Iyer, S. et al. (Eds.) (2022). Proceedings of the 30th International Conference on Computers in Education.
Asia-Pacific Society for Computers in Education

Prototype System of Evacuation Training in Metaverse

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Abstract: The observation of users evacuating in a virtual reality (VR) earthquake simulator, in which a sudden significant earthquake occurred, indicated that paired users evacuated more methodically but with greater uncertainty than a single user. This discovery sparked curiosity regarding how a large number of people would react to a sudden earthquake in a virtual world. Therefore, we developed a prototype of an evacuation training in metaverse (ETM) system that integrates users' normal time (everyday life) with a simulated earthquake evacuation. In this work, we describe how to prototype the ETM system while demonstrating its requirements and techniques of implementation. Through this method, we hope to educate individuals on the significance of being prepared for unforeseen natural disasters like earthquakes.

Keywords: Metaverse, evacuation training, evacuation behaviors, earthquake simulator

1. Introduction

Natural disasters endanger humanity. Owing to the impossibility of predicting when and where earthquakes may occur, they are especially regarded as a significant threat. Since 2010, there have been approximately 190 earthquakes of magnitude 7.0 or higher globally (United States Geological Survey, 2022). In a country prone to earthquakes, for instance, the 2011 Tōhoku earthquake and tsunami (magnitude 9.0) caused approximately 20,000 fatalities. Consequently, individuals must be prepared for unexpected earthquakes. Generally, earthquake evacuation training requires participants to reach a safe location (e.g., a shelter) within a specified period of time. In Japan, earthquake evacuation training is regularly conducted in schools, businesses, and communities. In most instances, however, participants are notified of the start time of the evacuation training in advance. During the evacuation, they take predetermined actions (e.g., drop, cover, and hold on) while hearing a pseudoalarm. Then, they simply follow a predefined route to a safe location. Conventional earthquake evacuation training does not place participants in challenging situations (or does not require them to make difficult decisions) when evacuating. During a simulation of an earthquake amid heavy rain, for instance, participants must determine whether to evacuate to a shelter near a cliff, considering the risk of landslides. In other words, conventional earthquake evacuation training does not imitate actual earthquakes and should be more realistic in terms of simulated experiences.

Evacuation training has become more realistic owing to advances in information and communication technology. By depicting the arrival of a tsunami triggered by a catastrophic subduction-zone earthquake, for instance, a mobile application provides users with great engagement and training effect (Yamori & Sugiyama, 2020). Another mobile application with a geofencing framework makes evacuation training more realistic by presenting digital materials (e.g., a video and a single-choice question) that depict disaster scenarios (e.g., a fire and injured people) corresponding to specific areas (Mitsuhara et al., 2015). These mobile applications are utilized for outdoor evacuation training, their execution of which presents the following challenges:

- ★ It must ensure safety by preventing injuries and traffic accidents.
- ★ Because of severe weather, it cannot always be conducted (e.g., heavy rain).

Safety is a prerequisite for evacuation training, and simulating evacuation under different weather conditions can enhance training efficiency by providing simulated experiences of more complex evacuations. To overcome these challenges, virtual reality (VR) has been actively included in evacuation training to ensure safe execution regardless of the weather. Mobile application-based evacuation training is less immersive and engaging than VR-based evacuation training. For instance, a VR-based evacuation training system in which a participant evacuates from a fire accident in a 3D-modeled school while using a fire extinguisher (Mystakidis et al., 2022) was developed. Another system was developed to integrate various disasters, such as earthquakes, tsunamis, and fires, to enable simulations of disasters in more complex scenarios (Takeichi et al., 2018). Both systems mimic scenarios that are difficult to encounter in real life and are believed to provide participants with sufficient training benefits.

In recent years, the metaverse has garnered significant interest from several fields, including businesses, digital games, and education. The metaverse can be considered a vast virtual space where multiple users can communicate with others simultaneously as avatars, i.e., social/collaborative VR. VR has enabled the development of a cooperative training system for the efficient training of specific decision-making, wherein users interact with one another while responding to human-induced emergencies like explosions and shooting incidents in buildings (Sharma, 2020). Considering the possibilities of the metaverse, we developed a simple VR-based earthquake simulator in which a large earthquake suddenly occurs while users play a simple game in a virtual world. Observing users evacuate the scene revealed that, compared to a single user, paired users evacuated with caution but were confused (Mitsuhara et al., 2021). The findings sparked curiosity regarding how several individuals in a virtual world react to a sudden earthquake. Consequently, we proposed evacuation training in metaverse (ETM) and outlined the requirements for an ETM system focusing on earthquake evacuation (Mitsuhara & Shishibori, 2022). Accordingly, we prototyped the ETM system to meet these requirements.

This paper is organized as follows. Section 2 outlines the system design, including the requirements and a training model for evacuation. Section 3 describes how to develop the prototype while introducing the employed technology and software. Section 4 summarizes this study and outlines areas for further research.

2. System Design

The metaverse does not yet have fully acceptable definitions and standards. For instance, economic activities by users are required in certain metaverse services (such as Second Life) but not necessarily appropriate depending on the purpose (e.g., education). Because the ETM system's primary goal is education, it is not required to support economic activities. Focusing on metaverse implementation technology, as a minimum requirement, an ETM system must enable several users to interact simultaneously in a vast virtual world.

2.1 Requirements

In addition to the fundamental requirements, the ETM system must meet the following criteria for earthquake evacuation training.

Requirement 1: A comfortable virtual world

The ETM system should permit users to spend time in a pleasant virtual environment as an extension or component of their daily lives. Comfort can contribute to enticing users. For example, when dealing with earthquake evacuation training for university students, the ETM system offers users (students) a 3D-modeled campus where they can attend classes and interact with their peers. Depending on the users, gaming features may enhance comfort. A comfortable virtual world accentuates the advent of an unexpected earthquake.

Requirement 2: High-fidelity virtual world

From the perspective of earthquake evacuation training, the ETM system's virtual world should be identical to the real world. This is because if the virtual environment is significantly different from the real world, the training effects (e.g., knowledge acquired in the virtual world) may not contribute to a successful evacuation in the event of a real earthquake.

Requirement 3: Sudden earthquake

The ETM system should induce a sudden (unexpected) earthquake in the virtual environment while allowing users to live comfortably without earthquake concerns. In the real world, earthquakes strike without warning. The ETM system can make evacuation training more realistic by suddenly transforming a normal environment into an emergency scene. In contrast to conventional evacuation training, in which an imaginary earthquake is announced before the training begins, the ETM system can transform a normal period into an emergency.

Requirement 4: Reflection

The ETM system should enable users to reflect on their evacuation (e.g., route and decision-making) after training to enhance the training effect. In addition, reflection encourages users to consider how they should respond to an actual earthquake.

2.2 Evacuation Training Model

The ETM system switches from normal to emergency time mode in response to a sudden earthquake (trigger). In emergency mode, users can decide whether or not to evacuate. If an evacuation is required, every user begins an evacuation as a participant in an evacuation exercise. The evacuation training includes evacuation and reflection phases. Figure 1 depicts the transition between normal and emergency modes, illustrating whether or not users evacuate.

(1) Evacuation phase

A participant moves to a safe location. While en route, participants can interact and occasionally evacuate together. Observing users act normally and not evacuating may cause a participant to underestimate the magnitude of the earthquake and stop evacuating. In a real earthquake evacuation, some individuals do not evacuate despite the impending danger. To make disaster scenarios more realistic, the ETM system allows users to avoid evacuating.

If a predetermined time elapses (i.e., if the evacuation time limit is exceeded), the ETM system switches from an emergency time mode to a normal time mode. In other words, it is the end of the evacuation training. The ETM system considers a participant a successful evacuee if the individual reaches the designated safe location within the allotted time.

(2) Reflection phase

Participants should reflect on their evacuation after the training. It is critical for users to visualize their evacuations based on the log data (such as route and speed) to objectively reflect on the evacuation, even though the reflection method has not yet been determined. Moreover, visualizing the evacuations of other participants will promote objective reflection.

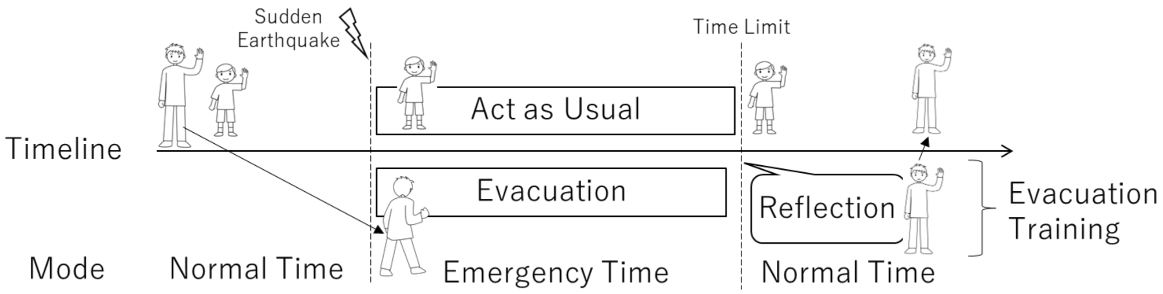

Figure 1. Evacuation training modes.

3. Prototype System

We adopted Unity as the prototyping environment because it enables efficient cross-platform software development (including VR) while utilizing the Assets Store, which contains several 3D models and scripts. We employed Meta Quest2, an immersive head-mounted display (HMD), as the principal VR device.

3.1 Multiple Users

Incorporating multiple simultaneous users is one of the ETM system's fundamental requirements and satisfies Requirement 1. Therefore, we adopted Photon, a network framework for Unity with stable connectivity even with a large number of connections, which enables the easy implementation of synchronous processing and essential metaverse functions (e.g., voice chat). We implemented these functions by adding several add-ons, including Photon Fusion and Photon Voice.

3.1.1 Implementing Simultaneous Users

Photon Fusion is utilized to enable multiple simultaneous user capability. First, the host computer (terminal PC) creates a room by connecting to the server on the Photon Cloud Network. When a room is created, the Photon Voice add-on is added to support voice chat within the room. The client computer then connects to the Photon Cloud Network and joins the room, allowing multiple users to enter the room simultaneously. This is accomplished by comparing the ID at the time of room creation to the ID at the time of joining. Currently, this ID is fixed. In addition, all objects set as Network Objects in the room are synchronized so that all client computers (i.e., users) can visualize the same environment.

The prototype system primarily renders static 3D models and only synchronizes the coordinates of the characters. Therefore, the processing is not computationally expensive, and it is expected that 2,000 users can simultaneously access the system (i.e., the maximum number provided by Photon). However, if the system moves 3D models such as chairs and desks during an earthquake, traffic between the host and client computers will undoubtedly increase. As a countermeasure, we want to reduce the number of polygons in the 3D models and the amount of data that must be synchronized.

3.1.2 Implementing a Nonplayer Character

Multiple users can access the virtual world and can engage in evacuation training using the ETM technology (i.e., take evacuation actions when a sudden earthquake). However, not all users enter the virtual world, and complex responses (e.g., panic and cognitive bias) produced by many users could not be simulated. Therefore, we implemented nonplayer characters (NPCs) that behave normally or evacuate during the emergency time mode. NPCs move based on the log data of previous users (i.e., movement data in or between buildings). When the time mode switches from normal to emergency, the ETM system searches the log data for the NPCs whose starting coordinates are closest to the present user, moves to those starting coordinates, and acts in accordance with the log data. We believe that these NPCs will make earthquake scenarios (evacuation) more realistic, even if there are few users. Figure 2 depicts a screenshot of NPCs moving in a room based on log data.

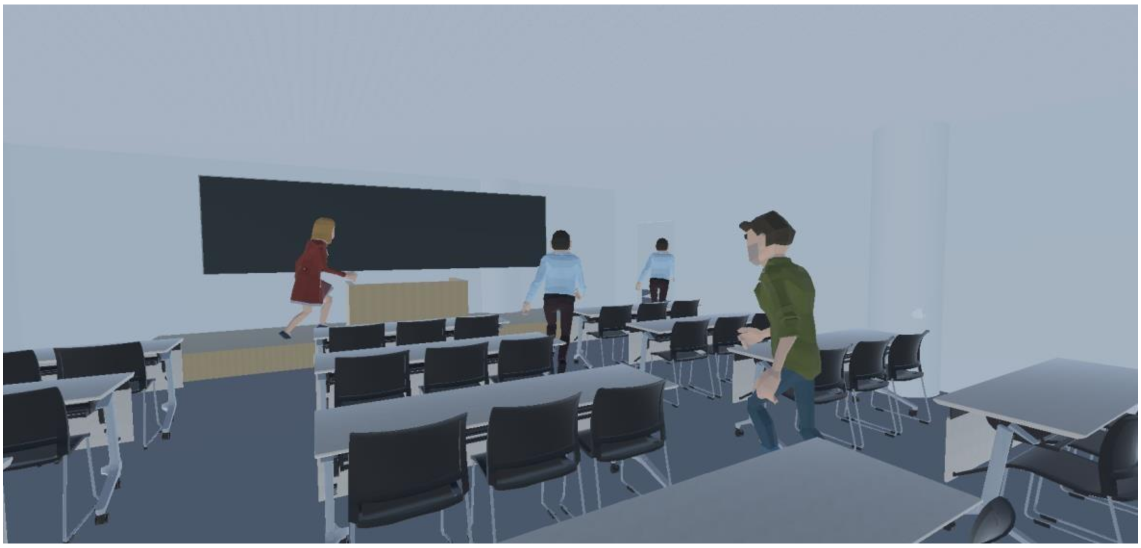

Figure 2. NPCs rendered in an emergency mode.

3.2 3D Modeling

The ETM system proposed in this study was employed for earthquake evacuation training on Tokushima University campus. To satisfy Requirement 2, we constructed a virtual world consisting of high-fidelity 3D models of the university campus using multiple software packages. The buildings were modeled in 3D using SketchUp Pro, a commercial 3D modeling application, and the outdoor landscape was modeled in 3D using Scaniverse, a 3D scanning application. Finally, the 3D-modeled outdoor scene was imported into Blender, a 3DCG creation software, for modification and integration. The 3D modeling process, including the application of each software, is outlined below.

3.2.1 Using SketchUp Pro

The process of creating a 3D model of a building consists of the following steps. Figure 3 shows a screenshot of the SketchUp Pro at the end of the fourth step.

1. Importing the building's architectural drawing data into SketchUp Pro.
2. Adjusting the 3D model to match real-world sizes.
3. Creating objects not available in the data (e.g., stairs).
4. Hollowing out the frames to create the windows and doors.
5. Pasting seamless images onto the walls, floors, and ceilings as the textures.

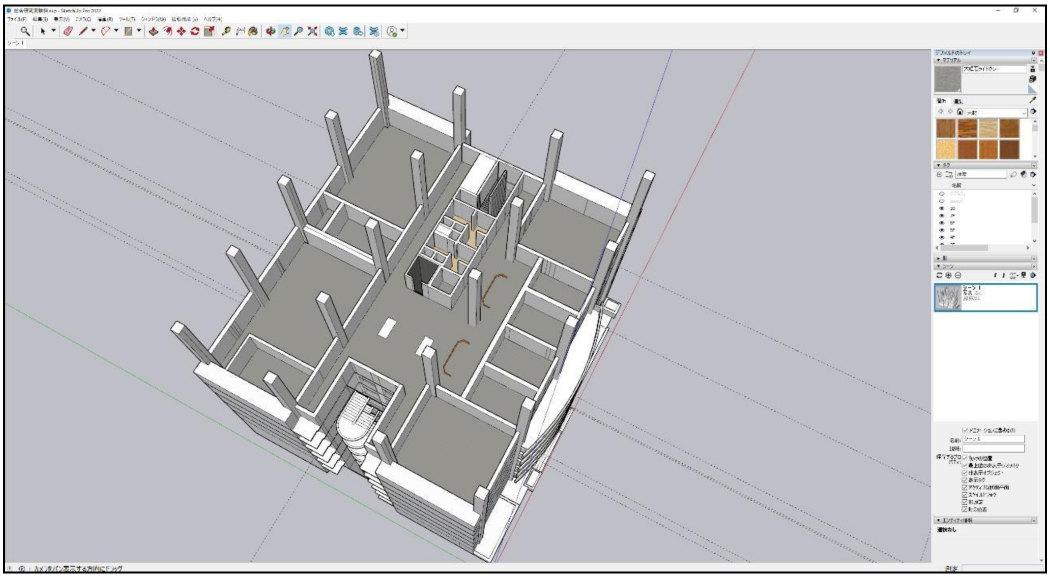

Figure 3. Scene view of the model in SketchUp Pro.

3.2.2 Using Scaniverse

Using photogrammetry, photorealistic 3D models of real-world objects have been created. Scaniverse is a popular photogrammetry program that works on a LiDAR sensor-equipped smartphone (such as iPhone 12 Pro) and simplifies 3D modeling using a visual prompt. Because 3D modeling of a large region at once would result in numerous distortions and breakdowns, we shot the campus in parts to eliminate the distortions and breakdowns. Figure 4 shows a screenshot of the university campus modeled in 3D by Scaniverse. For the efficient elimination, we have established the following guidelines.

★ Taking single shots. This is because shooting the same scene repeatedly would result in duplicate models.
★ All objects (areas) in a scene are shot once. Because complex shapes are difficult to repair when distorted.
★ Shooting a few objects that overlap with other models. When integrating models, it is necessary to match the locations of shot objects.

As depicted in Figure 4, the 3D model (i.e., the photorealistic part) was limited to scenes around the ground floor because the shots were taken from the ground. To model a tall building in 3D, we must shoot from a higher altitude by utilizing a drone or other equipment.

Figure 4. Scene view of the model in Scaniverse.

3.2.3 Using Blender

Scaniverse's 3D models (sections) cannot be utilized directly as the virtual world because of varying degrees of distortion. We utilized Blender to rectify the distortions and merge the individual 3D models. We corrected the 3D models based on the ground. If portions of the ground were duplicated, we removed one and shifted the vertices to level the height. If the 3D model is distorted, we cut only the distorted portions, reshape, and merge them into a single model. In both instances, we reshot those scenes if such corrections are too difficult to make. Merging the split 3D models is easy. Scaniverse creates 3D models using laser distance measurements and does not need to alter the sizes of 3D models, even if they are split or shot independently. Therefore, if appropriate corrections are made, the 3D models can be integrated by simply moving or rotating them.

Figure 5 depicts a before-and-after Scaniverse 3D model (section) of the corrected university campus. On the left side of this figure, the square area is distorted, whereas the area on the right was corrected.

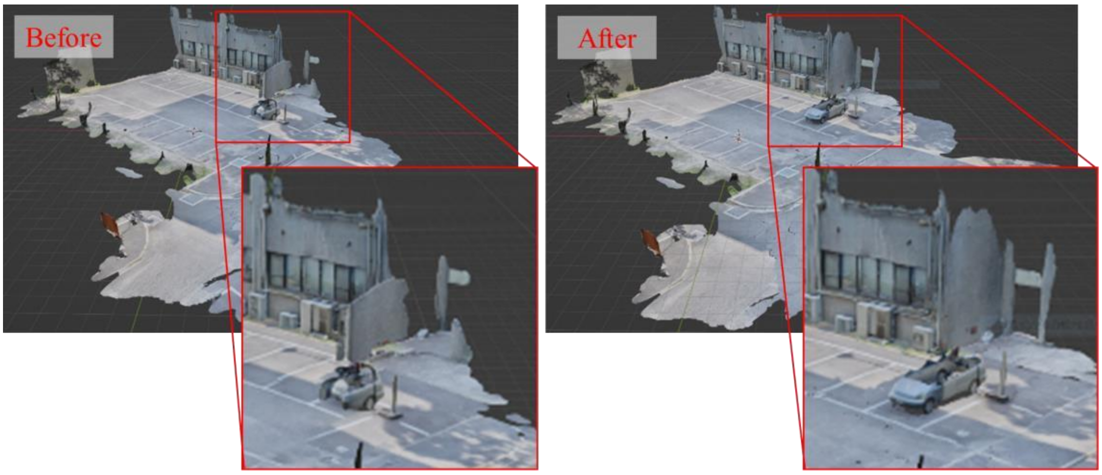

Figure 5. Before-and-after 3D model (created by Scaniverse) under correction.

3.2.4 Using Unity

The 3D models can be nearly completely generated using the above procedure (software usage). To effectively depict earthquake-induced disaster scenarios, however, extra modeling is required. Glass-paned windows and light objects should be broken or moved precisely by the tremors. We adopted Unity assets as 3D objects and placed them in the virtual world. On the basis of a physics calculation or assets' settings, the 3D objects could break or move.

3.3 System Flow

The ETM system performs evacuation training according to the steps outlined below. The third and fourth steps correlate to Requirement 3, whereas the sixth step corresponds to Requirement 4. Figure 6 depicts the evacuation training flowchart.

1. Opening a room and setting up a scenario

A host computer designated by the ETM system opens a Photon room and configures a user-selected or randomly selected scenario **2. Permitting entry into the room.**

Client computers (i.e., users) are allowed to enter the room. Nevertheless, the users are unaware of which scenario is implemented. The client computer downloads the scenario file from the host computer.

3. Obtaining earthquake information

The host computer obtains real-time earthquake information (in XML format) from the Japan Meteorological Agency.

4. Generating an earthquake in the virtual world

If an earthquake of magnitude 4.0 or more occurs in Japan (i.e., if such an earthquake is included in the received information), the host computer generates an earthquake equivalent to the real earthquake in the virtual world (i.e., shakes the virtual world) based on the scenario. It is worth noting that approximately one earthquake of magnitude 4 or higher occurred every week in 2021.

5. Expressing the destructive events caused by the earthquake

On the basis of the scenario, the destructive events caused by the earthquake (such as fire, debris, and injured person) are expressed in the virtual environment. In addition, events, including window shattering and the movement of light objects, are expressed based on physics computation or asset settings in Unity. When approaching a particular area, a user (a participant in evacuation training) will observe the event and will then be prompted to consider how to respond. Evacuation training (emergency mode) ends when the user reaches a safe location (e.g., a designated shelter) within the allotted time or fails to evacuate.

6. Providing reflection

Right after the evacuation training, the host computer prompts the user to reflect on the evacuation by observing the user's and/or other users' log data (e.g., evacuation routes and behaviors) and considers how the user should evacuate. The user may discover his/her own concept (or belief) for successful evacuation (e.g., “Evacuate without caring about injured persons”).

7. Setting up another scenario

The host computer randomly configures a new scenario in the room.

When a date/time-specified scenario is due, the host computer begins shaking the virtual world. In addition, step 7 is ignored because it is a one-time event.

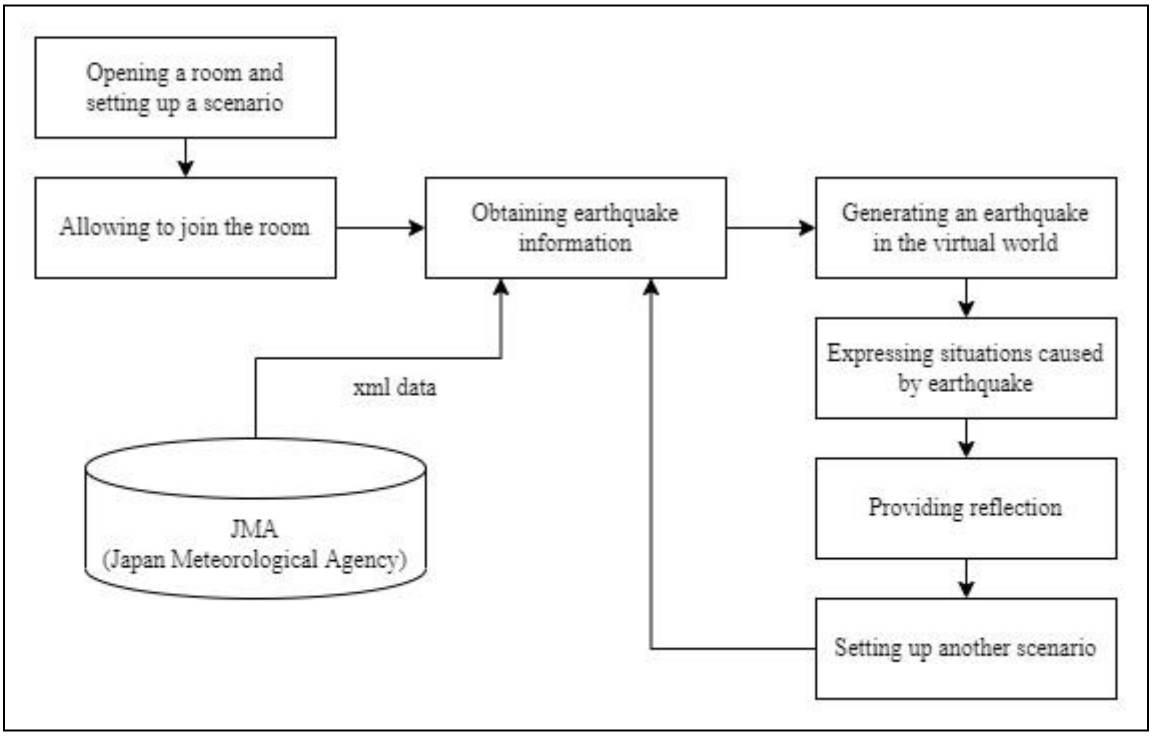

Figure 6. System flowchart.

4. Conclusion

This study discussed a proposed ETM prototype system designed for earthquake evacuation while demonstrating the requirements for evacuation training in metaverse. The prototype system adopted a more realistic and effective evacuation training by enabling multiple users (students) to simultaneously enter a high-fidelity virtual world (university campus). It is also equipped with sudden earthquake generation capability in the virtual world. In addition, the prototype system renders NPCs to compensate for the small number of simultaneous users. Multiple software packages, including SketchUp Pro, Scaniverse, and Blender, were utilized to generate 3D models.

Although the focus of this study is earthquakes, we believe that the established models and NPCs can be applied to other natural disasters. Typhoons, for instance, can be modeled in numerous virtual worlds through the audiovisual effects of heavy rain and strong winds (shaking trees). However, for disasters that do not occur in the modeled locations, it is better to reconstruct areas where they could occur to avoid unrealistic models. We also believe that new audiovisual effects (e.g., programmed animation) should be developed for various disaster scenarios (e.g., poor visibility and puddles in the case of heavy rain). To achieve realistic evacuation training, the scalability of the virtual world is also essential. In this study, we modeled a university campus as a relatively small virtual world, but generally, the metaverse is expected to provide a vast virtual world. Depending on the platform, a larger virtual world would increase human loads in 3D modeling and would make the ETM system more complex and computationally demanding (e.g., HMD and PC). Therefore, we should explore a virtual world that is sufficiently realistic and large enough for evacuation training.

To meet the requirements of the proposed model, a function enabling users to reflect on their evacuations (e.g., route) should be developed expeditiously. In addition, we must introduce attractive services that can entice users to routinely access the ETM system, where evacuation training can be suddenly executed by interrupting their normal lives.

Acknowledgments

The authors would like to thank Y. Ichino and S. Nagahama for their cooperation in this study. This work was supported by the Japan Society for the Promotion of Science Grants-in-Aid for Scientific Research (Grant No. 18H01054).

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