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Space Management on Campus of a Mobile BIM-based Augmented Reality System

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Abstract Over the past decade, building information modeling (BIM) has gained a foothold in the construction sector. However, as digital data generated in the virtual space of a computer environment, BIM-based data have an inherent limitation in their application efficacy under field conditions. To overcome this, the present study employs augmented reality (AR) to reduce the discrepancy between the digital data generated in virtual spaces and real-world conditions. We assessed the potential applicability of an AR-based interface by analyzing existing examples of Apple, Google, and Facebook, which reflect the recent developments of technologies focusing on user experience. We then proceeded with an AR study, restricting the scope of application to a mobile environment in which an efficient information transmission between a digital model and real life can take place. Object-oriented software engineering was employed to ensure an efficient implementation of a BIM-based AR system for campus space management (CSM) in a mobile environment. Finally, we conducted a module test to check the reliability of the CSM method by using an AR-based mobile system with a prototype of the model used in university campuses, and extracted and itemized the supplementary requirements for CSM by using BIM tools for running AR applications.

Keywords: Building Information Modelling (BIM); Space Management; Campus; Mobile; Reality System

1. INTRODUCTION

The increasing informatization in campus environments has given rise to growing difficulties related to campus space management (CSM) using documents in digital format managed in a particular space. Large universities have introduced a Computer-Aided Facility Management (CAFM) system to efficiently manage physical facilities in campus spaces necessary for campus activities. The CAFM system collects data related to facility maintenance and management, and uses such data for the efficient maintenance and management of campus facilities in line with the increasing trends toward intellectualization and informatization in the facility maintenance and management sector. However, the CAFM system, as currently utilized at universities for the maintenance and management of campus spaces and facilities, has a disadvantage of being cost-intensive and time-consuming because it involves document reporting, and this dual operation system is cumbersome in field applications. In particular, facility management for different campus areas takes place in a recurring six-month cycle with the beginning and end of the semester, and as public facilities, they are at high risk of damage or theft from improper treatment such as frequent displacements and careless use. Whereas log data on the entrance and exit activities stored in the terminals of security service agencies can be useful for the security management of campus spaces, such data are considered volatile and thus have low utility. To solve such problems, thereby reflecting the paradigm shift of individual work environments toward smart mobile environments, information-portability enabled application methods customized for individual situations are emerging. Before the smart mobile environment gained a firm foothold, desktop PC and notebook computers were used as suitable devices with adequate screen sizes. They were installed in offices and could not be used in field settings, which made it difficult to acquire information in onsite situations. Devices using a mobile platform can overcome such disadvantages. Although the low resolution and small screen size of the early mobile platform were supported by an adequate interface, the remarkable advances

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made in the mobile platform have achieved a resolution and functionality superior to a traditional PC environment. Nowadays, documents in the construction sector are digitally stored and managed using software. In particular, the recent trend in building maintenance and management is document output, such as spatial data, scheduling, and user pattern analysis, through the linkage of 3D models and instant information by using building information modeling (BIM) tools. However, all data are presented as a 2D output for onsite inspections. The real-world spatial perceptions of BIM engineers still rely on 2D drawings, such as site plans, elevations, or sectional views, and on 3D projections on a 2D display despite attempts to present the desired information on a digital display from a mobile-based BIM browser instead of printing. One such attempt concerns augmented reality (AR), which integrates digital data on a space with real-world objects through a process of mapping virtual 3D data and 2D documents into a real-world environment. An AR-based system generally consists of three stages: data preparation, computation, and merging. At the data generation stage, shape and non-shape data are prepared for AR, and virtual and real-world environments are detected, computed, and merged. This three-stage process is operable in an Internet mobile device environment with the aid of a central space management server. The hardware performance of early mobile devices was not sufficiently refined for the use of prototype devices implementing AR. Owing to the recent advances made in the hardware performance of mobile devices, however, various prototypes can be conceived for a powerful AR implementation. Two common methods of access to the AR system are mobile devices, such as smartphones and tablets, and special head-mounted displays, such as Google Glass. Although there are several AR systems using specialized hardware and software, AR applications reflecting specialized work processes have yet to be developed. The foci of this study are the optimization of data for BIM-AR linkage and the establishment of a user-centered interface. In this study, the following objectives were set to enhance the usefulness and applicability of BIM data in CSM: (1) understanding the usefulness and feasibility of BIM data for obtaining relative space management information from the user's position, and (2) understanding the high-efficacy information to enhance BIM data application in CSM.

2. RELATED PROCEDURES AND BACKGROUND

This chapter describes the approaches pertaining to the implementation of BIM-based space management and AR-based application of digital data in real-world environments, as well as the conversion of these two technologies.

2.1. Building information modeling based on Campus Space Management

BIM is a life-cycle assessment-based approach to design, characterized by digital representations of 3D models used to derive the required data through the precise digital modeling of architectural structures expressed through plans, overview tables, reports, and other related documents utilizing shape data. The definitions related to the BIM process involve complex linkages of architectural information modeling, construction, and engineering, in which various commercial software suppliers have contrasting interests regarding the file sharing of available models. Remote data offer interfaces for resolving the problems at hand. Whereas CAFM is used for a computer-aided space management of the overall facilities in a campus area, architectural plans including spatial data and equipment information are managed through other departments with different databases. As such, there is no integrated model in the existing systems. The main problems encountered by campus space managers are uncorrected plans, a failure to consider the corrected spatial information, and a difficult identification of the facilities and devices and their locations because they are described only in texts and codes. As limitations of a CSM system, three problems can be pointed out: (1) a difficulty in the correction and updating of the plans, (2) a low system utilization rate owing to a lack of integrated system and dispersed information management, and (3) the use of 2D graphical data and text-based descriptions, making it difficult for facility managers to understand and manage the spatial information intuitively. BIM seems to be a practical method for solving these problems because it helps managers to efficiently manage and easily correct any existing problems with the spatial information; in addition, it helps general users generate space management data and thereby offer systematic information rapidly.

2.2. Augmented reality

In an AR system, digital 3D shapes and information are directly merged into a real physical world environment. AR can be defined through a summary from Alex Kipman and Seth Juarez of Microsoft's Hololens Team: AR means an environment in which data are generated in a coordinate system using the detection information from computer vision depending on the viewing environment of the user within a real physical space. Fig. 1 juxtaposes virtual reality and augmented reality to demonstrate their differences more clearly. AR is a process of selecting desired data from data lists held in a central information repository and linking them to the real environments of individual users for different purposes. In other words, AR retrieves desired information from the virtual digital world and links it to visual geometric information and attribute data, bringing and arranging them into real-world images. The technical process of AR, for the case of video clips, involves capturing images at a speed of 24 frames per second, and analyzing them. The smartphone penetration in South Korea is as high as 80% of the entire population, and the embedded high-performance camera in such devices is best suited for the implementation of AR technology.

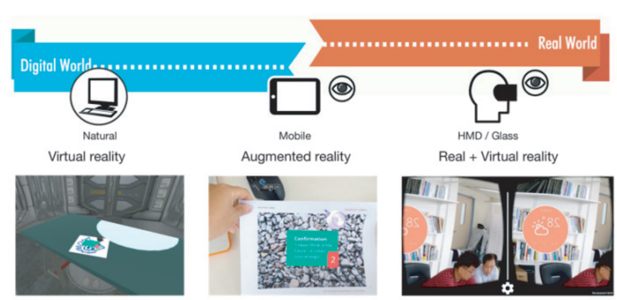


Figure 1. Virtual reality and Augmented reality

AR allows interactions between the real and virtual worlds by means of digital components merged into a real physical environment, where the user creates additional visual content or loads digital mockups supporting their work on a heads-up display.

2.3. Campus Space Management by using Augmented Reality

AR- and BIM-based space management types are interrelated under two aspects. The operational definition of Campus Space Management with AR (CSM-AR) by using BIM-based space management information is as follows. BIM-based CSM-AR is the process of extracting the space management data contained in BIM, editing the data in an AR environment, and locating the relevant BIM information. In a 3D space, a real-world spatial coordinate system is more efficacious than a 2D desktop computer screen. This approach enables CSM-AR user access to data under a direct coordination. We implemented the CSM-AR system under three scenarios: (1) reviewing the solution proposed in relation to campus space usage, (2) monitoring the general user-centered space usage, and (3) monitoring the professional user-centered space usage. At the levels of individual tasks and comprehensive CSM-AR process, the AR process was used for an optimized layout, inspection, management, and information services. For campus spaces containing a large number of rooms, the room occupancy schedule changing based on the semester is reflected in setting up the room utilization strategies and coordinated alternative usage plans. Additionally, the inspection of rooms and facilities prior to usage and their maintenance and management were taken into consideration as related items. The CSM-AR system consists of three integral parts: (1) the user location tracking from the start point, (2) the BIM server location and calibration process, and (3) the display of data synchronizing the real-world environment and calibration location. The mobile-based AR components can be categorized into data, image tracking computations, and mobile platform image implementation. The related processes can be linked to AR-enabled heterogeneous devices and technologies. Previous studies on AR have focused on extracting data resulting from the combination of AR components. This study aims at implementing AR components in general and professional work processes by focusing on data generation customized to the current work conditions related to space management and applying the stored data to the CSM-AR implementation stage, thereby implementing a mobile display interface synchronized for end users.

3. ARCHITECTURAL FRAMEWORK FOR THE CAMPUS SPACE MANAGEMENT AUGMENTED REALITY SYSTEM

Use This section describes the process of AR-based BIM and space management data management. The information flow is displayed in an activity diagram taking into account the major decision points. Structural marks are assigned to the system information, and objects clustered into groups according to their functions, as shown in Fig. 2, are associated with four types of activities: (1) the Objects cannot be expressed in an AR environment without final geometric models (IFC) and space management data (JSON). This is implemented in the model generation of object A2 for screen output on the display for an optimized image quality. For a smooth transfer of shape data in a mobile environment in pre-processed IFC models, a 3D Collada format should be employed, and the models used should be linked to the space management information. A Collada-supported AR system is inoperable unless the models used are linked to the space management information task. The geometric values of the 3D shape components have their own ID numbers, which is necessary for establishing relationships between real-world positional information and modeling information by means of AR implementation. The last stage, A3, aims at displaying the actual augmented reality displayed on the mobile device. There is no need for specific parametric values for the implementation of AR. generation of BIM models, (2) the generation of campus space data, (3) the generation of data for AR, and (4) application to tagging-based AR implementation for individual spaces.

The first stage of CSM is the generation of BIM models for the spaces concerned. BIM models can be generated from shape and spatial data used for maintenance and management. In the example considered in this study, the generation of shape data (A0) and non-shape spatial data (A1) was achieved using software processing and CAFM data, respectively. The initial and second expressions of object segmentation were chosen as those accentuating reciprocal information flows, analogous to the decision-making process for controlling two processes representing the 3D BIM model generation process and the "Creation of Space Management."

Objects A0 and A1 are output as 3D model (IFC files) and space management information (JSON files), respectively. It is essential that they be stored in a manner allowing easy access. Their respective servers are defined as BIM and JSON servers. Technical descriptions related to their use and implementation are provided in Section 3.1 (Fig. 2). The system creates a mobile environment, in which the level of spatial information can be adjusted in consideration of the actual onsite spatial locations depending on the user's utilization and task levels through a feedback process.

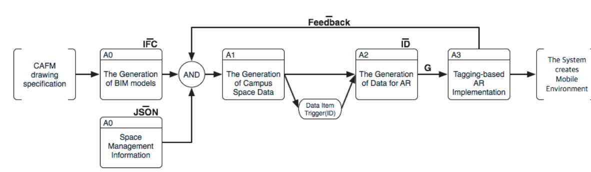


Figure 2. Diagram of OOSE-based Process

4. PROTOTYPE SPACE MANAGEMENT TESTING

The results presented in this section were obtained by testing the BIM-based CSM-AR system. The tests were conducted to prove the hypothesis established in Section 2.3 that the application of AR to a CSM system is a technology suitable for retrieving adequate information from BIM and spatial data for space management. The tests were conducted on BIM models existing in actual campus spaces. The stepwise tests of individual components were conducted to identify the most vulnerable objects of the system and determine the boundary conditions of the system functions. The tests were applied in the order of the automatic system operation process for individual system objects. A complex building model was created for the application of various BIM tools enabling the extraction of IFC objects consisting of basic building components for a spatial division. Basic campus space ID data such as security, rental, and energy consumption data, are additionally transferred from the CAFM system to be linked to the BIM-based CSM-AR system. A naming system should be established from the outset to assign all components with their own ID numbers for a systematic identification of the components, although they are not often used in the initial design stage.

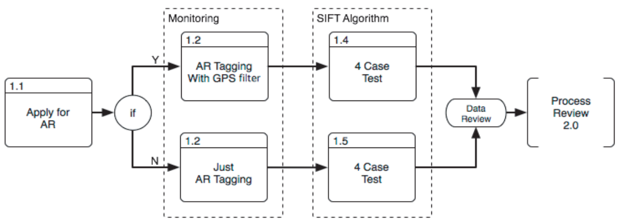


Figure 3. Test Process of AR Technology and BIM Data

To prove the hypothesis that it can easily monitor a CSM-AR system, the developed prototype was tested in a campus space on its usability for CSM-AR. Specifically, the prototype was tested to determine whether it can be efficiently used for BIM-based CSM-AR. The test results were derived by identifying the data matching and object recognition rates according to the flow chart shown in Fig. 3. Specifically, the prototype was tested to determine whether it can be efficiently used for BIM-based CSM-AR. The test results were derived by identifying the data matching and object recognition rates. The main concern of the prototype was to find out whether AR technology can be efficiently applied to CSM by using BIM data on the basis of security log and space rental information. The CSM was monitored on the AR-based interface in the assigned tag information part according to the user's utilization level. Instead of conventional type tags for AR, (Fig 4-a), we used the terminals of a security agency installed in individual rooms, as shown in Fig 4-b.

a) Conventional type tags for AR **b)** Terminals of a security agency

Figure 4. The naming process for Space Management

First, the object recognition rate was tested by placing the objects around the tags of the security agency at intervals of 45 degrees in a fan-shaped range (Fig. 5 (1)–(4)). Testing was conducted after establishing two comparison groups, thereby varying the conditions for the recognition locations and GPS filter (presence or absence). Table 1 presents the results of a recognition rate test by using the data matching through a SIFT key point detection. When comparing the two test methods, the merits and demerits of the traditional and current interfaces were highlighted as follows. The elements associated with the current spatial information and space management are highlighted in orange, and past history spatial information is shown in transparent blue. Fig. 5 shows the results exhibited on the display.

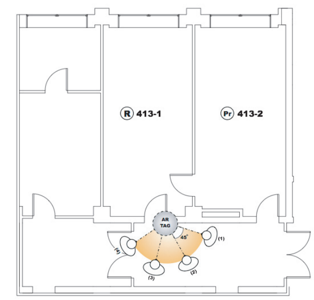
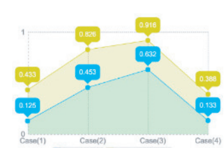
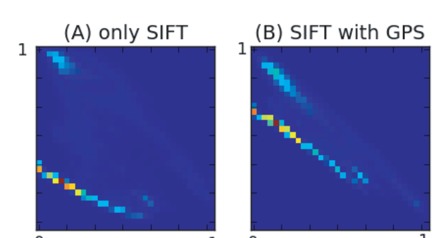


Figure 5. Plan and Location of Test Space

Therein, the original and current locations of displaced facilities are shown in their respective colors along with the information of the person in charge during work such as security issues or the process of obtaining the non-shape data on the project schedules and entrance and exit logs. As demonstrated by the highlighted parts of the two comparison groups in Table 1, the total score of the SIFT key point detection identified through the object recognition rate under different situations was twice that in the GPS Group (B) than in the non-GPS Group (A) (0.641 vs. 0.258), proving that the use of GPS leads to more accurate information and data expression.

Table 1. The Total Score of The SIFT Key Point Detection

10 opportunity per case	(A) only SIFT (max = 1)	(B) SIFT with GPS (max = 1)	
case(1)	0.125	0.433	
case(2)	0.453	0.826	
case(3)	0.632	0.916	
case(4)	0.133	0.388	
total	0.258	0.641	
histogram			

However, both groups showed problems and drawbacks in AR screenshot and rendering accuracy. Technological improvement the AR system was mostly attempted through the GPS-based filtering process for an accurate detection of the user location. To use the GPS function based on the gyroscope and compass embedded in a mobile device, AR systems require data on the current location and alignment of the information. The field test relies on the precision of the GPS embedded in the mobile device. The detection accuracy of GPS greatly depends on external factors. In the future, this method for accurately matching 3D models and real-life objects by using a marker as a reference point will be the standard method applied to commercial AR software or computer vision. Another technological difficulty or issue is the accurate alignment of the user perspectives. Not only is AR-based 3D rendering recommended through the test results, so is the efficient generation of CAFM space management information on the interface. The camera is configured for rendering, and the facilities placed in the pre-determined locations are aligned as if they were BIM components (Figs. 6 and 7). Figs. 6 and 7 are clearly different in their visual method of 3D visual-image centering or non-shape-information centering. The problems associated with Fig. 6 are a continuous image update in the AR approach and adequate screen resolution for the graphics on mobile devices. When comparing the practical conditions of the actual space and registered in a BIM model, two practical problems arise. First, physical objects are placed in the space between the user and the target space, and can be removed in the rendering process. The AR approach expressed in Fig. 7 is a dynamic space management process sensitive to different circumstances, which makes the user-centered decision vulnerable to errors. When implemented in Fig. 7, the column and other floor information located in the model terrain is not seen. According to such logic, supplementary processes added to pre-determined spatial information will increase as the field of view of the user decreases. In such a case, practical problems can be partially identified and solved by selecting an optimal viewpoint. Problems encountered during the testing can be summarized into GIS and AR information. As for the AR environment, because existing terminals of the security agency are used, there are no new issues or additional installation-related problems. The highlighted problems and applicable responses were discussed in Section 2.2.

Figure 6. 3D visual-image centering

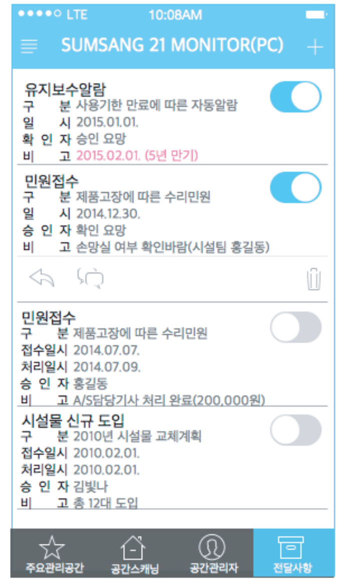


Figure 7. non-shape-information

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTION

In this study, we established objects necessary for BIM-based campus space management with AR (CSM-AR), which is combinable with the existing management system. However, a tremendous amount of coding is necessary for developing the entire scope of AR features. Therefore, we limited the system level to the linkage of the open-type Photon server and AR mobile platform. The server features were selectively used based on meeting the necessary conditions. For example, the officially approved campus information data were updated in real time, and the corresponding spatial information was utilized through a mobile device. We created a prototype to demonstrate the feasibility of a space management model in an AR environment. The objects merging the 3D geometry and time-dependent spatial information data proved their usability in time-to-space applications, and we generated an information-object pair in an event-by-event manner. This paper showed the feasibility of object merging by using the IFC and BIM formats for the utilization of CSM information. Future research will have to extend the scope to more comprehensible processing of BIM data and AR technology. One of the constraining factors is the limited capacity of mobile device hardware. In the test settings, the model size should be optimized by taking into account the mobile device display expressions of an uncertain number of general users. OOSE-based development systems present theoretically the most vulnerable components of the objects. In the context of the current system construction, OOSE identifies the most vulnerable objects at the AR application level. However, in Section 4.1 we presented a process for providing information through open access of the AR to BIM model data at pre-determined time intervals.

The CSM process with assumed monitoring can be summarized as follows: (1) the proposed prototype enables users to compare the spatial information and the current onsite condition without any drawings or documents, and (2) users have only to compare the drawing and actual space in a campus space resorting to their own spatial judgment or recognition. Users need only the current coordinates calibrated on the mobile device and the desired information provided by the campus. The main focus of this paper is on a system function review from a technological perspective, and not on the superiority of AR-based monitoring of a campus space over 2D drawings. Users were asked to examine three aspects of the compared monitoring processes: (1) a Gantt chart, (2) simulation run, and (3) augmented reality. The results reveal that AR can optimize the monitoring process and thus reduce the recognition workload in both onsite and office settings.

In this paper, three problems were identified during the testing of the proposed prototype when comparing the current function of the system with the conceptual vision to be enabled in future research: (1) the limitations of the mobile device capability, (2) visual occlusion, and (3) a high error rate in collecting GPS data. Future research will focus on three issues: (1) a questionnaire survey with information transfer process experts to achieve an in-depth understanding, (2) the development of additional software objects, and (3) the construction of an efficient interface reflecting supplementary items related to AR and the work process. It is expected that the application fields of AR hardware devices, such as Google Glass, Tango, and Oculus will be extended in areas encompassing our daily lives and professional sectors, and that AR technology will be employed in various specialized domains of the construction sector.

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