Play to Prepare: AR-Based Citizen Resilience

Zsolt Jankó[*]
HUN-REN Institute for Computer Science and Control (SZTAKI), Budapest, Hungary
zsolt.janko@sztaki.hun-ren.hu

Botond Hölbling
HUN-REN Institute for Computer Science and Control (SZTAKI), Budapest, Hungary
botetta@gmail.com

András László Majdik
HUN-REN Institute for Computer Science and Control (SZTAKI), Budapest, Hungary
andras.majdik@sztaki.hun-ren.hu

ABSTRACT

Our study presents a work-in-progress augmented reality (AR) application available on iOS and Android platforms that supports citizen preparedness through the simulation of various disaster scenarios. The system applies a serious game approach to provide an interactive, decision-centered learning experience for non-expert users. The aim of the application is to facilitate the acquisition of fundamental behavioral protocols, risk recognition skills, and appropriate response patterns within a safe and controlled environment. The proposed solution emphasizes experience-based learning embedded in the real environment, thereby increasing situational realism and the transferability of knowledge. The paper describes the technical architecture of the system and discusses in detail the challenges encountered during development. The system helps demonstrate that AR-based serious games can be an effective tool for strengthening citizen resilience and disaster preparedness.

Keywords

augmented reality (AR), serious game, disaster preparedness, interactive learning, citizen resilience

INTRODUCTION

Our world and environment are continuously exposed to various natural and human-induced disasters, such as fires, floods, earthquakes, and terrorist attacks. Emergency management plays a critical role in mitigating these risks, as prevention, preparedness (safety planning and training), response (evacuation and rescue), and recovery processes can reduce both the likelihood and impact of such events. Since reconstructing disaster situations under real conditions is difficult, and exposing participants to actual danger raises legal and ethical concerns, the past two decades have seen the increasing adoption of emerging technologies, particularly virtual reality (VR), augmented reality (AR), and mixed reality (MR), in this field. These technologies enable the simulation of emergency situations without causing real harm, thereby resolving moral conflicts and allowing strict control of variables during research.

The development of immersive technologies creates opportunities to enhance citizens' safety awareness and disaster preparedness in an experiential and interactive manner. This is especially important given that most citizens do not possess formal disaster management training, yet their initial reactions during unexpected events can significantly influence survival chances and the extent of damage. Traditional educational approaches (such as lectures, informational brochures, or drills) are often limited in their ability to model the complexity and stress of real decision-making situations. In contrast, AR-based solutions enable context-dependent learning embedded in the real environment while maintaining safe and controlled conditions.

The aim of our research is to present an AR-based application operating on iOS and Android platforms that simulates various disaster events and supports prior user preparation in the form of a serious game. The system is designed not

[*]corresponding author

for experts but for individuals and the broader public, focusing on acquiring fundamental knowledge applicable in everyday environments. The application does not provide real-time emergency support; rather, it aims to proactively develop decision-making skills, situational awareness, and knowledge of basic action protocols. The gamified approach is intended to maintain motivation, deepen the learning experience, and support long-term knowledge retention.

This paper presents the structure of the work-in-progress system and the related technological considerations. Our results contribute to understanding how emerging technologies and tools of social innovation can strengthen citizen resilience and enhance disaster preparedness.

RELATED WORKS

A promising direction in preparing the public for emergencies is the development of AR-based guides and safety instructions. Traditional guides are typically paper- or video-based; however, many people do not read printed disaster preparedness materials, do not watch longer videos completely, or find them difficult to interpret. In contrast, AR interfaces can improve knowledge transfer by embedding instructions directly into the user's environment. For example, De León Aguilar et al. (De León Aguilar et al. 2023; De León Aguilar et al. 2024) developed an AR application that uses machine learning object recognition models to identify household items (such as heavy furniture or electrical appliances) and display brief, one-line safety instructions directly next to them.

In the field of safety training, the concept of *Serious Games* (Abt 1970; Michael and Chen 2006) has become one of the most effective tools. These are games whose primary purpose is education and skill development rather than entertainment. VR-based serious games place participants in a virtual environment as if they were part of it, increasing cognitive learning efficiency and physiological alertness, which may result in better knowledge retention compared to traditional methods such as lectures or brochures. George and Oliva (George and Oliva 2019) comprehensively analyzed the application of such technologies in school disaster preparedness. They highlighted that VR and AR can transform learners from passive recipients into active participants, partly due to the technology's *wow factor*. During simulations, participants can experience the severity of disasters, i.e. through a life bar that reflects the consequences of unsafe decisions, thus receiving immediate feedback on their behavior.

Although VR solutions are generally more widespread than AR in safety simulations, many games can be adapted to AR due to technological similarities. De Fino et al. (De Fino et al. 2023) developed a VR-based serious game prototype that addresses multiple hazards, such as simultaneous heatwaves and earthquakes, based on the typology of Italian urban spaces. The system integrates quantitative simulation data from surface temperature maps (UTCI), falling debris distribution, and crowd movement to create more realistic decision-making scenarios in open urban spaces and enhance community resilience. Ussenov et al. (Ussenov et al. 2025) created a VR-based fire safety training system for residents of multi-story apartment buildings, interactively teaching proper use of fire extinguishers (PASS method) and safe evacuation route selection. Comparative analysis showed that immersive VR training resulted in significantly higher presence and knowledge levels compared to traditional video-based instruction.

AR can also be used to effectively simulate fire scenarios. Domgue K et al. (Domgue K et al. 2025) demonstrated that AR outperformed video-based training in knowledge retention and self-efficacy in fire extinguisher training and, although initially transferring less knowledge than VR, resulted in less long-term forgetting. Paes et al. (Paes et al. 2024) confirmed that AR-based building evacuation exercises more effectively increased intrinsic motivation and supported self-efficacy retention than video. A similar AR solution is described in the study of Catal et al. (Catal et al. 2020), in which a gamified mobile app uses interactive 3D models and animations in a university setting to teach the fastest escape routes and the correct actions to take in the event of a fire, earthquake, or chemical attack.

Although the application of XR technologies is highly promising, developers must also face several limitations. One of the most common issues is motion sickness, which may cause dizziness and nausea, particularly in fully immersive VR applications that completely obscure reality (Khanal et al. 2022; Zhu and Li 2021; Goyal et al. 2025; Calisanie et al. 2025). Moreover, a high degree of realism may induce psychological trauma in sensitive individuals, making appropriate psychosocial guidance and age restrictions essential. From a technical perspective, the primary challenges include high computational requirements, hardware costs, accurate indoor localization, precise recognition of real-world objects, and correct occlusion and alignment of virtual objects within the physical environment. Future research directions include integrating artificial intelligence (AI) for personalized learning, leveraging 5G technology for cloud-based simulations, and developing haptic feedback (touch-based sensing) to achieve even greater realism. Overall, augmented and virtual reality are not merely educational tools but are becoming integral components of disaster management strategies, empowering citizens to recognize hazards and respond more effectively.

GENERAL OVERVIEW OF THE SYSTEM

During the design of our system, several aspects had to be considered, which we detail below. One primary consideration was that we were not developing a standalone AR/VR application; rather, the mini-games would form part of a larger system. This larger system consists of a multi-step teaching process in which the topic is always linked to a specific location, such as the site of a previous flood, fire, earthquake, or other natural disaster. Users are guided through past events by a downloadable *virtual walk* application, named **IM-prepared** (HUN-REN SZTAKI 2026a), on their mobile phones, where a narrator explains what happened and how. Each walk consists of multiple stations, and upon reaching a given station, the application provides additional information or supports knowledge acquisition through playful test tasks. Our application is integrated into this process, where the test task, i.e., the serious game, appears to the user in augmented reality.

The considerations described above explain why, in our case, AR was the logical choice instead of VR. VR games are ideally played in closed, obstacle-free environments, where fully obscuring the outside world poses no safety risks and users do not have to worry about colliding with objects or people. During predominantly outdoor walks, using VR headsets would therefore be impractical. In contrast, applying augmented reality is a logical step if we want the game to appear within the given environment while taking environmental characteristics into account. It should be noted that these considerations also exclude the use of a HoloLens-2 device for displaying AR games. The HoloLens-2 has numerous excellent and highly useful features, such as the ability to scan the environment and create a 3D model of it, track eye and hand movements, and free both hands by being worn on the head, thus separating the input (hands) and display (glasses) devices similarly to VR headsets. However, it is not practical in our case. First, it functions less effectively outdoors in sunlight; second, an average user rarely leaves home for a walk carrying a HoloLens-2 device.

Accordingly, we designed our application, named **IM-prepared AR** (HUN-REN SZTAKI 2026b), to operate on smartphones that most people already carry, whether running Android or iOS. For Android devices, ARCore compatibility is required, meaning support for AR functions through the *Google Play Services for AR*. Fortunately, most well-known brands meet this requirement. In the case of iPhones and iPads, the latest versions all support augmented reality via ARKit. More specifically, all Apple devices equipped with an A9 processor or newer and running at least iOS 11.0 are capable of AR visualization.

In smartphone-based AR visualization, it is important to note, following on from a previous line of thought, that the display and input devices are the same, which must be considered in game design. In VR games, the handheld controller serves as the input device; for example, we can pick up an object from the ground while simultaneously directing our gaze elsewhere to determine where to throw it. In mobile AR, however, the phone must be used both to manipulate objects and to view the augmented environment containing virtual elements. These functions cannot be separated. It is therefore essential that this constraint be properly integrated into the game logic.

During development, our primary goal was to create a framework that enables AR games to be quickly and efficiently integrated into the virtual walks. In the following sections, we first describe the main characteristics of our framework and then present the details of the four mini AR games already developed using it.

THE FRAMEWORK

We used Unreal Engine (Epic Games 2025) to develop our system, a high-performance real-time 3D graphics engine developed by Epic Games. Originally designed for video game production, it is now widely used in film visualization, architectural design, simulations, and scientific research. The engine supports advanced rendering technologies that ensure a high degree of visual realism. Unreal Engine is particularly well suited for creating interactive, immersive applications and complex simulation systems, and it also enables AR development for both Android and iOS platforms.

The framework consists of multiple components. First, we developed a base application that handles functions independent of the AR mini-games, such as communication with the partner application, downloading the mini-games, etc. The name of this base application is the previously mentioned IM-prepared AR (HUN-REN SZTAKI 2026b). It launches the separately developed AR mini-games. Also part of the framework is a development pipeline that assists in the development of the AR mini-games. We will detail this below. The third part of the framework is an Unreal Engine plugin responsible for converting desktop games into AR (see Fig. 3). We will refer to the combination of these components as the framework hereafter. The goal of the framework is to allow mini-games modeled and created in Unreal Engine to be transformed through a few simple steps so that they integrate seamlessly both technologically into the partner application containing the virtual walks and logically into the walks themselves, linked to the appropriate location.

From the perspective of playability, the mini-games can be divided into two categories. The first category includes games that are not closely tied to a specific location and can be played anywhere where sufficient space is available around the user. An example is the resuscitation of a virtual person: regardless of the environment, we can imagine a person lying on the ground in need of assistance. The second category includes games that are closely linked to a specific location and can only be played there. For instance, simulating a flood or fire at a particular point in the city, where the tasks are related to surrounding objects and buildings.

For games in the second category, a digital replica of the environment, a so-called digital twin, may be required. Its primary purpose is to enable the AR application to orient itself in space and determine what is in front of or behind other elements. This is particularly important when an object or building occludes part of the scene. Consider, for example, an urban flood: the water should reach the wall of a building but must not extend into it, as this would immediately break realism (see Fig. 5). The smartphone cannot directly scan the building facade in front of us or determine its exact boundaries; therefore, we require its digital replica to compute these relationships. Aligning the real environment with the digital twin requires a calibration step at the beginning of the game; this will be detailed later. It should be noted that some iPhones are equipped with built-in LiDAR scanners alongside their cameras, designed specifically for 3D environment scanning; however, we did not use them in our system. The reason is that these LiDAR sensors are mainly effective indoors due to their limited range and reduced accuracy in sunlight. Moreover, we aimed to develop a solution that functions equally on Android and iOS devices, which would not have been possible if we relied on LiDAR.

Creating a digital twin is not straightforward. Professional 3D laser or optical measurement devices can be used and provide excellent accuracy; however, the process is time-consuming and might be costly, as it requires physical presence on site. The built-in LiDAR of an iPhone can also be used to create a 3D model, but it offers lower accuracy than professional equipment and, as mentioned, is not suitable for outdoor use. Furthermore, it also requires on-site presence. If high precision is not required, an alternative is the Cesium for Unreal plugin (Cesium GS, Inc. 2025), which enables real-time visualization and streaming of global-scale geospatial data (3D Tiles, photogrammetry, terrain models). The plugin provides precise georeferencing, high-accuracy coordinate management, and dynamic data loading, making it highly suitable for simulation, urban planning, defense, and digital twin applications. For example, Google Earth 3D city models can be imported, facilitating the development of games set in distant locations without the need to travel there. The accuracy of the 3D model is crucial: smaller objects such as trees or lampposts often lack sufficient resolution to support occlusion calculations, whereas building models are typically good enough to determine which parts of the visualization appear in front of or behind them.

Developing an AR mini-game

Figure 1 illustrates the steps followed during the development of the mini-games.

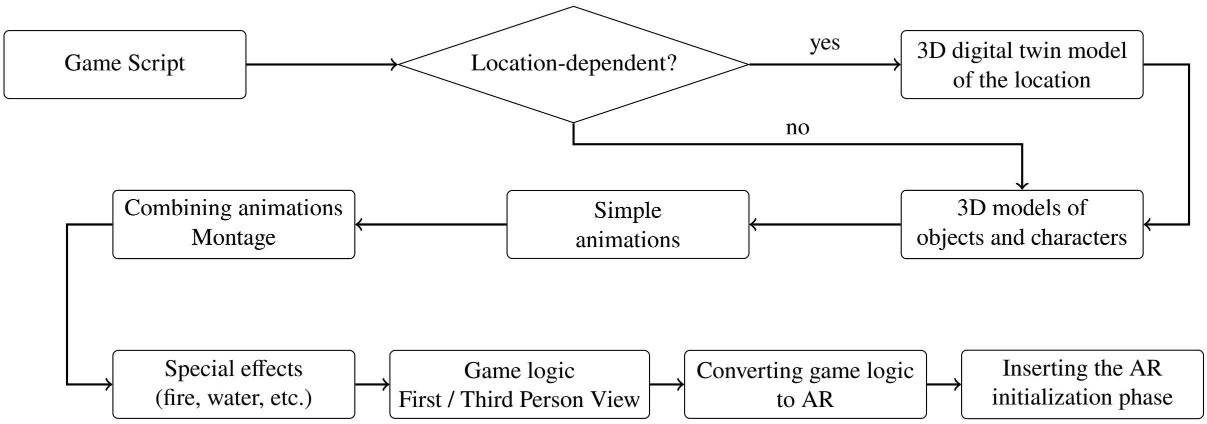

Figure 1. Stages of developing an AR mini-game.

The script describes in detail the sequence of the game, what appears on the screen at each step, what tasks the player must complete, and which tools are available for this purpose. It is prepared with the highest possible level of detail, similarly to a film production script.

If a location-dependent AR game is being developed, the next step is to create the 3D digital twin model of the location. The tools described earlier are available for this purpose. The level of detail of the 3D digital twin always depends on the specific game: in some cases, smaller objects such as benches or statues must be modeled precisely, while in others it may be sufficient to represent building facades with simple planar surfaces. More detailed 3D models may require significant post-processing after scanning, including the removal of non-manifold elements, cleaning, decimation, smoothing, etc.

Scenes typically contain additional 3D models as well. These models can be created directly within the Unreal Engine editor, or external software such as Blender (Blender Foundation 2025) can be used. Numerous online repositories also provide suitable models. In recent years, artificial intelligence systems capable of generating 3D models based on text prompts have also emerged. However, in this field AI still has considerable room for improvement.

During gameplay, 3D models may also move, particularly in the case of human characters. Animating these models represents the next step. Blender, mentioned earlier, is an excellent tool for creating animations. In addition, databases have been developed for certain types of human motion, where movements can be transferred to arbitrary human character models. One of the best-known online databases of this kind is Mixamo (Adobe Inc. 2025).

If simpler movements must be combined into more complex animations, this can be accomplished directly within the engine. Unreal Engine provides powerful tools for managing and blending animations. Animation blending can be implemented using Animation Blueprints and the AnimGraph, where different movements, such as walking, running, or jumping, can be smoothly combined through the Blend Space functionality. Furthermore, the Montage system enables the creation of complex, event-driven animations, such as sequences of character interactions, where different segments can be handled as separate sequences and their timing, weight, or triggered events can be fine-tuned. Montages are particularly useful for gameplay mechanics, as they allow animations to be divided into multiple sections, easily interrupted, or overridden by other animations without breaking the entire motion sequence (see Fig. 2).

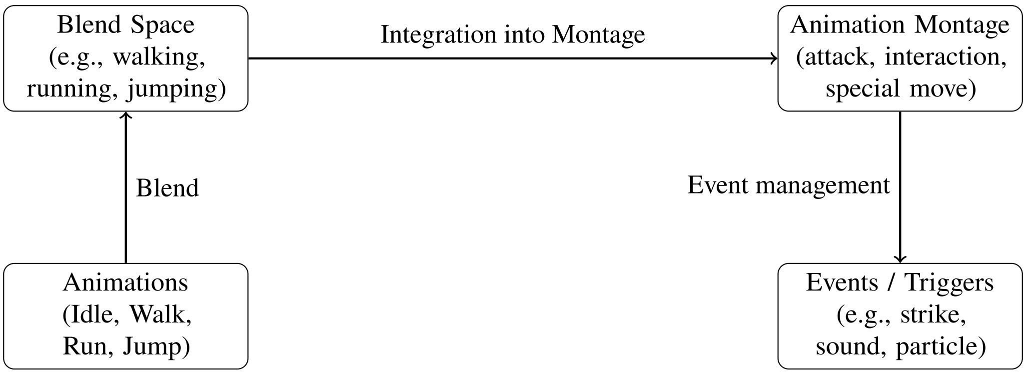

Figure 2. Stitching animations and creating montages in Unreal Engine.

When simulating disaster scenarios, various visual effects are often required. Within Unreal Engine, the primary tool for this purpose is the Niagara VFX system, which allows the dynamic creation and fine-tuning of particle-based effects such as fire, smoke, explosions, or weather phenomena. Niagara features a visual programming interface, enabling developers to edit particle behavior, lifecycle, movement, and interactions using node-based logic. Additionally, the engine includes the Material Editor and Post Process Volumes, which can be used to create and combine specialized materials and post-processing effects (such as bloom, motion blur, or color grading) with Niagara particles. Numerous plugins have been developed to further enhance visual quality in Unreal Engine; however, when developing AR applications for smartphones, it is essential to ensure that effects remain lightweight. Otherwise, frame drops and stuttering may occur, significantly reducing the sense of realism. From this perspective, an excellent extension is FluidNinja LIVE developed by András Ketzer (András Ketzer 2025), which performs reliably on mobile devices in augmented reality environments.

Now that all building blocks are available, the game logic can be assembled based on the script. Testing games under development is significantly easier if they are not initially created directly for AR but instead use First Person View or Third Person View modes. In this case, the game can be launched directly within the editor without compiling it to a device, which greatly accelerates testing and debugging processes. Once the game logic has been completed and thoroughly tested in the editor, it can be converted into AR. To facilitate this process, we developed an Unreal Engine plugin that adds a panel to the editor. By following the necessary steps within this panel, an AR version of the game can be generated within minutes. The plugin panel is shown in Fig. 3.

The AR version of the game differs from the desktop, editor-playable version primarily in that an initialization phase is required at the beginning to define how the virtual world aligns with the real environment. This is referred

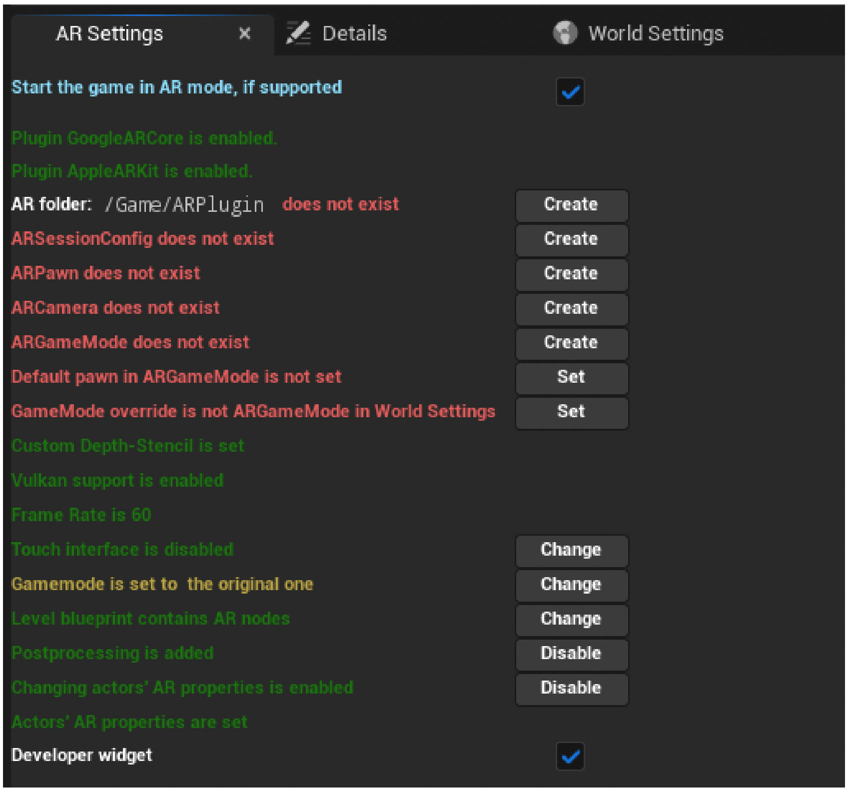

Figure 3. The plugin panel for AR conversion in the Unreal Engine editor.

to as the AR initialization phase, for which multiple solutions are possible. In one of our games, the device camera must be directed toward the ground; after detecting a surface, tapping on the screen determines where the virtual objects are placed. In another game, a bounding box is drawn around the scene, and by moving the device, users position this box to define where they want the events to appear. In a third game, which takes place in a narrow street, the two building facades enclosing the street must be aligned with schematic overlay bands. In the fourth case, a specific building must be placed within a circle displayed on the screen. The different AR initialization methods are illustrated in Fig. 4.

Automatic solutions for AR application initialization also exist, where the user only needs to scan the environment with the phone, and the system automatically recognizes it and aligns the real and virtual environments. A general solution that previously worked on both Android and iOS was Microsoft Azure Spatial Anchors, a cloud-based service that enabled persistent and cross-device synchronized storage of spatial anchor points in AR applications. This allowed the creation of augmented reality experiences in which virtual objects remained fixed to the same physical location across different devices and sessions. Unfortunately, Microsoft discontinued this service in November 2024. A possible alternative on iOS is ARWorldMap, an ARKit object that allows the environment mapped by the device to be saved and later reloaded in the same state. The WorldMap contains spatial point clouds, anchors, and positions of AR objects linked to the environment, thereby preserving spatial consistency across sessions. By default, the WorldMap is stored locally on the device; to share it across devices, it must be saved in the cloud and appropriate access must be provided through the application. A similar solution for Android is Persistent Cloud Anchors, part of ARCore, where saved data are automatically stored in the cloud. In this case, the application must simply obtain the UUID identifying the stored data. Although both solutions were integrated into our system, field testing showed that the stored data did not accurately represent the environment, and upon reloading did not result in precise alignment. In AR applications, even small misalignments can significantly degrade quality. Moreover, if the scene is visited at a different time of day than when the data were saved, achieving accurate alignment becomes even more challenging. For these reasons, we currently do not use this solution in our games.

In this context, we also mention another issue encountered during development. We intended to create a scene depicting a district, a square, and several surrounding streets that had been flooded nearly two hundred years ago when a river overflowed its banks. Historical records indicated the water level, and since the square includes a three-meter-high terrace, we planned to present the scene from an elevated perspective to show how the environment

Figure 4. Various AR initialization methods.

might have appeared during the flood. (Demonstrating a flood at street level, with water up to one's neck, is not particularly effective.) The problem arose because trees surrounded the terrace. In winter, when the trees were bare, they did not significantly obstruct the view, and it was barely noticeable that they stood in the water. In spring, however, when they turned green and grew dense crowns, they occluded nearly everything, rendering the entire scene unrealistic. This effect is clearly visible in Fig. 5. Creating detailed 3D models of the trees would not have solved the issue, as trees grow and change shape over time, which would again result in incorrect occlusion. Consequently, we were forced to abandon this scene.

Figure 5. Flood simulation in AR in winter and summer. The lush foliage of the trees significantly detracts from the realism.

Finally, regarding system architecture, it is important to note that mobile applications should be kept as small as possible, ideally within a few hundred megabytes. In 3D games, file size is crucial, as complex models and textures can quickly increase the size to several gigabytes. To prevent the base application from growing dynamically as additional games are added, we separated the core application containing the program code from the content associated with individual games. As a result, the base application size remains around 200 MB, and before downloading and launching a mini-game, users can decide whether to proceed based on the required data size. Although 200 MB may still seem large for a base application, it includes the necessary Unreal Engine modules, which themselves occupy significant space.

MINI-GAMES

Below, we briefly present the four mini-games developed so far, primarily from the perspective of how they contribute to improving individual preparedness in disaster situations.

Cardiopulmonary Resuscitation - CPR

Objective: In the case of natural disasters, it may frequently occur that we encounter an unconscious person lying on the ground who requires assistance. It is essential to be familiar with the basic steps of chest compressions to maintain circulation until professional help arrives.

What can be learned: How to determine whether chest compressions are necessary, and the correct technique: proper positioning, hand placement, appropriate force, and rhythm.

What is measured: Whether the user knows where to place their hands and how to position them correctly. If the applied rhythm is incorrect, or the compressions are performed too forcefully or too weakly, the user loses points. The correct balance must be maintained for a specified duration; otherwise, the attempt is unsuccessful.

Initial experiences: Positioning and correct hand placement generally did not cause difficulties; however, many users initially struggled to find the proper rhythm. Repeated attempts helped improve performance, and the rhythm became increasingly accurate over time. Snapshot: Fig. 6.

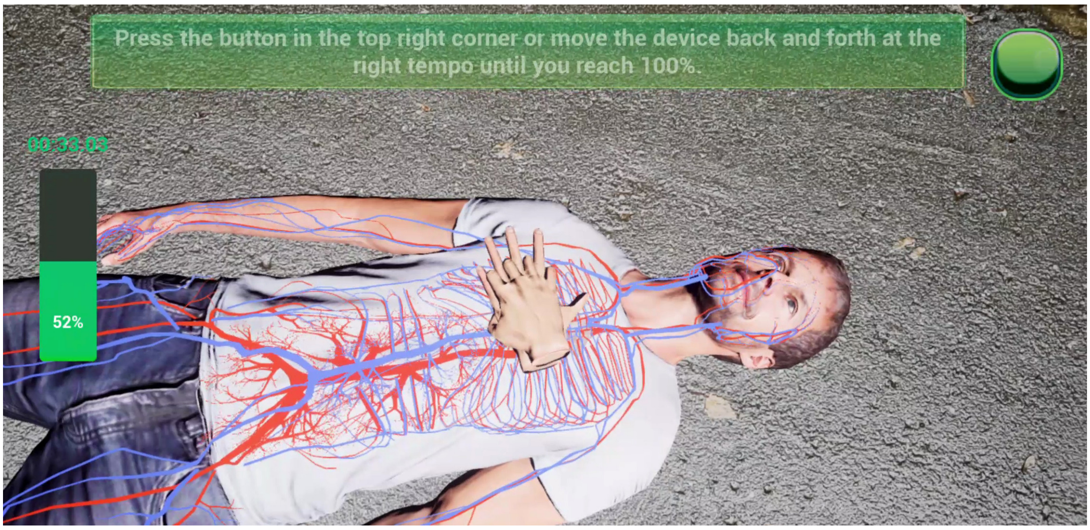

Figure 6. Snapshot from the AR mini-game on cardiopulmonary resuscitation.

Fire Incidents

Objective: Three different types of household fire scenarios are presented. In each case, a different material is burning. It is important to know which extinguishing method is appropriate for each type of fire.

What can be learned: In certain fire situations, using conventional extinguishing techniques, such as water, may cause even greater damage if applied incorrectly. The game also teaches the proper use of fire extinguishers, following the PASS method (Pull, Aim, Squeeze, Sweep).

What is measured: Whether the user selects the appropriate extinguishing technique and applies it correctly. In one scenario, a time limit is imposed; if the user waits too long, the fire spreads further.

Initial experiences: Users did not always select the optimal solution on the first attempt, but most succeeded on their second try. In our questionnaire-based evaluation, we will also assess whether users were previously familiar with the PASS method and whether they successfully acquired it through the game. Snapshot: Fig. 7.

Flood

Objective: This game is set at a specific location that was flooded several years ago. The user must construct a mobile flood barrier in a narrow street before the rising water reaches it.

What can be learned: Beyond traditional sandbags, modern techniques exist that provide rapid solutions in the case of smaller floods.

What is measured: Whether the user is able to complete the mobile barrier with the required elements within the given time frame. The elements must be moved and rotated to fit properly into place.

Figure 7. A snapshot from the AR mini-game depicting fires.

Initial experiences: Manipulating the objects initially posed difficulties; therefore, we included a practice phase in the game. A key challenge may have been that users are accustomed to interacting with 3D objects on mobile devices by dragging them directly with their fingers. This is common practice in touchscreen video games and many AR applications. In our game, however, we implemented a different interaction method: when a virtual object comes into focus at the center of the screen, touching anywhere on the display lifts it from the ground and holds it at a fixed distance from the user (e.g., two meters). When the touch is released, the object is dropped and falls to the ground. Since the object always remains at a fixed distance from the user, it can only be moved by physically walking to the desired location. We chose this interaction method instead of the conventional one to avoid allowing objects to be manipulated while standing still, which would not fully exploit the possibilities inherent in AR and would resemble a standard video game. Snapshot: Fig. 8.

Figure 8. A snapshot from the flood AR mini-game.

Forest Fire

Objective: This game also takes place at a specific location where a severe forest fire occurred several years ago. Here, AR primarily serves visualization purposes, simulating the fire so that users can immerse themselves in the situation of having a forest fire nearby.

What can be learned: A forest fire should not be fought alone. It is unlikely to succeed. It is important to assess the risks, call for help, and move to a safe location as quickly as possible.

What is measured: While observing the fire in the background, the user must complete a series of questions assessing situational awareness and appropriate decision-making.

Initial experiences: No evaluation results are yet available for this game, as testing is still ongoing. Snapshot: Fig. 9.

Figure 9. A snapshot from the AR mini-game simulating a forest fire.

CONCLUSION

In this paper, we presented a work-in-progress system aimed at using augmented reality to enhance public knowledge regarding responses in disaster situations. The application is designed for smartphones and tablets and can be used on any Android or iOS device that supports augmented reality (ARCore or ARKit). The base application is currently available in the respective app stores (HUN-REN SZTAKI 2026b). Individual mini-games can be downloaded separately if the user decides to do so based on the amount of data available. Currently, four types of AR mini-games are available, and we plan to expand the collection to cover additional hazard scenarios. The actual effectiveness of the games will be evaluated through questionnaire-based assessments, which will be conducted in the next phase of the project.

ACKNOWLEDGMENT

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Grant Agreement No. 101121134. The authors thank HUN-REN Cloud (Héder et al. 2022) for providing support for the project.

REFERENCES

Abt, C. (1970). *Serious Games*. Viking compass book. Viking Press.

Adobe Inc. (2025). *Mixamo*. https://www.mixamo.com.

András Ketzer (2025). *FluidNinja LIVE*. https://www.fab.com/listings/80fcf53e-49f7-4635-a71c-ba81280c6618.

Blender Foundation (2025). *Blender*. https://www.blender.org.

Calisanie, N. N. P., Sansuwito, T. b., Dioso, R. I., and Lindayani, L. (2025). "The Impact of Virtual Reality Simulation Training on Earthquake Preparedness Knowledge and Practices Among Rural Volunteers in Indonesia: Quasi-Experimental Repeated-Measures Study". In: *Journal of Medical Internet Research* 27, e74108.

Catal, C., Akbulut, A., Tunali, B., Ulug, E., and Ozturk, E. (Sept. 2020). "Evaluation of augmented reality technology for the design of an evacuation training game". In: *Virtual Reality* 24.

Cesium GS, Inc. (2025). *Cesium for Unreal*. https://cesium.com/platform/cesium-for-unreal/.

De Fino, M., Tavolare, R., Bernardini, G., Quagliarini, E., and Fatiguso, F. (2023). "Boosting urban community resilience to multi-hazard scenarios in open spaces: A virtual reality – serious game training prototype for heat wave protection and earthquake response". In: *Sustainable Cities and Society* 99, p. 104847.

De León Aguilar, S., Matsuda, Y., and Yasumoto, K. (2023). "Mobile AR Interface for Instruction-based Disaster Preparedness Guidelines". In: *14th International Conference on Mobile Computing and Ubiquitous Networking (ICMU)*.

De León Aguilar, S., Matsuda, Y., and Yasumoto, K. (2024). "Mobile Augmented Reality Interface for Instruction-based Disaster Preparedness Guidelines". In: *Sensors and Materials* 36.10, pp. 4585–4606.

Domgue K, L. I., Paes, D., Feng, Z., Mander, S., Datoussaid, S., Descamps, T., Rahouti, A., and Lovreglio, R. (2025). "Video see-through augmented reality fire safety training: A comparison with virtual reality and video training". In: *Safety Science* 184, p. 106714.

Epic Games (2025). *Unreal Engine*. https://www.unrealengine.com/.

George, M. and Oliva, E. (2019). *Immersive technologies & digital games for school disaster preparedness*. Research Paper. Global Disaster Preparedness Center.

Goyal, A., Raj, H., Venkatesh, S., Joshi, P., A., A., Krishna, P. S. S., and Margathrajan, D. M. (2025). "Virtual Reality Simulation for Natural Disasters Preparedness". In: *International Journal for Research in Applied Science & Engineering Technology (IJRTI)* 10, a510–a513.

Héder, M., Rigó, E., Medgyesi, D., Lovas, R., Tenczer, S., Farkas, A., Emődi, M. B., Kadlecsik, J., and Kacsuk, P. (2022). "The Past, Present and Future of the ELKH Cloud". In: *Információs Társadalom: Társadalomtudományi Folyóirat* 22.2, pp. 128–137.

HUN-REN SZTAKI (2026a). *IM-prepared*. https://play.google.com/store/apps/details?id=hu.sztaki.infoathand_bprepared, https://apps.apple.com/hu/app/im-prepared/id6468037424.

HUN-REN SZTAKI (2026b). *IM-prepared AR*. https://play.google.com/store/apps/details?id=hu.sztaki.mplab.IMpreparedAR, https://apps.apple.com/hu/app/im-prepared-ar/id6746214061.

Khanal, S., Medasetti, U. S., Mashal, M., Savage, B., and Khadka, R. (2022). "Virtual and Augmented Reality in the Disaster Management Technology: A Literature Review of the Past 11 years". In: *Frontiers in Virtual Reality* 3, p. 843195.

Michael, D. and Chen, S. (2006). *Serious games : games that educate, train, and inform*. eng. Boston, MA: Thomson Course Technology PTR.

Paes, D., Feng, Z., King, M., Khorrami Shad, H., Sasikumar, P., Pujoni, D., and Lovreglio, R. (2024). "Optical see-through augmented reality fire safety training for building occupants". In: *Automation in Construction* 162, p. 105371.

Ussenov, B., Temen, A., Srymbetov, Z., Yeshmukhametov, A., and Akhmetov, T. (2025). "Development of a Virtual Reality-Based Fire Safety Training System for Apartment Residents". In: *Astana IT University Journal* 23, pp. 63–77.

Zhu, Y. and Li, N. (2021). "Virtual and augmented reality technologies for emergency management in the built environments: A state-of-the-art review". In: *Journal of Safety Science and Resilience* 2.1, pp. 1–10.