Article

BIM to AR matching technology of building maintenance platform using 5G-based AR

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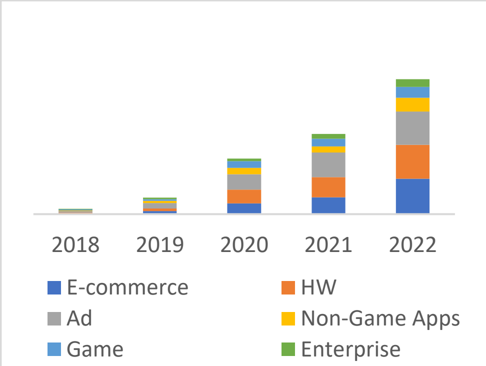
Abstract: The significance of virtual reality (AR/VR/MR) technology stands out because it can be used in various construction fields such as urban design, construction review, maintenance and education, etc. As to prove this, conglomerates such as Facebook, Google, Sony, Microsoft, and Samsung are increasing their investments to preoccupy the virtual reality market and are competing to dominate the contents and platform market. Virtual reality technology has a concept that collectively refers to VR (Virtual Reality), AR (Augmented Reality), and MR (Mixed Reality), but technically, the two technologies are strictly separated. While VR technology is an immersive virtual environment using computer graphic technology, AR technology is a more advanced technology that combines real data and VR data, and MR technology is a technology that combines both AR and VR. In Korea, Republic of, the use of BIM (Building Information Modeling), a 3D information model, becomes mandatory and based on this, the demand for a new market where VR/AR/MR technologies and advanced sensing equipment are combined increases. This study implemented a building maintenance platform using AR based on 5G, and developed matching technology between BIM of the building maintenance platform and AR equipment. Besides this study implemented the technology to enhance the matching rate of the matching technology and carried out the process to enhance the matching rate empirically through continuous tests. As a result, the initial target of 90% matching rate could be improved to 96%. Based on this, it is expected that effective EV (Optimum Life Cycle Cost) could be achieved at a lower cost compared to the previous one by using it for maintenance monitoring after construction and completion of the building, and can be used as an effective solution in the aspect of building maintenance as well.

Keywords: 5G; AR/VR; BIM; Building maintenance; matching

1. Introduction

As 5G communication network is commercialized, issues are focusing on the immersive industry such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). Virtual reality is defined as a system and its related technology that builds a specific environment, situation, or virtual scenario in actual reality through computer modeling, and helps users interacting in a virtual environment[1]. Augmented reality is defined as a system and its related technology that provides virtual information about space and situations by overlapping virtual objects (eg, objects, texts, videos, etc.) created through computer modeling in a real environment[2]. Mixed reality is a technology that includes augmented reality and virtual reality. Technically, it refers to a technology that combines the elements of reality, augmented reality, and virtual reality to strengthen the interaction with the user. With the commercialization of 5G in major countries such as the US and China, starting from Korea, the immersive content market is expected to grow rapidly, and the global immersive content market will reach 364.1 billion dollars (about 411 trillion won) in 2023 increasing by 12.6 times (annual average 52.6%) comparing to that of 2017[3].



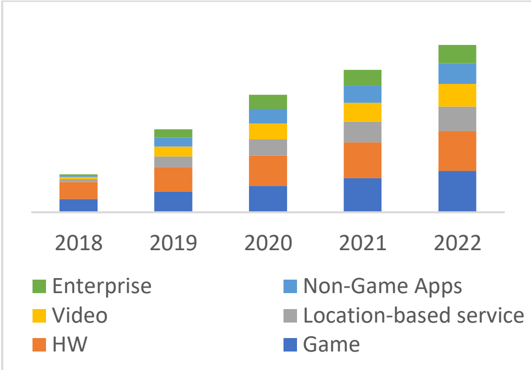


Figure 1. below shows the prospect of using virtual and augmented reality[4]

In the domestic immersive content field, there are difficulties in vitalizing the market due to a lack of quantitative and qualitative contents and a lack of corporate competitiveness. Some device-related fields have world-class competitiveness, but immersive content-related technologies are still at a low level compared to advanced countries. Virtual and augmented reality technologies are analyzed to stay at 80% level compared to the US[5]. The commercialization of 5G gave an opportunity to spur the speed of immersive content services. The communication speed of 5G is about 30 times faster than the current network from 300Mbps to 100Gbps while the delay time is shortened from 20ms to within 1ms. In the case of VR and AR contents, users and contents can actively interact with each other, as if the image moves according to the view when the user raises his head. Mobility using 5G's wireless network is able to realize immersive content while moving at a distance through the linkage of a smartphone and a virtual reality device (AR glass, etc.).

In this study, the author implemented a building maintenance platform using AR based on 5G and developed a matching technology between the BIM and AR equipment of the building maintenance platform. Besides it implemented a technology to increase the matching rate of the matching technology and performed a process to improve the matching rate through continuous testing. As a result, the initial target of 90% matching rate could be achieved and further improved to 96%.

2. Related studies

In the case of construction field, the model conversion support function has been strengthened due to the recent development of various software and solutions (Unity, Enscape, VisualLive (HoloLive3D), IrisVR) for 3D model conversion that creating models for augmented reality (VR/AR) became possible. However, the model creation is used as a technology for planning and arrangement, and consultation with the building owner in the design stage, or as provision of information on complex structures during construction.

With the global commercialization of 5G in 2019, the level of network technology has greatly been improved, and large-capacity content that requires high-level network specifications is attracting attention. 5G has the characteristics of ultra-high-speed, ultra-low latency, and hyper-connection, and provides an environment that can service immersive content by providing an environment suitable for real-time service implementation with large capacity. The characteristics and expected effects of 5G are shown in [Table 1] below.

Table 1. Characteristics and expected effects of 5G[6]

special feature	4G(LTE)	5G (IMT 2020)	Expected effect

ultra-high speed	Maximum speed	1Gbps	×20	20Gbps	Enabling the use of ultra – high - definition video and large - capacity data - based content such as AR and VR by transmitting larger data faster
	Perceived speed	10Mbps	×10	100Mbps	
ultra-low latency	Delay speed	10ms	×10	1ms (Ultra low delay priority) 4ms(speed priority)	Real-time service implementation with no delay by being used in telemedicine and self - driving cars that require immediate response and response
	speed	350km/h	×1.5	500km/h	
hyper connection	Connection density	Per km^2 100,000 Units	×10	Per km^2 1 million	By greatly increasing the number of terminals and sensors that can be connected to the Internet, the Internet of all things, a large-scale Internet of Things (IoT) environment is implemented, and it is also used as a smart home and smart city-based technology.
	Energy efficiency	Low efficiency	× 100	High efficiency (100 times compared to 4G)	

Kwon Soongak et al. (2018) proposed technology for providing travel information using AR based on the mark recognition[7]. Based on this, the author tried to increase the travel experience through an augmented reality of the travel place[8-10]. Huh Taeho et al. (2018) implemented VR content for viewing the exhibition[11], and Oh Seonae (2012) classified and analyzed four types of augmented reality implementation through analysis of domestic and overseas use cases that introduced augmented reality in museum exhibition spaces[12]. Lee Seok-hee and et al. (2019) carried out a study on mobile AR technology that guides emergency exits to evacuate in case of fire[13]. Ryu Jeong-rim et al. (2010) reviewed the possibility of applying AR technology to support decision-making in residential complex layout planning, and then photographed and measured the interior and exterior → Creation of 3D sketch-up model → Registration of the marker of the main model → Utilization of AR tool (BuildAR), HMD (ITS- VR Pro AR) → Review of the main building layout was presented[14]. Kim Jung-hoon (2016) applied VR technology for tourism/promotion in the exhibition facilities of the Onyang Museum[15]. Hong Seung-Wan (2017) conducted a process for virtual reality-based architectural design education by applying VR design education and evaluating barrier-free design plans[16]. Milgram (1994) presented Reality-Virtuality Continuum that defines the world that the user can experience as Real Environment, Virtual Reality, and Mixed Reality. Continuum)[17]. X. Wang (2009) developed AR technology grafting process in the introduction of AR-related hardware and application implementation technology for building design into AutoCAD → customized AR program → Utilization of Tracking Marker → HMD visualization → Design quality review and FM utilization[18]. W. A. Abdelhameed (2013) reviewed VR utilization and effectiveness in terms of education and proposed a process for planning and designing cities and buildings applying AR technology[19]. D. Broschart et al. (2014) presented AR Use Cases in the field of architecture and urban planning to visualize through AR-based digital tours of historical buildings and layers of reconstructed parts[20]. M. Gheisari (2014) presented Semi-AR technique that constructs a virtual space and overlaps BIM data through panoramic images acquired at the actual site to make it possible to experience AR similar to the site even though the user does not stay in the site[21]. J. Wang et al. (2014) developed the AR system BAAVS (AR for Architectural Visualization System) through the shape and meta-information of BIM data and applied meta-information on real objects to AR visualization[22]. J. Du et al. (2018) developed the BIM-VR real-time synchronization system called BVRS that interprets and communicates with cloud-based BIM metadata, enabling real-time display through VR headsets such as Oculus Rift DK2[23]. [Table 2] below shows the contents of VR/AR technology, architecture, and immersive content research.

Table 2. contents of VR/AR technology, architecture, and immersive content research

Researcher	Contents
Kwon Soon-gak and et al. (2018)	Technology to provide travel information using AR based on mark recognition
Heo Tae-ho and et al. (2018)	Implement VR content for viewing the exhibition
Oh Seon-ae (2012)	Analysis of augmented reality use cases in museum exhibition spaces and classification of augmented reality implementation
Lee Seok-hee and et al. (2019)	Mobile AR technology that provides information on emergency exits to evacuate in case of fire
Ryu Jeong-lim and et al. (2010)	Review of the possibility of applying AR technology to decision-making support for residential complex layout plans
Kim Jung-Hoon (2016)	Applying VR technology for tourism/promotion in the exhibition facilities of Onyang Museum
Kim Jung-Hoon and et al. (2017)	Realization and evaluation of VR visualization in public library design
Hong Seung-wan (2017)	Applied for design education of VR and used for evaluation of barrier-free design
Milgram(1994)	Presenting Reality-Virtuality Continuum, which defines reality as a mixed reality (mixed reality) of real and virtual
X. Wang (2009)	AR-related hardware and application implementation technology introduction
W. A. Abdelhameed (2013)	Reviewing the possibility and effectiveness of VR utilization in terms of education
D. Broschart and et al. (2014)	Presenting AR use cases in the field of architecture and urban planning
M. Gheisari (2014)	Constructing a virtual space through a panoramic image of the actual site and presenting a Semi-AR technique that superimposes BIM data
J. Wang and et al. (2014)	Present an approach using BIM and AR tools to improve visualization of building data and support decision making
J. Du and et al. (2018)	Developing a BIM-VR real-time synchronization system that analyzes and communicates cloud-based BIM metadata (BVRS)

This study develops the BIM to AR matching technology of the integrated building maintenance platform using the features of 5G and AR, and improves the matching rate to increase the usability in the actual field. It is expected to create an effective building maintenance environment through smartphone, and to create a new convergence market/new industry through BIM in the construction industry.

3. AR/VR application status in the construction field

Innovation is being made in the existing architectural design, management and education fields of the construction industry through a technology that can efficiently construct spatial relationships and interact with architectural models through VR/AR-based mixed reality technology. As construction projects from the construction planning and design stage to maintenance are becoming larger and more complex, simultaneous and multifaceted collaboration is required. Virtual buildings should be verified through VR/AR technology, and design drawings should be revised to induce decision-making and the high participation of architectural users to achieve high performance. Besides, through VR-based construction safety and technical education, workers' safety and satisfaction with education can also be increased.

3.1. Architectural design field

Trimble, a global leader in 3D BIM technology in construction, has collaborated with Microsoft to improve the efficiency of the building and structural design work through the wearable holographic technology of HoloLens based on mixed reality. Also, construction experts have the advantage of being able to more intuitively check and work on design data and collaborating with remote companies in real-time[24].

Urbanbase, a domestic 3D spatial data platform startup, has developed ‘AR Scale', an augmented reality presentation service based on 3D cloud specialized in architecture based on AR technology beyond converting the floor plan of existing buildings into 3D. This service has an advantage that the architectural expert does not need to create a real model to show others the actual architectural design plan but uses the 1:1 scale mode through AR scale to display a 3D model on the actual building site to check the harmony with the surrounding environment and buildings in advance. [Figure 2] below is the technical description of Trimble and Urbanbass, respectively.

Figure 2. Mixed reality-based architectural design (trimble/Up), developed AR scale (urban base/Down)

3.2. Management of underground facilities

Meemim, a Canadian startup company provides a solution to visualize spatial information through AR technology for underground facility management. Meemim's "vGIS" app is a service created based on GIS, AR technology, and cloud technology through collaboration between Microsoft and Esri. The service puts the images of underground facilities in the 3D model through location data and LiDAR scan function, and provided rendering work on them such that they look more visually three-dimensional. Besides, the vGIS app allows field workers to complete the management of underground facilities more accurately and in less time. It is possible to comprehensively systemize the management of underground facilities by accurately grasping the location of pipelines based on AR technology through development of the "Smart Facility Management System" by domestic companies in the future. In particular, it is possible to convert the data held on the pipes buried in the past and to detect important power lines and water pipes in advance, and identify the location of the surrounding management facilities based on AR technology without drawings for effective and systematic management of underground facilities. This technology makes it possible to prevent excavation accidents in advance. Below [Figure 3] is a view based on vGIS app and AR technology.

Figure 3. VGIS app view (Meemim/Up), AR technology-based underground pipeline view (Chahoo/Down)

3.3. Construction education

Construction education based on virtual augmented reality is indispensable due to the nature of a job dealing in dangerous sites. In particular, for the safety of construction education, it is mainly used in a variety of training scenarios through virtual reality-based technology rather than augmented reality. Gammon, an overseas construction company, provides excavation training to workers through VR technology. The conversation itself was impossible due to the noise between the site, educators and workers, but the VR technology enables two-sided conversations in a non-dangerous space, and the delivery power is higher than that of general excavation lectures and can be conducted more efficiently that the satisfaction of workers is very high. In Korea, Kolon Benit and M-Line Studio, a domestic VR company, developed 'VR Industrial Safety Education' using VR technology to prevent safety accidents at construction sites. Together with the safety manager of the construction site, eight types of accidents were applied among the ten major accidents in various scenarios (fall, electric shock, collision, fire, vehicle overturn, jamming, etc.). Like this, by applying virtual reality technology to accident situations that are not possible to experience, visual effects and vibration effects are combined to develop contents that can educate workers in preparation for accidents as well as awareness of safety accidents. [Figure 4] below is an example of Gammon's excavation training and Kolon Benit's industrial safety training utilizing VR.

Figure 4. VR-based excavation training (Gammon company/Up), VR industrial safety training (Kolon Benit company/Down)

4. Design and implementation of BIM to AR matching technology

The error between the BIM and AR equipment acts as a factor for the operator to reduce work efficiency and the reliability of the equipment. In this paper, to reduce the error between BIM and AR equipment and increase the matching rate, the author designed and implemented BIM to AR matching technology as shown in the sequence diagram in [Figure 5].

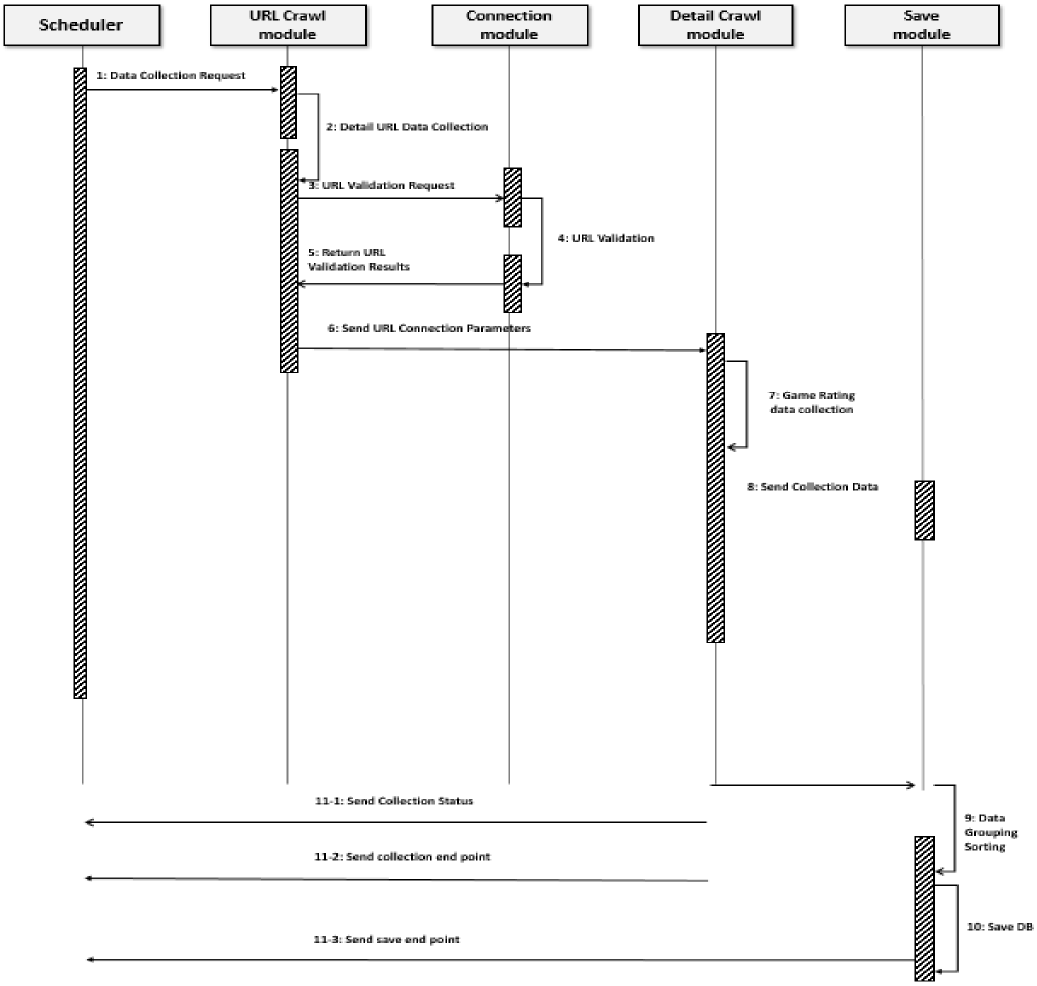


Figure 5. Sequence diagram for implementing BIM to AR matching technology

For implementation, 3D drawings converted to DataSmith were imported using Unreal Engine 4 (Version 4.25) and then used for 3D data augmentation using Android ARCore and iOS AR Kit. However, when recognizing a virtual space using AR Core and AR Kit, the starting point and viewing direction are variable. In the case of camera, it is a camera of the device and plays the role of a first-person virtual camera at the same time, so the vector values of the location and rotation will be digitized. When they want to augment something at a certain position by using this vector value, it is possible to derive the calculation of the position, the rotation vector (the position to be augmented) from the original point of the object and the rotation vector of the camera can be calculated. However, since the human body cannot operate the device in completely immobile condition, a fine error may occur in calculation of the position and angle when the user makes a fine vibration and trace the position. To solve this error, the anchor optimization technique was implemented and applied so that the user can adjust manually. Besides, for efficient and systematic management, drawings (plan, cross-sectional view, air conditioning piping, fire extinguishing facility diagram, guidance light facility diagram, automatic fire detection facility diagram, air conditioning facility diagram, etc.) are categorized and maintained by floor and category at interfaces and stages to design the program structure. After assigning a QR code to the classified category and importing the coordinates of the location of QR code of the BIM data through QR code recognition, the location of the QR code and the distance and direction between users are calculated, and this value will be calculated together with QR Code's position coordinates of BIM data to make the position matching by obtaining the position coordinates to be placed on BIM and time direction by the actual user. Thereafter, the BIM data is loaded at the same time as the program is started, and the program checks whether the load is complete, and then proceeds with the next process according to the programming flow. Upon the resource is loaded, the classification will be configured to refer by entering a certain protocol in the data smith between the BIM provider and the programmer through the classification. When the QR code is recognized using the QR code, the contents saved inside will be read and analyzed. For the analysis content, information such as a unique ID and corresponding floor will be entered so that search is possible in the database and if the search result is identified to exist in the database and maintain an appropriate distance from the QR code, matching will be tried by obtaining the location and rotation information of the QR code.

5. Verification and correction of matching technology through field test

The implemented BIM to AR was tested with real buildings. The target building was Hillstate Mobius building located in Anyang City, Gyeonggi-do, as shown in Figure 6 below, with 43 stories above the ground and 7 underground stories.

•Construction name: Hillstate Mobius
•Site location: Hogye-dong, Dongan-gu, Anyang-si, Gyeonggi-do 1040, 1040-1
•Building area: 3,426.1194 ㎡
•Building Scale: 43 stories above ground / 7 stories below ground
•Main use: Officetel (622 rooms) / neighborhood living facilities
•Architect: Haean Architects & Engineers Co., Ltd.
•Contractor: Hyundai E&C

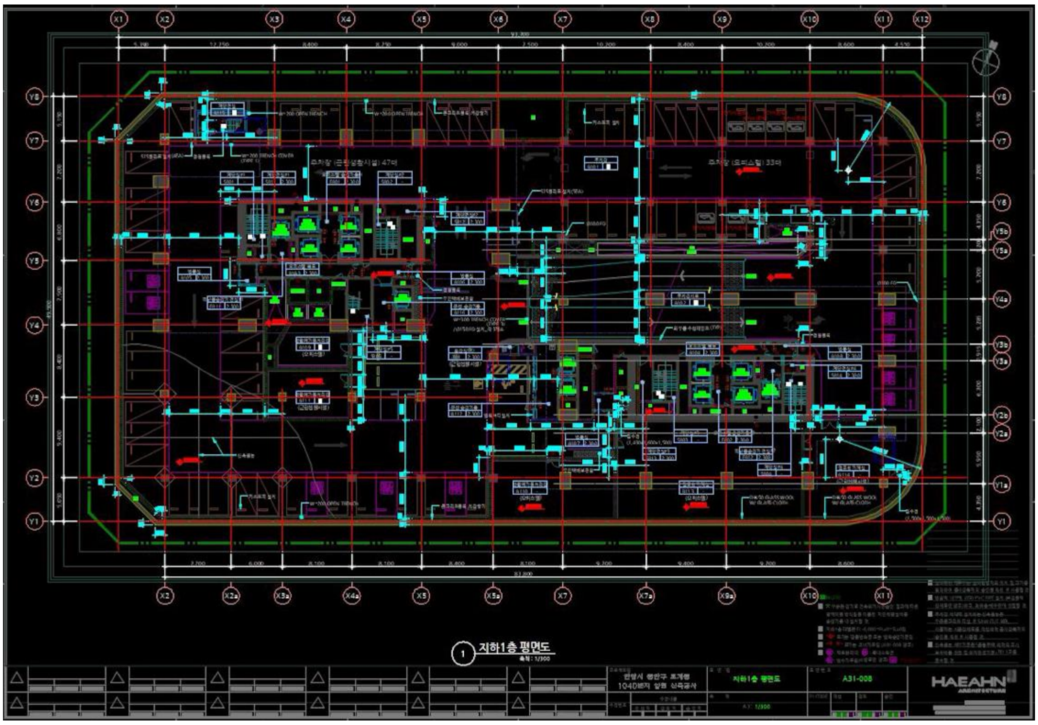


Figure 6. Outline of buildings subject to BIM to AR field test

The field test aims to check the degree of matching with the data augmented at the target location of the site as shown in [Fig. 7] below, and the following items were tested.

First, check/compare the drawings provided by the contractor with the MEP data changed during the on-site construction process.

Second, test the degree of matching between the 3D data and the actual site according to the location of the targeting image.

Third, list and test the planned UI menus.

Fourth, designate a suitable range of matching degrees by QR code scanning.

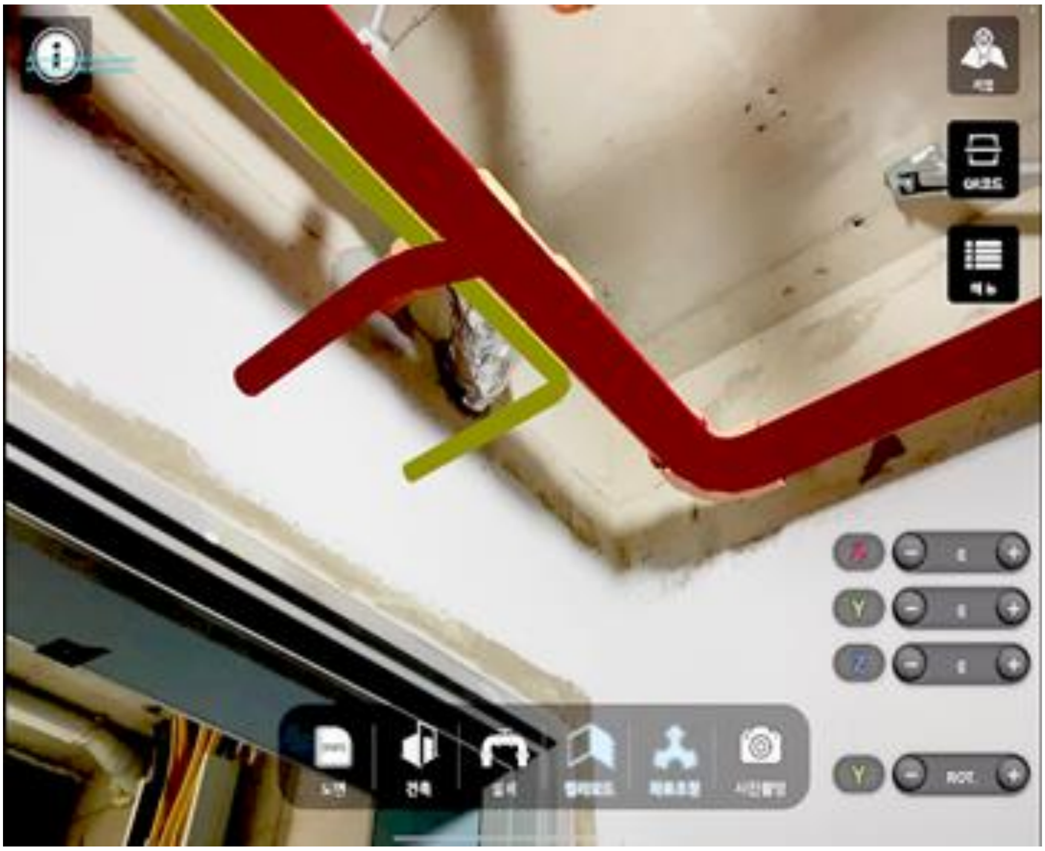


Figure 7. Field test items

5.1. Primary test progress

The test was conducted using a representative image (earth image) selected based on whether the object can be recognized and traced. As shown in [Fig. 8] below, the target image (QR Code) programming and 3D drawings converted to FXB and some BIM data architectural modeling will be augmented to the target location of the site to check the matching status.

Figure 8. Primary test progress

5.2. Results and Improvements of the Primary Test

As a result of the primary test, there was a problem in which the drawing was inclined according to the slope of the floor as shown in [Figure 9] below, and the author tried to improve the problem by using AR Pin as an inclination or change of augmentation position occurs during augmentation. To improve this, it is necessary to consider a recording means that can preserve test results, and it was found that it is necessary to establish a manageable program system according to model categories.

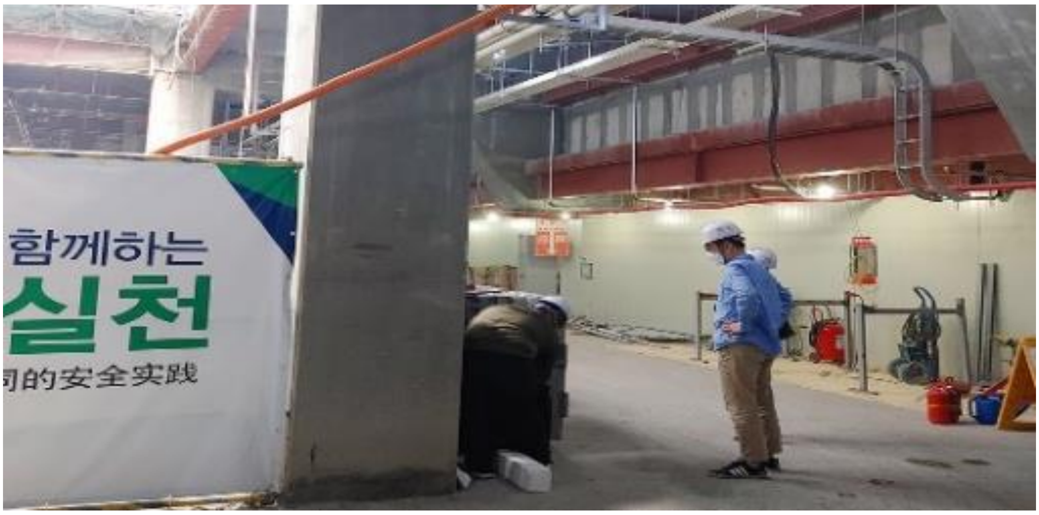
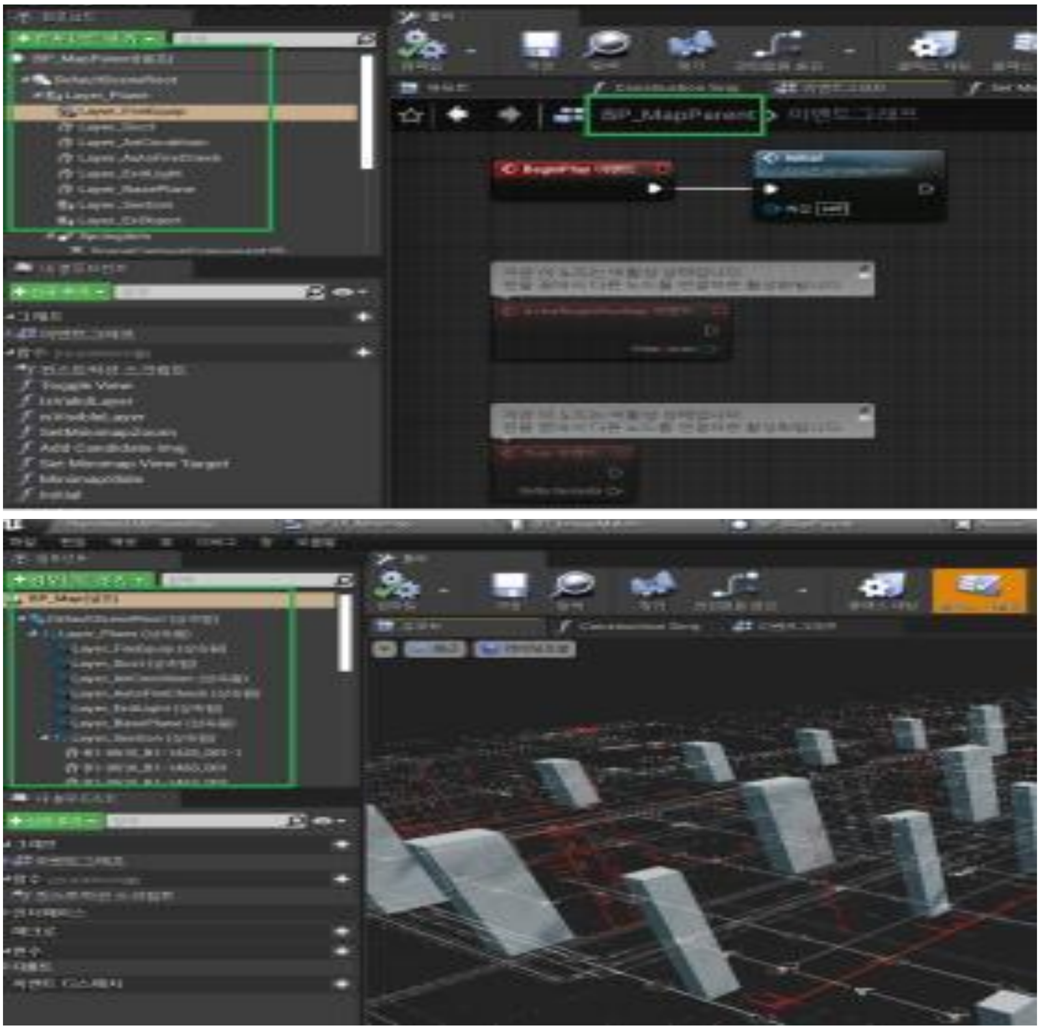


Figure 9. Results of the Primary test

5.3. Secondary test progress

The test was conducted using images of 300×300 pixels or more with clear feature points, and the images used in the test were 6 images that received 100 points from the recognition test tool by AR Code. Create a Map Interface as shown in [Figure 10] below to register additional drawings and establish a management system, classify sections by drawing category, interface them and program the program structure to enable maintenance by floor and category.



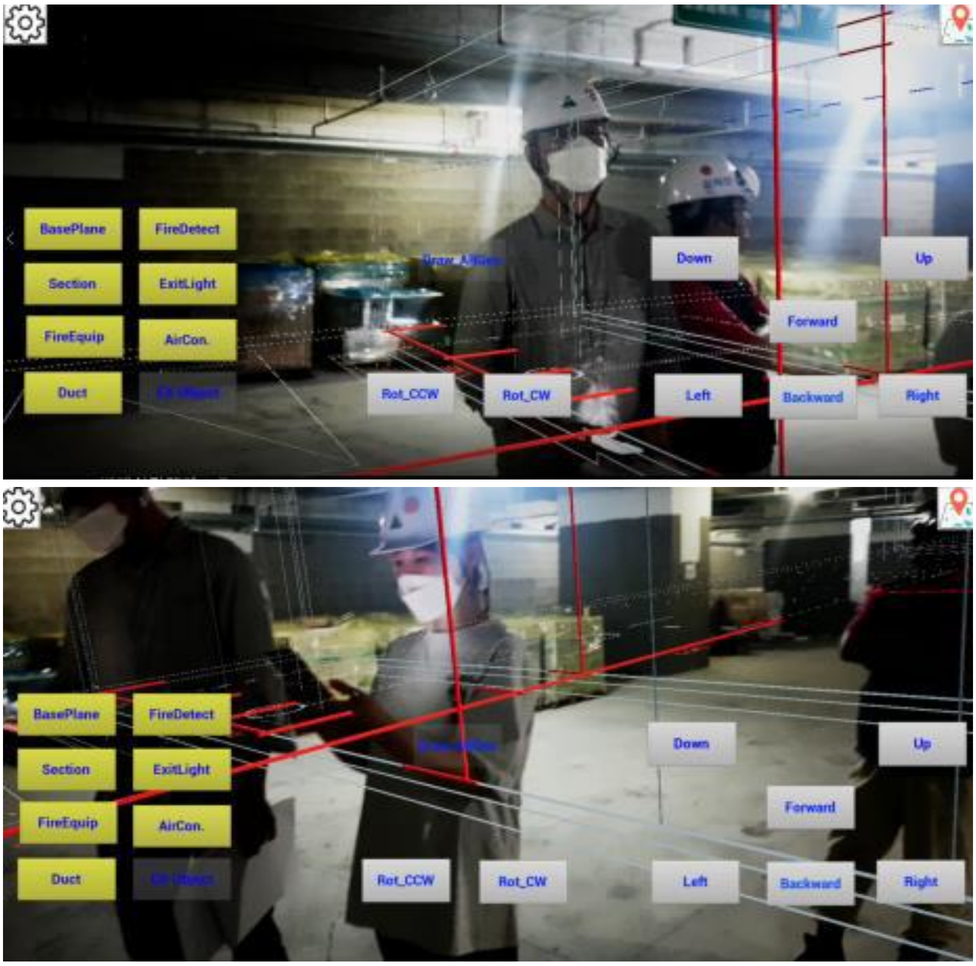
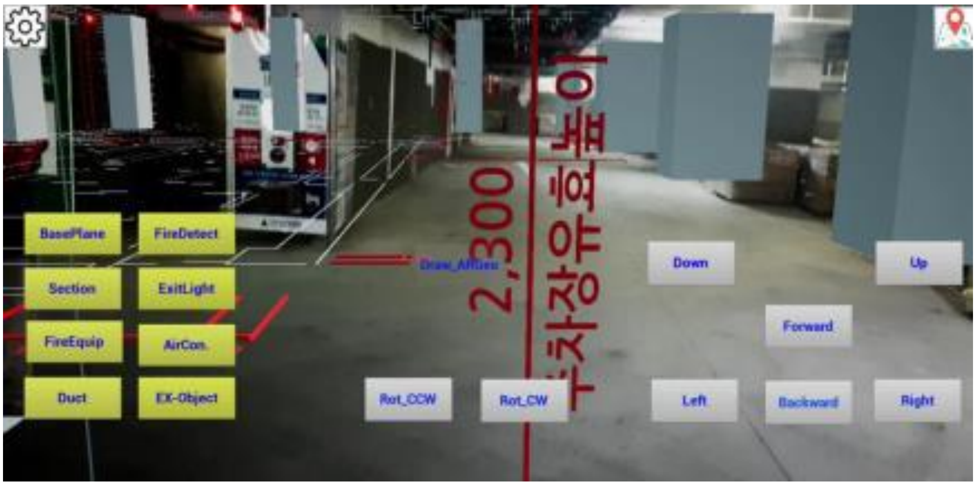


Figure 10. Secondary test progress

5.4. Results and Improvements of the Secondary Test

As a result of the secondary test result, it was possible to measure the matching rate and manage the model category as shown in [Figure 11] through the establishment of program system, and the error rate analysis during the test was available through the establishment of the matching algorithm. As a result of the test, a matching rate of at least 90% was secured. The problem that the drawing was inclined according to the floor inclination as in the primary test, and to improve this, an additional plan for the target matching rate (95% or more) was devised, and an additional device search was necessary to prevent displacement of the augmented object and implement a stable augmentation state.



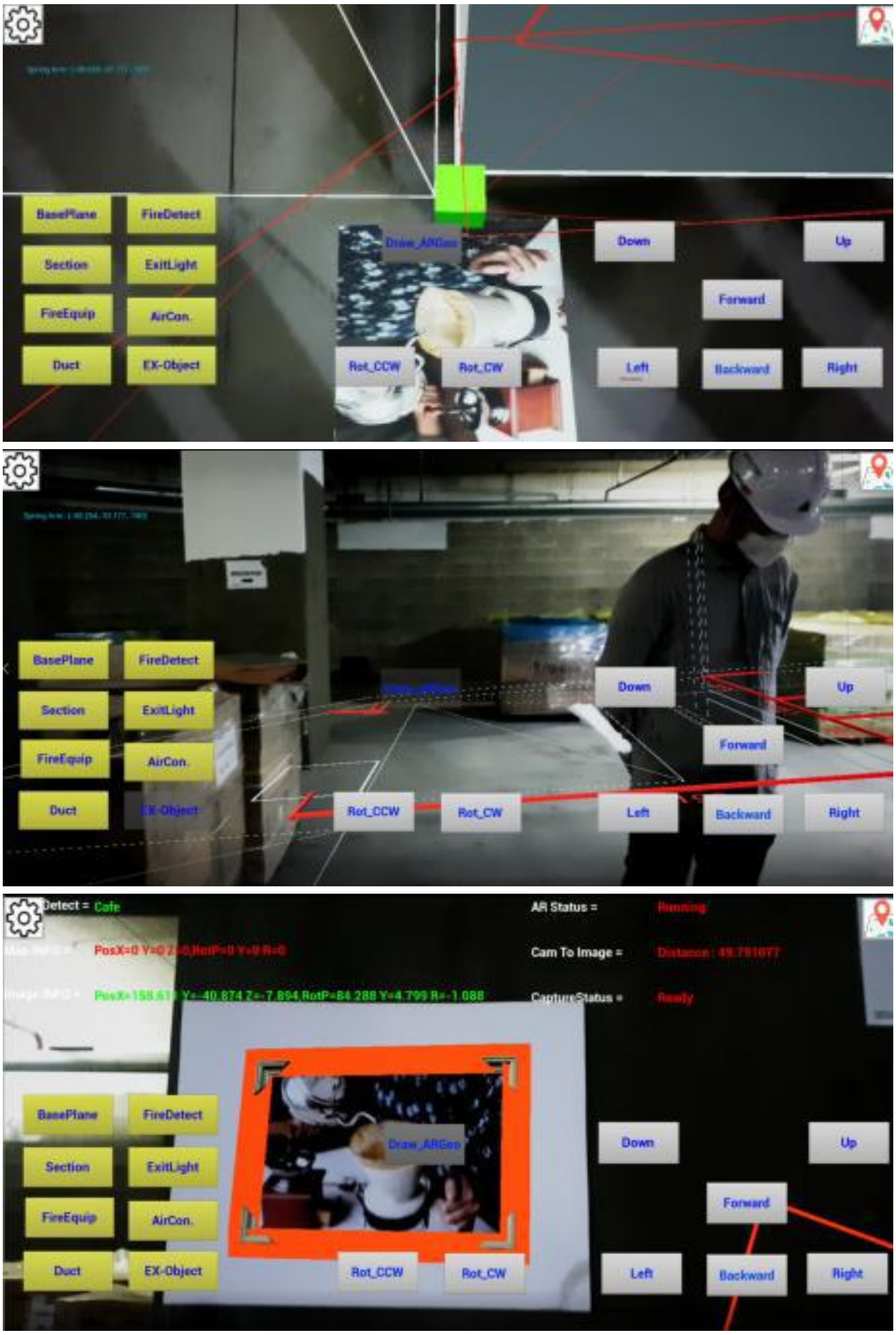


Figure 11. Secondary test result

5.5. Tertiary test progress

Unlike the conventional rough method of placing markers at arbitrary points, the error could be reduced by calculating the location of the marker and the size of the marker in detail as shown in [Fig. 12] below. According to the improvement of the secondary test result, the author searched for new devices such as Hololens 2 and iPad and conducted the test after completing the program modification for multi-platform compatible with existing devices.

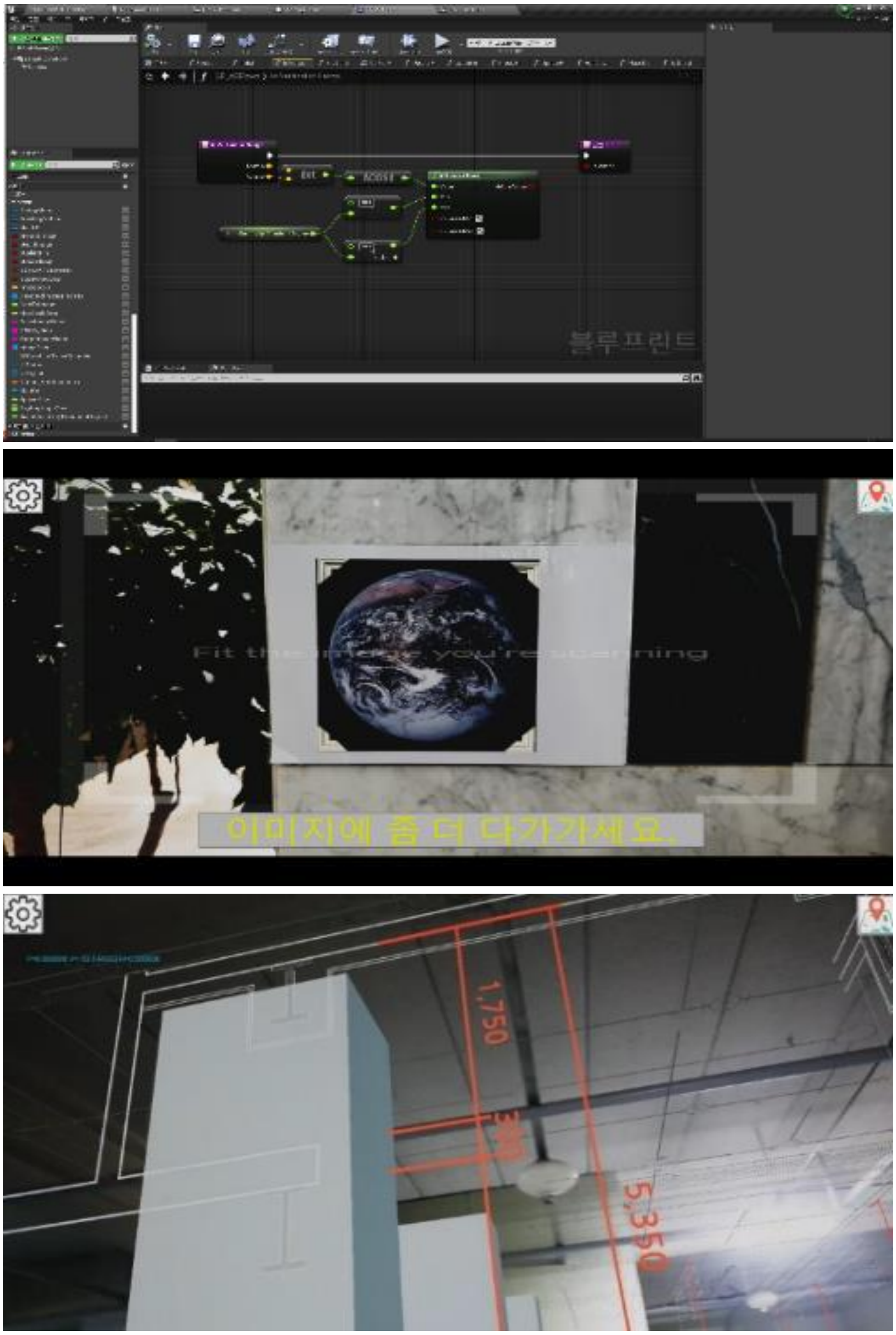
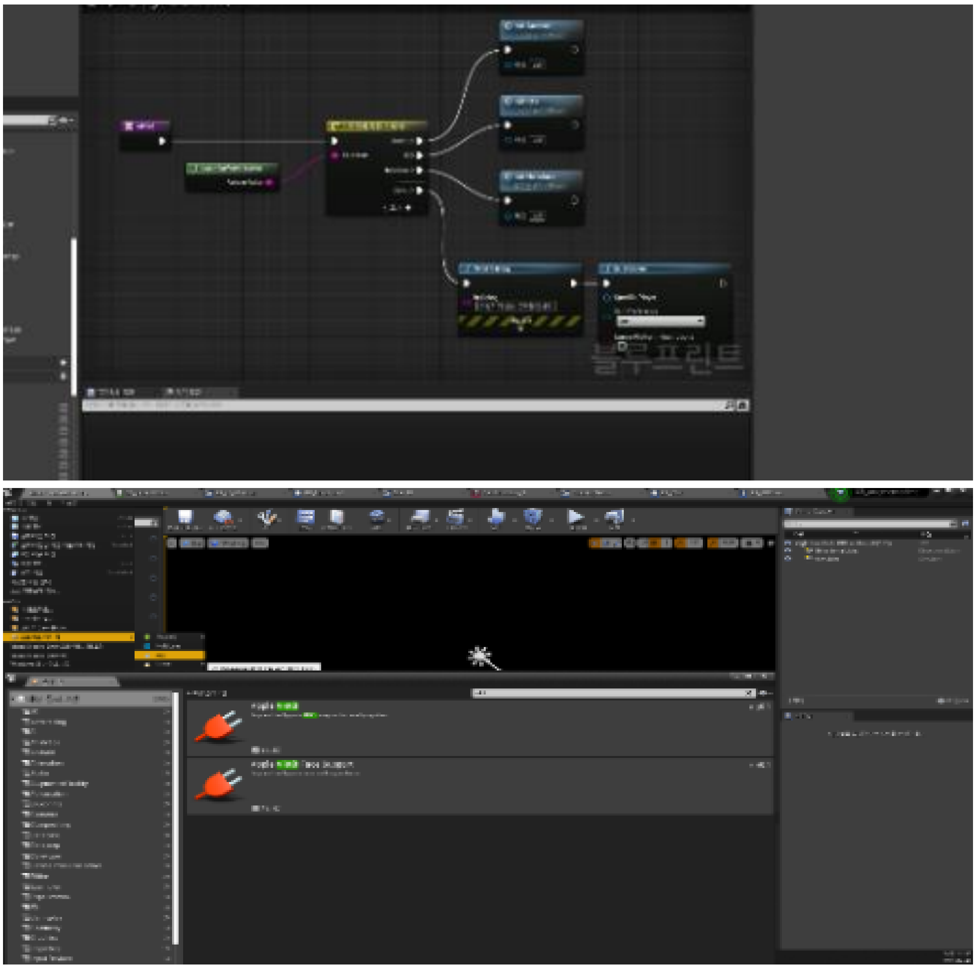

블루프린트
Fit the image you're scanning
이미지에 좀 더 다가가세요.
1,750
5,350

Figure 12. Tertiary test progress

5.6. Results and Improvements of the Tertiary Test

As a result of the tertiary test, the matching rate was increased (90% -> 95%) through the improvement of the matching algorithm as shown in [Figure 13] below, but a phenomenon in which spatial recognition was not available (augmentation was not possible) occurred under a certain condition. As a result of finding out the problem, it was confirmed that terrain recognition is affected by device performance and lighting, and was revealed that it is necessary to switch to a device that supports the depth sensor among Hololens 2 or iOS devices.



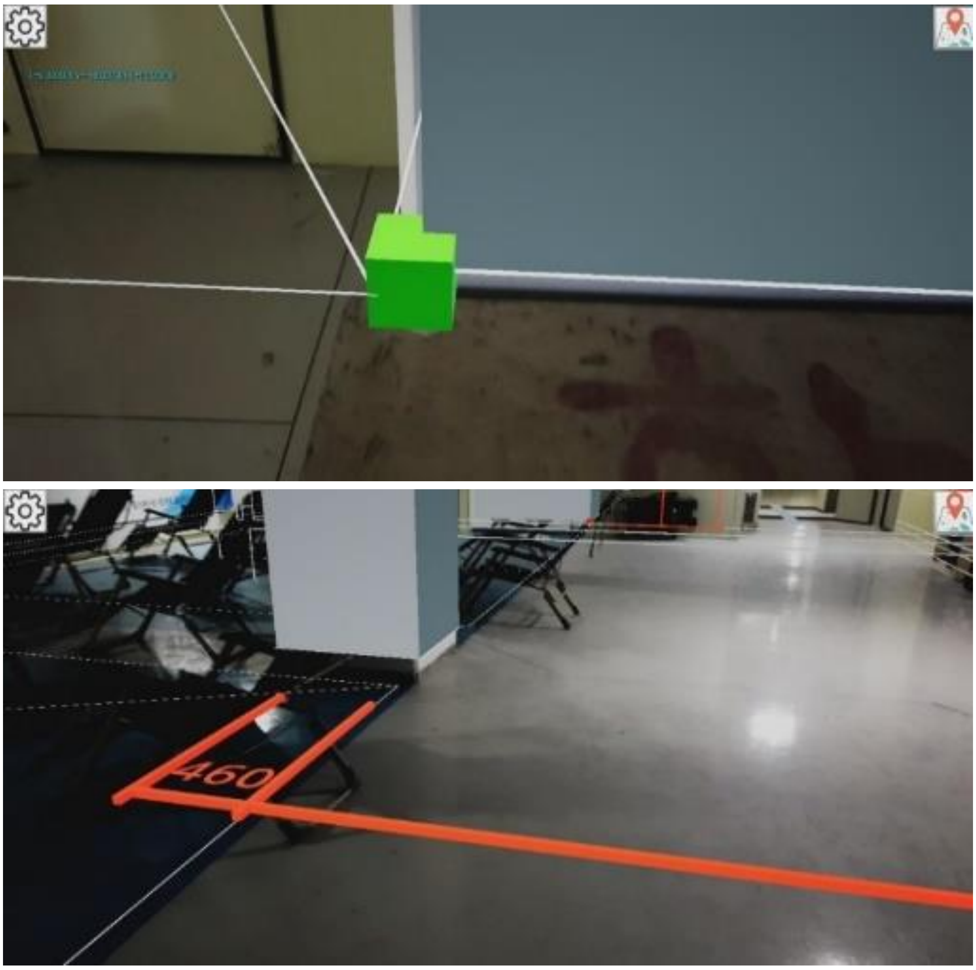


Figure 13. Tertiary test result

5.7. Hololens2 based Primary Test

By using Hololens 2 as shown in [Figure 14] below, most problems such as the inability to recognize space or distorted objects that occurred in existing Android devices have been improved. It is easy to maintain a marker through the use of QR Code, and a stable matching rate (95% ->96%) was seen. As a problem of the primary test based on Hololens 2, there was a phenomenon that the installed App could not be executed, the image quality was lowered or broken when using the recording function, and the App driving frame was not smooth. To improve this, it was necessary to devise a plan for optimization/minimization to solve the execution problem and frame problem of Hololens 2, and also solving the problem of poor quality during recording Hololens 2 was required.


AR Marker
Transform
Layer
도움 요청 시 환자의 증상 및 위치를
상세하게 알려주세요

Figure 14. Hololens 2 based Primary test and results

5.7. Hololens2 based Secondary Test

Through the secondary test, the optimization/minimization problem which was the problem of the primary test, was solved. As shown in [Figure 15] below, running the app with desktop performance through the packaged windows streaming method and applying the method that renders only the result screen to Hololens 2 solved the execution problem and the frame problem at the same time, and the recording quality problem was also solved. This problem is caused by the special rendering method of Hololens 2, which processes the black color transparently, and gray background was inserted to prevent black color occurrence, and the image quality is improved. The disadvantages identified in the secondary test are that the implemented UI is not compatible with the existing 2D UI of Android, and unwanted expression occurs when it is affected by the light source of the app. To improve this, the user's accessibility has been improved through the implementation of 3D responsive UI that is not affected by the light source.

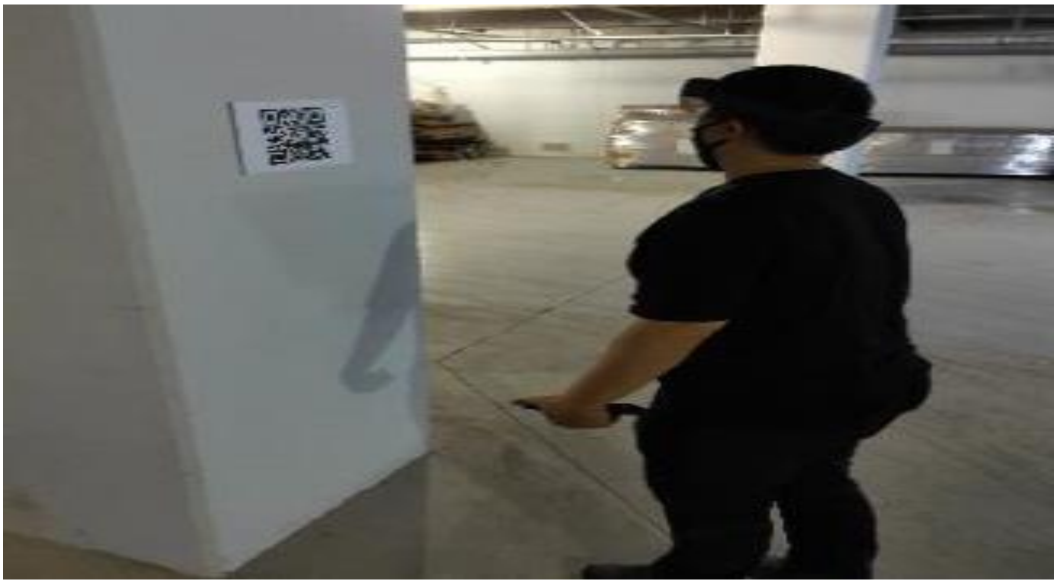


Figure 15. Hololens2 based secondary test and results

6. Conclusion

Technologies such as virtual reality, augmented reality, and mixed-reality are continuously emerging thanks to the commercialization of 5G, the generalization of smartphone, and the demand for visualization by users. Besides, rapid distribution, settlement of the BIM and software development in fields such as architecture, civil engineering, and urban environment are made. At home and abroad, universities and private companies are conducting various experiments by implementing virtual test spaces. Based on the powerful immersive environment of virtual reality, it is evolving to 2D → 3D → 3D+AR/VR, and for this, there is an urgent need for research and development on content in addition to the investment.

In this study, the use of BIM and its use through connection with 5G were considered and based on this, the development of BIM using virtual reality based on 5G and the development and testing of BIM to AR matching technology were conducted, and developed to a level that can be used in the field. The author conducted empirical research on the test, correction, and progress to make it happen. Using the QR code and 2D image FR sensor, the site location was recognized and the error was checked and corrected by matching it to the AR device. The matching rate, which is important for using the technology in the field, has been raised from 90% to 96%, and the technology and know-how for BIM to AR matching technology have been improved and accumulated by solving problems that appeared in the process of implementing and testing the technology. By using AR based on 5G for building construction and maintenance monitoring after completion, effective EV (optimal life cycle cost) can be achieved at a lower cost than before, and it will be used as an effective solution in terms of building maintenance as well. BIM field of the construction industry is a high-value-added future technology field for the realization of a creative economy. It is also a technology suitable for future growth, the creation of new added value and job creation, and an effective building maintenance environment can be established through the diffusion and advancement of 5G, AR, and smart construction industries.

Future research shall be carried out to develop BIM using virtual reality based on 5G and cloud and to develop BIM to AR matching technology so that it can be used in the field. For this, First, it needs to build a cloud server-based two-way communication service and realize a unique platform through the development of two-way real-time collaboration communication technology between practitioners through the advancement of cloud server technology based on 5G network. For this, it needs to expand to a multifunctional maintenance platform such as recording during communication, memo and information sharing, etc. Second, after converting the actual environment into feature points using the spatial mapping function of Hololens 2, a Markerless implementation test that maps the current location and augmented reality based on the feature points will be continuously conducted to finally correct and improve the matching rate. Third, it is to build a server-based Remote Rendering/multiple access service. BIM models that require high specifications will be rendered on the server and built to enable real-time streaming services based on 5G to clients. Finally, by reducing the error between drawings (BIM) and AR devices (including smartphones), the matching rate will be continuously increased so that real workers can work conveniently and efficiently when using them in the field and research will be expanded to provide a more realistic environment through matching AR devices being launched.

Author Contributions: Conceptualization and methodology, J.H.K.; data curation, J.H.K.; funding acquisition, J.Y.K.; investigation, J.H.K.; supervision, J.Y.K.; visualization, J.H.K.; writing—original draft, J.H.K.; writing—review and editing, J.Y.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2019R1G1A110034111).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: This paper has supported by building maintenance platform using 5G-based AR project of KOREA RADIO PROMOTION ASSOCIATION, This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2019R1G1A110034111).

Conflicts of Interest: The authors declare no conflict of interest.

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