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THESIS:

Augmented Reality Supported Disaster Management System

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Contents

Proofreading confirmation

Declaration of original work

I, Shqipe Salii hereby submit my master thesis, entitled Augmented Reality Supported Disaster Management System, and truthfully declare that the thesis is my original work. To the best of my knowledge, the thesis contains no materials previously published or written by another person, apart from reviewed references in accordance with the rules of referencing. Any contribution made to the research by others, with whom I have worked at South East European University is explicitly acknowledged in the thesis.

Acknowledgments

Abstract

Considering the rapid technological advancement in the recent decades, Augmented Reality (AR) technologies have been adopted to address various challenges in different domains, including challenges in disaster management operations.

This thesis addresses the adoption of AR technology and tools by first responders in context of disaster relief operations and how the advancements on AR technology also expand the possibility for integrating drone capabilities with AR technology in context of disaster risk management.

The thesis presents the fast evolvement of AR technology and reviews different applications in this rapidly evolving area. A range of existing AR applications, that are aimed to enhance various processes associated with pre-emergency preparedness and responses during emergency are reviewed in detail. Moreover, a disaster management AR system and various tabletop holographic maps are implemented, deployed in AR devices, and tested.

The main aim of the thesis is to present the feasibility of implementing AR and AR systems on disaster management and at the same measure and understand their impact on emergency operations.

Abstrakt

Duke marrë parasysh përparimin e shpejtë të teknologjisë në dekadat e fundit, teknologjitë e realitetit të shtuar janë implementuar dhe adaptuar për të adresuar sfida të ndryshme në fusha të ndryshme, duke përfshirë sfidat gjatë operacioneve emergjente për menaxhim të fatkeqësive.

Kjo tezë trajton adoptimin e teknologjive dhe mjeteve të realitetit të shtuar nga ana e reaguesve të pare. Ky trajtim bëhet në kontekst të operacioneve me menaxhim të fatkeqësive dhe sesi përparimet dhe zhvillimet në teknologjinë e realitetit të shtuar zgjerojnë gjithashtu edhe mundësinë për integrim të dronëve në proceset e menaxhimit të fatëkeqësive

Teza trajton evoluimin e shpejtë të teknologjisë së realitetit të shtuar dhe analizon aplikimet e ndryshme të cilat janë bërë në këtë fushë me zhvillim të shpejtë dhe dinamik. Një sërë aplikacionesh ekzistuese të realitetit të shtuar që synojnë të përmirësojnë procese të ndryshme të lidhura me gatishmërinë para urgjencës dhe përgjigjet gjatë urgjencës janë shqyrtuar në detaje. Për më tepër, një sistem i realitetit të shtuar për menaxhimin e fatkeqësive, dhe harta të ndryshme holografike janë implementuar dhe tesuar ne paisje korresponduese për realitet të shtuar.

Qëllimi kryesor i tezës është të paraqesë lehtësine e zhvillimit dhe impementimit të sistemeve të realitetit të shtuar, dhe vetë teknologjisë së realitetit të shtuar në operacionet për menaxhimin e fatkeqësive. Përvec asaj, në të njëjtën kohë dhe të kuptojë dhe masë ndikimin e tyre në operacionet emergjente.

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1. Introduction

The physical environment constructed for human habitation is continuously exposed to the risk of disasters. Considering that natural and human disasters severely destroy environments and make it hard to access the affected environments, there is an increasing need for decisions to be taken quickly to minimize evolving hazards and to start with the rescue and relief operations. Disaster management is crucial to reduce the probability and impact of the calamity and enable rapid restoration when disasters occur. However, it is necessary to emphasize that disaster management is a complex process, usually dealing with a large amount of uncertain, incomplete, and vague information, which normally requires the coordination and collaboration among a variety of actors. (Nunes, Raquel, Simões-Marques, & Correia, 23 June 2017). The information presented to the actors has to be simple enough to support cooperation between actors from different organizations but at the same time it has to be rich enough for an actor to convince them in facilitating decision making.

The broad concept of emergency management covers:

1. Hazard Prevention
2. Emergency preparedness (safety planning and training)
3. Emergency response (evacuation and rescue), and
4. Disaster recovery (restoration of fundamental services and lifelines)

(Nunes, Raquel, Simões-Marques, & Correia, 23 June 2017).

Studying disaster management can help researchers and professionals gain a better understanding of the response methods needed for various disasters, so that they can improve disaster management measures and provide safer environments. Recently when studying disaster management, the usage of Augmented Reality and Virtual Reality has become essential. With the rapid development of technology in the recent years, Augmented Reality and Virtual Reality have been continuously adapted to address various challenges in different domains, including the domain of disaster management and disaster relief operations. This adoption has been possible due to the release of affordable pieces of hardware and software which support the development of customized applications. Various studies have shown how Virtual and Augmented Reality can be used to advance the conventional disaster management and response approaches (Zhu & Nan, 2021). Scientists, decision-makers, and professionals benefit from Virtual and Augmented Reality, as these technologies provide researchers with virtual emergencies and simulated environmental disastrous scenarios without causing any real-world danger.

Virtual Reality can be defined as an environmental building technology that enables participants to immerse themselves into complete virtual surroundings and interact with the elements. Augmented Reality, on the other hand focuses on enabling participants to view the real environment but also apply virtual elements into it at the same time. Mixed Reality is a combination of both, it is a hybrid technology that blends virtual and real objects, where either interactable virtual objects are incorporated into a real three-dimensional environment or real objects are placed into a virtual world. The focus of this research is mainly concentrated on the implementation of Virtual Reality, Augmented Reality and Mixed Reality in the field of disaster management. It analyzes their advantages, challenges, and limitations. These concepts are elaborated briefly in the sections below.

1.1 Problem Statement

Disaster management is a very complex process, where in addition to the constant technical skill-upgrade required by the nature of the humanitarian context, the post-disaster information provided to the first responders is also crucial. The disaster management process requires multidisciplinary experts for preparing the relief operations and brining the situation back to normal. The conditions on-site in most cases are dangerous and unstable and there is an increasing need for such life-saving decisions to be taken quickly to minimize evolving hazards and to start relief operations.

The implementation of Augmented Reality and Virtual Reality in disaster management brings several advantages such as:

1. Pre-disaster planning which helps in reducing the number of casualties and their impact,
2. First responders' training to enhance capacities for prevention and response by simulating and reconstructing virtual calamities entirely,
3. Real-time and accurate inspection of the disaster from drone deployment,
4. Design and visualization of 3D maps, etc.

1.2 Research Field

During the last 20 years, the advances in the internet of things (IoT), intelligent sensors, artificial intelligence technology, wearable tools, and Augmented Reality (AR) have significantly impacted emergency management. AR technology was invented back in 1968, however research on VR/AR applications in built environment emergency management dates back to 1995, when the possibility of applying VR to emergency decision making was first raised (Zhu & Nan, 2021). Since then, with the rapid development of computer technology, research in this field has also constantly evolved.

Augmented Reality presents one of the most advanced technologies that has been adopted to address relief operations. It is a promising technology that is being applied in many contexts as diverse as:

1. Crisis management,
2. Emergency management-related health care (Croatti, Ricci , & Viroli, 2018),
3. Education (Zhu & Nan, 2021),
4. Training (Valentina & Michele, 2020) and
5. Natural disasters (Morra, Revetria, & Scaramozzino, 2020, September)

(Luchetti, Mancini, Sturari, Frontoni, & Zingaretti, 2017)

The focus of this research is centered on:

1. The adoption of Augmented Reality and Virtual Reality techniques and tools by first responders in context of disaster management and disaster relief operations.
2. Analyzing how the technological advancements on Augmented Reality and Virtual Reality technologies also expand the possibility of integrating drone mapping capabilities with Augmented Reality in context of disaster risk management.
3. Briefly reviewing the advantages, disadvantages and challenges encountered during:
    a. Implementation of Augmented and Virtual Reality in domain of disaster management.
    b. Integration of Augmented Reality with drones equipped with cameras
    c. Integration of Augmented Reality tools with existing crisis management systems

1.3 Aims of the Research

Primary aim of the research is to present the feasibility of implementing Augmented Reality on disaster management and measure and understand the impact of Augmented Reality tools and systems on emergency operations.

The following are the major objectives:

- Review the current literature related to Augmented Reality applicable to emergency operations.
- Examine the potentials of:
    - Implementing Augmented Reality and Virtual Reality technologies in the domain of crisis management and relief operations.
    - Using drone capabilities in the domain of disaster management.
    - Integrating drones equipped with cameras and sensors with Augmented Reality to support decision making during relief operations.

- Implement Augmented Reality tools to support mission planning.
- Integrate existing crisis management software with developed Augmented Reality tools.
- Identify the key benefits and advantages of developing Augmented Reality applications in support of disaster response.
- Highlight the key challenges related to Augmented Reality implementation on disaster operations.

Accordingly, the thesis aims to achieve the following goals:

- Understand the application of AR in the domain of disaster management and disaster relief operations
- Understand the feasibility of implementing AR in the domain of disaster management
- Development and implementation of Augmented Reality supported disaster management system that can assist first responders during disaster management and relief operations
- Analyze the efficiency of using drones and drone mapping capabilities in disaster management.
- Integration of drone mapping and inspection capabilities with AR to support mission planning
- Integration of AR systems with existing crisis management software
- Analyze the advantages and deficiencies of AR in research on disaster management context
- Identify possible directions for future research

By achieving these goals, this thesis is expected to provide a synthetic and critical review of existing knowledge on AR applications in the domain of emergency management and disaster relief operations and facilitate further advancements in both research and practice in this field.

1.4 Importance of thesis

Although Augmented Reality technologies are being used for various applications including hazard recognition and prevention, the research on the field of Augmented Reality is still at an early stage, especially in the domain of disaster management operations. The importance of the thesis primarily lies on the given impetus to research and product development in the field of Augmented Reality for disaster management.

1.5 Hypothesis

Augmented Reality has emerged to be a revolutionary technique which has a vast application particularly in disaster management. Many studies cover its advantages, limitations, and challenges, related with disaster relief operations. Based on the reviewed literature and the defined boundaries, we formulated our primary research question to narrow the field of investigation further. This study addresses the following questions:

RQ1: Can the advantages of Augmented Reality experiences be used during relief operations?

RQ2: Can Augmented Reality be utilized to improve mission planning processes?

RQ3: What role can Augmented Reality play in decision making?

RQ4: Can Augmented Reality tools be developed to assist first responders during crisis management?

RQ5: What are the benefits of using drones in disaster management?

RQ6: What are the benefits of integrating drone mapping and inspection capabilities with Augmented Reality?

RQ7: Which existing crisis management system is used for disaster management in North Macedonia?

a. Can we integrate Augmented Reality tools with existing crisis management systems?

RQ8: What are the deficiencies of Augmented Reality regarding crisis management relief operations?

In order to conduct this scientific work, the research questions have been synthesized into 3 main hypotheses to be tested. The following hypotheses are associated with the abovementioned research questions.

H1: Augmented Reality technology is used to aid first responders during crisis management.

H2: Augmented Reality tools can be developed to improve mission planning processes.

H3: Existing Crisis Management Software support integration with Augmented Reality tools.

1.6 Structure of thesis

Chapter 1. Introduction. This chapter provides a brief introduction of the research and sets the research within a context. It summarizes key concepts such as the problem to be solved and the reasons that led to the development of the thesis, the field in which the research will be conducted, the importance that lies behind the thesis, the general aims of the research and the hypothesis raised in the thesis.

Chapter 2. Literature Review. In this chapter a general overview of Augmented Reality and Virtual Reality technologies and tools in domain of Disaster Management is illustrated briefly. It provides a detailed literature review to summarize the previous work done on implementing Augmented Reality and Virtual Reality in natural disaster management. Moreover, it analyzes how advancements in Augmented Reality allow the integration and usage of drone mapping capabilities, making it possible to access areas which are destroyed and inaccessible by humans and also deliver real-time information to first responders using different live-streaming servers. The remainder of the chapter focuses on existing software for crisis management: Next Generation Incident Command System (NICS).

Chapter 3. Implementation. This chapter shows the steps undertaken for implementing the Augmented Reality system, the integration with existing crisis management software (NICS), the process of adding the points of interests (POIs) in the rendered terrain, and also enabling the livestreaming capabilities.

Chapter 4. Deployment and Testing. This chapter consist of the steps undertaken to deploy and test the implemented solutions such as: the Augmented Reality based Disaster Management system and the Tabletop Holographic Maps. The first solution is deployed and tested incrementally, step by step as the features were added, starting from rendering the terrain, adding the POIs, and then enabling the livestreaming capabilities. Each of the steps are explained in details and real time scenery testing is provided through images. Tabletop holographic maps are all tested individually, and real time scenery testing is also provided for them.

Chapter 5. Conclusions. This chapter summarizes the importance of the topic and presents the conclusions from the main findings. The key findings based on the raised hypothesis are discussed in detail. The main results and findings are then summarized.

Chapter 6. Limitations and Future Work. This chapter gives a general overview of the limitations and directions for future research based on the key findings of the research.

References

2. Literature Review

2.1 Virtual Reality and Augmented Reality

Virtual Reality and Augmented Reality have received a continuous growing amount of interest that has led to the development of different fields of investigation. Although Virtual Reality and Augmented Reality rely on different technologies and provide different solutions, they are both in the same category. They enhance or replace the real environment with a simulated one but rely on different components and serve different audiences. Wilson (Wilson, 2010) categorises AR as a form of VR, while Drascic and Milgram (Drascic & Milgram, 1996) describe VR and AR in terms of a 'reality-virtuality continuum'. Based on them, AR is defined as a mixed experience in which the main component is reality while the digital components (i.e. holograms) are a secondary components, and VR represents the extreme of this continuum and can be defined as a completely synthetic experience where users are presented with only virtual contents.

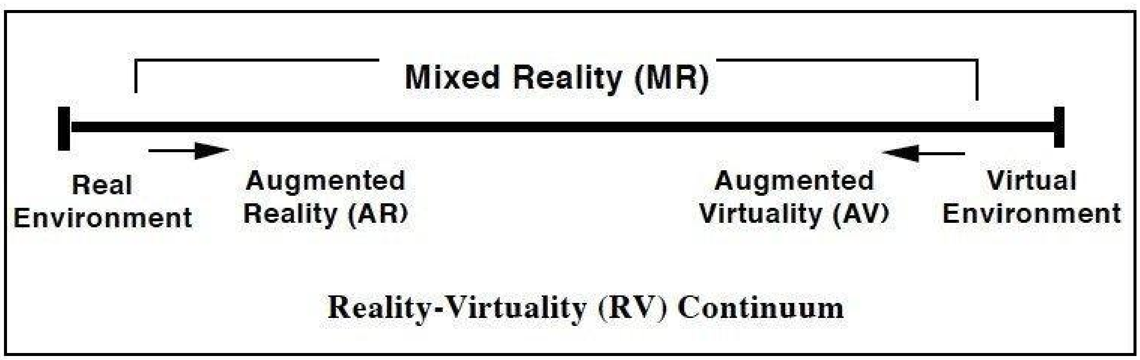

Figure 1: Milgram and Drascic's Mixed Reality on the Reality-Virtuality Continuum (Drascic & Milgram, 1996)

Moreover, Virtual Reality can also be defined as a three-dimensional computer-generated environment, updating in real time, and allowing human interaction through various input/output devices. By providing a variety of representations it completely replaces the real world with a virtual one. On the other hand, Augmented Reality (Lovreglio, 2022) can be defined as the enhancement of the real world by a virtual world, which subsequently provides additional information (Feiner, Macintyre, & Seligmann, 1993). It lays over content in the real-world using devices such as smartphones or a headset.

AR and VR can be classified on the base of the hardware solutions.

VR technologies can be categorized into:

1. Immersive
    a. Head Mounted Displays (HMDs)
    b. Cave Automatic Virtual Environments (CAVEs))

2. Non-immersive solutions

    Non-immersive VR can be achieved by visualizing the virtual content by using a display (traditional videogames represent instances of non-immersive VR) (Lovreglio, 2022).

In the recent years, Virtual Reality and Augmented Reality have been subject of investigation and implementation in different fields of study, including the field of disaster management and disaster relief operations.

2.1.1 Microsoft HoloLens 2

As already mentioned, Augmented Reality presents one of the most advanced technologies that has been adopted to address crisis management operations. This adoption primarily has been possible due to the release of affordable pieces of hardware (wearable glass device, head-mounted device, or smartphone applications) and software which support the development of customized applications. Among these pieces, there are the following:

1. Oculus Quest 2,
2. HTC Vive Cosmos Elite,
3. Merge AR/VR Headset
4. Vuzix Blade Upgraded,
5. HTC Vive Pro 2,
6. Magic Leap,
7. Epson Moverio BT-300
8. Snap Spectacles 3
9. Google Glass Enterprise Edition 2,
10. Raptor AR headset,
11. ThirdEye Generation,
12. Kopin Solos,
13. Micrososft HoloLens2, etc.

One of the most widely used Augmented Reality devices is the Microsoft HoloLens 2 (Figure 2).

Figure 2: Microsoft HoloLens 2

According to Microsoft, HoloLens is the first fully self-contained, holographic computer, enabling users to interact with high-definition holograms. This makes HoloLens unique and very much different from the existing augmented and mixed reality technologies. Users can wear the headset, which weights 580-gram and runs Windows 10 to map their environments and display virtual or holographic 2D and 3D objects anchored to that environment.

Although Augmented and Mixed Reality seem to have lots of applications in several various sectors, Microsoft lists disaster and emergency management as one of the main application areas of HoloLens and encourages research and development in this field (Asgary, 2017).

Microsoft HoloLens 2 can be used to simulate various operations needed for rescue and evacuation processes. Moreover, applications can be developed to address specific disaster management processes. Thus, we will be using Microsoft HoloLens device to deploy and test the implemented Augmented Reality tools.

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enabling users to interact with high definition holograms (Figure 1) that is very much different from the existing augmented and mixed reality technologies

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2.2 Drone integration with Augmented Reality

During a disaster there are many cases when first responders fall short due to the damage of the disaster itself, because the conditions make it difficult to access the affected areas and provide aid. The two most important things to do during a disaster are: to spot the people in need of urgent help and assess the extent of the damage. So, in order to mitigate suffering and further damage, one asset that rescue teams can utilize is drones. Drones can be used to support infrastructures, deliver supplies, establish communication, collect data, provide communication services, etc.

Figure 3: DJI Inspire 2

Drones are useful in different occasions such as when infrastructure supply lines are cut and disabled, or when roads, bridges, communication cables are compromised. By deploying drone aircrafts over these impossible to reach areas, supplies such as food and water can be delivered to people in danger, without needing to place human-operated aircraft in harm’s way. Bigger drones can also be used to transport people, while on the other hand small drones can be deployed to provide accurate situational awareness and inspection. Drones that are outfitted with communication systems bring also the advantage of sustaining contact between the command center and firefighters on the ground.

Figure 4: DJI Mavic AIR 2

Although drones have received lots of criticism because of their associations with invasion of privacy, integrating drones with Augmented Reality makes it possible to highly improve operational efficiency during crisis management. Drones come in hand in dealing with different disasters and calamities, thus they are being counted as a valuable tool for many reasons. They come with a variety of sizes and prices, which means that they provide greater advantages in costs and in response times when compared to traditional methods. Small drones are affordable, and they deliver the same view available from a helicopter at a fraction of the cost. They are able to fly at low altitudes and offer a detailed and accurate inspection of the situation (Velev, Zlateva, Steshina, & Petukhov, 2019).

Figure 5: DJI Mini 2

Drones equipped with cameras, together with Augmented Reality and other devices pave an efficient way for disaster management. They make it possible to deliver crucial information in real time, thus they enable first responders to mark the locations where to search for survivors, analyze the overall situation of the disaster and the hazard done, create different types of maps that help rescuers locate critical spots, find ways on how to access and restore resources, etc. On the other hand, drones can also be equipped with a variety of sensors to achieve various functionality, including infrared cameras which can visualize temperature range variability. Finding a human’s heat signature is the first step towards rescue and recovery and such drone technology is a great tool to locate people in cases of earthquakes, landslides, hurricanes where many search and rescue missions occur.

Figure 6: DJI Phantom 4 V2.0

These advantages and more, make drones a very important tool which is being used more often in emergency and disaster response situations. They are proving the ability to save lives and prevent damage in dire situations.

2.2.1 Live Streaming

Amongst all the advantages that come out of using drones during disaster management, one of the crucial ones is also the possibility to live stream and inspect the overall situation in the affected areas. Live streaming from a deployed drone equipped with a camera can be achieved using various existing streaming protocols. In the section below we analyze two of the main protocols which are commonly used for live streaming: ANT Media Server and RTMP.

2.2.1.1 Ant Media Server

One of the mainly used streaming protocols is Ant Media Server. Ant Media Server is a streaming engine software that provides adaptive, ultra-low latency streaming by using WebRTC technology with ~0.5 seconds latency or low latency by using HLS or CMAF. Ant Media Server is highly scalable both horizontally and vertically and can run on-premises or on any cloud provider (Ant Media Server Enterprise and Community Edition, 2021).

2.2.1.1 RTMP

The Real-Time Messaging Protocol (RTMP) specification is another commonly used streaming protocol. It provides high-performance transmission of video, audio and data between encoder and server across the internet. Originally it was developed by Adobe to work with Adobe Flash Player and it was used to transmit content between a video player and a hosting server, which was referred to as “RTMP delivery.”

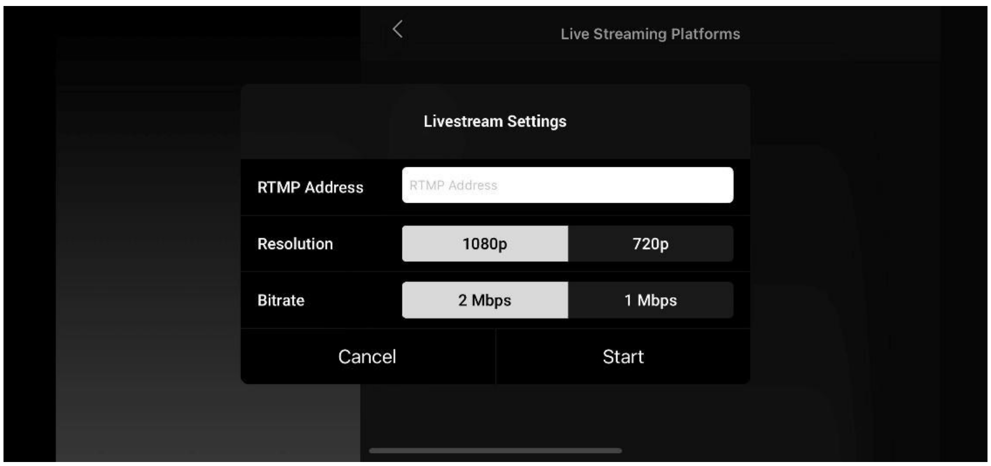

Figure 7: RTMP Address configuration in DJI Fly Application

In the context of live streaming, RTMP is very powerful. It is capable of low-latency streaming and it is also known for its minimal buffering, which truly enhances the user experience.

There are several variations of RTMP, including RTMP proper, RTMPS, RTMPE, RTMPT, and RTMFP.

Figure 8: Setting up livestreaming in DJI GO 4

We will be using the RTMP protocol for streaming directly from drones to get real-time information and inspection of the situation directly in our deployed application in the HoloLens 2 device.

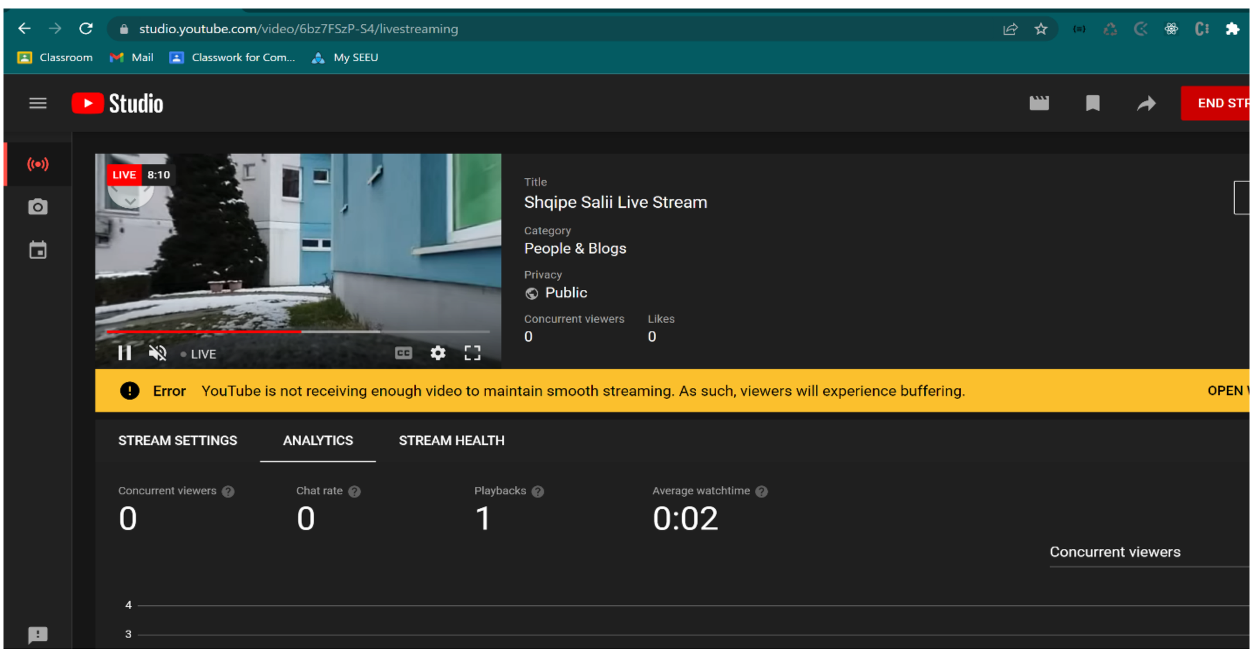

Figure 9: Livestreaming from deployed drone to YouTube

2.3 The Next Generation Incident Command System (NICS)

One of the biggest technical challenges commonly faced during large scale disasters is the lack of interoperability among technology tools used by governments at national, regional, and local levels. Not being able to share information about the disaster, makes international collaboration difficult and at the same time complicates relief efforts as well.

The Next Generation Incident Command System (NICS) is a mobile and web-based communications platform that allows first responders and commanders to coordinate large-scale emergency responses.

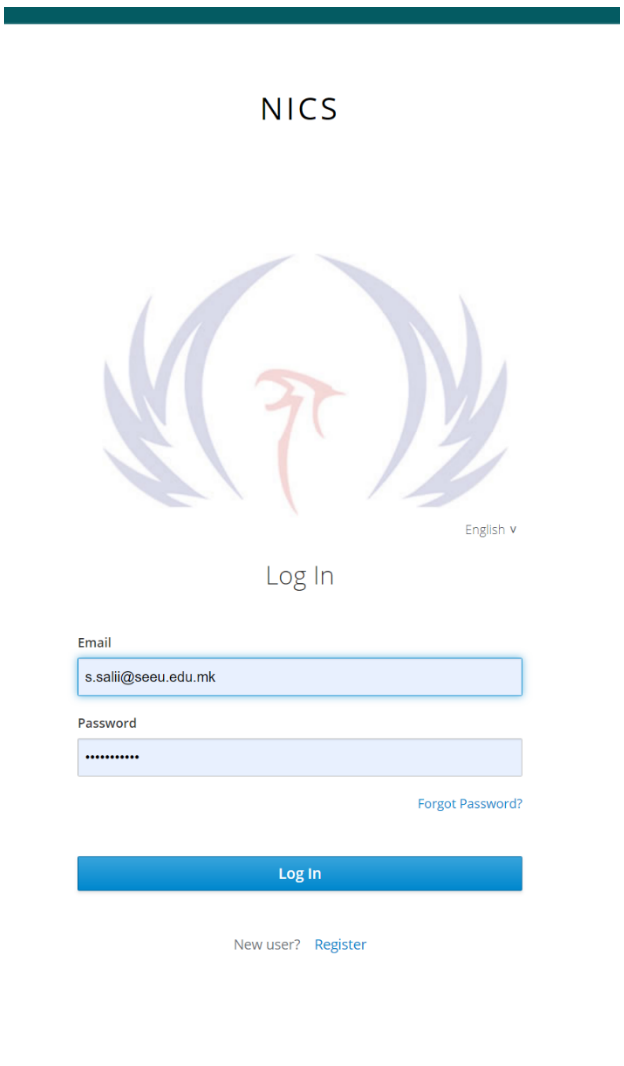

Figure 10: Next Generation Incident Command System (NICS)

The system is accessed via the internet. Using a collaborative online incident map, it enables responders to add and share critical information like location, scale of the disaster, wildfire boundaries, evacuation zones, or GPS locations of personnel. and this way it improves first responder situational awareness, collaboration, and interagency interoperability. Moreover, first responders can also upload photos and videos from the scene, send messages, and check-in with other responding agencies in real time. Apart from enhancing information-sharing capabilities, NICS can also be interoperable with existing technology platforms and databases (Security, 2020).

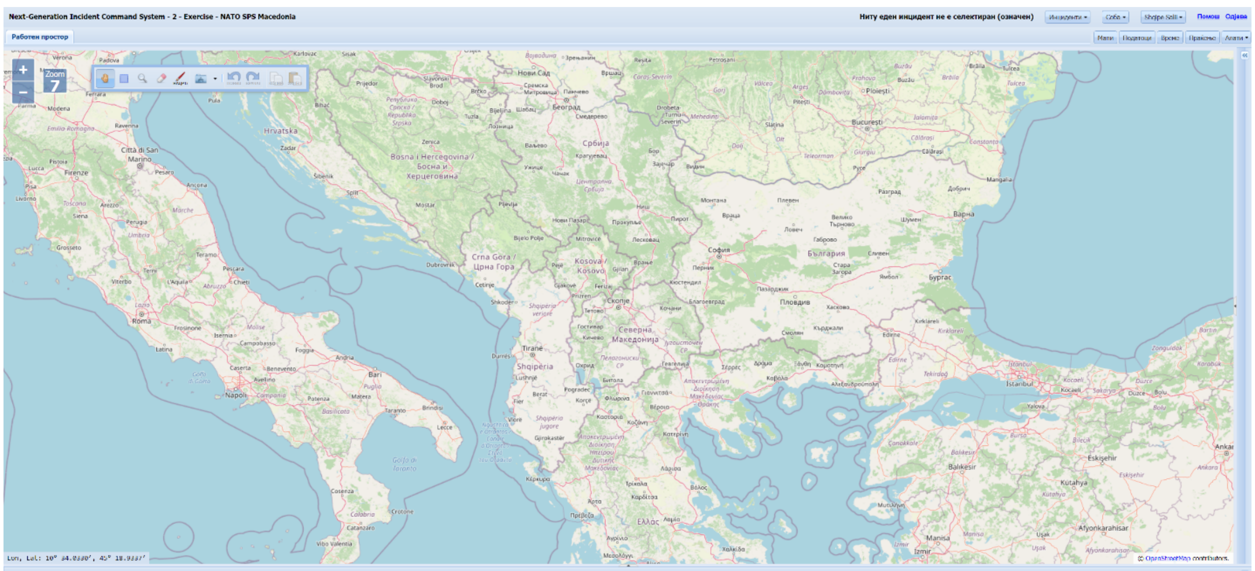

Figure 11: NICS Map

North Macedonia has also adopted NICS, as its official crisis management system. This software solution enables all emergency agencies to be digitally unified, aiming on improving and simplifying coordination of disaster response services.

Considering that NICS is interoperable with other technology platforms, it will be integrated with the developed Augmented Reality tools, to facilitate better collaboration and get real-time information and inspection of the disaster. Information such as the location of critical points and endangered areas, will be further visualized and presented on the designed AR maps, to improve mission planning and decision-making during relief operations.

2.4 Related Work

Since the decision for applying Virtual Reality in emergency management was first raised, there has been enormous research done in this area. However, despite the growing body of relevant literature, reviews of VR/AR applications in the context of emergency management are scarce. Several research regarding Augmented Reality implementation in crisis management and disaster relief operations have been conducted, mainly targeting the benefits, advantages, and limitations of implementing Augmented Reality and Virtual Reality in this domain.

Augmented Reality is a promising technology that is being applied in various contexts in disaster management. The table below lists Augmented Reality applications in disaster management during the period of 2015-2021.

AR applications in emergency	References
Health care	(Croatti, Ricci , & Viroli, 2018)
Education, studying emergency management	(Zhu & Nan, 2021)
Training	(Valentina & Michele, 2020)
Natural disasters	(Morra, Revetria, & Scaramozzino, 2020, September) (Luchetti, Mancini, Sturari, Frontoni, & Zingaretti, 2017)
Hazard recognition and prevention	(Park, et al., 2018) (Berglund, Monroe, Ahmed, & Noghabaei, 2020) (Perlman, Sacks, & Barak, 2014)
Search and rescue	(Zhang, Xia, Liu, & Li, 2021)
Damage detection and Building reconstruction	(Kim, Kerle, & Gerke, 2016)

Table 1: AR applications in disaster management during 2015-2021

Creating disaster scenes in real life is very difficult and costs a lot, but also at the same time forcing trainers to face natural hazards and put them in danger violates the law and morality (García, Trejo, & García, 2021). To overcome these problems in emergency management training, Augmented Reality is essential to reconstruct and simulate disaster scenes in the virtual environment without having to face any real danger during the studies and training of emergency management teams. By implementing Augmented Reality in disaster management, we are able to avoid legal and ethical constraints, solve moral conflicts and create virtual disasters in real life without subjecting subjects to danger. Thus, we have the opportunity to explore causative factors of disaster management during the research studies.

Research in Augmented Reality is also focused on hazard recognition and prevention, such as by creating accurate and scientific fire safety plans. In their paper (Park, et al., 2018), the authors suggest an AR based Smart Building and Town Disaster Management System, that implements fire safety route guidance in a Smart City. The suggested system provides visualization information, visual direction, quick evacuation, and quick rescue. Consequently, it is expected to reduce the risk of large damages and many casualties. Similarly, (Berglund, Monroe, Ahmed, & Noghabaei, 2020), suggested a smart city with an AR-based emergency management system. Another, AR-related emergency simulation system has been designed to simulate road accidents in a construction project by (Perlman, Sacks, & Barak, 2014) as well. The main aim of the research was to explore the extent to which construction superintendents perceive hazards and how they assess risk.

(Valentina & Michele, 2020) conducted a survey to understand workers' perception and acceptance of AR use in emergency management training. Their main aim was to detect the strengths, weaknesses, and the degree of acceptance of the use of virtual and augmented reality in training of workers, including how they perceive the risk and how they manage the negative emotions that hinder the success of the work. The results showed that there should be frequent and advanced professional training for workers in "high risk, deadly prone' workplaces. At the same time, further research has been focused on this context, where authors such as (Valentina & Michele, 2020) concluded that active teaching methods with theoretical and practical knowledge are essential to teaching and developing specific disaster management skills for relief operations. Therefore, there is a vital role of using AR in training because virtual tools improve and speed up the learning process of operators, speeding up the perception of risk, etc.

The challenges of using AR for training in emergency management are the lack of knowledge of the trainers in the use of AR, lack of understanding of the potential that these supports have in training, the belief that the use of AR technological tools does not develop permanent skills, unavailability of professionals to use these tools to train themselves, etc. Despite these challenges, different researchers on their papers such as (Perlman, Sacks, & Barak, 2014) and (Valentina & Michele, 2020) conclude that AR's use supports training to be safe, teaches how to perceive risks, manage the operators' negativity, and identify more hazards correctly.

Medical environments and the usage of Augmented Reality in this area has also been a target of the AR research. The authors (Croatti, Ricci , & Viroli, 2018), use Mobile augmented reality tools for emergency management research related to the medical environment. The innovative system is called SAFE (Smart Augmented Field for Emergency). It is integrated with wearable computing and augmented reality technologies, consisting of intelligent agents and multi-agent systems for supporting rescuers for effective individual and whole team coordination and collaboration. SAFE represents a beneficial tool for teams of rescuers and operators involved in a rescue mission.

Evacuation and rescue in emergency management on the other hand is also a topic highly discussed. There are several studies focused on the influences of warning signs and warning messages on evacuation's behaviors. There are quite a lot of advantages of a virtual environment for the evacuation process, such as access to warning signs and messages, reduce of the conflict between obstacles in the background and evacuation path, and making evacuations safer, quicker, and easier (Zhu & Nan, 2021) (Figure 7).

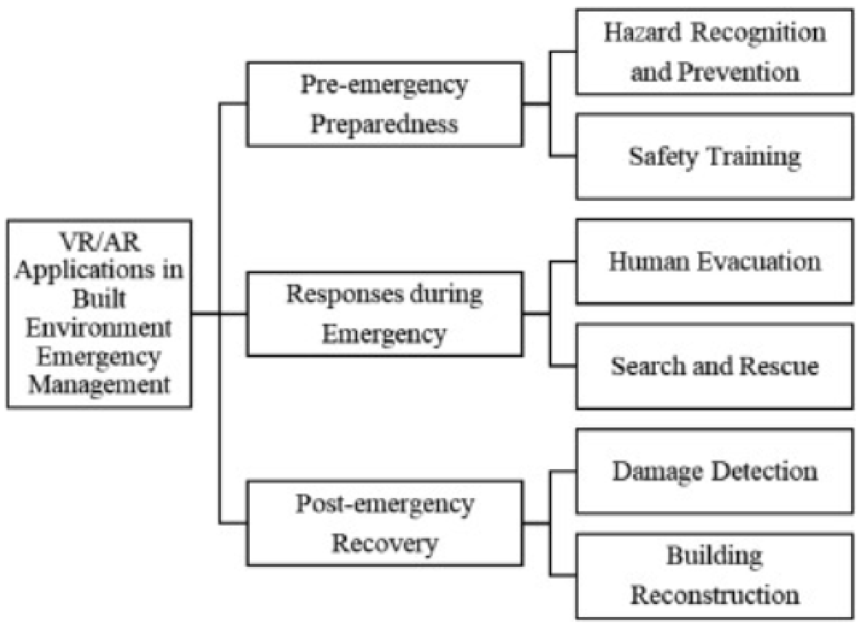

Figure 12: AR/VR applications in the disaster management cycle (Zhu & Nan, 2021)

Compared to the print map or a compass, an AR-based 3D layout map or AR-based software, these devices can support easy way finding for rescuing (Zhang, Xia, Liu, & Li, 2021). Considering the results, it is concluded that the main findings of this research extend the existing knowledge that this kind of application reduces human workload for cognitive tasks during an emergency and further verify that augmented reality technology can be used for prevention and manages natural disaster events/ crisis management. Moreover, (Luchetti, Mancini, Sturari, Frontoni, & Zingaretti, 2017) have used a mobile application with AR, integrated with crowd-mapping (CM), social media platform, IoT, and sensors to make decisions about natural disasters. In this application, AR provides users qualitative details that sensors cannot capture, offers real-time analysis, examines historical events and accessible monitoring facilities.

Augmented Reality can also be used to assess the damage to the build and reconstruction. The research is concentrated in this domain as well, starting from the paper of (Kim, Kerle, & Gerke, 2016) who used AR for ground-based rapid and accurate assessment of buildings after a disaster for emergency response actions and effective rehabilitation and reconstruction. The AR-based survey helps to reduce cost and time of evaluation, reduces human-induced errors providing location and navigation information, offers real-time interaction for users and 3D graphical details for safety and building assessment. (Morra, Revetria, & Scaramozzino, 2020, September) on the other hand, innovated an augmented reality system with the help of the Internet of Things (IoT) inside an airport to manage the fire-caused emergency. Usually, the evacuation of passengers in the airport in case of an indoor fire is ordered by the traditional safety management system. With advanced technology, IoT-based sensors and augmented reality tools, like AR smart-glasses or tablets, support safety decisions, and emergency interventions. (Ermacora, 2013) used AR technology and cloud robotics drones to manage emergencies in an innovative city environment. Augmenting live drones captures images with information to address the crisis real time situation. These live drones can be used to plan evacuation rooms, treatment rooms, parking spaces for operations forces (Mirbabaie & Fromm, 2019). A drone gives general information about the design and layout of the building, the number of people in danger of affected by the crisis, how many elders and disabled/children are in the risk, risk areas in the building, etc. (Barrett, et al., 2019) designed drones for resuce operations in such cases when there are dangerous situations and inaccessible terrain to find targets in emergency situations. Furthermore, (Velev, Zlateva, Steshina, & Petukhov, 2019) identified challenges of using drones and augmented reality for disaster risk management. Furthermore, they compare the traditional disaster preparedness process, which would consist of an instructor who would give lessons to first responders inside a classroom with nowadays advanced options of implementing VR/AR in training. They concluded that nowadays drones happen to be the best solution to assess the damage and spot survivors, and at the same time combining drones with VR/AR supports training to be safe. It allows first responders to practice as many times as necessary to master the techniques used during relief operations. and according to them an efficient way for dealing with disaster management operations is paved when using drones in combination with AR/VR technologies. In the future, drones will take the main role in disaster relief operations such as search and rescue, this way reducing human life risk and enabling first responders to react proactively.

3. Implementation

An Augmented Reality System (ARS) is a system that integrates an image of reality with a virtual image that extends the visible scenery of reality. In context of crisis management its use lies on representing invisible and unreachable disaster relevant information and overlay it with the image of reality (Leebmann, 2004). The design of an ARS is a challenge because the system integrates different components like mapping, 3D visualization and photogrammetry, real-time streaming, etc.

In the scope of this thesis, we will design and implement an Augmented Reality tool where we will render a 3D map of the terrain where the disaster is active. Furthermore, in order to provide first responders essential information about the disaster, the AR tool will be integrated with NICS to get the critical spots with accurate longitude and latitude. These critical sports will be then further marked in the map and real-time inspection of these areas will be done by deploying drones and streaming directly.

Apart of that, we will integrate deployed drones with NICS to livestream directly there. And finally various 3D maps for different purposes will also be rendered.

3.1 Development environment

As a working environment for building Mixed Reality applications, Unity (2020.3.17f1) with Unity Hub will be used. Moreover, Mixed Reality Toolkit (MRTK), as a toolkit that provides various components and features, used to accelerate cross-platform MR app development in Unity will be utilized as well. And finally, to be able to target the HoloLens 2 device, Mixed Reality OpenXR plugin will be installed and the XR configuration will be setup.

On the other hand, to develop and render the 3D terrains in the maps, Maps SDK (Maps SDK, Microsoft Garage project, n.d.) will be used. It presents a Bing Maps API that makes it possible to incorporate 3D world data into Unity based Mixed Reality experiences and at the same time handles streaming and rendering of 3D terrain data with world-wide coverage.

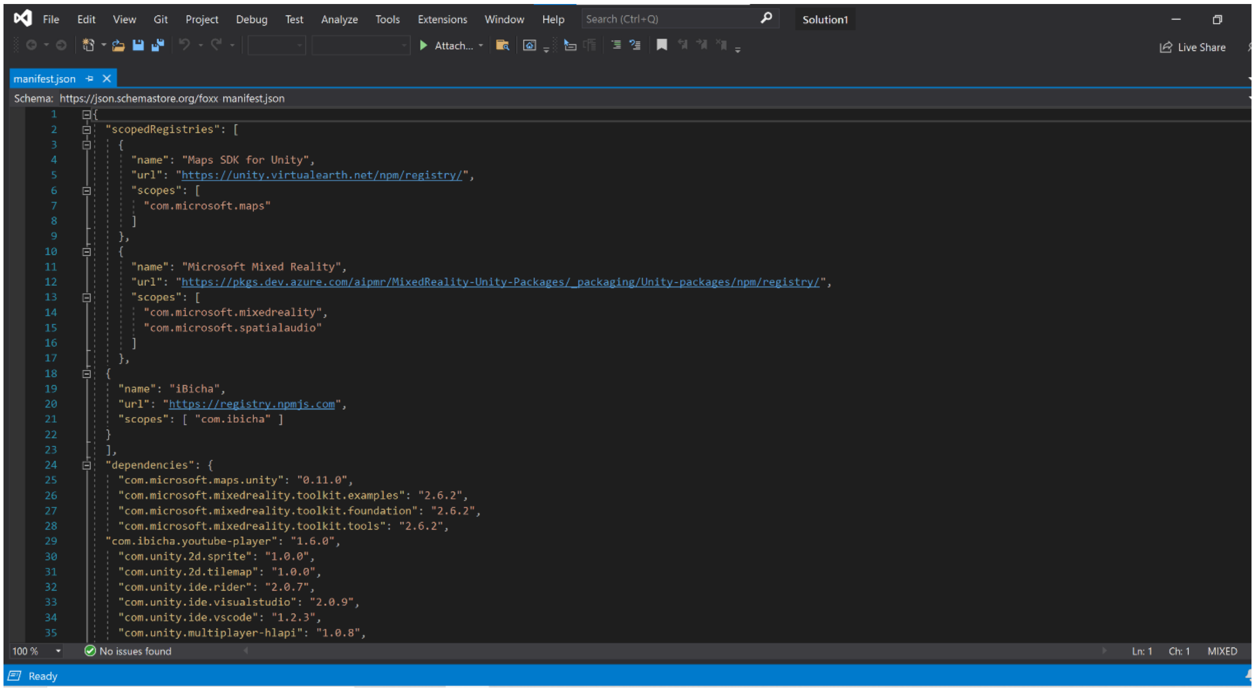

Figure 13: Reference to the Maps SDK Package

A Bing Maps Developer key will be used to enable the mapping functionalities of the SDK.

We start by implementing the Augmented Reality tool with points of interest and then proceed with various tabletop holographic maps.

3.2 Augmented Reality supported disaster management system

People involved in disaster management operations expect data represented in a clear and understandable form. The new approaches for visual representation of virtual environments give life to such new ways of coping with disaster management. They enable users to obtain a clearer perception of the disasters and its characteristics, including providing specific and brief details about it.

The initial question to be asked during a disaster is ‘WHERE?’. Answers to the questions such as: Where is the disaster? Where are the rescue units? Where are the most endangered areas? Where should the survivors be relocated?, in most cases come in a 3D component, e.g., ‘The 5th floor is on fire’, ‘The rescue units are still down in the valley’, ‘The dam up the hill is in critical condition.’, thus it would be much more illustrative and beneficial for the improvement of the estimates of evacuation conditions if these answers would be accompanied with 3D maps. (Konečný, Zlatanova, & Temenoujka, 2012).

In this section we present step by step the implementation phases of the Augmented Reality tool. This tool consists of an Augmented Reality based 3D Map, which is a 3D map that marks the locations (points of interest) which are in danger, shows the geo-location information, including longitude and latitude and provides a real-time accurate inspection of these locations from drones deployed in these areas.

During the first phase of the implementation, we start by rendering the terrain where the disaster is happening and focus the center of the disaster.

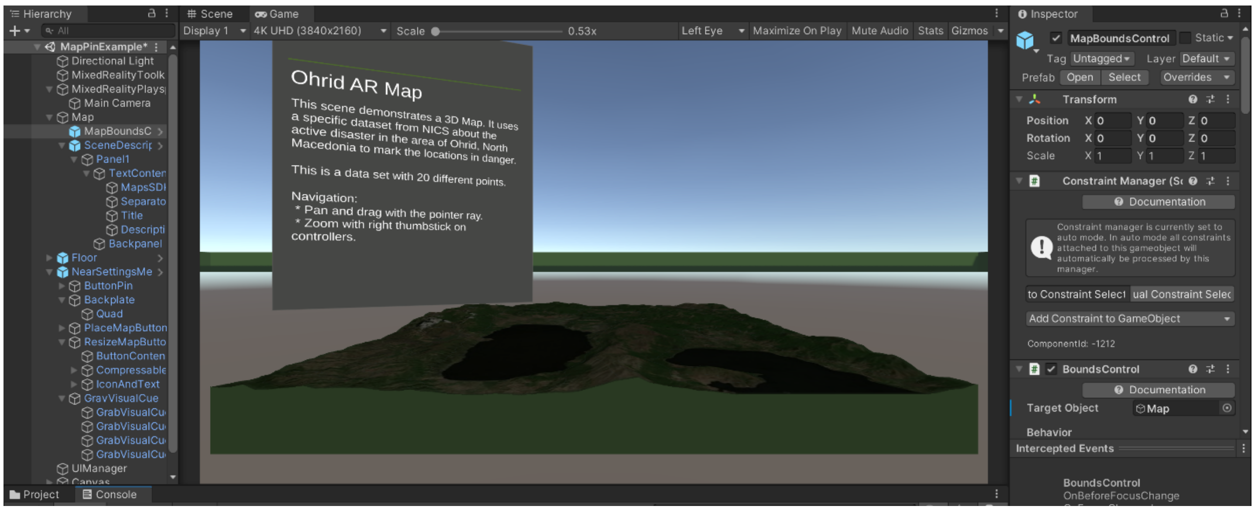

Figure 14: Implementation Phase 1 - Rendering the terrain

3.2.1. Implementing POIs

During the upcoming phase, we will mark the locations in danger from the calamity area by adding specific components. We use the information for the longitude, latitude, and altitude from the xml file that we have from NICS. Initially, the POIs are clustered based on their distance and the map view is able to change via translation or zoom. The maps are grouped, until the level of detail of the map view is high enough to display individual pins.

The reason behind clustering is that when dealing with large datasets, the number of component instances to be rendered for zoomed out views is reduced. The Figure 5 presents a screenshot of the rendered map in Unity.

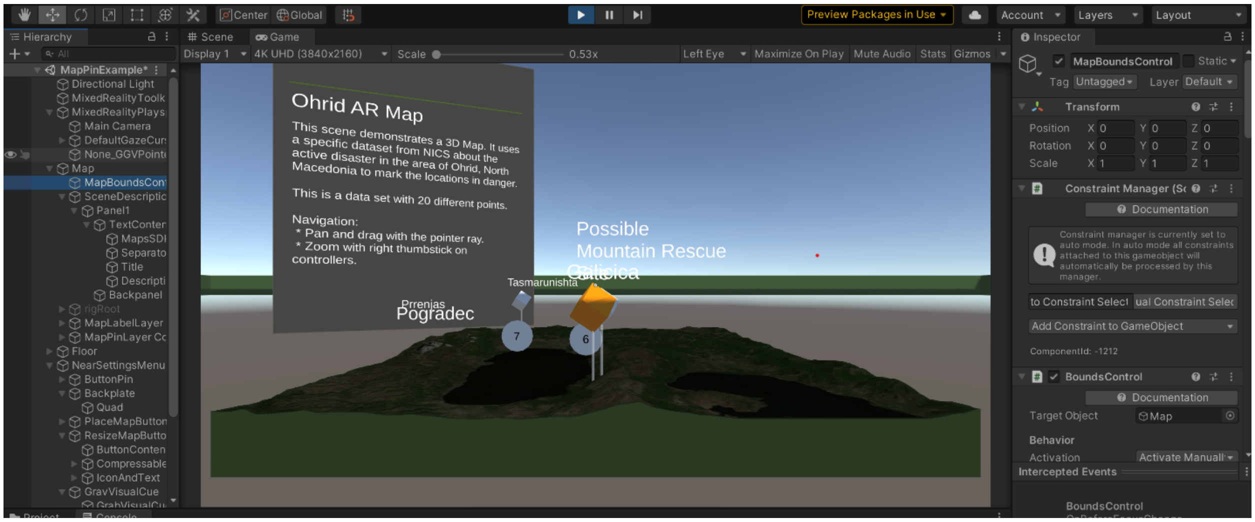

Figure 15: Implementation Phase 2 - Presenting Clustered POI

3.2.1.1 Converting long/lat to x, y, z coordinates in Unity

3.2.2 Drone integration for improved situational awareness

The last phase includes enabling interaction with the components that mark the POIs and enable live-streaming functionality. By clicking on each of the POIs, we will get the basic information about that location, such as the: name, longitude, and latitude. Moreover, we will also add a video player, to which we will live stream directly from the drone. The drones will be deployed in the areas where the disaster is active and there is still danger.

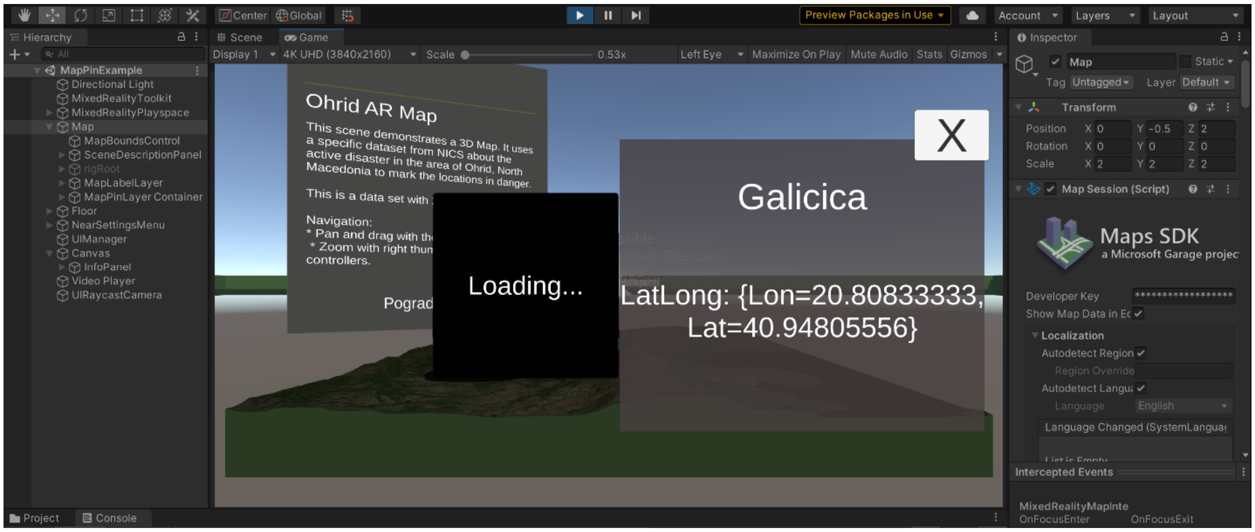

Figure 16: Implementation Phase 3 – Adding interaction and live streaming

We will be livestreaming using custom RTMP Address.

Figure 17: Livestreaming from DJI GO 4

We map the same RTMP address to the video player in our Unity application, and we can see the real-time images of the drone in the video player of our application.

FIGURE

Figure 18: Live streaming in Unity

The implemented tool will be deployed to HoloLens 2 and then tested. For testing purposes, we will use different drones of different sizes and capabilities such as: DJI Mini 2, DJI Mavic 2 Pro, DJI Inspire 2, etc.

3.3 Tabletop holographic maps

Using Maps SDK, we can also easily render different types of 3D maps. Different maps serve different purposes. Today having clear representations of a city in 3D prior to a disaster such as an earthquake, hurricane, etc, allows us to compare the terrains before and after the disaster, and at the same time assess the damage which was done.

The first tabletop holographic map we developed is a 3D map of a city which supports interaction such as clicking, zooming in and out, moving the map, etc. The figure below shows the map of Seattle.

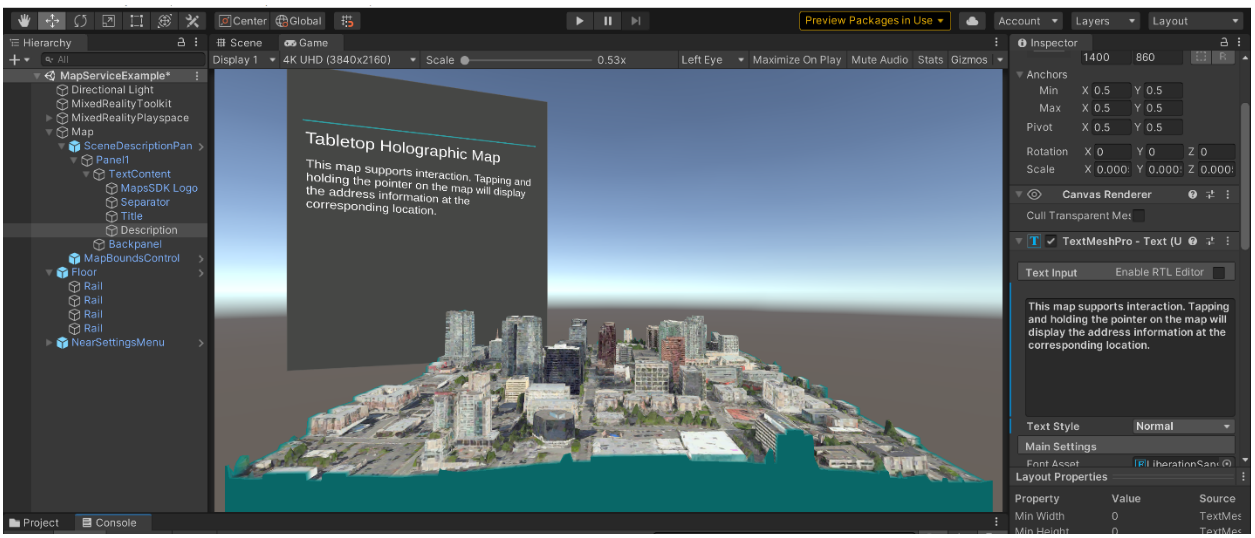

Figure 19: Tabletop Holographic Map 1

There are countries and areas which are not available in 3D in Bing Maps SDK, and North Macedonia is one of them. However, rendering the map is still possible and interaction is supported, such as clicking on specific locations and getting the details of that area.

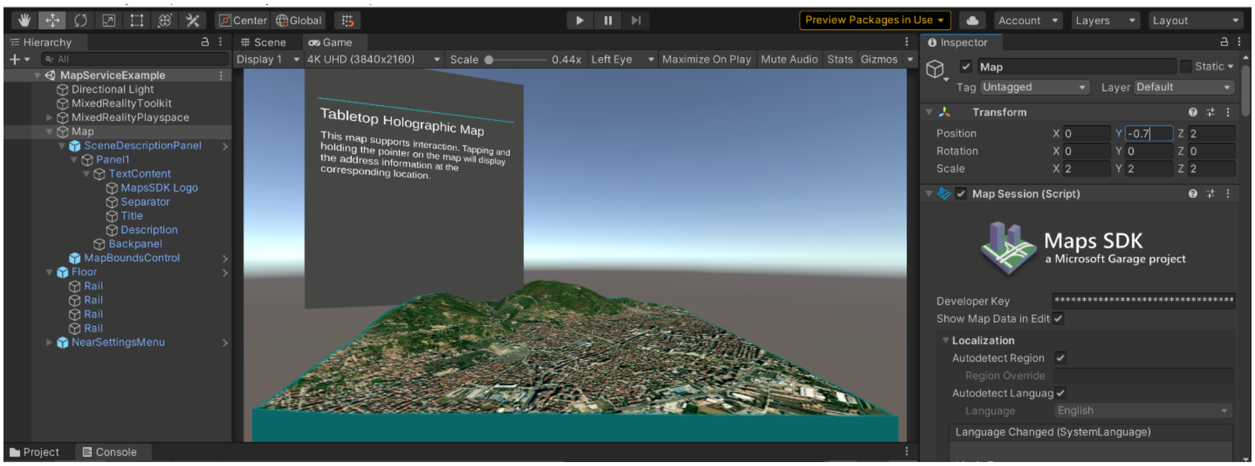

Figure 20: Tabletop Holographic Map 2

Using Bing Maps SDK, we can render different maps in 3D, starting from configuring it to a specific city and center it to a geolocation, as the map in Figure 7.

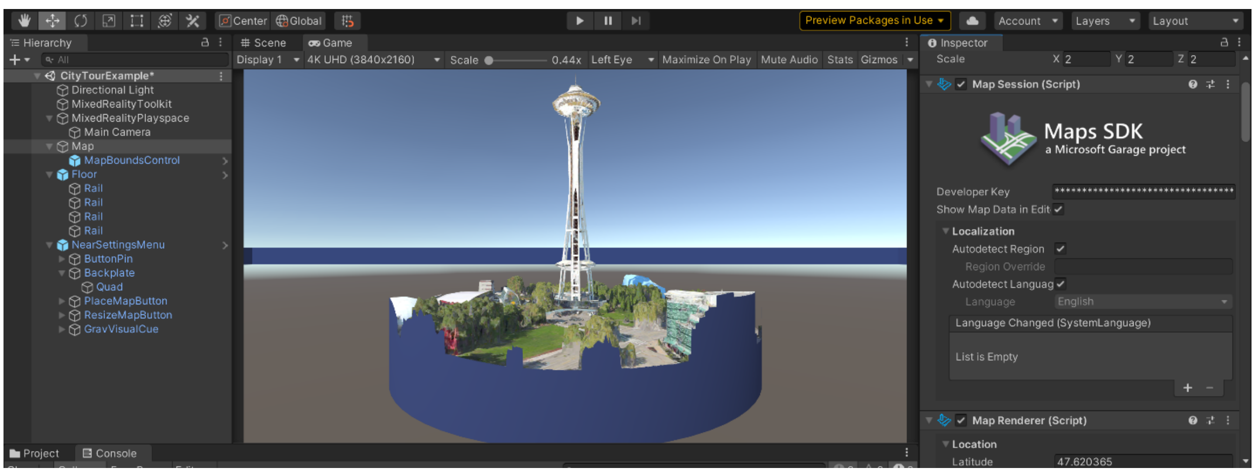

Figure 21: Tabletop Holographic Map 3

At the same time, we are also able to configure the map to switch between different cities around the world as in Figure 8.

Figure 22: Tabletop Holographic Map 4

Using Bing Maps SDK, we are able to easily render such 3D maps and enable various interactions.

3.4 Livestreaming deployed drones to NICS

As already stated, NICS supports integration with various technologies and platforms. In scope of the thesis, we will also integrate livestreaming from deployed drones to NICS. For streaming purposes, we will use RTMP and stream directly to NICS.

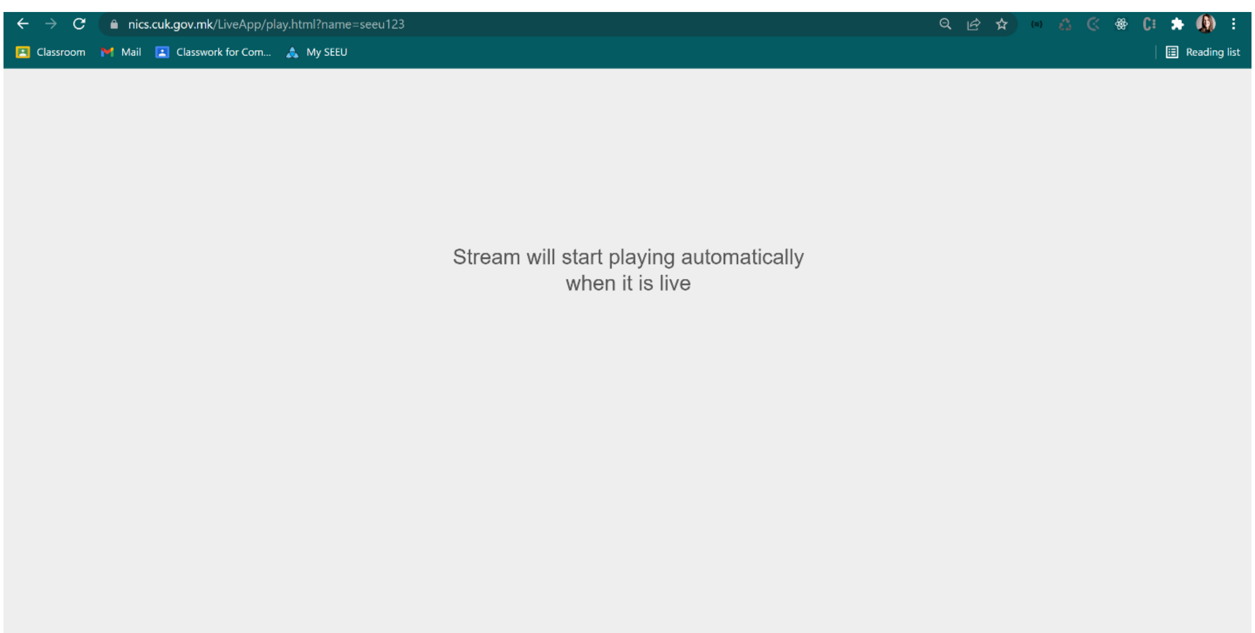

Figure 23: Stream status in NICS before it is live

Once the connection is set and it is live, the following figure (Figure 22) shows an image from the deployed drone to NICS.

4. Deployment and Testing

Maps SDK is optimized for various devices including HoloLens 2. The testing phase includes deploying the applications to HoloLens 2 and testing them.

4.1 Deployment and Testing of Augmented Reality based disaster management system

The deployment and testing process was started with the implemented AR tool. We start by deploying incrementally the implemented features and test them step by step.

The first figure shows the rendered terrain together with the points of interests, identified with cubes.

Figure 24: Rendered terrain with POIs

Next, we continue with the deployment of the other increment where the interactivity is added, and we are able to click on the cube and the address information for the critical point is displayed in the panel. For testing purposes, we also display the video player, but the streaming functionality is not added yet.

Figure 25: Displaying address information for the POIs

The last deployed increment consists of enabling live streaming to the video player from drone cameras, mapping of the RTMP address and some last adjustments in the map description panel.

Figure 26: Flying DJI Phantom

FIGURE LIVE STREAMING TO HOLOLENS 1

Figure 27: Live images from deployed drone to HoloLens

FIGURE LIVE STREAMING TO HOLOLENS 2

Figure 28: Additional livestreaming from deployed drone to HoloLens

FIGURE LIVE STREAMING TO HOLOLENS 3

Figure 29: Additional live streaming images 2 from deployed drone to HoloLens

4.2 Deployment and Testing of Tabletop Holographic Maps

After testing the implemented AR tool, as a further step, the interactive tabletop holographic maps were also deployed, and the interactivity was tested.

The following figures present the interactive tabletop holographic maps for Seattle and North Macedonia.

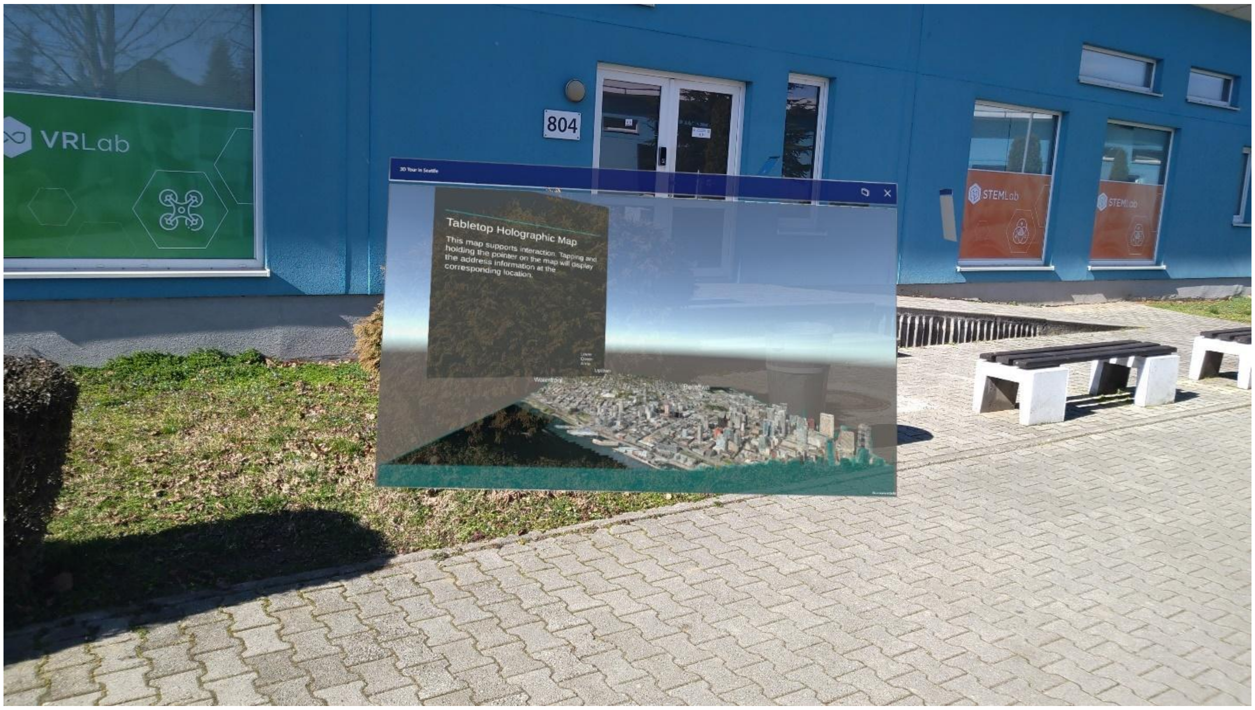

Figure 30: Tabletop Holographic Map – Seattle

As already shown in the following figure, the region North Macedonia is not available in 3D and we are unable to see the buildings.

Figure 31: Tabletop Holographic Map – North Macedonia

However, functionality is the same and when pointing on a specific location, it displays the address information for it.

Figure 32: Address information in Tabletop Holographic Map

Being able to render 3D buildings is a great advantage. In the following figure we can see the deployed Seattle map and its 3D buildings.

Figure 33: 3D Buildings, Seattle

Next, we can see how this map was adjusted and different countries available in 3D were also added.

Figure 34: Tabletop Holographic Map Interaction

Furthermore, the functionality and the interaction with the map was tested. The map offers various functionality, starting from being able to change shape, switch from displaying the terrain to 3D buildings and finally move across different countries. By clicking inside the map, we are able to zoom in and out specific regions.

The following figure shows switching to San Francisco.

Figure 35: Tabletop Holographic Map – San Francisco, USA

While the next figure shows switching to Europe, more specifically it displays the 3D building of the Colosseum in Rome.

Figure 36: Tabletop Holographic Map – Colosseum, Rome

5. Conclusions

The Conclusions chapter will conclude the topic by addressing the research questions and hypothesis.

Research Questions

1. Can the advantages of Augmented Reality experiences be used during relief operations?

The advancements on Augmented Reality technology and tools, bring lots of advantages, including enabling its usage and implementation in context of disaster management. Augmented Reality can be used during all stages of disaster management operations, such as:

- Disaster preparedness
  - Hazard recognition
  - Safety training
- Disaster response
  - Human Evacuation
  - Rescuing Survivors from casualty incidents
- Post-disaster recovery
  - Damage Detection
  - Building Reconstruction

2. Can Augmented Reality be utilized to improve mission planning processes?

To answer the main question, yes. Augmented Reality can be used to highly improve mission planning processes. Applying Augmented Reality during hazard recognition and prevention by creating virtual disasters, firmly assists in the design of disaster management plans before the disasters themselves occur. Augmented Reality allows various virtual emergencies to be simulated for first responders to train until they master the necessary responding techniques. The responding techniques include the development of various skills to mitigate the hazard of a disaster and reduce the loss when a disaster occurs.

3. What role can Augmented Reality play in decision making?

Decision making in emergencies requires non-traditional approaches and tools. If implemented, Augmented Reality can play a crucial role in decision making. It makes it possible for disaster management teams and emergency responders to get vital and real-time insights about:

- The state of the unfolding situation and its progress,
- The rescue teams in the terrain and their operations' statuses,
- The situation in the highly risked areas, etc.

Being provided such information, proactive reaction is possible and the risk for wrong decisions is highly minimized.

4. Can Augmented Reality tools be developed to assist first responders during crisis management?

With the latest advancements on Augmented Reality and Virtual Reality technologies, the release of affordable pieces of hardware and software has also been possible. These pieces pave an efficient and easy road towards the development of various customized applications, including applications and tools that can assist during crisis management.

To answer the main question, yeas AR tools can be developed to assist first responders during crisis management. In scope of this thesis, in the Literature Review section, a considerable number of existing AR tools and applications were reviewed. Furthermore, an Augmented Reality based disaster management system was implemented and tested successfully.

5. What are the benefits of using drones in disaster management?

The benefits of using drones in disaster management are plenty.

The usage and implementation of drones during disaster operations primarily provides a great advantage in cost and time, compared to manned aircraft or satellite mapping traditional methods. Among other benefits, we can list the following:

- They are capable of providing instant video streaming to assist with disaster operations
- Provide high-resolution and accurate real-time inspection of the calamity
- Provide communication services
- Generate high-resolution 3D Mapping
- Eliminate the risk of placing human-operated aircraft in harm's way
- Can transport people and supplies in inaccessible terrains
- Can be integrated and live stream to existing disaster management software.
- Can be used to effectively close existing disaster preparedness gaps.

6. What are the benefits of integrating drone mapping and inspection capabilities with Augmented Reality?

The benefits of integrating drone mapping and inspection capabilities with Augmented Reality are also plenty.

When adding Augmented Reality to a drone, operational efficiency in context of disaster relief operations is further improved. It enables various additional functionality to help first responders during disaster planning, recovery, and preparedness, such as:

- Assessing the extent of the damage when flying a drone in inaccessible areas with blocked or destroyed roads.
- Facilitating the locations where first responders should search for survivors or

- Sending information about closed roads and bridges to command centers.
- Structural inspection of civil structures.
- Visual data modelling for risk management professionals.
- Simulation of calamities and safety training for mastering life-saving techniques

7. Which existing crisis management system is used for disaster management in North Macedonia?
    a. Can we integrate Augmented Reality tools with existing crisis management systems?

Next Generation Incident Command System is the software system used during disaster management operations in North Macedonia. It plays the fundamental role in on-scene response efforts during a disaster. It has been implemented and adopted for allowing efficient collaboration between all the agencies in the country.

NICS is interoperable with various technology platforms and databases, including Augmented Reality tools and systems.

8. What are the deficiencies of Augmented Reality regarding crisis management relief operations?

Virtual environments cause dizziness, nausea, and stress among first responders. Participants' behavioral modes and mental states sometimes are not able to create a real-world situation.

Hypothesis

1. Augmented Reality technology is used to aid first responders during crisis management.

This hypothesis was proven to be true. Augmented Reality technology is used to aid first responders during crisis management.

2. Augmented Reality tools can be developed to improve mission planning processes.

This hypothesis was also proven to be true. Augmented Reality tools can be developed to improve mission planning processes.

3. Existing Crisis Management Software support integration with Augmented Reality tools.

This hypothesis was also proven to be true. Existing Crisis Management Software support integration with Augmented Reality tools.

6. Limitations and Future Work

In the scope of this thesis, existing applications of Augmented Reality tools in the domain of disaster relief operations were reviewed, and some further application ideas for integrating drones, Augmented Reality and existing crisis management software were presented. Moreover, the live streaming capabilities and the interaction with the Augmented Reality system were subject to testing. Apart for advancements on livestreaming delays, we have listed the following directions for future research:

1. The lack of studies on post-emergency recovery compared to other stages of emergency management, so more studies can be performed to fill this gap.
2. Training using AR technology can be limited due to lack of knowledge of the trainers, lack of understanding of the potential, and unavailability of professionals. To overcome this, more awareness programs and training should be implemented.
3. Motion sickness as a main potential subject for future research.

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