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Potential of an Interactive Metaverse Platform for Safety Education in Construction

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Abstract: The construction industry is considered the most hazardous industry globally. Therefore, safety education is crucial for raising the safety awareness of construction workers working at construction sites and creating a safe working environment. However, the current safety education method and tools cannot provide trainees with realistic and practical experiences that might help better safety awareness in practice. A metaverse, a real-time network of 3D virtual worlds focused on social connection, was created for more interactive communication, collaboration, and coordination between users. Several previous studies have noted that the metaverse has excellent potential for improved safety education performance, but its required functions and practical applications have not been thoroughly researched. In order to fill the research gap, this paper reviewed the potential benefits of a metaverse based on the current research and suggested its application for safety education purposes. This paper scrutinized the metaverse's key functions, particularly its information and knowledge sharing function and reality capture function. Then, the authors created a metaverse prototype based on the two key functions described above. The main contribution of this paper is reviewing the potential benefits of a metaverse for safety education. A realistic and feasible metaverse platform should be developed in future studies, and its impact on safety education should be quantitatively verified.
Keywords: construction safety education, metaverse, information and knowledge sharing, reality capture

1. INTRODUCTION

The construction industry is well-known for its high accident rate worldwide. In 2020, the construction industry accounted for 47.3% of all industrial accidents in South Korea [1]. Therefore, the government encourages safety education to improve construction workers' safety awareness and induce voluntary safety activities. Also, it recommends safety education nationally and promotes educational materials and safety information. However, safety information produced and distributed by the national government and public institutions is limited to general information instead of task-related specific information, and it does not reflect the actual work environment or associated risk factors happening on the construction site [2]. Workers who acquired safety knowledge through work experience or a colleague's injury had higher safety awareness than those who acquired safety knowledge through safety education [3]. The current safety education method leads to low awareness of the educational contents because it simply includes listening, reading, and watching [4]. In contrast, direct experience and interactive activities can improve educational efficiency by 20–70% [5,6]. Thus, developing an interactive and effective education system that allows construction workers to acquire safety knowledge and gain practical experience conveniently is necessary [7].

The concept of the metaverse was first used by Neal Stephenson in the novel Snow Crash [8]. Metaverse is a virtual space where users can experience many interactions that mimic their everyday offline experiences [9]. It has great educational potential for providing learners with a high degree of freedom, immersiveness, and many experiences [10]. Likewise, effective construction education needs to be conducted not by simple cramming education methods but by methods that enable interaction and two-way communication [11]. Thus, a virtual environment platform compatible with construction safety education may provide learners with safety education materials reflecting various on-site situations [12,13]. However, despite the educational potential of a metaverse in the construction industry, its usage is limited to space for real estate sales, consultations, and communication between employees [7].

Furthermore, the actual construction company's metaverse was not used for practical fieldwork, and the building's virtual environment was limited to simple 3D rendering [11]. In addition, research on metaverse applications in the construction industry is fragmented. In particular, research on integrating a metaverse and industrial operations is insufficient. Therefore, additional research inevitably focuses on the framework and methods of the educational utilization of a metaverse in the construction industry [14].

In order to solve these issues, as a preliminary study, this paper aims to organize the key technologies necessary to utilize the metaverse platform in construction safety education. Then, the authors made a prototype to test its potential benefits. This research aims to provide high educational outcomes by enabling interaction and two-way communication. Reality capture technology was used for building a virtual environment within the metaverse by reflecting various site conditions. The proposed framework was validated by building a virtual environment using reality capture.

2. PREVIOUS STUDIES AND LIMITATIONS

2.1. Metaverse and virtual environments

A virtual reality (VR) environment is a virtual world that provides the activity base for various individuals and objects in the virtual space [15]. A study that created a construction safety education system based on a VR environment and produced 3D simulation-based construction safety education content did not find a difference between the lecture-type education method and the 3D simulation-based method [14]. Thus, the educational effect was insignificant. VR and online education struggled to leverage 3D simulation-based content without the help of educators [14]. In addition, users' interaction and expression methods and user functions were limited, and the monotonous environment was restrictive [7].

A metaverse is a virtual environment where users can engage and experience a variety of interactions that are similar to those they would have in real life [9]. Two-way communication in real-time, expandability to various fields, including economic and production activities, and autonomy are added to a VR environment, and then a metaverse is configured [16]. By utilizing these characteristics of a metaverse, the limitations of the VR environment-based construction safety system, such as restrictions on interaction, communication, and functions, can be partially eliminated.

2.2. Metaverse for education

According to Maharg [17], a metaverse has great educational potential as a new social communication space, providing a high degree of freedom for learners, experience points, and a high degree of immersion. However, Maharg's research was limited to creating a virtual environment in the form of a lecture room and advancing lecture-based education within the created environment [17]. Most of the studies on education in the metaverse environment did not focus on the composition and content of the educational environment. Existing studies are limited to analyzing only educational effects or concentration obtained during education in a virtual environment [18].

It was confirmed that the construction industry is interested in and makes efforts to utilize a metaverse [19]. Company G has embarked on the industry's first safety management education using a metaverse, but it does not reflect an on-site construction situation and is still in the demonstration stage [19]. Company G's metaverse is not used for practical fieldwork, and the environment construction is limited to simple 3D rendering. In addition, there are rare cases where a metaverse was used for construction safety education. Also, some cases used a metaverse, but it only involved showing educational content in a virtual environment.

Research on integrating a metaverse and industry is lacking. Furthermore, research on the framework and process for utilizing a metaverse is insufficient. There are few cases when a metaverse was directly built and utilized for business in other industries, not just the construction industry [20]. In addition, there are very few studies on a specific framework for building a metaverse [20].

3. RESEARCH METHODOLOGY

3.1. Research objectives and methodology

This research systematically organized the key functions needed for construction safety education to use a metaverse platform. Thus, environment types were defined for the expected user types, and the required functions were analyzed according to the user and environment types. In addition, to verify the feasibility of the proposed framework, reality capture technology was used, and virtual environments similar to real-world sites were built based on the captured data.

3.2. Environment by user type

There are two main types of environments to be implemented in a metaverse— an individual project user and a general user. Both environments have a common aim of sharing safety information. However, each environment has different objectives.

1) Individual project user environment: Every construction site has different environments and processes, and workers need to grasp information about the work site. It is possible to build a 3D virtual environment for a target project, which is updated daily, and use it for daily safety education. It also provides an opportunity for new project participants to understand the work site before they enter it. In this environment, the main users may include an owner, a general contractor, and a subcontractor, who are project participants.
2) General user environment: This virtual environment is for general users. The main users of the virtual environment are students in construction-related majors and safety education institutions, not construction industry officials or professional personnel. It is an environment where content can be generated and shared based on user participation. Safety information and personal experience knowledge can be shared freely within this environment among construction industry personnel, and discussions and communication can be held.

3.3. Function definition

Table 1 shows the required functions for each user type in the metaverse platform. The proposed metaverse environment has basic communication functions such as text, video, and voice chat.

Communication at construction sites is oral, and it is challenging to convey clear safety information [21]. In particular, communication between workers and managers significantly raises workers' safety awareness [22]. Therefore, communication is necessary to convey safety information accurately and educate workers. In addition, since it is necessary to create safety education content and share it with other users, a communication function is required. The functions required for construction safety in a virtual environment are similar to the basic functions proposed in previous studies, such as chatting, real-time presentation, and task information delivery. Accordingly, in the case of functions for construction safety collaboration within a virtual environment, basic functions were classified by referring to previous studies [23].

Table 1. Classification of functions used by user type

Function		General User		Individual Project User			
		Site Manager	Site Worker	Specialists	Safety Education Institution	Construction Major Student	Supervision & Management
Communication	Text Chat	○	○	○	○	○	○
	Voice Chat	○	○	○	○	○	○
	Video Chat	○	○	○	○	○	○
	Real-Time Presentation	○	○				○
Content Creation	Material & Information Sharing	○	○	○	○	○	○
	3D Mesh Upload	○	○				
	BIM Model Upload	○	○	○	○	○	○
	360-degree Panorama Upload	○	○	○	○	○	○
Work Instruction & Confirmation		○	○				
Automatic Translation			○		○		
NPC Conversation			○			○	
4D BIM Cooperation		○		○			○

This study focused on environmental components such as reality capture to create a virtual environment reflecting the actual construction site. In addition, since it is a platform where users in a metaverse directly produce content and provide information to each other, necessary functions were classified accordingly. The content creation function refers to the ability of users to easily and freely create content within a virtual environment. With this function, the environment users are free to create and add personal experiences and content that other users may need. It enables continuous content production for different processes in the environment. In addition, to generate safety education content that reflects various on-site situations, it is necessary to enable uploading reality capture data: 3D photogrammetry, 360-degree panorama, and BIM(Building Information Model) model.

It is possible to determine when work does not proceed properly and ensure safety using the work instruction and verification feature. By utilizing the 4D BIM, problems such as poor workability can be checked, and the stability of the building can be ensured. Also, a non-player character (NPC), which contains safety information, allows communication even if there is no user to convey it in a metaverse. The automatic translation function for foreign workers can help them communicate and create safety information.

4. CONCEPT MODEL AND VALIDATION

4.1. Data flow of a metaverse platform for safety education

Figure 1 shows the overall structure of the proposed construction metaverse platform. General users can upload personal experiences and safety information to the virtual environment and utilize it. By utilizing the communication function, users can communicate and share safety information.

The virtual metaverse environment is built based on the 3D photogrammetry, 360-degree panorama, and BIM model. It is possible to create safety education content by utilizing the constructed virtual environment.

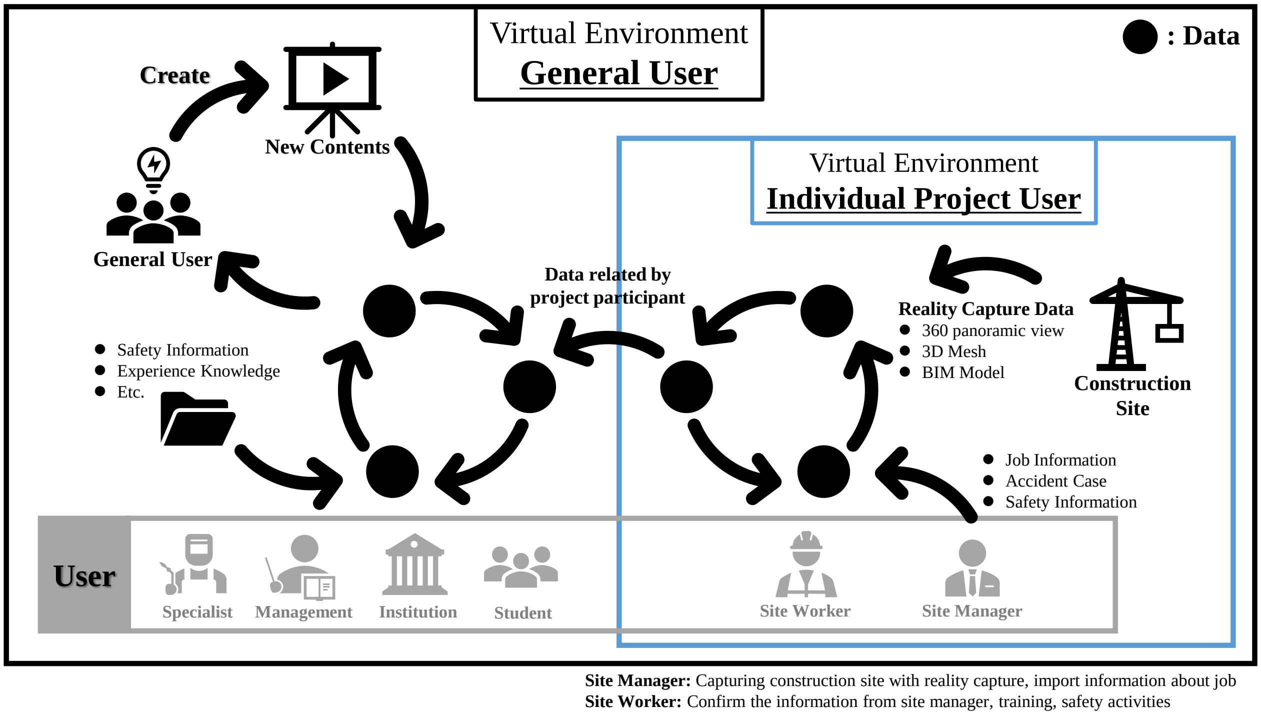


Figure 1. Data flow in the proposed metaverse

The proposed 3D virtual environment of the metaverse is divided into two spaces, one for general users and another for particular project participants. Virtual environment data (3D mesh, work information) generated in the space for individual project participants are not accessible to general users. However, general users can only access public information if the administrator publishes the information to be shared. The 3D virtual environment at each construction site should be accessible only to project participants for security reasons. Project participants must enter their identification information to connect to the 3D virtual environment of the project. The personal information-based approach can prevent unauthorized users from accessing the project's 3D virtual environment. When a user enters personal information in the project's virtual environment after joining, the input user log remains, ensuring the information's reliability.

4.2. Building a 3D virtual environment

The virtual environment for a metaverse platform can be built using a simple 3D rendering virtual model as with existing platform cases. However, this research applies reality capture technology to create a realistic virtual environment in a metaverse to reflect the characteristics of the construction site (Figure 2). Construction safety education can be enhanced by sharing realistic site conditions.

There are two reality capture technologies used in this research:

1) Image-based 3D photogrammetry technology analyzes overlapping patterns of captured images and converts 2D image information into 3D mesh information. This image-based reality capture technology has the advantage of generating 3D mesh information faster than laser scanning [24].
2) The 360-degree panoramic view photograph technology utilizes photo nesting and two or more high-angle cameras. This technology allows seeing a 360-degree panoramic view at the

shooting point. As a result of the test, it was found that the work status of the construction site can be obtained most easily. The 360-degree panorama view alone can show the actual scene on the metaverse, which can be used as image data.

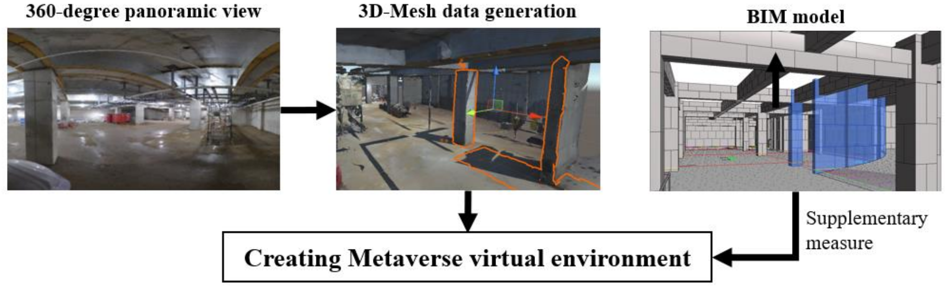
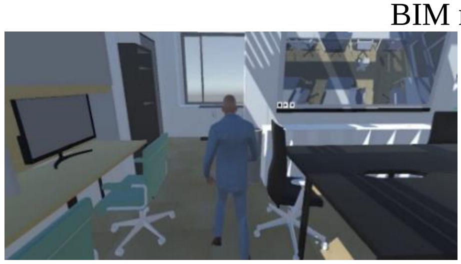
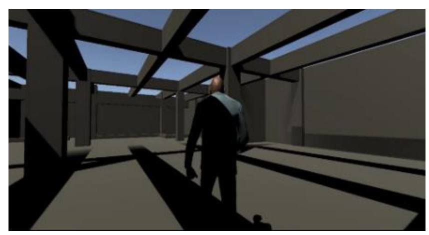
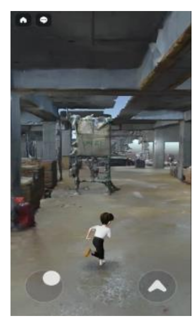


Figure 2. Virtual environment building process

The BIM model used in the construction industry can also be an additional measure. It is less realistic than the reality capture, but it is valuable as an adjunct because users can expect the project's final result. It can be used to check the current work status, construction defects, and changes in blueprints based on the comparison with the 3D mesh data.

4.3. Case study

Table 2. Test example

Based Data	BIM model	
Scene		
Function	Sharing materials & information Real-time presentation	Upload BIM model
Based Data	3D mesh	
Scene		
Function	Avatar identification Text chat	Import 3D mesh data to a metaverse platform

The core technology for building a virtual environment proposed in this research is 3D photogrammetry. It constructs a virtual environment using 3D mesh data generated based on images taken at a construction site. After that, necessary functions are added to the environment. Then, 360-degree panoramic images are used as an auxiliary means of 3D mesh.

A 360-degree panoramic view was generated using reality capture technology at an actual construction site. The captured 360-degree image was used to extract 3D mesh data using 3D photogrammetry technology. The target site for capturing was located in Yangcheon-gu, Seoul, Korea. The building had seven floors from B1 to 6F, and the total floor area was 5,422.07m^2. The site's basement floor (B1) was captured in this study. RICOH's Theta V 360-degree camera was used as the photographing equipment. Matterport's application was used to convert the photographed data into 3D mesh data. As shown in Table 2, a virtual environment was created using the metaverse environment construction program (Unity) based on the captured 3D mesh data. It was confirmed that the 3D mesh data could be converted into an FBX (Filmbox) file and imported into Unity to build an environment similar to the actual site. Moreover, this result confirmed that it is possible to build an environment by importing the existing BIM model and the 3D mesh file taken by 3D photogrammetry technology.

The functions applied to the built virtual environment were identified by analyzing the required functions for each user type. Also, avatars and identifiable user nicknames were displayed, and among the communication functions, the data/information sharing function and the text chat function were implemented. These functions were imported into the virtual environment built with reality capture data and analyzed. In addition, a virtual environment was built using a commercial metaverse platform (ZEPETO), and the availability of reality capture data was further examined. It was confirmed that the proposed virtual environment could deliver actual construction site information, unlike the virtual environment constructed by the existing 3D rendering.

5. CONCLUSION

5.1. Results

This research proposed the framework of a metaverse platform for construction safety education to share expert knowledge and practical safety information. For real-time communication and information exchange, which are the primary advantages of a metaverse, communication functions, data, and information upload functions were defined, and partial verification was conducted through function implementation within the virtual environment built by the authors.

In safety education, the educational effect can be increased through real-time interaction. When conducting education based on a virtual environment reflecting the field situation, it is possible to expect high educational outcomes by providing experiences as in the actual environment. The metaverse platform configuration method proposed in this study allows users to interact in real-time and selectively acquire the information they want. In addition, reality capture technology was used to build a virtual environment that is the background of a metaverse platform. After filming at the actual construction site, a virtual environment was created based on the data. It was confirmed that an experience similar to an actual construction site could be recreated in a virtual environment based on the reality capture data. Through this, the proposed metaverse platform can be applied in construction safety education.

5.2. Future Research and Limitations

Current technology has technical limitations in implementing functions to generate content in a virtual environment. Also, the proposed virtual environment functions were only partially implemented and verified.

In future research, the possibility of building the framework of the proposed metaverse platform should be verified via feedback from actual users. In addition, by implementing the trading system of the user-generated contents through non-fungible tokens (NFT), which allow identifying the uniqueness of digital assets, the authors would like to validate the effectiveness of the connection between the proposed metaverse platform and the real economy.

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