Pre-disaster Training for Firefighters Using Augmented Reality: Hologram Characteristics

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ABSTRACT

The utilization of Augmented Reality (AR) holograms in firefighters' training presents a significant opportunity for the acquisition of first responders' practical skills. Nevertheless, given that AR represents a nascent and evolving technological paradigm, its integration within the framework of the crisis management cycle has not yet been firmly established. We analysed three hologram characteristics: dimension, scalability, and interactivity and report on the results of using five holograms (one 2D and four 3D) in a training application FightARs. The holograms were tested among in-service firefighters and commanders with the purpose of improving their knowledge in pre-disaster traffic accident training involving hazardous materials. The results indicate that QR-code scanning to open non-interactive non-scalable holograms can be used effectively to integrate holograms into physical training environments. A full-scale holographic scene is useful for training situation awareness. We propose that 3D non-interactive scalable or non-scalable holograms should be used to exercise practical skills. The paper emphasizes the necessity of extensively testing and incorporating AR into the training of first responders prior to its application in the response phase of crisis management.

Keywords

Augmented Reality (AR), Hologram types, FightARs, Holographic scene, firefighters' training

INTRODUCTION

Historically, a variety of methods have been employed to enhance the training process through the visual presentation of information. Many technologies are used to create and display 3D visual content (Ahmad et al., 2021) and one of the most important 3D display technologies is an Augmented Reality (AR) device which allows to augment a three-dimensional virtual element into the real world (Rauschnabel et al., 2015) such as HoloLens 2. The utilization of AR in firefighters' training presents a significant opportunity for the acquisition of practical skills. Looking ahead, it is anticipated that augmented reality (AR) devices will become more cost-effective, reliable, and proficient in data management, while Wi-Fi technology is expected to achieve greater speeds. Artificial intelligence (AI) could be effectively employed for the rapid analysis of multimodal data derived from algorithms and sensors. Nevertheless, the integration of augmented reality (AR) technology within the crisis response phase is currently ready solely for training purposes and remains a target yet to be achieved in real-world applications. In the project RESCUER, a smoke-removal algorithm, an object detection model and AR HoloLens 2 application were used for visualisation purposes (Gkika et al., 2023). In the FASTER project, the same device was used to improve situation awareness by marking the points of interest (Christaki et al., 2022). In this project, the experiences created with HoloLens 2 were called "a real Mixed-Reality experience" (ibid p. 758). The RESCUER project was designed to enhance the capability to locate individuals in smoky environments, while the FASTER project focused on identifying points of interest on maps and employing HoloLens in the real world. These aforementioned applications developed for first responders were meant to be used in the response phase of crises. Notwithstanding, the learning experience was not the main focus of these studies. The authors simply noted that the HoloLens applications required some initial practice by the majority of participants, due to the participants lack of prior experience with the developed technology (Christaki et al., 2022).

To successfully integrate any new technology into educational settings, three critical dimensions must be considered: the technology, the pedagogical approach, and the learning content (Kurt, 2019). Firefighters use simulation-based training extensively (Polikarpus et al., 2021), and the trainer's role of choosing a suitable pedagogical approach for virtual simulation-based training has been highlighted (Keskitalo, 2022; Polikarpus, Luik, et al., 2023). If trainers are unable to operate the technology and have not acquired the necessary vocabulary for instructing trainees, they might experience difficulties in conducting situated learning (Herrington & Oliver, 1995). Furthermore, "hologram technology differs from augmented reality in several aspects, as the way in which the three-dimensional images are created and the properties of the images itself (Elmahal et al., 2020)". Even if the use of holography in education has a positive trend in last five years, the studies are limited to small age groups, subjects, and the technological support needed to achieve learning outcomes are still unclear (Yoo et al., 2022).

Therefore, it is important for the ISCRAM community and the trainers of first responders to further study using new technologies during training so that they could be more effectively used to prepare for future crises. Preparedness activities, primarily training and public education within pre-disaster hazard management, are crucial for enhancing survival during disasters when effectively implemented (Bullock et al., 2013). Processes like preparing, teaching, simulating, and training are essential for an efficient transfer from the post-disaster phase to the pre-disaster phase in the crises management cycle (Aligne & Mattioli, 2011).

This paper is organized as follows: initially, we present the related work on using AR in education and describe hologram characteristics. After this, we present the holograms used in the FightARs project in four case studies. the ensuing section, we explore the integration of HoloLens 2 hologram types with different phases of crisis management, suggesting the appropriate hologram for each crisis management phase.

RELATED WORK

Mitigation, preparedness, response and recovery are seen as the four classical phases of disaster management (Bullock et al., 2013). To emphasize the significance of context, the initial two phases have been combined into a single phase, resulting in three phases (see Figure 1): pre-disaster, response, and post-disaster (Aligne & Mattioli, 2011). To the best of our knowledge, the potential of firefighters using AR has so far been focusing on the response phase of crises (Christaki et al., 2022; Gkika et al., 2023), as this is where it has the biggest potential to save lives by improving the situation awareness of first responders. Nevertheless, the training needs of the users of AR were not studied.

In education, three-dimensional (3D) learning environments are used as it gives a possibility to view a given problem from different perspectives and include virtual activities that are difficult to practice safely in real life (Reisoğlu et al., 2017). Virtual reality (VR) is the use of computer-based simulation enabling a user to interact with a 3D synthetic environment which often simulates a real world or imaginary scenario (He & Zhu, 2022). VR offers possibilities of making trainings both safer as well as repeatable when compared to other methods that have proven to be expensive or pose considerable risks to firefighters (Heldal & Wijkmark, 2017; Polikarpus et al., 2019). Virtual simulation-based training has been shown to be an effective way to train dynamic decision-making across all levels of crisis management (Lamb et al., 2021) and immersive VR based simulation for training firefighting skills are being developed for simulated fire extinguishing (Wijkmark et al., 2021, 2022). However, a significant limitation of virtual simulation-based training, whether utilizing virtual reality or computer-simulated videos, is that trainees are immersed in a virtual environment rather than interacting with the real world. Consequently, trainees are unable to practice their skills in virtual reality with the same level of practical application as they would in real-life scenarios.

AR mainly consists of the real world and is supplemented by virtual images generated by a computer, (Ma & Choi, 2007) and it has not gained widespread adoption in firefighter training programs (Hofmann & Polikarpus, 2022). A *hologram* is a special type of 3D object which can be seen with the eye and there are various types of hologram technologies (Elmahal et al., 2020). Yoo et al. (2020) propose that contemporary applications of holography in educational settings could be categorized into three distinct types: (a) pseudo-holograms, (b) analog holograms, and (c) digital holograms and they attributed all AR and VR device-assisted holograms into digital holograms. Işik, (2014) introduces the concept of "dimensional holograms," defining a 1D hologram as a linear recording along one of the x, y, or z axes. Conversely, a 3D hologram is described as a luminous, transparent, three-dimensional image that is visible from all viewpoints and can be physically circumnavigated. Consequently, all studied holograms in this paper are 2D or 3D digital holograms produced with augmented reality glasses Hololens 2. Furthermore, holograms generated by the HoloLens 2 invariably contain data along the x, y, and z axes. As a result, merely distinguishing between 2D and 3D holograms does not provide software developers with sufficient information to accurately classify the type of hologram.

Holographic-type communication (HTC) will facilitate the transmission and interaction with holographic data across a network from remote locations (Clemm et al., 2020). HoloLens 2 already enables HTC when the “Dynamics 365 Remote Assist” app is used (Microsoft, 2024). For HTC, it is crucial to understand the specific characteristics that the transmitted holograms should possess. During the study of the FightARs application, the digital twin served as an object that allowed firefighters to interact with it virtually (The Fightars Partnership, 2021), whereas the scientific definition of a digital twin is that it “is a virtual representation of a physical object or process capable of collecting information from the real environment to represent, validate and simulate the physical twin’s present and future behaviour (Botín-Sanabria et al., 2022, p. 1)”.

Prior research did not give any suggestions on which hologram characteristics help to train firefighters knowledge and skills using HoloLens 2. Consequently, end-users of HoloLens 2, such as firefighters and trainers of first responders, lack the ability to specify to developers the types of holograms required for future training sessions, assessments, or the response phase to improve knowledge and skills in crisis management.

HOLOGRAM CHARACTERISTICS AND DATA COLLECTION

The FightARs project aimed to introduce a new AR device HoloLens 2 to the training of firefighters and rescue incident commanders (FightARs, 2022). We aim to answer the following research question: “**what type of holograms supports firefighters' knowledge and skills' training in which crisis management phase?** We categorized the holograms used in the FightARs' application based on three characteristics: *dimension* (2D or 3D), *scalability and interactivity* (see Figure 1 and Table 1). In our case study we linked HoloLens 2 hologram characteristics and firefighters' preparedness to use AR in the crisis management cycle taking account the current technological level in firefighters' training in Estonia.

For our case study, we used the results from four different empirical studies. All the HoloLens 2 holograms presented in this paper have been tested with success by 30 in-service first responders in fire stations in Estonia by students (Guž, 2023; Liping, 2023; Pärnamets, 2023; Rasva, 2023). The aims of the bachelor theses, FightARs testing methodology as well as the results are published online in the Estonian language (Polikarpus et al., 2023). In our case study we first look at the dimensions of holograms, we then analyse whether the holograms are scalable or not and thirdly, we considered whether the trainee could interact with the hologram or not (see Figure 1).

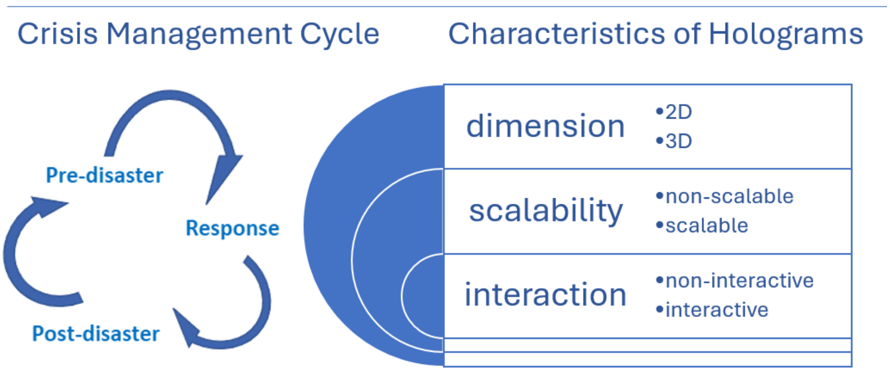

Figure 1. The characteristics of holograms and the crisis management cycle

AUGMENTED REALITY APPLICATION DESIGNED TO TRAIN FIREFIGHTERS: HOLOGRAM TYPES IN FIGHTARS

The FightARs application was developed within the FightARs project. HoloLens 2 augmented reality glasses were used (Figure 2), where the holograms were tested and integrated in addition to which educational materials were also created. The topics of educational materials covered: first aid, situation awareness, UN marking of dangerous goods and deactivation of an electric car. The FightARs application and its code, QR-codes, voice commands' guide, pedagogical guidelines and FightARs best practice guide can be downloaded from the project homepage (http://fight-ar.com/) free of charge.

Figure 2. HoloLens 2 augmented reality classes and their use (Photo by Stella Polikarpus)

The application was connected to a learning management system (LMS) (Figure 3). Figure 3 shows the connection of 2D (the blue menu on the left) and 3D holograms (see in the centre of the figure). The project homepage and LMS are published on a WordPress web-based platform. 2D holograms were linked to the LMS specific pages in the FightARs course (an example can be seen in Figure 3 on the right). Connecting the AR application with a web-platform through 2D holograms meant that the learning materials could be automatically updated.

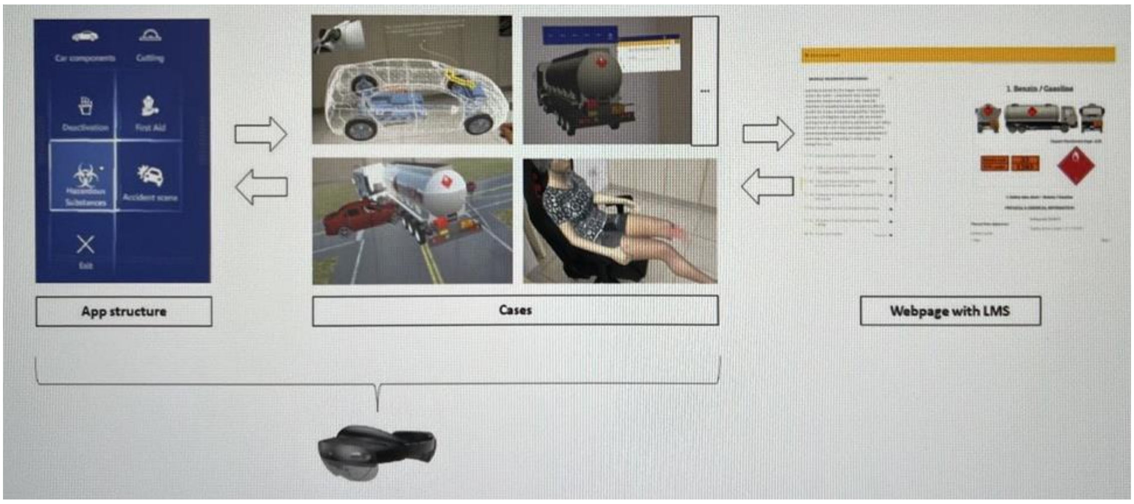

Figure 3. FightARs application connection to holograms and LMS (FightARs Partners 2023)

If the FightARs application is installed in HoloLens 2, the app icon could be found on the menu list (see Figure 4). In the first picture on the left we have illustrated the main menu of HoloLens 2. The right picture is the 3D hologram that pops up when FightARs application is "clicked" on in the main menu. The user needs to push the play button (Figure. 4 right) to open the 2D main menu of the FightARs application (Figure 5.).

Figure 4. FightARs application icon in HoloLens 2 menu (FightARs Partners 2023)

The FightARs application menu gives access to all learning content and holograms created in the project. To access these designated sections, referred to as 'chapters,' users were required to select them from the main menu of the FightARs application (see Figure 5).

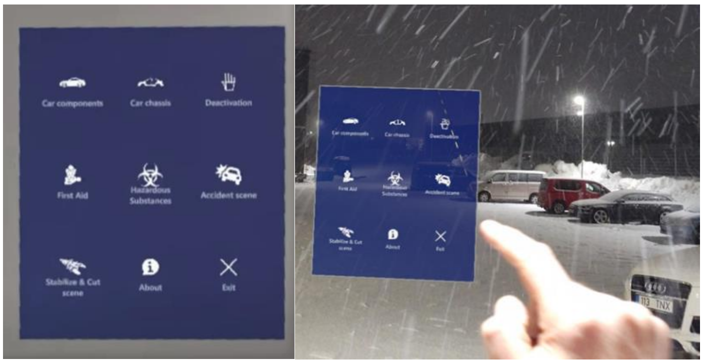

Figure 5. FightARs application menu (FightARs Partners 2023 and Liping, 2023)

First, we looked at the *dimensions of holograms*. In this paper, 2D holograms are holograms where the menu of the AR glasses is opened to move around in the application (e.g. Figure 5). Secondly, we identified if it is a *scalable hologram*, which implies that the user has the capability to independently modify the x, y, or z axis, or alternatively, adjust all axes simultaneously while maintaining consistent proportions (see the two upper photos from the case studies in Figure 3). If it is a non-scalable hologram, the user might be able to decide where in the physical room he/she wants the hologram to appear, but the user cannot reduce or increase its size (see the two lower photos indicating a woman and a collided truck in Figure 3).

The third important characteristic of a hologram is whether the user can interact with it or not. By *interaction*, we consider a hologram that the trainee can "click" on or in the future type something into the hologram and then the application checks the accuracy of the answer. Not every interaction with a hologram constitutes a digital twin, as the hologram may not simulate a real-life process. Instead, it could be designed to assess the correct sequence of the activities of the trainee (e.g. interaction in the form of a 2D hologram such as quizzes created using H5P). In FightARs two interactive holograms were used: car cutting and electrical car deactivation. These interactive 3D holograms were programmed inside the application to be responsive to the actions of the trainees and therefore can also be called digital twins. An overview of the dimensions, scalability, and interactivity of the FightAR's holograms and use cases are provided in Table 1.

Table 1. FightARs' hologram types, characteristics and use cases

Hologram types in FightARs	Dimen-sion	Scalable / non-scalable	Interactive / non-interactive	Description of use cases

2D hologram	2D	LMS window is scalable	Non-interactive or interactive e.g. H5P content	Used in the app to open LMS or application menus
3D non-interactive hologram	3D	Scalable	Non-interactive	Used to review firefighters' knowledge about UN hazard marking on a digital twin truck (Guž, 2023)
QR-code scan for 3D hologram	3D	Non-scalable	Non-interactive	Used to train triage of digital twin victims and first aid (Pärnamets, 2023)
Holographic scene	3D	Non-scalable	Non-interactive	Used to measure incident commanders' situation awareness with quantitative analyses of situation awareness on a digital twin accident site (Liping, 2023)
3D interactive hologram	3D	Scalable	Interactive	Used to train firefighters to respond to traffic accidents with digital twin electrical car (Rasva, 2023)

Non-Interactive Scalable Holograms

2D holograms linked to LMS in the FightARs app gave some freedom to trainers to tell a new story or give a new task with the same 3D hologram. This approach significantly enhances the efficiency of updating educational content, as it primarily involves modifications to the webpage, thereby reducing the necessity for extensive programming efforts. The only issue with this type of holograms is that HoloLens 2 needs to be connected to Wi-Fi, the connection must be stable, and the trainee must log onto the LMS. These 2D holograms could not be scaled, but they moved and some of them could be pinned in the air to fix their location in the physical room. As opposed to this, the windows of the LMS could be scaled. Rasva (2023, p. 33) notes that using the HoloLens 2 induced fatigue among users, suggesting that tasks typically performed on a LMS are more suitably executed on a flat screen device rather than reading lengthy text via 2D holograms associated with the LMS.

3D non-interactive scalable holograms were used to train firefighters' knowledge about the parts of an electrical car (see Figure 6) and for identifying the markings of trucks carrying hazardous material (see Figure 7).

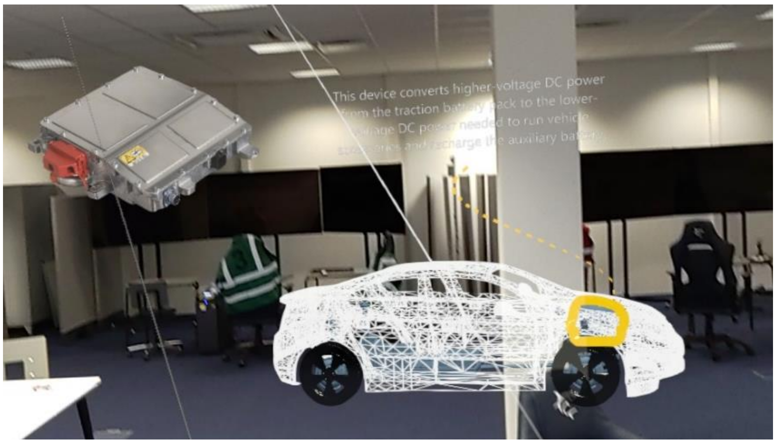

Figure 6. 3D digital twin scalable but non-interactive part of an electrical car

These holograms could be positioned, relocated, rotated anywhere within the room, and scaled to the authentic dimensions of a truck or passenger car. They were used to either gain new knowledge (Rasva, 2023) or review and assess existing knowledge and misconceptions trainees might have had (Guž, 2023).

Figure 7. 3D non-interactive hologram that can be scaled and moved (FightARs Partners 2023)

Non-Scalable Real-Size Holograms and QR-Code Scanning

QR-code scan to open 3D non-interactive hologram allowed to connect specific victim holograms to the physical training environment. In the study a variety of learning scenarios was created to train firefighters' and rescue incident commanders' first aid skills (Pärnamets, 2023). These holograms can be superimposed on dummies, allowing for the practical training of CPR skills, which is why they are non-scalable. These 5 holograms opened with 5 different QR-codes could be used simultaneously and create an accident with multiple casualties (see Figure 8). All these holograms were non-interactive holograms. However, web-based 2D LMS window was opened together with the hologram and their videos, H5P content or something else could be added for interactivity. It was interesting to open the hologram victim by scanning the QR-code in real life. After this, the scanning mode was kept active because sometimes the hologram could be moved in the physical room by moving the paper with the QR-code. If several holograms were opened at the same time, it was sometimes not possible for HoloLens 2 to process the situation well, after which the application crashed.

Figure 8. QR-code scan to open non-interactive 3D holograms. There are three victim holograms on the photo and above two victims head is LMS 2D hologram opened (FightARs Partners 2023)

Holographic scene (see Figure 9) is a term taken into use to describe non-interactive and non-scalable almost real-life sized 3D hologram that is a digital copy for the whole traffic accident scene (Liping, 2023). Navigation within a virtual reality environment is facilitated through the use of input devices such as joysticks, keyboards, gamepads, or other similar tools. Therefore, information collection from the VR scene for attaining situation awareness is different than in real life. To the contrary, a holographic scene allows to gather information similarly as in real life, through walking and getting new information. A holographic scene hologram can be overlayed with real cars and then practical skills of cutting the car can be practiced. In Figure 9, (see the left picture) the holographic scene is opened in a mat room indoors and in the right picture (see Figure 9) it is opened outside, where the holographic red car with holographic victims is overlaying a real-life red car.

Figure 9. Holographic scene is 3-D is almost real-life size hologram (FightARs Partners 2023)

Interactive Scalable Holograms

A 3D interactive and scalable hologram is the most difficult digital twin type of hologram to program (see Figure 10). However, when this type of hologram is overlayed with real life objects, very interesting mixed-reality experiences can be created for users. In the application FightARs there are two types of this hologram, one is to deactivate an electrical car (upper picture in Figure 10) and the other is to select correct tools to rescue a victim from the passenger car (see the picture below in Figure 10). To use HoloLens 2 and interact with the holograms, trainees needed prior training on how to use HoloLens 2 (Rasva, 2023). Another issue emerging from that study is connected to language. Namely, when translating content in the LMS into all languages is rather easy, then creating the whole HoloLens 2 application in different languages is rather time consuming as it needs to be programmed in different languages and afterwards reinstalled.

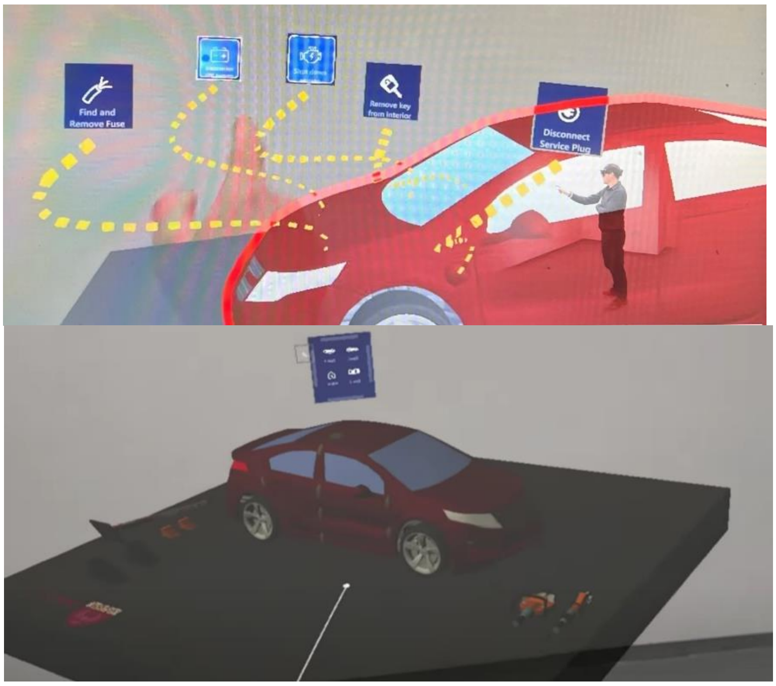

Figure 10. A 3D interactive and scalable hologram as a digital twin model created to interact with the actions of trainees (FightARs Partners 2023)

POTENTIAL USE OF AR IN CRISES MANAGEMENT TRAINING

We suggest that AR firstly needs to be taken into use during the pre-disaster phase. When firefighters and rescue incident commanders are accustomed to train with the AR application, they will have acquired practical skills to use HoloLens 2 like scaling and turning the holograms. If better internet connection were to be integrated into incident response vehicles, we believe that AR devices could be used in the response phase in the future as well. For example, we believe that communication efficiency could be enhanced with HoloLens 2. A commercialised product Dynamics 365 Remote Assist was tested during the FightARs project and was found to be useful to show others on the screen what the person wearing HoloLens 2 is seeing (see Figure 11).

Needless to say, the utilization of this tool necessitates the acquisition of a licensed program. Nevertheless, we see a big potential for AR and HTC in the response phase of crises, because the "caller" can have their hands free for emergency actions and the "adviser" can see the same visual as the caller. Simultaneously, the advisor is visible for the caller as a 2D hologram and clear audio is heard from the AR-glasses. In addition to this, calls from AR-glasses to AR-glasses are an option.

Figure 11. A trainee using HoloLens 2 vision is seen on screen in class through the Dynamics 365 Remote Assist software. HoloLens 2 could also be connected to screens using mirroring functions.

Post-disaster phase is about learning from real incidents. In the post-disaster phase, feedback from experiences is analyzed to improve the anticipation and forecasting of potential issues, identify risks, and revise established procedures (Aligne & Mattioli, 2011). Naturally, if AR is employed during the response phase, its usage should extend to the post-disaster phase, or at a minimum, experiences from its application should be gathered and the employed procedures, ethics, and equipment critically analyzed. In Table 2 we have brought together the crises management phases and studied hologram types.

Table 2. The connection of FightARs hologram types to crises management phases

Hologram types in FightARs	Phase	Examples	Knowledge and Skills
2D hologram	All 3 phases	Video calls, representation of sensor data, resource allocation, AI decision suggestions, recordings, photos, LMS and H5P in it, guides in pdf files etc.	Standard operational procedures or details of an equipment, or any other text or 2D visual information.
3D non-interactive hologram	In pre-disaster and response phases	Examples Figure 6 and 7. In response phase points of interests (POI) could be marked (Christaki et al., 2022).	To enhance knowledge of firefighters with 3D objects when composition of the object needs to be well understood or POIs marked in learning environment.
QR-code scan for 3D hologram	In pre-disaster and response phases	Example Figure 8. In response phase POIs could be marked (Christaki et al., 2022) using QR-codes and then information could be updated and read from the web.	To create any practical skills training scenario in training ground or to guide self-directed learning
Holographic scene	In pre-disaster phase	Example Figure 9.	Same as above, plus dynamic decision-making training
3D interactive hologram	In pre-disaster phase	Example Figure 10. digital twin.	Better to use VR or LMS, because skill to use HoloLens is need.

DISCUSSION AND FUTURE RESEARCH

AR has the potential to improve situation awareness and through that dynamic the decision-making of first responders (Christaki et al., 2022) and firefighters while smoke-diving (Gkika et al., 2023). However, to train staff to execute safe actions during incidents, the implementation of new technologies should start from the pre-disaster phase. We analysed AR digital holograms in the training of first responders. We wanted to find out what type of holograms support firefighters' knowledge and skills training in which crisis management phase. For this reason, we analysed three hologram characteristics: dimension, scalability and interactivity in the application FightARs.

In Figure 12 we present the hierarchy of these digital holograms. 3D non-interactive scalable holograms or 3D non-scalable real-size holograms like a holographic scene seem to be the best option to train practical skills, because they can be overlayed with physical objects, or the physical environment can be enriched with holograms using QR-codes. Besides training practical skills like cutting a car or sealing a leak, a holographic scene is a good way to train situation awareness and dynamic decision-making. However, programming these 3D models for AR is rather time consuming compared to VR. 3D interactive scalable holograms or digital twins are the hardest to program and to use. To use these holograms, trainees and trainers first need to learn the skill to use HoloLens 2, they need to get used to the specific movements required for each corresponding action and related processes. These practical skills should be learned by first responders during the pre-disaster phase only if AR technologies will be used in the response phase in the future. Otherwise, it merely consumes valuable training time.

We know from the FightARs project that HoloLens 2 offers a possibility to make video calls (Figure 11), record videos, take photos, scan or place holograms etc. All these new functionalities should be further tested in order to find out how they can support situation awareness and dynamic decision-making and other practical skills training for firefighters. If HoloLens 2 were to be combined with a powerful laptop and great Wi-Fi connection, we could even use AI to help make predictions from sensor data collected by robots or firefighters about gas-cloud movements or fire spread. AR devices in combination with other technologies have great potential in all crises management phases.

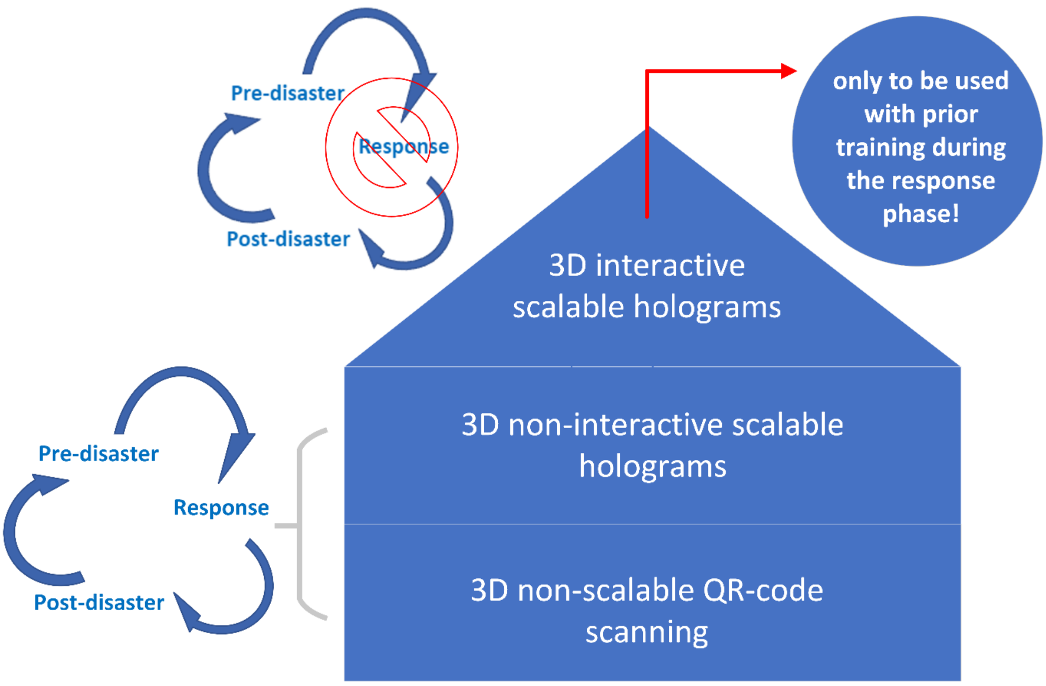

Figure 12. The hierarchy of holograms and crises management cycles

In this article we focused on the ability of HoloLens 2 to produce different holograms. From the experience of implementing VR in first responders' training, we claim that AR will be quickly implemented into firefighters' training if trainers can create 3D non-interactive scalable or non-scalable holograms themselves with the help of VR. VR has been used to train firefighters for a long time, therefore these 3D models already exist in VR. In VR, these models can be combined into holographic scenes and training scenarios (Polikarpus et al., 2021). If the scene or even scenario could be imported into HoloLens 2, it could enhance the research and training of situation awareness to be more authentic and accessible. We could also train firefighters' practical skills when holograms are overlayed with reusable physical simulators that allow for example the use of hydraulic tools. Simultaneously, a virtual layer might allow interactions and information presentation that is not possible in the physical world.

We are a bit more hesitant about the need to develop interactive holograms by trainers themselves for AR as movements to interact with these holograms require more practical training on how to use HoloLens 2. Additionally, we are not sure if this practical skill of using AR is later needed in the response phase. Earlier research has stated that HoloLens 2 applications required some practice, especially by the majority of participants who had no prior experience with holographic displays (Christaki et al., 2022). We found out that problems with using AR solely appeared when interactive holograms were used, or if the trainee had to scale the hologram him/herself. A holographic scene and QR-code scan to open non-interactive holograms did not require any special skills from the trainee and therefore could these hologram types be more easily integrated into training and the response phase of crises. During the response phase, everything is time critical and has to work flawlessly. Therefore, if AR were to be used in the response phase, then all these types of holograms should be used in the pre-disaster phase in order to train the needed AR practical skills. In addition to using AR in training, the technology needs to be developed to be weatherproof, and not cause explosions or any other hazard for anyone.

Limitations

There are some limitations in our typology of holograms. The term interactivity can be misleading, as clicking on the menu does instigate a new hologram or menu, but we named these 2D holograms as non-interactive. Throughout the testing phase conducted in fire stations it was observed that the holographic scene, which is designed to be non-scalable and of authentic size, encountered spatial constraints within indoor environments. Consequently, its application was occasionally extended to outdoor settings. However, it is pertinent to note that the HoloLens technology is not inherently designed for outdoor operation. Also, the holographic scene had 15 possible holograms and in one case, there was a leak under the truck and in another case the smoke to make the scene more dynamic. Our typology did not discuss whether holograms had moving parts in 3D models. In other studies, they have been differentiated as dynamic and static holograms (Polikarpus, Terep, et al., 2023).

CONCLUSION

The study investigated what type of holograms support firefighters' knowledge and skills training in which crisis management phase. We propose that 3D non-interactive scalable or non-scalable holograms should be used to exercise practical firefighting skills. Mixed-reality experiences and holographic scenes should be created in VR by trainers themselves in future AR applications. The technology should enable being exported from VR and imported to AR to give firefighters and incident commanders a rather cheap, repeatable, and comparable way to train their situation awareness, dynamic decision-making, and other practical skills.

It is important to remember that any new technology used by first responders should improve their situational awareness and dynamic decision-making and end-users should have training and vocabulary to use and develop it. The technology ought to be flawless, easy to use and before being integrated into the response phase of crises, it first needs to be tested and used extensively in the pre-disaster phase during the training of first responders. This foundational integration in training contexts is essential for ensuring an effective utilization in future emergency situations and post-disaster analyses.

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