data. To do this, a study on improved process of sequential and repetitive task elements was conducted by applying AR/VR technologies to existing maintenance tasks [18].

Data such as drawings, historical information, and related documents stored in a distributed manner in the facility maintenance tasks are linked and integrated with BIM data to overcome the limitations of simple repetitive tasks and inefficient data utilization.

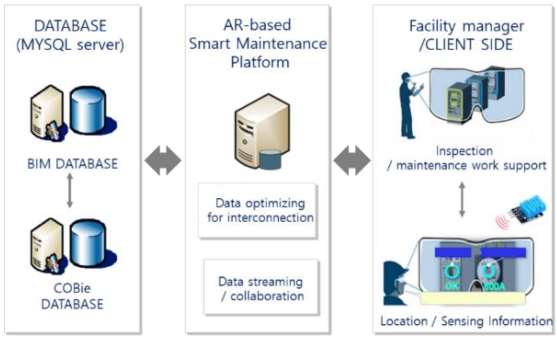

Figure 1. Configuration of proposed system

As shown in Figure 1, variably distributed data can be gathered, and each request can be processed as a hub through the AR-based smart maintenance platform, which manages the facility management database in the center. This study's scope is limited to building interior constructions (floor, wall, ceiling, window, door etc.) among the maintenance target facilities.

3.2 SFM Work Process

A BIM attribute information and the historical management information required by task units in the maintenance work may be different from each other. To define the information clearly and store them in a database for the utilization of AR visualization, task units were classified based on maintenance work scenarios.

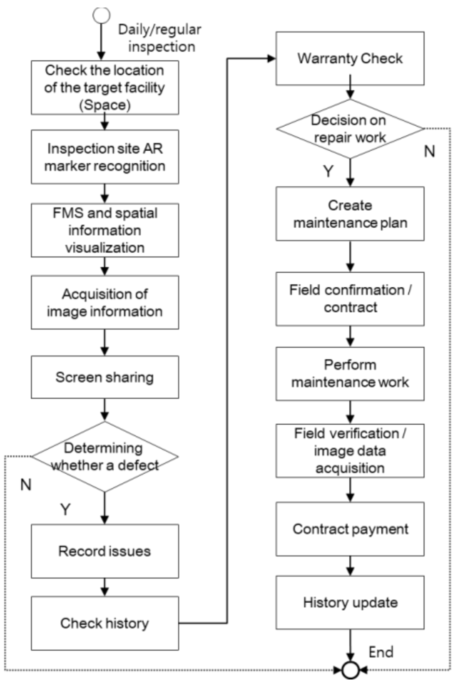

Figure 2. Scenario-based workflow

As shown in Figure 2, an on-site inspector checks the inspection-required facility location and recognizes the AR marker attached to the inspection target space in the daily inspection task scenario. Inspection-required members and checklists in the corresponding space are visualized through the markers by which the inspector can perform visual inspection and photo shooting. In this process, video information through the inspector's camera is shared in real time so that various decision-making participants can judge together whether there are defects or not. If decision making determines that there is a defect through the inspection, historical information, such as installation, warranty, and management companies, is visualized, and the status information can be sent to the corresponding companies directly from the site. After this, a maintenance manager decides whether repair work is needed. If repair work is done, task-related guidance and progress are monitored in the construction process, and stored in the FMS.

The core technologies of AR visualization in this process are the following: 1) AR-based surveillance task support technology, 2) 3D information plus AR overlaying technology, and 3) 3D data conversion technology for AR/VR.

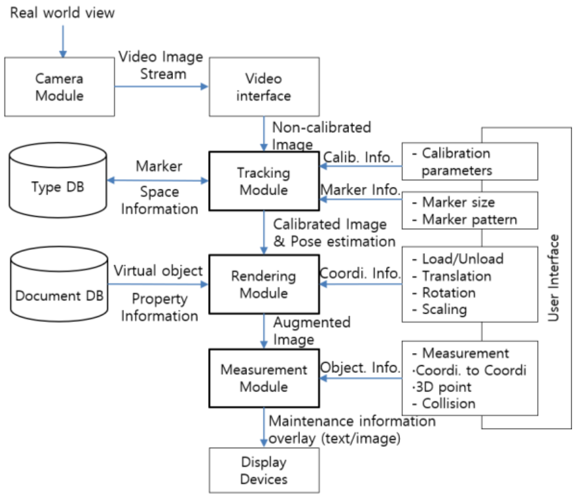

Figure 3. AR visualization process in inspection work

3.3 Definition of the COBie System

To implement the AR-based smart maintenance process proposed in this study, COBie is benchmarked and utilized. COBie is an information exchange data format based on a spread sheet jointly developed by public institutions that take project orders of major facilities in the USA led by the US army corps of engineers. It was developed as a means to replace a large amount of documents related to facility management at the time of completing the construction of a project. COBie includes definitions and formats of information required during the maintenance phase among a BIM information created in a series of phases during construction projects: planning, design, construction, operation, and maintenance.

Table 1. COBie data sheets and contents by phase

Phase	Sheet	Contents
All	Contact	People and Companies
	Document	All applicable document references
	Attribute	Properties of referenced item
	Coordinate	Spatial locations in box, line, or point format
	Issue	Other issues remaining at handover.
Early Design	Facility	Information on Facilities and Standards
	Floor	Vertical levels and exterior areas
	Space	Spaces
	Zone	Sets of spaces sharing a specific attribute
	Type	Types of equipment, products, and materials
Detailed Design	Component	Individually named or schedule items
	System	Sets of components providing a service
	Assembly	Constituents for Types, Components and others
	Connection	Logical connections between components
	Impact	Economic, Environmental and Social Impacts at various stages in the life cycle
O&M	Spare	Onsite and replacement parts
	Resource	Required materials, tools, and training
	Job	PM, Safety, and other job plans

As presented in Table 1, COBie consists of 18 data sheets, and the related detailed contents can be expanded through expandable templates. In the data sheets that can be utilized in the whole phases of construction projects, contract-related items of construction participants, drawings, coordination systems, and building completion-related issues are included. In the initial design phase, facility information and floors, spaces, and material types are included, and in the detailed design phase, the connection of all members and assembly, system configurations, processes, and costs are added. In operation and maintenance (O&M) phase, replacement and repair items and required resources and tasks are included. In addition, COBie is configured to expand the required attribute information constantly.

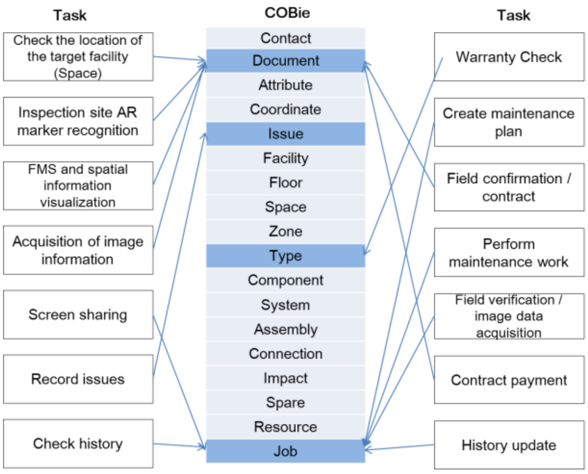

Figure 4. Smart maintenance tasks and COBie data mapping

All of these data sheets are not needed in the COBie system definition, which were required for the previously proposed maintenance work by the scenarios, but it is important to utilize only minimum information considering the link between attribute information and data lightweight, which are essential for AR visualization. Thus, the information required for the previously proposed maintenance work by the scenarios and COBie data sheets was mapped. This process was conducted through prior literature reviews and through interviews and surveys with on-site maintenance workers, as shown in Figure 4.

Through this process, document, issue, type, and job data sheets were found to include attribute information required for the on-site maintenance work. However, excessive attribute information was required in the document and job sheet among these four data sheets, and unnecessary information was also included depending on maintenance work participants. Thus, warranty and plan data sheets were additionally created and used for optimization of AR-based visualization information.

Table 2. COBie data sheet for field maintenance

Sheet	Contents
Document	Submittals and approvals, DWG.
Issue	Other issues remaining at maintenance
Type	Types of equipment, products, materials, model, Warranty data
Job	PM, Safety, and other job plans

Contents included in the newly added warranty data were the product names of the interior finish materials, repair (warranty) responsible companies, contact details, and warranty-related document information. Through this information, which companies are responsible can be identified when defects occur, and requests for repair can be achieved rapidly. A plan data contains information that is utilized when maintenance construction occurs, which includes construction progress status, follow-up tasks, and next maintenance inspection date.

4 Information Exchange Process to Implement the Prototype

4.1 Smart Maintenance BPMN

To implement a prototype of an AR-based, on-site support module for the SFM on the basis of maintenance scenarios proposed in this study, a BPMN, including the current status of data input and output, is required. BPMN is a visualized notation method to represent business processes. It is developed to notate a message flow between activities over a time flow in the process. BPMN that defines and represents the data inputs and outputs required in the maintenance work process, based on daily inspection scenarios, is shown in Figure 5.

Most of the 3D models and attribute information of the inspection-required objects are extracted from a BIM information and stored in a database as COBie Excel sheets. Here, the additionally required attribute information is AR market information, inspection date, and warranty period, which requires a manual input process by the maintenance manager or supplier.

The most important thing in the utilization of BIM in maintenance work is to clarify the definitions of requirements and use cases. Thus, the proposed BPMN facilitates detailed implementation of smart maintenance use case.

between users and managers who use the AR system.

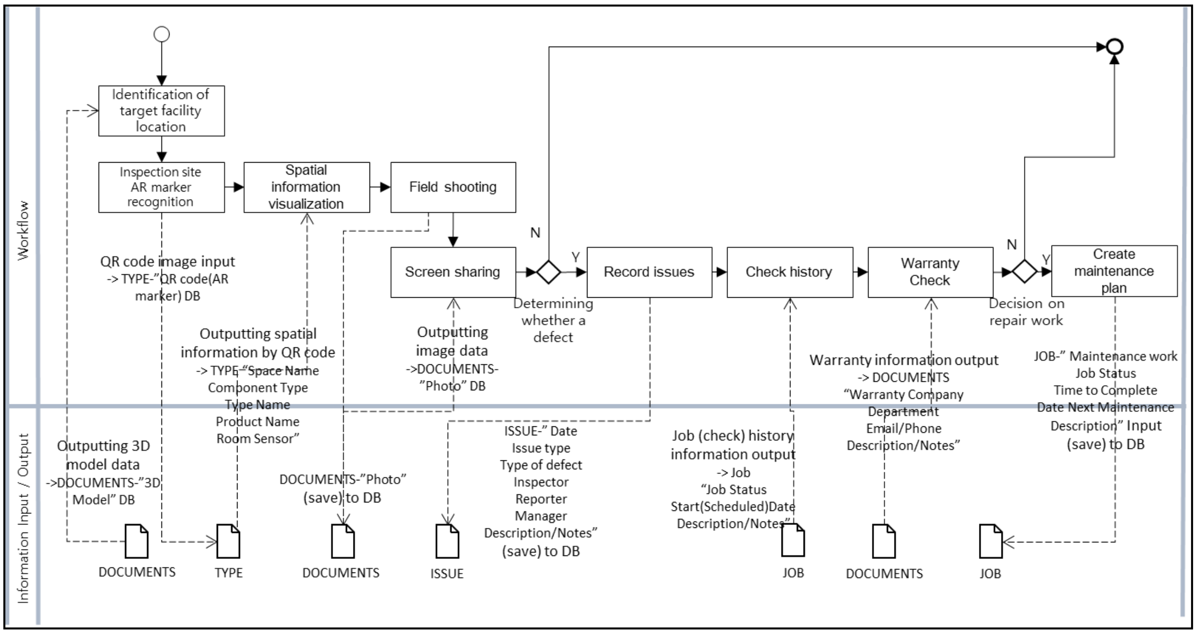

Figure 5. Daily / regular maintenance scenario based BPMN

4.2 Functional Screen Configuration and UI

Basically, an AR system consists of a camera, an image converter, tracking, and a video background render. A camera component helps efficient delivery to the camera frame. A camera frame is provided automatically according to the device, depending on image format and size. Once markers are recognized through the HMD camera, users define the targets that will be observed through the AR via the pixel format conversion. Targets defined in the database configured with COBie system monitors objects through the tracking module. After detected object's status is identified, the 3D virtual objects are modeled, and information is provided on the display. Auxiliary information about augmented 3D virtual object in display is managed by the web-based FMS and augmented through XML. In web service application, auxiliary information about augmented objects was composed of a management system and two-way communication systems. The auxiliary information management system was configured to provide various pieces of information rapidly to users and overcome the existing problem, which only showed 3D object augmentation. Two-way communication system was configured to provide information in real time—which was not provided by the auxiliary information management system—through two-way communication

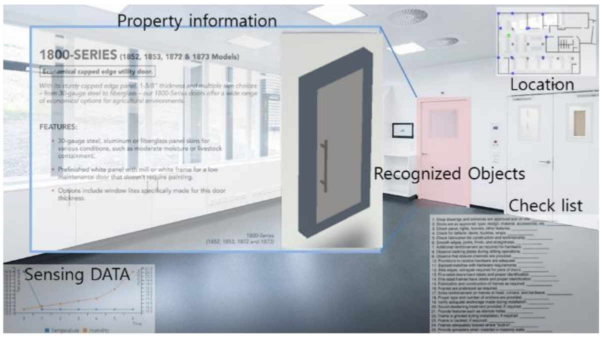

Figure 6. Example of AR-based SFM system UI

UI in the AR application, which emphasizes interaction functions through real world, requires different designs from those of existing mobile applications. Most mobile devices utilized in site are smart phones and tablets, which support a touch-based interface. However, since on-site maintenance support application proposed in this study targeted HMD devices, existing touch-based operations cannot be used. Thus, controls through gesture or voice recognition are needed, which require more user-friendly and intuitive UI. Consequently, menu button items were removed, and required attribute information was laid out on the lower side of the screen. Since augmented reality interacts with the real world, visualized information supports a transparency control function to project the real world.

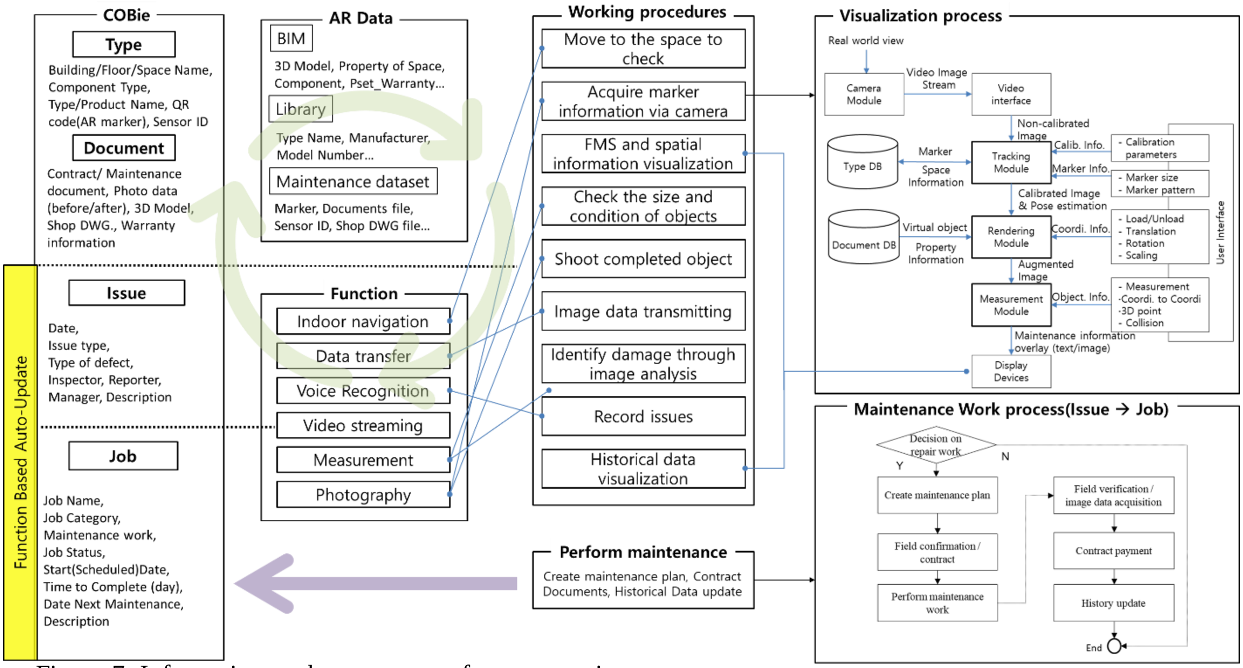

Figure 7. Information exchange system for smart maintenance

This feature excludes obstacles in the view when workers move or perform works, and it helps to verify the worker's location by positioning a navigation map inside the building on the right upper side of the screen. Figure 6 shows the example of the screen configuration of the prototype implementation, in which site inspector visualizes specification information about door. Information about supplier expert who supplied door, information about temperature and humidity of room, and information about interior finish inspection can be found in the lower side of the screen. An inspector observes target facility, such as door, window, wall, and column, and can record inspection results about inspection items through checklist.

4.3 Definition of SFM System Information Exchange System

Entire information exchange process of the SFM System described above is shown in Figure 7. Preliminary data use BIM data at handover. BIM information at this stage includes more detailed information of the space and the interior finishing material, and the space information and the property information of the space are used in conjunction with COBie. Among the information required for AR visualization, 3D model shape information does not work directly from BIM, so it is processed through information processing and optimization, and additional information necessary for maintenance is also included at this time. Basic information required before performing all these operations is stored in the Type and Document sheets of the COBie data.

After that, procedure of performing the work by the site inspector is moved to the site, the marker recognition, the space and absence information are visually confirmed, and the result of inspection is automatically transmitted. In order to recognize the AR marker information and visualize necessary information, modules needed are tracking / rendering / measurement module and implemented through separate API. In addition to the AR visualization function, there is an additional need for indoor navigation, data transmission, voice recognition, video streaming, automatic measurement and photo shooting functions, which are linked to each stage of operation.

When inspection is completed, the result information is stored in COBie's issue sheet, and it is used when maintenance work is in progress. As the maintenance work progresses, newly generated contract information is automatically saved in the Job Datasheet again, and COBie repeats this process and updates it.

5 Conclusions

This study proposed that data exchange procces through data item configuration and functional definition to apply AR technology to on-site maintenance works in a BIM-based SFM system.

As a result, this study determined that when maintenance and management information are configured based on the COBie system, interoperability in various software environment can be ensured. In addition, if AR visualization technology of maintenance information through overlay with real site circumstances is utilized, it can enable rapid information sharing about on-site working conditions and decision making. Furthermore, the utilization of BIM datasets generated in design and construction phases is meaningful in terms of utilization BIM data throughout the whole life cycle.

However, since the study scope was limited to filed inspection works, the study results cannot be applied to all maintenance works in general. This study also needs some feedback through user satisfaction surveys regarding the proposed system development and UI configuration. For a future study, a technology that can visualize the information of complex facilities which cannot be identified visually should be developed through AR technology by expanding the maintenance target to mechanical, electrical, and plumbing in addition to the interior finish.

Acknowledgment

This research was supported by a grant (19AUDP-B127891-03) from the Architecture & Urban Development Research Program funded by the Ministry of Land, Infrastructure and Transport of the Korean government.

References

[1] Teicholz, E. Overview and current state of FM technology. FACILITY MANAGEMENT—AN, 2004.

[2] Sacks, R., Eastman, C., Lee, G., & Teicholz, P. BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. John Wiley & Sons, 2018.

[3] Jieun, K., Hyunsang, C., Taewook, K. Derivation of System Requirements and Implementation of System Framework for BIM-based Urban Facility Maintenance System. Journal of the Korean Content Association, 14(4):397-406, 2014.

[4] Yu, K., Froese, T., & Grobler, F. A development framework for data models for computer-integrated facilities management. Automation in construction, 9(2):145-167, 2000.

[5] Mendez, R. O. The building information model in facilities management. PhD Thesis. Worcester Polytechnic Institute, 2006.

[6] East, W. E., & Brodt, W. BIM for construction handover. Journal of Building Information Modeling, 28-35, 2007.

[7] Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. Application areas and data requirements for BIM-enabled facilities management. Journal of construction engineering and management, 138(3):431-442, 2011.

[8] Lee, S. G., & Yu, J. H. Prerequisites to utilize BIM (Building Information Modeling) for Facility Management. Journal of the Korea Facility Management Association, 8(1):27-39, 2013.

[9] Choi, J. H., & Um, D. Y. A study on the feasibility of COBie to the wastewater treatment plant. Journal of the Korean Society of Civil Engineers, 34(1):273-283, 2014.

[10] Kang, T. W., & Hong, C. H. A study on software architecture for effective BIM/GIS-based facility management data integration. Automation in Construction, 54:25-38, 2015.

[11] Hu, Z. Z., Tian, P. L., Li, S. W., & Zhang, J. P. BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase. Advances in Engineering Software, 115:1-16, 2018.

[12] Hammad, A., Garrett, Jr, J. H., & Karimi, H. A. Potential of mobile augmented reality for infrastructure field tasks. In Applications of Advanced Technologies in Transportation pp. 425-432, 2002.

[13] Koo, B., Choi, H., & Shon, T. Wiva: Wsn monitoring framework based on 3D visualization and augmented reality in mobile devices. In International Conference on Smart Homes and Health Telematics pp. 158-165, Springer, Berlin, Heidelberg, 2009.

[14] Piekarski, W., & Thomas, B. H. Tinmith-mobile outdoor augmented reality modelling demonstration. In Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality pp. 317, IEEE Computer Society, 2003.

[15] Moon, S. Y., Yun, S. Y., Kim, H. S., & Kang, L. S. Improved Method for Increasing Maintenance Efficiency of Construction Structure Using Augmented Reality by Marker-Less Method. Journal of The Korean Society of Civil Engineers, 35(4):961-968, 2015.

[16] Bae, H., Golparvar-Fard, M., & White, J. Rapid image-based localization using clustered 3d point cloud models with geo-location data for aec/fm mobile augmented reality applications. In Computing in Civil and Building Engineering, pp. 841-849, 2014.

[17] Koch, C., Neges, M., König, M., & Abramovici, M. Natural markers for augmented reality-based indoor navigation and facility maintenance. Automation in Construction, 48:18-30, 2014.

[18] Chung, S. W., Kwon, S. W., Moon, D.Y., & Ko, T. K. Smart Facility Management Systems Utilizing Open BIM and Augmented/Virtual Reality. In 35th International Symposium on Automation and Robotics in Construction, 2018