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Simulating Emergency Management through Extended Reality Technology – bases on a Digital Twin Perspective

Xiaozhong BAO

Master in Management

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Full Professor,
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BRU-Iscte

June, 2023

BUSINESS
SCHOOL

Department of Marketing, Strategy and Operations

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Acknowledgement

I have always liked the saying in Forrest Gump, life is like a box of chocolates, you never know what you are going to get. Looking back on my whole postgraduate experience, I have met many people along the way and have been fortunate enough to see many beautiful sights. Just like in the movie, always tell yourself, "Run like a fool." Because you will find that the plight of your legs, which are like braces, is loosening a little with your violent running until it falls off completely. All the way from a small mountain village in western China, the road is full of flowers and beautiful scenery but also met a lot of like-minded friends. Professor Sandra and Maiana are not only teachers but also friends to me. They are my strongest support in the process of my research. Such help is not only very useful for my paper, but also makes me feel the communication between two different cultures and the friendship revealed in addition to academic research. Just like the beautiful summer in Lisbon, Sandra and Mariana gave me the best memories!

Parting is always the hardest moment, but every time I look back, I always find the silhouettes that still silently watch over me at the beginning. In those shadows are a pair of simple, kind-hearted silhouettes who, with their rough backs, brought me out of the small mountain village and sent me step by step on the road to pursue my dreams. They are my pure and kind parents. Amongst these figures was a lovely lady. Although she was my teacher, she appears to me more as a friend. She was always cheerful, but she also got angry and cried, and I saw in her the most shining trait, which was sincerity. On this path of life, we encounter many things, some of which we need to let go of, and some need to stick to it for a lifetime. Thank you all!

A time in life, you will find someone who's iridescent, and when you do, nothing will ever compare. I am so lucky to have such a name in my heart. Once I mention her name, my mouth will involuntarily rise, because she is the most precious beauty. In her company, time seems to press the fast-forward button, and years seem to blink. When she wasn't around, time was like frozen amber and every minute of it was so clear in my memory. She always said that I had helped her a lot, but in fact it was she who made me brave and gave me the motivation to keep going. Life is few, and it is hard to find a soulmate in life, but luckily I have not only met mine, but she is the one I want to take care of with everything I have. There were many boring moments in the process of writing my dissertation, but every time I thought of her warm smile like a spring breeze, everything was easily solved. It is she who gives me the courage not to fear tomorrow, because we have seen yesterday and love today.

Once again, I would like to thank all my mentors and friends who have helped me during my research. Finally, I would like to say, don't forget what kind of child you were and what kind of adult you want to be!

Resumo

A realidade virtual tem a capacidade de criar um ambiente virtual tridimensional altamente imersivo, proporcionando efeitos de aprendizagem aprimorados quando aplicada à educação ou à simulação de eventos. O objetivo deste estudo é determinar a eficácia das técnicas de extended reality (XR) na formação de actividades de gestão de emergências em cenários de grandes dimensões. Este estudo investiga eficácia da utilização de métodos convencionais de simulação versus utilização de tecnologias imersivas para treinos de simulação. Neste sentido, o estudo adota um ensaio controlado aleatório, que divide os sujeitos em dois grupos. O grupo experimental utilizou a tecnologia XR para a simulação de casos e o grupo de controlo utilizou métodos convencionais. Foi também criado um grupo de peritos para avaliar o comportamento profissional de todos os sujeitos, tendo sido utilizado o teste T de amostras independentes para analisar os resultados. Os resultados experimentais mostram que o grupo experimental teve melhor desempenho profissional do que o grupo de controlo. A tecnologia de realidade virtual XR pode melhorar o desempenho dos gestores, bem como de outros trabalhadores médicos no processo de gestão de emergências, proporcionando um ambiente de treino realista e científico. Tendo em consideração os resultados, XR deve ser considerada na conceção de atividades de simulação de gestão de emergências. Ao mesmo tempo, também é necessário prestar atenção às características geográficas locais e ao ambiente de vida dos casos de emergência no processo de conceção, para se adaptar às condições locais, só assim o papel da tecnologia XR pode ser maximizado.

Palavras-chave: Realidade alargada; Gestão de emergências; Exercício de simulação; Ensaio controlado aleatório

Códigos de classificação JEL: M10; M15

Abstract

Virtual reality technology can build a virtual three-dimensional space with strong immersion, which can lead to better training effects when applied to education or event simulation. The purpose of this study is to determine the effectiveness of extended reality (XR) techniques for training emergency management activities in large scenarios. This study investigated the effectiveness of using conventional case simulation methods versus using extended reality for case simulation training. This study adopted a randomized controlled trial, which randomly divided the subjects into two groups. The experimental group used extended reality technology for case simulation, and the control group used conventional methods. An expert group was set up to evaluate the professional behavior of the all the subjects, and the independent sample T-test was used to analyze the results. The experimental results showed that the experimental group using XR technology had better occupational performance than the control group. The XR virtual reality technology can superiorly improve the performance of managers as well as other medical workers in the emergency management process, while this virtual simulation pathway provides a scientific training environment for emergency management in a real environment. On this basis, XR should be considered when designing emergency management simulation activities. At the same time, it is also necessary to pay attention to the local geographical characteristics and the living environment of emergency cases in the design process, to adapt to local conditions, only in this way can the role of XR technology be maximized.

Keywords: Extended reality; Emergency Management; Simulation exercise; Randomized controlled trial

JEL Classification codes: M10; M15

Abbreviations

Abbreviations	Meaning
XR	Extended Reality
VR	Virtual Reality
AR	Augmented Reality
EM	Emergency Management
RCT	Randomized Controlled Trial
NFYY	Nan Fang Yi Yuan
STC	Skill Training Centre

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CHAPTER 1

Introduction

Since the beginning of the 21st century, the frequency of geological and human-caused large-scale disasters has been increasing worldwide, causing incalculable economic losses and, more distressingly, millions of lives have been lost in disasters, and the trend is on the rise (Guha-Sapir, 2012). Many countries have introduced the concept of emergency management (EM) based on lessons learned from past disasters and have adopted regular disaster simulation exercises to improve emergency management capabilities in response to various emergencies and to reduce the impact of emergencies (Waugh & Streib, 2006). However, most traditional simulation exercises are based on real-life scenarios. Due to the complexity of disasters and emergencies, the reproducibility of special scenarios is limited. Decision-making and on-site management are therefore limited in this traditional simulation mode. Virtual reality is a good solution to this problem due to its excellent situational and interactive properties. This project draws on the ability of extended reality technology to achieve scenario restoration and instantaneous multi-person communication, combining the virtual with the real to explore effective ways of enhancing emergency management.

A review of the literature reveals that technologies such as extended reality and virtual reality have been found to have a catalytic effect in enhancing participants' cognitive abilities, responsiveness, and organizational planning skills (Maura & Son, 2022). This project will design an extended reality-based emergency management program and conduct a controlled group trial in a tertiary hospital in China to explore whether extended virtual reality can be an effective tool to improve emergency response effectiveness in the future.

The project has important practical management implications for hospital managers, in that it can simulate various emergency scenarios through a figurative virtual environment, where managers can conduct repetitive decision-making simulation exercises in a highly reductive virtual environment to get close to realistic feedback. Joeri et al. (2019) have demonstrated through empirical research that crisis management capabilities can be significantly changed and improved through repetitive exercises. In addition, through the VR digital city simulation system designed by Ham (2020), virtual reality systems can be found to be effective in improving the city's disaster management capabilities and anticipation of unknown risk events.

Numerous studies have shown that virtual reality technology has unique advantages in case studies (Li et al., 2021). Therefore, this project suggests that this XR-based simulation exercise can, on the one hand, test the feasibility of the emergency management plan specified by the manager and, on the other hand, optimize the hospital's emergency management mechanism through continuous simulation. This will greatly improve the efficiency of response and the quality of treatment, minimize

the damage caused by emergencies, clear the way for the normal operation of hospital medical work, reflect the operational management capabilities of the hospital and is an important part of the modern public hospital management system. It is also of strategic importance for the government administration to actively explore and study the establishment of a hospital emergency response mechanism to improve the overall emergency response capability and treatment effectiveness of hospitals in public emergencies to save more lives.

1.1. About the company

The Southern Hospital of Southern Medical University (NFYY) is a large comprehensive tertiary hospital that integrates medical care, teaching, research, and prevention is one of China's Top 100 Hospitals (a title awarded by the Chinese Ministry of Health and the State Administration of Traditional Chinese Medicine.) Founded in 1941 and formerly known as the First Military Medical University of China, NFYY now has 5 national key disciplines and 17 national clinical key specialties. NFYY is ranked consistently in the top 15 of China's authoritative domestic rankings and is also a national (trauma) regional medical center. NFYY is committed to serving patients with love, fulfilling its social responsibility, cultivating excellence in talent, building distinctive technology, and climbing to the top of the medical ladder to make its contribution to human health.

In addition to its regular medical functions, NFYY is a hospital with many teaching and preventive exercises and has a Clinical Skills Training Centre, which is responsible for all training and assessment-related activities, including but not limited to clinical skills training and assessment for doctors, and emergency management training. The Centre has over 2,000 square feet of training space and hundreds of training aids. Analysis of the training data over the last five years shows that the annual average number of people trained at the Centre is increasing, and the rate of repeat training on the same topics due to poor training outcomes is also increasing. As these training activities are non-profit projects which to a certain extent increases the financial burden on the hospital (See Figure 1.1).

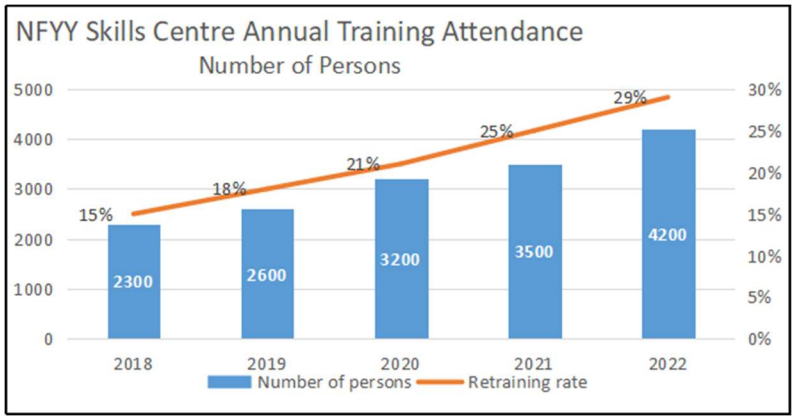


Figure 1.1 NFYY Skills Centre Annual Training Attendance (Source: Nan Fang Yi Yuan Academic Affairs Office)

Each year NFYY's Skills Training Centre not only undertakes training within the hospital, but also acts as an educational training base for the Guangdong Health Care Commission, and as such undertakes different types and topics of training each year, with slightly different training methods for different training populations and topics, but, overall the different training methods have a similar training model. The training process can be divided into three parts: before, during, and after the training. (See Figure 1.2) This model was developed by the Skills Training Centre (STC) through concrete practical experience. It can also provide guidance on the management of training activities, such as the management of training materials and personnel, and the management of training outcomes.

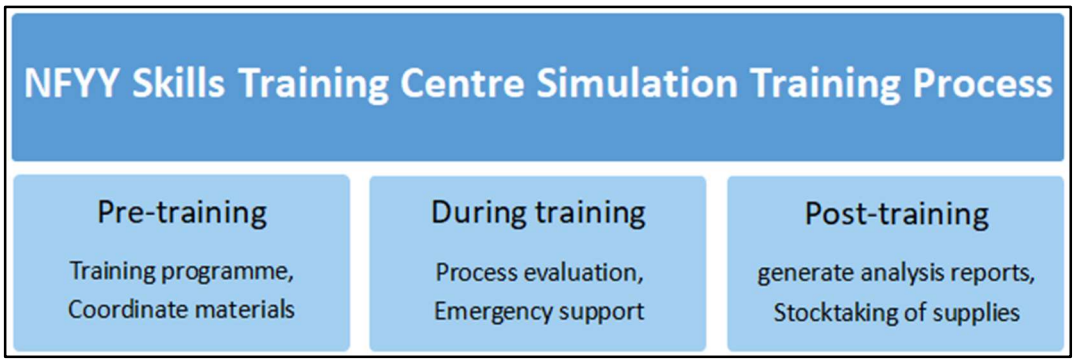


Figure 1.2 NFYY Skills Training Centre Training Process (Source: Nan Fang Yi Yuan Skills Training Center)

Under this training model, the STC has selected different training methods for different target groups. Undergraduate medical students are trained using dummies, while residents are trained using dummies with built-in electronics that provide some feedback. This approach is less demanding in terms of the environment and the people to be trained, so it can be delivered with basic medical teaching aids and is suitable for large-scale training activities. The costs and indicators of the training process are also clear and manageable (Nang Fang Hospital, 2023).

However, there are many problems that arise when this training model is applied to emergency management training activities. The scenarios that need to be simulated for emergency management activities are often large and complex and involve multiple departments and different responders (Li et al., 2022). With the current simulation exercise approach, simulations can only be carried out with real people and dummies. However, this leads to more complex coordination of materials, venues, etc., and consequently to higher investment costs (Zhao et al., 2023). To date the STC has only successfully conducted three emergency management drills in the last five years, and the long interval between these three training sessions has made the actual training results worrying. Whilst the current training model and methodology addresses the immediate training needs, there is an urgent need to find an efficient and repeatable training approach for emergency management capability to improve NFYY's and the region's emergency response capabilities and reduce the potential loss of life in the event of an emergency.

1.2. Problem statement & Aim of the project

Hospitals like NFYY are in fact very common in China, with a total of 1,651 tertiary hospitals in China in 2021 (National Department of Planning, Development, and Informatization, 2021). Not only do tertiary hospitals need to have better medical equipment and medical standards but they also need to be excellent medical education and training bases. In addition, many Level 2 and Level 1 hospitals are also actively engaged in various medical teaching activities, so there is a large demand for teaching and training at all levels of care. Most of these training activities are focused on medical skills, but in recent years, as the functions of medical staff have expanded, the content of the training has become more diverse, with a greater emphasis on management skills. As governments have become more aware of catastrophic events, public health emergencies, major epidemics, and accidents, the Chinese government has been investing in emergency management. Rules for the Implementation of the Accreditation Standards for Tertiary General Hospitals (2020) clearly emphasize that the construction of a hospital emergency management system is an important task in hospital management and is included in the core provisions of the evaluation. Hospitals are required to comply with national laws and regulations, strictly implement the emergency plans formulated by governments at all levels and undertake emergency medical rescue and emergency treatment for public health emergencies and major accidents and disasters.

In this context, medical institutions at all levels have started to experiment with different methods of emergency management drills, including but not limited to multimedia-based emergency drills, drills using dummies, and drills using VR technology. NFYY, as one of China's top 100 hospitals, is in the top tier in terms of medical resources and information technology but still adopts a traditional training

model for emergency management-focused drills. However, the traditional training model reveals several shortcomings in such large scenario exercises. The first point is that immersion is poor. As many emergency scenarios are complex and difficult to recreate in a realistic environment, most traditional emergency management exercises can only simulate emergency scenarios through smoke and sound effects, but participants often find it difficult to immerse themselves in them (Pucher et al., 2014). The second point is that exercises are complex to organize. Each emergency management exercise requires multiple participants, making it difficult to coordinate staff and materials (Pak et al., 2019). The third point is that training is costly and ineffective. The human and material resources invested in such large-scale simulation exercises far exceed those of ordinary training activities (Li et al., 2022). However, hospitals that are tasked with regional emergency response are often public hospitals, which undoubtedly increases their financial burden. However, it is not only a mandatory policy requirement for improving emergency management capabilities, but also a realistic need for hospital managers to effectively control risks. Therefore, it is imperative for hospital administrators to explore a model of emergency management exercises that is well-trained and feasible.

With the iterative development of new-generation information technologies such as artificial intelligence, big data, 5G, and virtual reality, the cross-fertilization of new information technologies in the field of modern medicine is becoming more and more successful. Larsen et al. (2009) demonstrated the effectiveness of Virtual Reality (VR) technology in improving surgical skills through a randomized controlled trial. VR can significantly enhance the immersion of trainees in events through the construction of realistic virtual scenarios. Almousa et al. (2021) applied VR technology to clinical training and found that this model was effective in improving the efficiency of training and facilitating the flow of educational resources. Pucher et al. (2014) tried to combine the two and found that VR technology was effective in emergency management training, but it still had many drawbacks. It is not possible to obtain relevant information from the manager's perspective, which is also an urgent problem to be solved in management ability training (Zhao & Li, 2023).

Based on the above research background, this project aims to find an emergency exercise model that can simultaneously reduce exercise costs, optimize simulation scenarios and improve exercise effectiveness. The ability of extended reality to provide multi-person interaction while simulating large scenarios is in line with the needs of emergency management exercises (Philipp et al., 2022). However, research focusing on XR in the management of emergencies is still highly unexplored, and further research from a management perspective is needed. Therefore, this paper has chosen to extended virtual reality as the topic of this project. Based on the digital twin theory, the feasibility and effectiveness of applying extended reality (XR) technology to emergency management exercises.

This project consists of three main parts. The first part focuses on the theoretical framework involved throughout the research process, including how to apply digital twin theory and SMART

theory. The second part introduces the design of the experiments, including the selection of the experimental subjects, the experimental methods, and the methods of data acquisition. It also introduces how to develop and design the virtual reality software used in the experiments. The third part is devoted to the analysis of the experimental data and a summary of the effectiveness of XR technology for emergency management.

CHAPTER 2

Literature Review

2.1. Digital Twins

In recent years, there has been a growing interest in digital twins (DT) in industry and academia. The digital twin has been described as the virtual counterpart of a physical entity and has facilitated many useful use cases that allow for cost-effective, user-friendly, and secure scenarios (David et al., 2020). DT is the dynamic mapping of physical entities in the virtual world, which can provide support for the expansion and upgrade of physical objects by using attributes, behaviors, and rules of real situations simulated in virtual models to perform virtual and real interactive feedback, data fusion analysis, decision-making iteration optimization and other operations (Lim, 2019). The core elements of DT include physical entities, virtual models, services, data, and connections (Liu, 2021). According to the technology stack and technology framework summarized by existing scholars in the field of DT, the key technologies can be divided into three categories: data modeling, and model simulation (Grieves & Vickers, 2017).

DT is frequently used in Industry 4.0 applications and has been shown to be frequently used and researched, especially in the manufacturing sector (Werner et al., 2018). However, there are several examples of digital twins in different application areas. Enders and Hossbach (2020) present a literature review of 87 digital twin applications and highlight that most digital twins are used in manufacturing. Nevertheless, the potential application scenarios remain diverse and include aerospace, energy, automotive, marine, oil, agriculture, healthcare and the public sector. The three main purposes of digital twins have been described as simulation, monitoring, and control. In recent years, many authors have demonstrated the potential of digital twins in various fields through literature reviews.

In model simulation technologies, multiscale simulation, finite element analysis, augmented reality (AR), and virtual reality (VR) technologies are the important aspects. The earliest conceptual model of DT dates back to a University of Michigan industry presentation, proposed by Dr. Grieves in 2002, but this model was referred to as the Mirrored Spaces Model (2003–2005), the Information Mirroring Model (2006–2011) in the early days, and emphasized on how to play a role in product lifecycle management (PLM) (Grieves, 2011). DT was attached to this model as an alias for the information mirroring model in virtually perfect: Driving Innovative and Lean Products through Product Lifecycle Management.

Digital twins in VR can be a great tool to allow different user groups to understand complex systems. Tomasz et al. (2020) demonstrate the combination of radio telescopes with digital twins and point out the advantages of an immersive visual experience with VR. Portable VR solutions are

described as excellent tools to support outreach. Havard et al. (2019) demonstrate the potential of digital labs for lab-based learning. It reduces the disadvantages of a purely virtual experience and adds the benefits of virtualisation and remote control of the lab, while decision makers are invited to better understand the current situation and find new solutions.

This project plans to use extended reality technology to simulate and reproduce common disaster scenarios in a virtual environment, providing users with a variety of simulated scenarios, thus realizing the process of information simulation, achieving a digital twin, and effectively improving people's ability to respond to and deal with emergencies.

2.2. Emergency Management

An emergency is a critical, sudden, and sometimes catastrophic event that requires an immediate response from people (Waugh & Streib, 2006). Given the seriousness of emergencies, effective and efficient emergency management (EM) plays a vital role in minimizing the damage and harm caused by the event and preventing subsequent events from spreading into larger disasters (Kwok et al., 2019). Emergency management is not a concept for a single group of people but involves the organization and management of large amounts of human and material resources in order to support the various phases of emergency response: disaster prevention, preparedness, response, and recovery (UNISDR, 2009).

Due to its complexity, EM has a variety of definitions, some representative ones are as follows: The US Federal Emergency Management Agency (FEMA) defines emergency management as the process of preparing for, mitigating, responding to, and recovering from emergencies in the event of a disaster (Federal Emergency Management Agency 1999). Emergency management deals with catastrophic events by implementing a range of activities including detection, preparation, planning, mitigation, response, and recovery (George et al., 2007). Modern emergency management is the process of effectively monitoring, responding, controlling, and dealing with emergencies by using modern technology and management methods, integrating various resources of society, and scientifically analyzing the causes, development process, and negative impacts of events (Chen et al., 2009).

In conclusion, emergency management is a complex, multifaceted task involving multiple management activities by managers and stakeholders to prevent emergencies, control social losses, and eliminate the impact caused by emergencies. When a mega-emergency occurs, managers are required to develop a reasonable rescue plan within a short period of time to reduce casualties and economic losses (Caballero & Niguidula, 2018). However, how to respond effectively to emergencies is a challenging topic worldwide. When managers in emergency management make decisions, it is

difficult to make the right decisions to deal with emergencies due to the complexity and uncertainty of emergencies and the strong time constraints (Liang et al., 2017). In addition, emergency decisions can be potentially serious risks, as wrong decisions can lead to unexpected and catastrophic consequences (Radcliffe et al., 2019). Therefore, EM issues have attracted more attention from researchers and practitioners in recent years.

The frequent occurrence of natural and man-made disasters has prompted countries to continuously improve their emergency management processes and mechanisms. In the United States (Department of Homeland Security of USA 2017), Congress passed the Emergency Banking Act in 1933, marking the beginning of emergency management, and in 1967, the country advanced its emergency response system. Later, the 911 terrorist attacks led to the release of the famous National Incident Management System (NIMS) in 2008.

Japan is one of the countries in the world with a particularly high number of earthquake disasters. In 1993, the International Emergency Management Society (IEMS) was published. in the 1990s, the government devised an evaluation system to assess government and provincial emergency management capabilities. Today, Japan has a multi-faceted, multi-disciplinary and multi-level coordination system from the Prime Minister's Office to all levels of authority.

Compared to developed countries, emergency management in China started late (Chen et al., 2009). after SARS in 2003, China initiated the development of emergency management to deal with various types of disasters ranging from natural disasters, industrial accidents, epidemics to terrorist attacks. in 2007, China enacted the Emergency Law, the first comprehensive document regulating emergency management in China. Since then, more and more special emergency plans have been introduced to meet practical needs, and in 2015, the enactment of the Anti-Terrorism Law became a milestone in China's emergency management.

In most cases, responding to an emergency requires a variety of emergency responders, such as police, firefighters, and emergency medical teams. The evolution of an incident generally consists of three phases, namely pre-incident, incident, and post-incident. Accordingly, emergency management refers to a three-stage process: (1) detecting early warning signs and anticipating potential events; (2) responding to, controlling and dealing with emergencies with the aim of reducing negative impacts; and (3) assessing the damage caused by the event and the performance of the response and recovering from the emergency. Chen et al. (2009) argues that from a manager's perspective, emergency management can be summarized as a '4Rs' process, namely reduction, preparedness, response and recovery, where reduction refers to the ex-ante phase, preparedness and response to the ex-ante phase and recovery to the ex-post phase of the incident. At each stage, the decisions made by managers significantly influence the evolution of the incident and the effectiveness of emergency management.

We can identify emergency management as being characterized by (1) the absence of immutable rules; (2) the existence of stochastic constraints on time, information and decision-making; and (3) the existence of a large number of conflicting decision directions. These characteristics pose significant challenges to the analysis and decision-making of managers in emergency response. The goal of emergency management is to use partial and incomplete information to make quick and effective decisions during emergency response. In order to respond successfully, emergency response organizations need to ensure that emergency responders are capable of responding to a variety of adverse events and associated hazards (Caballero & Niguidula, 2018). Basic vocational training for those involved in emergency response is particularly important; knowing how to manage the scene effectively is something that everyone needs in a large-scale disaster. To improve the skills and knowledge of emergency responders, one traditional form of training is to simulate actual events. However, this method of training has many limitations, such as excessive resources, costs, and risks, and comes with the creation of real hazards (Zahabi & Abdul, 2020).

2.3. Extended Reality

Training is required for humans to develop the necessary performance skills. Learning protocols can be both expensive and time-consuming (Kaplan et al., 2021). Thus, any advancement in technology or methodology that might reduce the cost, either in financial or temporal terms, will be of great relevance to many individuals, organizations, and industries (Alcaniz et al., 2018).

For this reason, simulation-based training has shown promise and is gaining acceptance as a means to increase training efficiency (Hancock, 2009). Although simulation- training can be delivered via portable tablets or conventional flat panel displays, we are witnessing the increasing use of augmented reality (AR) and virtual reality (VR) displays and new mixed reality (MR) displays which include both AR and VR. The essence of all these new information technologies is to enhance the user experience by providing the user with a simulated physical model based on a real environment through a virtual environment or screen, and these technologies can be used in combination with each other, thus giving rise to XR technology, which can therefore be said to encompass these virtual reality technologies (Philipp et al., 2022). VR technology generally uses a headset, blocking out visual stimulus from the real world. AR allows users to see the real world but overlays virtual elements. MR combines the two, including aspects of both the real and virtual worlds. Extended reality (XR) is the umbrella term that refers to these three different types of simulations. XR has revolutionized the way people experience their environment (tom Dieck and Jung, 2018). Rauschnabel et al. (2018) argued that AR and VR are different approaches, whereas – contradictory to the Milgram et al. (1995) continuum – AR can range from unrealistic and functional ‘assisted reality’ to realistic ‘MR’. As the mid-point of the

reality-virtuality continuum, AR can be defined as "the digital overlay of information (or image) into users' direct surroundings using devices such as smartphones or wearable smart glasses" (Tom et al., 2018). For example, smartphone users can download civilization AR app from BBC to explore various historical artifacts out of the display' and view them in 3D mode. Wearable smart glasses, on the other hand, are wearable devices with installed AR apps.

These technologies promise to reduce some of the costs associated with expensive training, especially where spatial information is important, such as in the field of aviation (Kaplan et al., 2021). XR training can also eliminate some of the risks inherent to high-level training by placing individuals in a simulation rather than a real-world dangerous situation (Pedram et al., 2021). Training in XR promises to have benefits beyond simply supplementing traditional training protocols. Whether it is a time-saving, cost-saving measure or not, the benefits that exist may still outweigh potential drawbacks (Kaplan et al., 2021).

Extended reality (hereafter referred to as XR) – the next-generation computing platform – has changed the way we work, learn, connect, and play by bridging the physical world to a digital one (Rauschnabel et al., 2017). It also transforms how enterprises train the workforce, serve customers, design products and manage their value chain (Chmielewski, 2017; Porter & Heppelmann, 2017). XR is an umbrella term encapsulating augmented reality (AR), virtual reality (VR), and mixed reality (MR). While AR integrates virtual and real objects in a real-time display, VR allows users to control and navigate their movements in a stimulated real or imagined world (Ro et al., 2018; Suh & Prophet, 2018). Both technologies are often melded together (i.e., MR) to induce more immersive experience. Whether watching 360° movies, playing games, walking through 3D models of the buildings, travelling through the universe, or any other immersive experiences, XR devices create the illusion to make people feel as if they are in an entirely new digital world (Donnell, 2018). Such technologies have been praised for its ability to create virtual tours in the stores and destinations, rehabilitate brain injury, and virtually inspect the interior and exterior design of a car which no existing technology could do (Sheikh, 2016).

Given its enormous potential, XR technology has been increasingly applied and studied in a plethora of fields, ranging from tourism (Jung et al., 2015), education (Kerawalla et al., 2006), retailing (Yim et al., 2017), gaming (Rauschnabel et al., 2017) and healthcare (Glegg et al., 2017) to manufacturing (Choi et al., 2015).

Recent forecasts by International Data Corporation (IDC) anticipate the global shipments of AR/VR headsets to soar from 4.2 million units in 2018 to 53.1 million units by 2022, achieving a compound annual growth rate (CAGR) of 88% (IDC, 2018a). By 2020, the sales of AR/VR devices are expected to generate a staggering $150 billion in revenue (Gaudiosi, 2015). Given its rise, Google, Alibaba, Warner Bros, and other firms have invested approximately $800 million of venture capital into an AR startup

called Magic Leap. Likewise, large brands like Coca-Cola, McDonald's, and Disney have rolled out AR/VR applications to create an enchanting experience for customers. Total spending on AR/VR is estimated to increase by 92% to hit 17.8 billion in 2018 and reach as high as $215 billion by 2021 (IDC, 2018b).

Seeing the rising hype in the marketplace, Jabil's recent survey documents that "AR/VR will become mainstream within five years" (Jabil, 2018) and Goldman (2016) concludes that "VR/AR has the potential to spawn a multibillion-dollar industry, and possibly be as game-changing as the advent of PC". Yet, despite the strong growth potential for XR, such technologies still struggle to gain traction among consumers and enterprises (Herz & Rauschnabel., 2018). Market research reports have indicated that cost, technical limitations, and performance issues, bulky hardware, among others, are the barriers that hold back XR from becoming mainstream (Jabil, 2018; Perkins, 2018). For XR technology to be successfully adopted, these obstacles need to be overcome, and at the same time, further strengthen the benefits (Adapa et al., 2018).

While an increasing number of studies have investigated the factors leading to XR market success, these studies so far seem fragmented and a thorough review of existing works remains scarce, thus impeding the progress of this field. The exception is a study by Suh and Prophet (2018) who have consolidated and mapped the factors associated with XR use onto the stimulus-organism-response (S-O-R) framework. The conceptual framework illustrates how technological (e.g., sensory and perceptual stimuli) and content features of XR lead to positive (e.g., learning effectiveness) and negative outcomes (e.g., cognitive overload) through the mediation of users' cognitive (e.g., immersion) and affective (e.g., pleasure) responses. However, the list of factors is not exhaustive, and they focus mainly on the technology and media aspects of XR, thus disregarding the fact that XR device is also a fashion accessory (Herz & Rauschnabel, 2018).

2.4. The current state of emergency management and its importance

Observation of historical data shows that the number and severity of disasters and catastrophes over recent decades has been increasing across the world. This fact applies to not only natural disasters but also terrorist attacks. According to CRED (2018), 1.3 million people lost their lives, and 4.4 billion people were injured or became homeless due to natural disasters between 1998 and 2017. As reported by the Emergency Events Database (EM-DAT, 2018), 4.2 billion people (i.e., more than half of the world's population) were potentially exposed to natural disasters in 2017. Although fewer natural disasters, deaths, and total affected people were declared in 2017, the mortality rate in African and American continents was higher than the annual average of the last decade due to the occurrence of landslides, earthquakes, and hurricane catastrophes (EM-DAT, 2018).These facts confirm that recent advances

in science, technology, and management have not been able to significantly decrease the number of disasters and their aftershocks.

All the decisions and operations regarding the management of a disaster are embedded in a four-phase cycle including (1) strategic mitigation to reduce/eliminate the impact of disasters, (2) tactical preparedness to lessen/avoid the effects of disasters, (3) operational response to preserve lives, properties, and the environment and finally, (4) long-term recovery to return affected sites to predicate conditions. Although each step has its own goals and importance, rebating negative consequences is, to a large extent, a function of the quality of decision-making and the efficiency of operations management during the response phase. Post-disaster circumstances are extremely challenging due to the loss of human life, human suffering, damaged infrastructure, limited availability of resources (transportation, relief commodities, equipment, manpower, and medical capacity), and uncertain and incomplete information. Having an effective real-time response in the aftermath of a disaster requires several interacting decisions to be made and numerous coordinated operations to be arranged quickly within a volatile, uncertain, and stressful environment.

In the first few hours after a sudden, or slow-onset mass casualty incident (MCI), thousands of casualties, which disrupt the normal functioning of emergency and healthcare services, need primary on-field assistance and treatment to survive before being taken to hospitals. Emergency management (EM) is one of the most important functions in the response phase, which needs comprehensive planning. According to the definition of the World Health Organization (WHO), EM is the process of efficiently utilizing limited resources to manage casualties in affected areas and transfer them to hospitals by a group of units and organizations, which work together aiming at minimizing the number of deaths and disabilities, maximizing the number of survivors and preventing possible outbreaks of diseases (Dean & Nair., 2014). In fact, all of the following human-related decisions made (or activities designed and operated) to save as many lives as possible fall under the term EM: searching, rescuing, and prioritizing casualties, transferring them to safer places (e.g., field hospitals or shelters), allocating timely relief teams, equipment, and supplies (e.g., food, clothing, and medicine) to affected areas, providing treatment services either temporarily on-site or comprehensively in hospital and coordinating the related flows of information.

EM is basically a complex, multi-disciplinary, and multi-agency effort as it may call for many organizations and the coordination of executives and practitioners, engineers, scientists, information technology (IT) experts, physicians, and medical personnel, and social scientists from governmental, public, private and non-profit organizations in unpredictable, time-limited and resource constrained post-disaster circumstance.

CHAPTER 3

Methodology

3.1. Research design

3.1.1. Subjects and data collection

The main subject of this experiment is the managers in the emergency management process, but in the light of the actual situation, in dealing with emergency events, management behavior exists throughout the entire chain, so this experiment did not limit the selection of the subjects to only the middle and senior managers in medical institutions but extended the scope to include highly qualified medical workers with many years of work experience because, in real emergency rescue work, these experienced volunteer workers often take on roles such as emergency squad leaders and will make management decisions during the rescue process.

Based on these factors, the target group for this project was selected to include medical and managerial workers with intermediate or deputy senior titles at the Southern Hospital in Guangzhou, Guangdong Province, China. Southern Hospital is a tertiary care hospital and is also one of the regional emergency management units in Guangdong Province, making the sampling site highly representative and the final study data highly transferable.

The project adopted an observational approach to collecting experimental data. The specific implementation method was to form an evaluation team by selecting experts who met the criteria and had some academic authority in the field of emergency management, and according to the logic of the experimental design, an evaluation scale capable of quantitative evaluation will be developed. During the experiment, the expert group will act as observers, observing the professional performance of the subjects during the experiment and rating them according to the scale. After the experiment, the experts' scales will be uniformly collected, cleaned, and entered into SPSS 25.0 software for subsequent analysis.

3.1.2. Development tools

Unlike traditional 3D simulations, virtual reality technology is able to generate a virtual environment with multiple sensory functions based on real scenes by computer, as well as automatically locating auditory, tactile, and kinesthetic senses, allowing the operator to interact with the virtual environment in a variety of ways (Almousa et al., 2021).

However, with the addition of physical simulation, collision, lighting, and interaction systems to the virtual environment, the process of building virtual systems has become increasingly complex, and there is an urgent need for a developing technology that packages the complex underlying logic in the

application of virtual reality technology (Eric & Loutfouz, 2021). There are currently two main virtual reality development technologies based on 3D simulation, Unity, and Unreal Engine 4. Both Unity and Unreal Engine 4 isolate the business logic and underlying functionality to a certain extent, making model design and program development independent of each other and ensuring the stability of the development architecture (Matt, 2019). The graphics module is the key to developing the engine, its main functions are to encapsulate the underlying rendering interface, customize the rendering pipeline (forward rendering, deferred rendering, multi-threading, etc.), adapt to different platforms, and perform basic rendering (Ruthenbeck & Reynolds, 2013). UE4 has a major advantage over Unity in this respect thanks to its large amount of API and the encapsulation of the underlying technology.

Consequently, the development of virtual systems is much less difficult and scenario developers can create virtual scenario code and interfaces through the blueprint scripting language without a strong programming skill, which is of great importance for the application of virtual reality in the field of management. Hence, Unreal Engine 4 (UE4) was chosen for the development and design of the virtual system.

3.1.3. Experimental subjects

As public emergencies are sudden and destructive, in order to mitigate losses and save more lives in the shortest possible time, multiple rescue forces and the participation of multiple parties are required (Green & Kolesar, 2004). Hence, this case covers three important levels in the scenario staffing and the relevant departments: government forces, which refer to the national comprehensive fire rescue team and local emergency command agencies; medical forces, which refer to professional emergency rescue teams; and social forces, which refer to various types of voluntary social emergency forces.

In the simulation, the professional medical forces from the medical institution are the mainstay, while the case is designed to include the roles of government and social forces to simulate a collaborative rescue environment in the event of a large-scale emergency, and to further optimize the problems encountered in the implementation of emergency management in medical institutions.

In terms of the division of roles, this case was scripted based on real data and case studies. The social context of the mass casualty event simulated in the case is a public building collapse emergency in a downtown area. The medical body carries out the emergency rescue tasks in accordance with the "Management, Control and Reality" simulation guidelines and is mainly responsible for the first aid of patients and other on-site operations; the governmental group is mainly the integrated fire and rescue team, which carries out the search and rescue of the injured; and the voluntary social group appears in the case scenario in an emergency mobile role. Trainees will be involved in the overall simulation as managers of the emergency command organization and will issue the overall rescue plan. In addition,

the roles of the above governmental and social groups are created in the XR virtual scenario and will appear in three dimensions during the case exercise, interacting with the trainees and creating an overall environment that is infinitely closer to a real large-scale incident.

3.1.4 Apply randomized controlled trial methodology

The aim of this project is to explore the effectiveness of XR technology in the field of emergency management. Supported by the digital twin theory and through literature review, it is found that this type of virtual reality technology has verifiable advantages over traditional conventional approaches in the field of education and training (Kaplan et al., 2021), therefore this project identifies the type of experiment as a superiority experiment. To further improve the scientific validity of the experiment, this project will adopt an RCT approach to verify the effectiveness of XR technology in the field of emergency management by randomizing the experimental and control groups.

(1) Experimental objectives

This experiment is a controlled trial of the effects of applying XR technology under the guidance of the digital twin theory. The experimental group used the XR emergency management simulation system to conduct a case-specific simulation exercise in a virtual environment. The control group used a traditional real-life simulation method, using the same case content as the experimental group. Both groups received two weeks of training with the aim of exploring the effectiveness of XR technology in the field of emergency management and comparing it with traditional simulation training to suggest new tools that could facilitate the further development of emergency management activities.

(2) Experimental procedure

The experiment was carried out in the Southern Hospital in Guangzhou, China. Based on the sample size determined in advance, a random sample of 50 cases each from the experimental group and the control group was selected for the study. In addition, 20 experts who met the requirements of the experiment were selected by controlling the authority factor of the experts to participate in the evaluation of the experiment, thus identifying all participants in the experiment. The experimental and control groups were divided into two groups of 50 participants each, with 10 participants divided into groups of 10. This division takes into account the different functions that the teams need to have in order to face different situations during emergency management. The following guidelines were established for the formation of the teams: a 10-person emergency team, consisting of two team leaders, 4 surgeons, 2 internal medicine doctors, and 2 test and epidemiology technicians. Although the experiment was conducted in small teams, the team was configured in such a way as to reproduce the elements involved in a real-life scenario and to maximize the extent to which management decisions could be made in different situations.

The experiment can be divided into three parts: pre-experiment, during the experiment, and post-experiment. The pre-experimental phase includes the preparation of the experimental site, the experimental materials, and the emergency plan. During this phase, both the experimental group and the control group receive the same form and content of basic emergency management training to eliminate differences in background knowledge between the groups. In addition, the experimental group should be familiarized with the virtual display equipment used in the experiment, so as to reduce the bias of the experimental equipment on the process. Once the experimental requirements were met, the study followed the established experimental procedure based on the simulated cases developed in the previous phase, and the participants were evaluated quantitatively during the experiment. At the end of the experiment, the main focus is on collecting, collating, and cleaning the experimental data and conducting a summary analysis.

(3) Selection of experts

Before the experiment is conducted, both the experimental group and the control group will learn the basic theoretical knowledge of emergency management, and this part of the training will use the internal emergency management learning materials produced by Southern Hospital. This is to eliminate as much as possible the differences between the two groups in their knowledge of emergency management, thus reducing experimental error. The experimental group will not require additional teachers for training during the formal experiment, while the control group will select a group of teachers and conduct the experiment using traditional case studies and simulation methods.

There are a total of two places involved in the course of this experiment that require guidance and training from the relevant experts, namely when the control group undergoes case training and for the behavioral evaluation of the two groups during the case simulation. The selection of the appropriate experts, therefore, has an important impact on the expected results of the presented experiment. The experiment was designed with the objectives and the expected effectiveness of the experiment in mind and based on the principle of screening for third-party unrelated interests, people who were not directly related to the experimental subjects were selected to avoid artificially caused bias in the experimental data to the greatest extent possible.

For the inclusion of relevant evaluators, relevant inclusion criteria were developed for this experiment. Inclusion criteria: a: master’s degree or above with intermediate title or above; b: more than 5 years of clinical as well as emergency management experience in a tertiary care hospital; c: voluntary participation in this project, knowledge of the study area before the survey, able to provide opinions with the reference value and able to continue to participate in this project until the end of the experiment. A total of 20 experts who met the requirements were included in this experiment, of which 11 masters and 9 were PhDs.

This experiment also controls for the degree of expert authority. The degree of expert authority refers to the strength of an expert's authority on a particular type of issue or domain, and its value has a significant impact on the reliability of the evaluation, so the degree of expert authority needs to be quantified. The authority coefficient of an expert is determined by two factors: the basis of the expert's judgment of the issue and the expert's familiarity with the issue. The coefficient of adjudication is expressed as Ca and the coefficient of sense is expressed as Cs. The coefficient of reliability factor Cr = (Ca + Cs)/2. An expert authority factor Cr $\geq$ 0.7 is generally considered reliable. The expert's judgment on the issue is mainly divided into four dimensions: practical experience, theoretical analysis, reference to domestic and foreign literature, and intuition, each of which is divided into large, medium and small degrees of influence; the different levels of large, medium and small assignments of different dimensions are divided into: practical experience (0.5, 0.4, 0.3), theoretical analysis (0.3, 0.2, 0.1), reference to domestic and foreign literature (0.1, 0.1, 0.1), and intuition (0.1), 0.1), and intuition (0.1, 0.1, 0.1). The familiarity of the experts with the issues was divided into five levels: very familiar (0.9), more familiar (0.7), generally familiar (0.5), less familiar (0.3), and unfamiliar (0.1). The specific evaluation form and see the scale (See Appendix C).

By analyzing the data of the experts included in this experiment, the following results were obtained. Comparing the authority coefficient (Cr), it can be found that the five groups of experts included in the experiment, are all greater than the standard value of 0.7, therefore the evaluation results made by this group of experts can be considered reliable and the experiment can be carried out. (See Table 3.1)

Table 3.1 Expert authority results

Expert Group	Coefficient of adjudication (Ca)	Coefficient of sense (Cs)	Coefficient of reliability (Cr)
1	0.883	0.733	0.808
2	0.941	0.81	0.879
3	0.954	0.86	0.884
4	0.952	0.881	0.889

Source: Own elaboration based on Expert authority factor

(4) Evaluation System

The evaluation system in this project focuses on the normative, scientific, and effective performance of the different professional behaviors of the key process actors involved in the case simulation throughout the emergency management process. As emergency management events often involve multiple functions, this study focuses on the decision-making performance of managers in a healthcare

organization, but also on other functions, such as doctors and nurses. This is because it will help to further reveal whether emergency management and rescue capabilities can be improved with the support of XR technology as opposed to traditional case simulation formats. In order to eliminate bias from human evaluation and to increase the authority and credibility of the expert evaluation, the case was set up for the selection and inclusion of the expert group. The experts' interests are not related to those of the participants and the evaluation results are credible.

The overall evaluation system can be divided into two parts according to the data collection process, process evaluation and outcome evaluation, as shown in Figure 2. The process evaluation is focused on the overall case process and scores the operations and overall performance of the personnel involved. In terms of quantitative evaluation indicators for the emergency management dimension, this case focuses on the delivery of instructions, deployment of personnel, on-site management, and post-event feedback, with seven primary indicators and 19 secondary indicators. In the dimension of improving the medical quality of emergency rescue, this case takes the classification of injuries, patient assessment, first aid measures and evacuation as the main evaluation indicators and has developed 35 secondary evaluation indicators (See Appendix D, Appendix E & Appendix F). This allows us to obtain the most realistic performance of the personnel involved and to uncover the gaps and shortcomings in the emergency rescue process.

In the outcome evaluation section, on the one hand, objective quantitative indicators were used to evaluate the outcome, including patient survival rate, time to rescue and resource utilization. On the other hand, a review of the case simulation was set up in which the managers of the experimental and control groups were asked to review the overall performance of all the participants in the case simulation and to use the root cause analysis (RCA) method to identify and address the root causes of the problem through a structured problem-solving approach. The RCA review is a systematic process of dealing with the problem, including analyzing the causes of the problem, identifying solutions to the problem and developing preventive measures for the problem, which is also based on the identification of problems in various types of evaluation data. (See Figure 3.1)

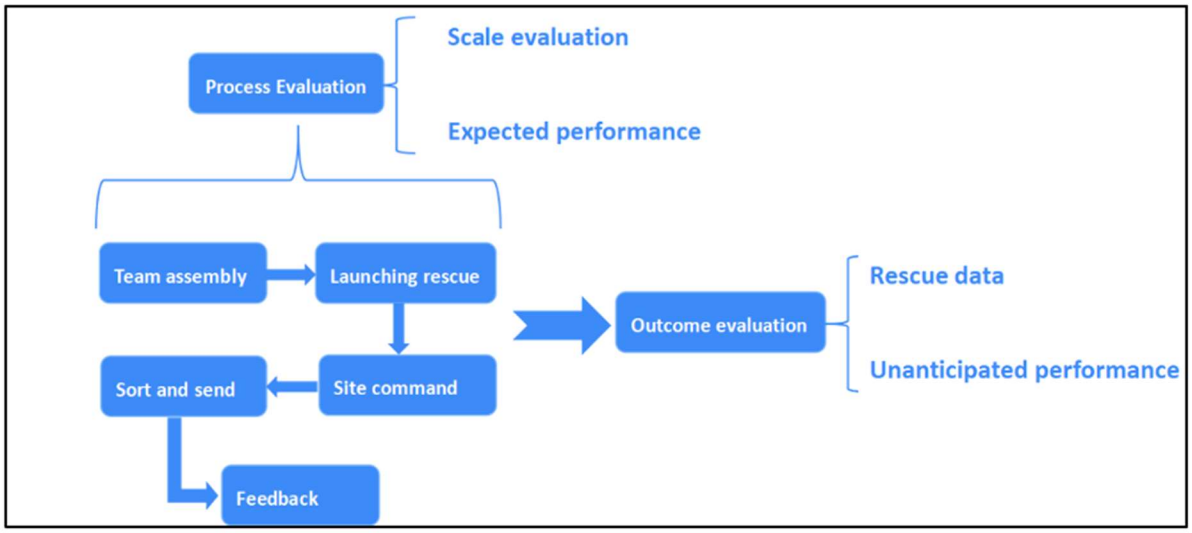


Figure 3.1 Evaluation System (Source: Own elaboration based on experiment path)

In addition, to further evaluate the performance of the core participating managers in the case, a Hazard Vulnerability Analysis (HVA) was added to the study. In distinction to the disaster analysis, managers need to analyze the ability of the healthcare organization to withstand the rescue situation encountered during the case simulation, and conduct a targeted vulnerability analysis of the emergency management plans currently in place, in order to optimize risk and emergency management organizational systems and procedures, establish an organizational chart of the emergency command system, and staff understand their roles and responsibilities when dealing with emergencies. (See Appendix G).

3.1.5. Statistical methods

(1) Statistical analysis software and variable representation

The trial conducted in this project was a randomized controlled trial of superiority. All statistical data analysis were performed using SPSS 25.0 statistical package (IBM, Armonk, NY, USA).

For Categorical variables, we calculated proportions and 95% CIs. Values are presented as the mean±standard deviation for data that were normally distributed or median.

(2) Statistical methods and setting of P-values

P-P plots was used to test whether the experimental data satisfy a normal distribution. For two-group comparison, P values were derived from the independent Samples t-test test to determine differences between groups with normally distributed data. All tests were two sided, and P values <0.05 were considered statistically significant.

3.2. Research Pathways

This project uses a theoretical model plus a controlled trial approach to the research. The digital twin theory provides the theoretical basis for this project, which refers to the simulation of the real environment through the method of digital maps that can effectively aid data prediction and problem analysis in a variety of complex environments (Glaessgen & Stargel, 2012). Emergency management drills are precisely the reproduction of complex scenarios, which suggests that it is theoretically feasible to apply XR technology to emergency management drills. With theoretical support and with reference to the emergency management process, this project has designed a digital twin-based virtual simulation system based on real data from a real emergency management case study. The design of this project was carried out on two levels: research structure design and simulation system design. After preparing the theoretical framework for the experiment, the next step was to prepare the design and related materials for the RCT experiment (See Figure 3.2).

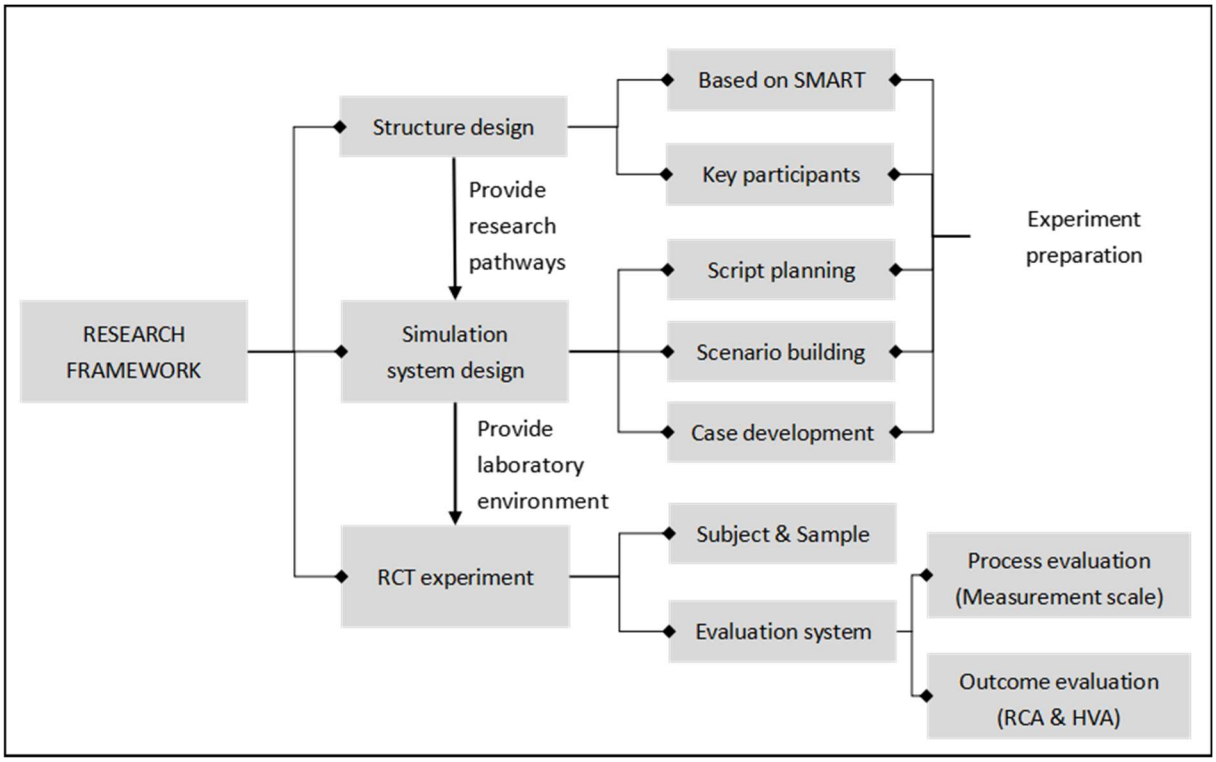


Figure 3.2 Research framework (Source: Own elaboration based on experiment path)

3.2.1. Research structural

In real emergency rescue management, the following characteristics are often present: the number of casualties is large and prone to medical crush in a short period of time (Bakker et al., 2019); the intensity of trauma to the casualties is high (Waugh & Straib, 2006).; and most emergency rescue scenarios occur in complex situations requiring the involvement of multiple rescue forces and how to

effectively avoid secondary injuries in complex scenarios (Kapucu & Garayev, 2011). The uncertainty and difficulty of rescuing people at the scene of a public emergency places greater demands on managers in terms of top-level design (Green & Kolesar, 2004). This research is guided by the digital twin theory and the needs of real-life emergency management cases, resulting in an effective design for a virtual simulation system.

In this project, the design of the virtual simulation system is based on the results of a preliminary study on the current situation of emergency management in China, and the overall design is based on the SMART principle (see Figure 3.3). The SMART principle is an approach to goal management that allows for effective organization of members and goal setting and control, leading to better performance (Siegert & Taylor, 2004). The principle is widely used in management activities, particularly in the development of theoretical frameworks (Shahin & Mahbod, 2004). Management activities based on the SMART principles can significantly increase the rate of achievement of set objectives while improving the overall logical framework (Swann et al., 2022). This project is guided by the SMART principles, which suggest measurable indicators in the design of the simulation case and guarantee the strong relevance of the design objectives. The specific design objectives are as follows (Fig.3.3):

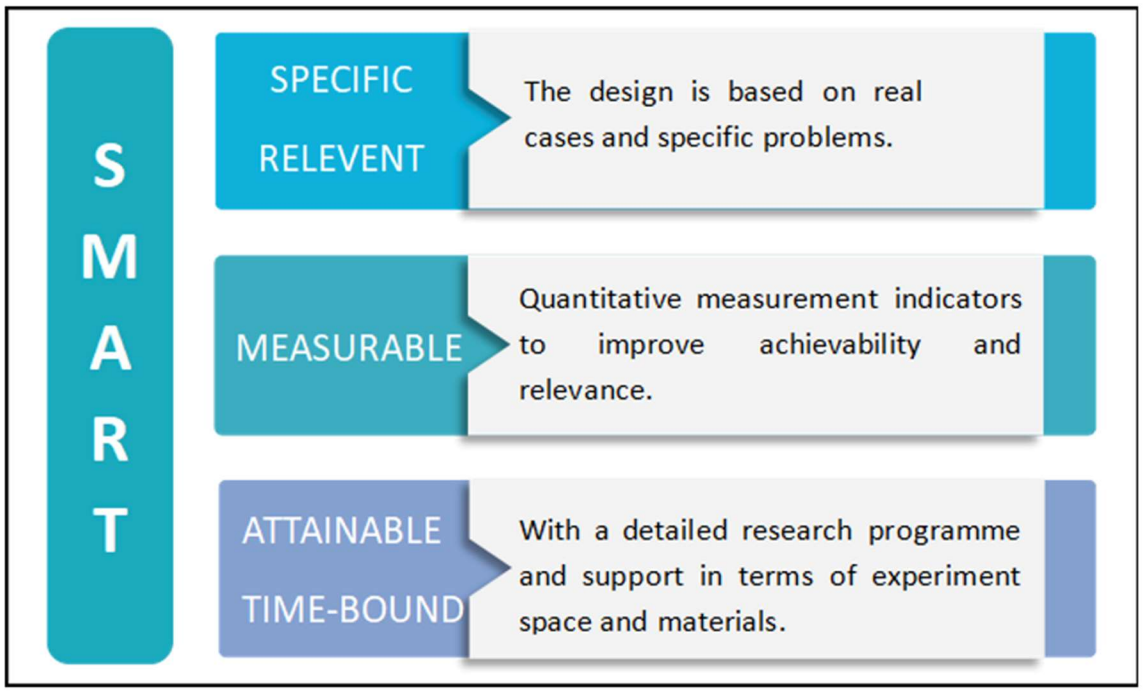


Figure 3.3 Design thinking based on the SMART principle (Source: Own elaboration based on SMART principle)

Guided by the SMART criteria, this project was designed with the first consideration of how to reflect specificity. A literature review was conducted to summarize the homogeneity of the current emergency management mechanisms in China, and the case design was developed in conjunction with the emergency relief case materials provided by NFYY. The analysis revealed that the main problems in emergency management in China are inadequate emergency response mechanisms, lack of reference in emergency response, and inefficient teamwork (Zhang et al., 2021). In complex scenarios, there is a lack of standardization in the operation and management of large numbers of casualties (Zhao et al., 2022). Rescue commanders are inexperienced and only follow operational principles, lacking flexibility (Qi et al., 2023). These three types of questions are the most frequent issues in emergency management activities and cover the three phases before, during, and after an emergency event. The project has therefore purposefully extracted three keywords from which the experimental design was developed (See Figure 3.4).

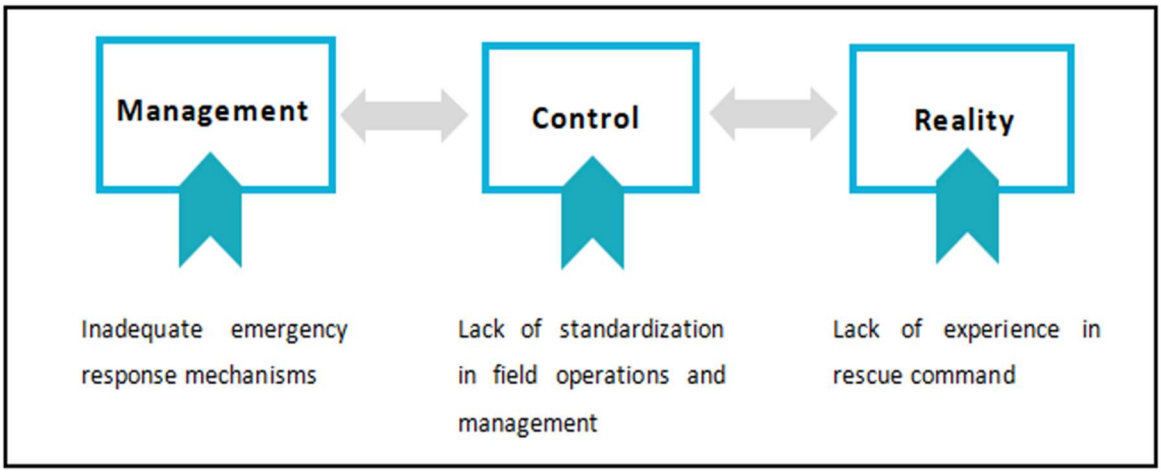


Figure 3.4 “Management-Control-Reality” Case design chain (Source: Own elaboration)

Therefore, the case was designed with the above three practical problems in mind, and a set of "management, control and reality" guidelines was established. "Management" means that the evaluation of emergency management is put into practice in real-life scenarios. In the case process design process, the case focuses on two aspects of the simulation: during and after the incident, starting from the front-line manager's ability to manage on-the-spot disposal, combined with a multi-dimensional quantitative evaluation index system, and establishing a simulation scenario of multi-issue coordination and emergency disposal to effectively improve the rescue command's ability to send instructions and deploy resources and on-site management. “Control", that is the control of emergency rescue medical quality. In response to the lack of standardization of on-site rescue operations, this case develops a set of detailed disposal principles and operational specifications in

rescue operations and combines quantitative indicators to evaluate the level of on-site competence of rescue personnel and management staff. "Reality" means in this project new information technology is used to enhance the authenticity of the training and the level of emergency management. This project uses the XR technology as a way to realize simulated case exercises. With the contextual restoration capability of XR technology and high-precision trauma simulators, the emergency scenes are restored to the greatest extent, ensuring the authenticity of the case exercises, and accumulating valuable experience for emergency management that is close to the real world.

Quantitative measurement indicators to improve achievability and relevance: after formulating the principles of "management, control, and reality", this case project establishes quantitative evaluation indicators of different dimensions for different design purposes. For the quantitative evaluation indicators of the emergency management dimension, this case mainly focuses on the aspects of instruction sending, personnel deployment, on-site management, and post-event feedback, constructing 7 primary indicators and 19 secondary indicators. In the dimension of improving the medical quality of emergency rescue, the case takes the classification of injuries, patient assessment, first aid measures, and evacuation as the main evaluation indicators and has developed 35 secondary evaluation indicators. To further optimize the case design, a post-event analysis module combining root cause analysis (RCA) and disaster vulnerability analysis (HVA) was developed in the case review phase. An SEQ (Service Quality Scale) based survey scale was also used for the XR-based scenario reproduction to further enhance the realism of the scenario in the case exercise. (See Appendix A)

In terms of the realizability of the virtual simulation experiment, this case relies on the Southern Hospital Clinical Medical Skills Education Centre of Southern Medical University, which provides strong support for the logistical preparation of the case and the realization of the venue. In addition, with the help of the center's XR virtual scenario technology, the case was highly realistic in terms of scene reproduction, effectively solving the problem of lack of realism and tension in traditional case drills. The XR technology was used to design the case with a clear timeline for each part of the exercise, so as to optimize the efficiency of the emergency response based on quantitative assessment. Further, the three objectives established in this case are integrated in the process of realization and exist organically in a coherent process, and each design objective is highly relevant to the others, with the realization of a single objective having a positive impact on the others.

3.3. Experiment stimulus (simulation system)

This project uses the principle of "combining reality with imagination" in the simulation, combining XR virtual context technology with high-end simulator operations to build a realistic event scenario with the help of virtual context and enhance the immersion of emergency rescue events. The dynamically

changing scenarios allow the case simulation to progress smoothly with other factors such as unexpected events, further making the case process simulation scientific and realistic.

The application of XR technology in case simulation is divided into three main core aspects, namely script planning, scene construction, and case generation.

3.3.1. Development Process

(1) Script planning

The application of XR technology is related to case design. The most important task before using XR technology to build a virtual situation is script planning. This step is editing for key events to produce a realistic storyline. In the design of this case study, the mass casualties caused by the collapse of a public building in the city were used as the main storyline for script planning, and the key events in the incident were edited for possible injuries to the injured, the classification of those involved in the rescue at the scene, the number of deaths that could result from the incident, and possible sudden secondary injuries. In carrying out the refinement of the storyline incident script planning in this case design was based on the real casualty incident as a reference and combined with various types of potential crisis situations that could potentially occur, resulting in the incident script in this case.

This case study was designed using the real-life "7-12 Hotel Collapse in Wujiang, Jiangsu Province" in 2021 as the basis for the script planning, with reference to the damage caused by the real event, including people, buildings, and surrounding facilities. Overall, a case simulation was run based on two main types of reference, real clinical data, and theoretical guidance.

In order to scientifically integrate the simulated cases with clinical scenarios, the group obtained, with the help of NFYY, secondary data from some of the hospitals that had undertaken emergency missions, such as the surrounding environment, the classification and severity of injuries, the first aid measures taken by medical staff, and the groups involved in the emergency. In addition, some authoritative materials were selected as theoretical guidance for the design of this case, including the Manual of Practical Trauma Care, Modern Trauma Surgery, and Emergency and Disaster Medicine, to provide a theoretical basis for the design of the case and the simulation run. After analyzing and summarizing the above information, the case was scripted, and scenarios were constructed in a way that the simulation was based on clinical scenarios and incorporated potential hazards. It also tests the participant's emergency management decision-making skills in an integrated environment.

(2) Scenario building and case generation

Once the event script has been planned, the virtual scenario needs to be built according to the script within the XR software development platform. In this case, the basic scenario was built according to the characteristics of the buildings and urban planning of the city in the province where it was located,

in order to maximize the number of locations that could be visited in an emergency management scenario. After the basic scenario is built, attributes are set for the injured, firefighters, commanders, and disaster subjects in the scenario, and dynamic attributes are given to each object in accordance with the script planning to create an overall interactive virtual scenario. (See Figure 3.5)

Based on the scenarios and scripts constructed, cases can be generated, but in the case generation process, XR technology needs to be combined with the use of conventional simulated dummies to set up a virtual rescue area and a field rescue area in the scenario. In the virtual treatment area, virtual events can be decided through virtual reality VR equipment; in the field treatment area, simulators and real actors act as patients, and participants are required to take appropriate field actions to rescue them. The division of the two zones allows XR technology to be used not only for scenario building, but also for the combination of reality and reality through new technological empowerment in the conventional simulation mode of case simulation, providing new ideas for diverse case simulation.



Figure 3.5 Modelling & Scenario building (Source: Own elaboration)

3.3.2. Development cases

In order to explore the effectiveness of XR technology in the field of emergency management, this project plans to use a controlled research approach and adopt the principle of randomization in the allocation of experimental subjects. A control group using traditional exercise methods will be tested against an experimental group using XR technology. Through a controlled variables approach, both study groups will use the same simulated emergency cases, thus effectively controlling for experimental bias.

In the development of the case, a real emergency was chosen as a reference for this project, and the case scenario was refined and enriched with a large amount of secondary data from emergency management. The case has both a mainline fixed content and a randomized adaptation module. The main content consists of a hotel building that has collapsed in the downtown area of a first-tier city, with a large number of people living in the hotel at the time of the collapse, massive casualties at the

scene, the scene not yet cordoned off, traffic semi-paralyzed, the building in a state of potential secondary collapse, emergency rescue forces urgently needed to rescue. In addition, the random adjustment module includes the time of day, weather, and rescue forces. (See Table 3.2)

Table 3.2 Random adjustment module

Random adjustment	Factors	Probability of occurrence
Time of event	8 AM	25%
	12 AM	25%
	5PM	25%
	21PM	25%
Weather	Clear	25%
	Fog	25%
	Rainstorm	25%
	Typhoon	25%
Related rescue forces	Fire brigade and traffic police have arrived	50%
	There were no rescue forces on site	50%
Status of regional medical institutions	Light hospital load	33%
	Medium hospital load	33%
	Heavy hospital load	33%

Source: Own elaboration

With the above randomized modules selected, the overall development process of the case can be divided into three parts: emergency response, on-the-spot decision making, and case review and analysis, with different events set up to test the participants' decision-making and command in a given situation. (See Figure 3.6)

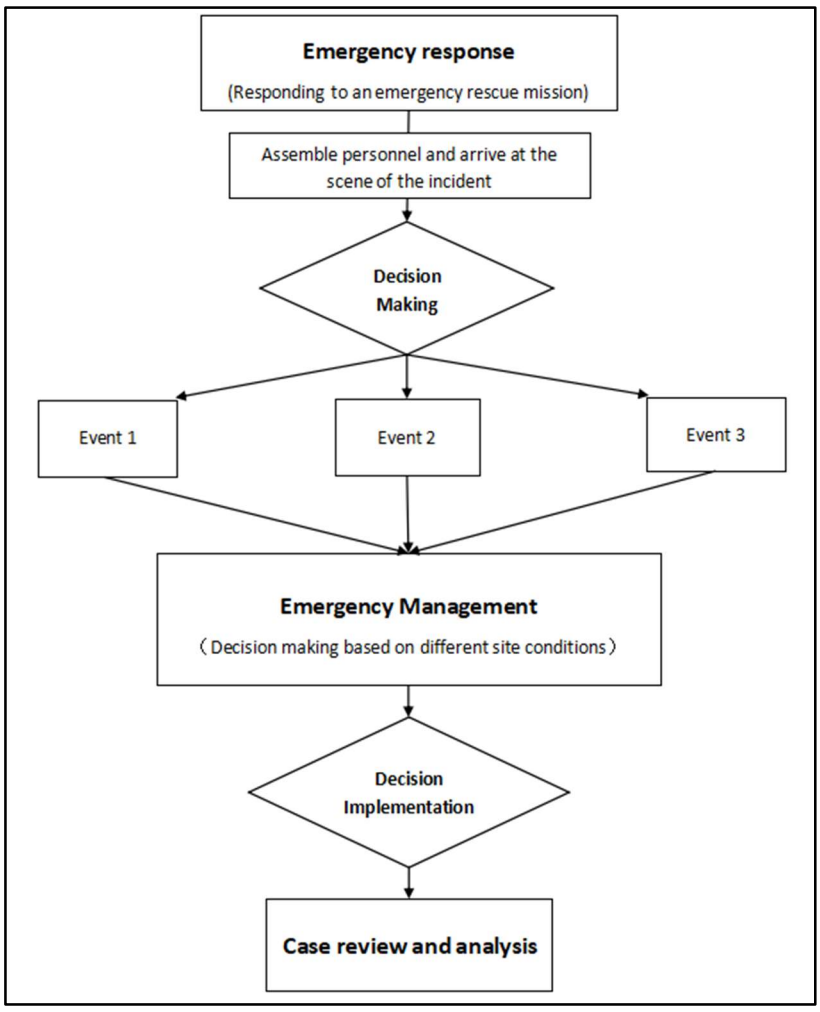


Figure 3.6 Case Simulation Process (Source: Own elaboration based on experiment path)

In conducting the design of the critical event in the case, this project focuses on two perspectives: the simulation objective as well as the targeted response. The simulation objective refers to the design purpose of the particular event and the outcome of the exercise. The target response refers to the decision and action that the participants are expected to take in a given situation, which is also an important indicator for quantitative evaluation of the whole simulation process. (See Appendix B)

CHAPTER 4

Analysis of the results

4.1. Analysis of descriptive research

This project is a prospective, balanced randomized (1:1 allocation), superiority randomized controlled trial conducted at Southern Hospital. Therefore α=0.05, δ=13.9%, p=0.5 was determined according to the purpose of the experiment, and the experimental sample N=50 was obtained by the formula $N = [(Z^2 * P * (1 - P)) / E^2]$. A random sample of 50 cases of each sex was drawn equally for the study population and randomized again to include 25 females and 25 males in the experimental group and the remainder in the control group. The mean age of the females in the experimental group (25±1.93) and the mean age of the males (24.5±1.91); the literacy level of the females: 48% bachelor's degree, 52% master's degree and above, and the literacy level of the males: 46% bachelor's degree, 54% master's degree and above. In the control group, the mean age was (25.24±2.00) for women and (24.08±2.14) for men; literacy level for women: 44% bachelor's degree, 56% master's degree and above, and for men: 40% bachelor's degree, 60% master's degree and above. When comparing the general information of the two study groups, the differences were not statistically significant (p>0.05).

The trial was a RCT (randomized controlled trial of superiority) with a total of 100 subjects, 50 in the experimental group and 50 in the control group, included in the trial according to the established requirements. The trial was evaluated quantitatively by a 20-member panel of experts, which was selected according to certain inclusion criteria.

The experiment consisted of 5 experimental groups and 5 control groups, each of which was randomly assigned two experts for the quantitative evaluation of the experiment. At the end of the experiment, a total of 200 rating forms were obtained from 20 experts, each of whom observed the same study group, so the consistency of the ratings of the experts within the group was tested using the ICC (Intraclass Correlation Coefficient). It can be found that the intraclass correlation for a single measure is 0.944>0.75 (See table 4.1), which can indicate that the scores of the two experts are strongly correlated and can be considered highly consistent within the group.

The ICC coefficients were calculated for the scores of the remaining nine expert groups, and Table 5 shows that the ICC coefficients were higher than 0.75 for both the experimental group and the expert groups, indicating a strong correlation and a high degree of consistency in the ratings of the experts within the group. (See Table 4.2) Therefore, for this experiment, the scores of the two experts in each group were averaged and used as the final score for the subject.

Table 4.1 Intraclass Correlation Coefficient

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.944a	.782	.986	41.431	9	9	.000
Average Measures	.971c	.878	.993	41.431	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent because it is not estimable otherwise.

Source: Own elaboration based on SPSS 25.0

Table 4.2 Expert Group Intraclass Correlation Coefficient

Expert Group	1	2	3	4	5	6	7	8	9	10
ICC	0.944	0.993	0.969	0.979	0.974	0.986	0.989	0.990	0.980	0.990

Source: Own elaboration

By taking the mean of the expert ratings for each group, 100 evaluation reports were eventually obtained, including 50 for the experimental group and 50 for the control group. Descriptive statistical analysis was performed on the data from both groups to obtain the following data such as mean standard deviation. (See table 4.3)

Through preliminary analysis of the means of the data from the two groups, it was found that the subjects in the experimental group scored higher than the control group. Through skewness and kurtosis, it was found that the two groups had similar degrees of data dispersion. The extreme values that emerged for both groups in the experiment were further analyzed in the subsequent extended analysis.

Table 4.3 Descriptive Statistics

	N	Minimum	Maximum	Mean	Std.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Deviation	Statistic	Std. Error	Statistic	Std. Error
Experiment group	50	60.50	95.75	80.5804	9.28605	-.157	.337	-.862	.662
Control group	50	53.50	94.75	75.6050	10.13305	-.143	.337	-.372	.662

Source: Own elaboration based on SPSS 25.0

4.1.2. Comparison of the differences between experimental and control groups

After obtaining the corresponding experimental data, the data were first cleaned and all data were entered into SPSS 25 analysis software. As the experimental and control groups belonged to two independent samples, different variables were taken, and they were not correlated with each other. The variables could be defined as quantitative type data during the analysis; therefore an independent sample t-test was chosen for this study to analyse the differences between the two groups.

The study data was first analysed for normal distribution (See Figure 4.1) and the P-P diagram showed that the total scores of the three groups of managers, nurses and doctors during the experiment met the normal distribution and continued to meet the normal distribution at the overall level.

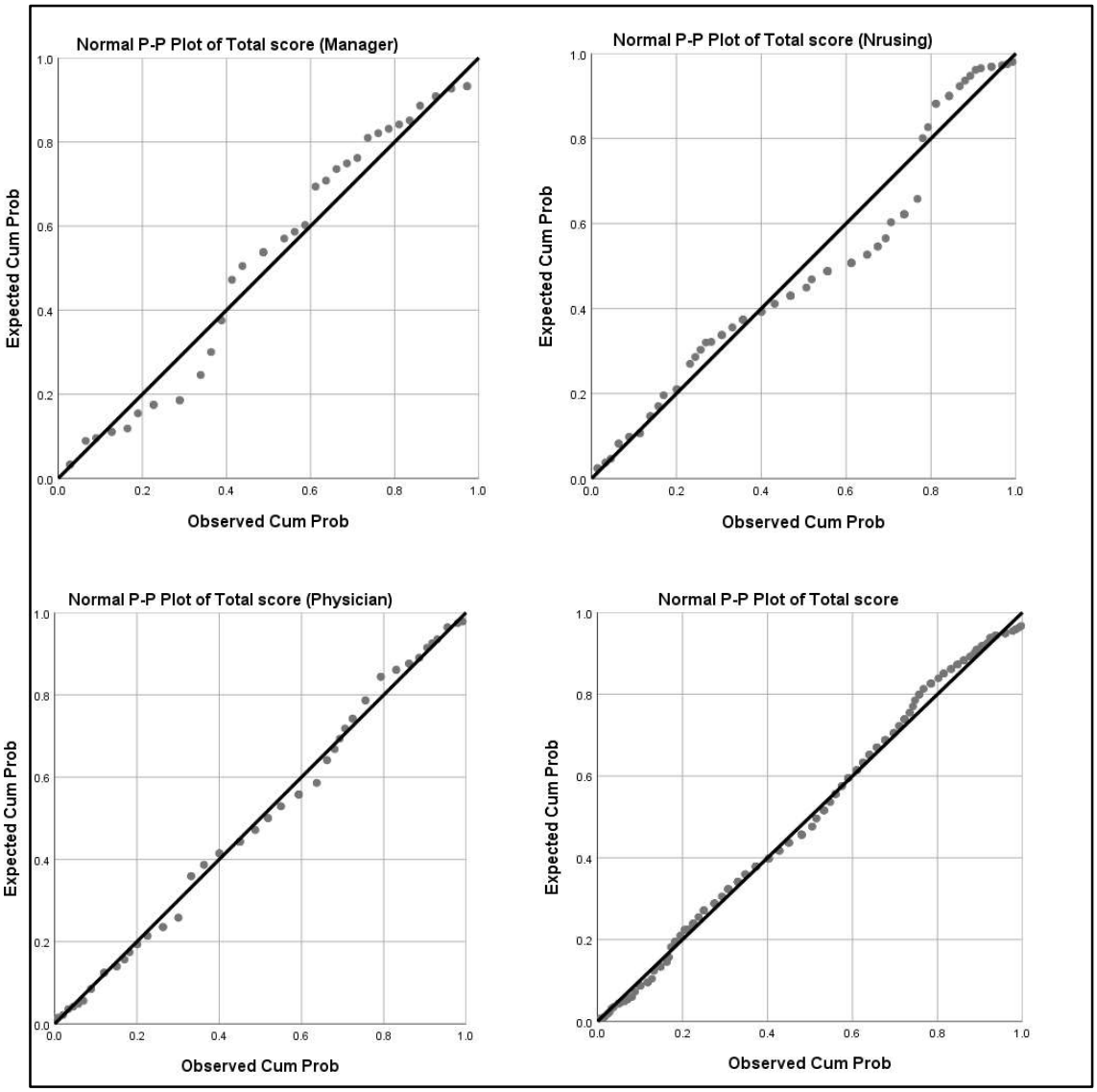


Figure 4.1 Normal distribution P-P plot (Source: Own elaboration based on SPSS 25.0)

Based on the above conditions, an independent sample t-test was carried out in this experiment. The original hypothesis was also set: the means of the two independent samples were equal (μ1=μ2) and the alternative hypothesis: the means of the two independent samples were equal (μ1=μ2).

For the two groups of samples, the sample sizes were n1=50; n2=50, the means were X1=80.58 and X2=75.60, and the standard deviations were S1=9.30 and S2=10.11. A t-test for independent samples was conducted (see Table 4.4) and in the chi-squared test, a significant p-value of 0.99>0.05 was obtained, indicating that the assumption of chi-squared was not met for the two groups of data. Therefore the t-test needs to be viewed (without assuming equal variance) for the results, the t-test significance p-value < 0.05, therefore the original hypothesis of no difference between the means of the two groups can be rejected, indicating that there is a difference in the means between the two groups of personnel performance in the different experimental settings using virtual reality technology and using conventional simulation technology.

Table 4.4 Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Total score	Equal variances assumed	.000	.990	3.619	198	.000	4.97540	1.37480	2.26427	7.68653
	Equal variances not assumed			3.619	196.631	.000	4.97540	1.37480	2.26416	7.68664

Source: Own elaboration based on SPSS 25.0

4.2. Analysis of RCT research

4.2.1 Comparison of superiority

The aim of the superiority experiment conducted in this experiment was to confirm the superiority of the XR virtual reality technology in the field of simulating emergency management and that the difference with the control group was greater than a predetermined superiority threshold, and the smallest practically significant difference between the experimental and control groups.

The comparison of superiority can be done by direct comparison of mean differences, but to ensure the reliability of the experimental results as well as statistical significance, prior to the

experiment, this study determined the Δ (superiority threshold) = 2 for this experiment by adopting the Delphi method and conducting expert interviews with the expert group assembled during the experiment. In terms of setting the hypothesis test for the superiority experiment (See table 4.5), the high superiority indicator was selected for this experiment in conjunction with the purpose of the experiment. A high superiority indicator is an indicator whose higher value indicates better validity. The absolute measure (mean difference) was chosen as the comparison indicator based on the type of data obtained from the experiment. Setting the H_0： $T- C \leq \Delta$ ($\Delta>0$); H_1:$T-C > \Delta$ ($\Delta>0$).

Table 4.5 Classification of hypothesis testing for superiority experiments

Indicators	High-performance indicators	Low-performing indicators
Absolute measure	H_0： $T - C \leq \Delta$ ($\Delta>0$)	H_0： $T - C \geq -\Delta$ ($\Delta>0$)
(mean/rate difference)	H_1: $T - C > \Delta$ ($\Delta>0$)	H_1: $T - C < -\Delta$ ($\Delta>0$)
Relative measure	H_0： $T / C \leq \Delta$ ($\Delta>0$)	H_0： $T / C \geq 1/\Delta$ ($\Delta>0$)
(RR/HR/OR)	H_1: $T / C > \Delta$ ($\Delta>0$)	H_1: $T / C <1/ \Delta$ ($\Delta>0$)

Source: Own elaboration based on superiority experiments theory

According to the one-sided test level of 0.025, according to the data in Table 4.4, the one-sided p-value of this experiment is significantly less than 0.025, indicating that the H_1 hypothesis can be accepted, and the overall score obtained by the participants in the experimental group is significantly better than that of the control group. It can be seen that the XR virtual reality technology can superiorly improve the performance of managers as well as other medical workers in the emergency management process, while this virtual simulation pathway provides a scientific training environment for emergency management in a real environment.

4.2.2 Experimental group post-survey data

To further improve the integrity of the experiment and the scientific validity of the data, a targeted questionnaire was administered to the 50 study participants in the experimental group after the experiment. The aim was to obtain the subjective feelings of those who participated in the XR technology simulation, as well as their suggestions for this exercise mode. A total of 50 questionnaires were distributed and 50 valid questionnaires were returned. The questionnaire was designed according to Likert's quantitative design principles, with six quantitative evaluation questions and two subjective fill-in-the-blank questions, containing questions about the advantages and disadvantages of XR technology, and whether it is effective in improving emergency management capabilities.

A descriptive statistical analysis of the quantitative questions in the questionnaire (see Table 4.6) revealed that the three questions on the experimental design and XR technology had the highest mean values in terms of the adequacy of the experimental staff and materials, indicating that a large proportion of the experimental subjects felt that the experimental process and logistics were very well developed. In addition, in the evaluation of the immersion of XR virtual reality technology, more than 50% gave a rating of 9 and above, indicating that the majority of experiment participants were able to obtain a more realistic experience in this type of emerging technology. For the evaluation process of the rationality of the content of the experiment case simulation, it received the lowest mean rating, indicating that the experiment still has room for further improvement in the case script design process.

Table 4.6 Descriptive statistical analysis of the questionnaire for the experimental group

		Immersive	Reasonable	Adequacy	Nursing	Physician	Manager
N	Valid	50	50	50	50	50	50
	Missing	0	0	0	0	0	0
Mean		8.72	8.40	9.30	8.08	8.72	9.04
Median		9.00	8.00	9.00	8.00	9.00	9.00
Std. Deviation		.970	.535	.580	.724	.536	.638
Variance		.940	.286	.337	.524	.287	.407
Range		3	2	2	2	3	2
Percentiles	25	8.00	8.00	9.00	8.00	8.00	9.00
	50	9.00	8.00	9.00	8.00	9.00	9.00
	75	9.25	9.00	10.00	9.00	9.00	9.00

Source: Own elaboration based on SPSS 25.0

In addition, we can find that although the overall rating of the XR technology immersion is relatively high, its variance is relatively large, indicating that the data fluctuates more significantly, considering that some of the experimental subjects have 3D vertigo symptoms, which is an influencing factor that needs to be taken into account when applying the technology in the future.

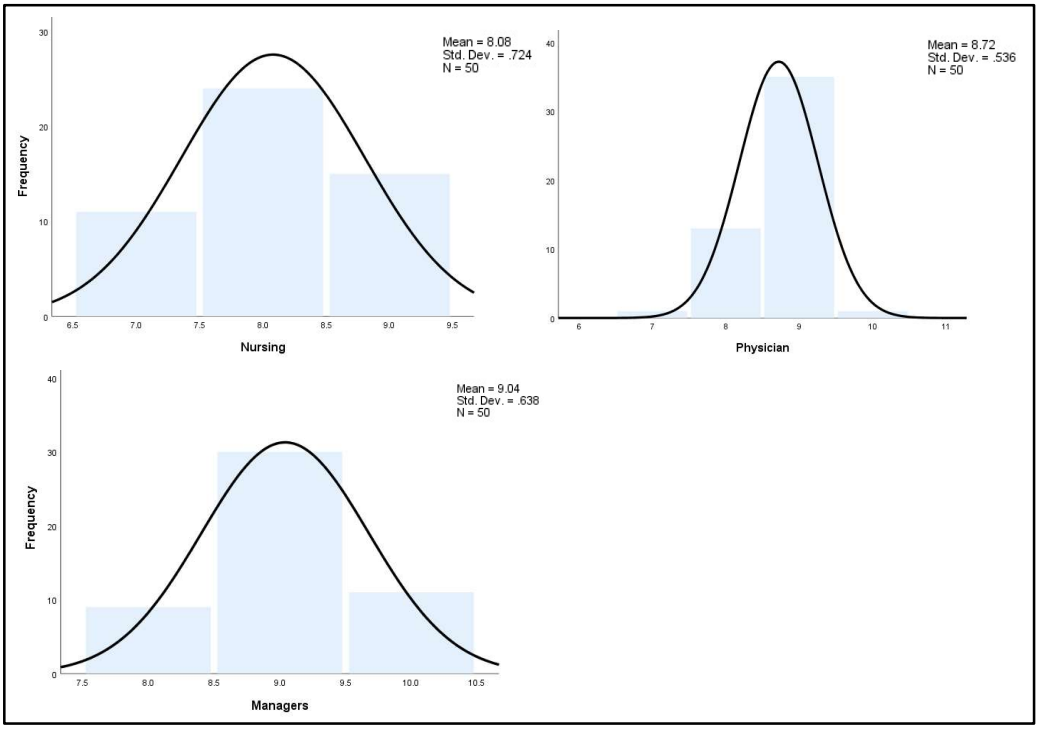


Figure 4.2 Experimental group Histogram (Source: Own elaboration)

Managers received the highest mean ratings in the evaluation of professional behavior of the experimental subjects, and more than 75% gave ratings of nine or more. The histogram shows that the physician group has the most concentrated distribution of ratings, which may be related to the relatively more specific evaluation of physicians' professional behavior. (see Figure 4.2)The overall distribution of ratings obtained by the nurse group is relatively more even, and it can be inferred that the performance of the nurse group in the XR virtual environment is relatively more varied, which may be related to the fact that the nurse group often acts as a communication role between the manager and the doctor in the emergency management process, and the design is more complex and requires a higher degree of flexibility for the experimental subjects.

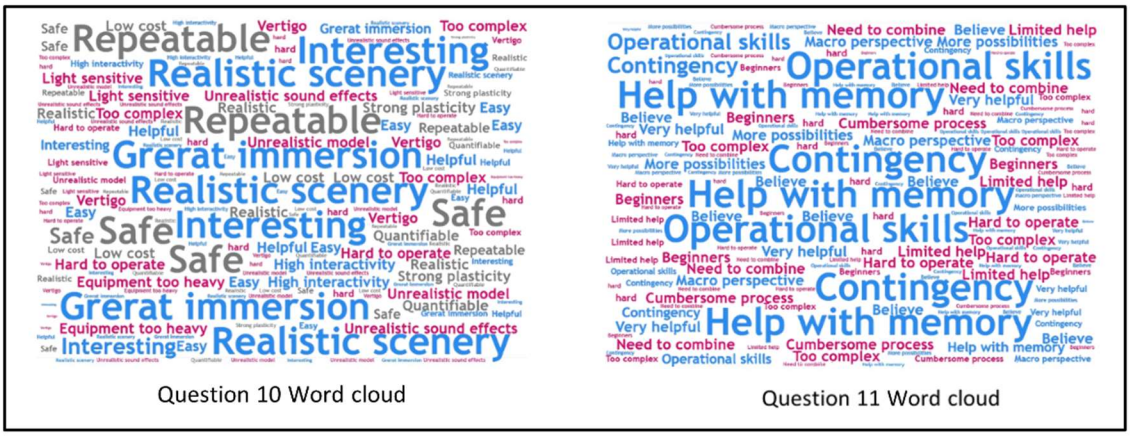


Figure 4.3 Statistical chart of word frequency of subjective questions (Source: Own elaboration Software base output)

For the two subjective questions, question 10 and question 11, lexical frequency analysis was used for the statistics. (see Figure 4.3) The valid texts obtained were first collated and compiled into a sample, which was analyzed lexically to obtain different frequency distributions for nouns, verbs, adjectives, and subjects. Questions 10 as well as 11, both focused on obtaining descriptive responses. Therefore, during the word frequency analysis, the main focus was on extracting adjectives for analysis.

Question 10 was designed to investigate the participants' evaluation of the advantages and disadvantages of XR technology after using it. The word cloud plot shows that the adjective "immersion" was mentioned several times, mostly in a positive way, indicating that the majority of the subjects considered the virtual environment built by XR technology to be highly reproducible. In addition, there were also more negative adjectives such as "heavy equipment" and "difficult to operate". This indicates that the user comfort level of XR technology needs to be further optimized in the process of application.

4.3. Expanded analysis

(1) Analysis of primary indicators

In the process of evaluating the professional behavior of the experimental subjects, in addition to obtaining a final overall score, the evaluation form was refined to a number of secondary and tertiary indicators, which were mostly figurative and operational in nature. In order to analyze the subjects' ability to manage emergencies under different experimental conditions, a summary analysis was conducted comparing the primary indicators of the experimental and control groups, thus providing a macro analysis of the subjects' overall performance.

Table 4.7 Independent sample t-test for indicators at the level of the nurse population

		Levene's Test		t-test for Equality of Means						
						Sig. (2-	Mean	Std. Error	95% Confidence Interval	
		F	Sig.	t	df	tailed)	Difference	Difference	Lower	Upper
Nursing competencies	Equal V(X)	.088	.767	3.390	78	.001	2.65	.78160	1.09396	4.20604
	Equal V(X) not assumed			3.390	75.249	.001	2.65	.78160	1.09306	4.20694
Communication and coordination skills	Equal V(X)	8.926	.004	3.471	78	.001	2.85	.82100	1.21552	4.48448
	Equal V(X) not assumed			3.471	65.502	.001	2.85	.82100	1.21059	4.48941
Human care competencies	Equal V(X)	5.045	.028	2.059	78	.043	.525	.254920	.017494	1.032506
	Equal V(X) not assumed			2.059	71.496	.043	.525	.254920	.016766	1.033234
Occupational protection competence	Equal V(X)	2.270	.136	3.989	78	.000	1.5635	.3919791	.7831295	2.3438705
	Equal V(X) not assumed			3.989	70.875	.000	1.5635	.3919791	.7818919	2.3451081

Source: Own elaboration based on SPSS 25.0

Table 4.8 Independent sample t-test for indicators at the level of the physician population

		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval	
									Lower	Upper
Resuscitation capabilities	Equal V(X)	.267	.607	1.840	78	.070	.7250	.3940	-.0594	1.5094
	Equal V(X) not assumed			1.840	77.687	.070	.7250	.3940	-.0595	1.5095
Communication and coordination skills	Equal V(X)	1.780	.186	3.171	78	.002	2.3625	.7449	.8794	3.8456
	Equal V(X) not assumed			3.171	76.548	.002	2.3625	.7449	.8790	3.8460
Human care competencies	Equal V(X)	2.835	.096	3.259	78	.002	.6125	.1879	.2384	.9866
	Equal V(X) not assumed			3.259	73.822	.002	.6125	.1879	.2380	.9870
Occupational protection competence	Equal V(X)	6.764	.011	3.614	78	.001	.9000	.2490	.4042	1.3958
	Equal V(X) not assumed			3.614	72.051	.001	.9000	.2490	.4036	1.3964

Source: Own elaboration based on SPSS 25.0

Table 4.9 Independent sample t-test for indicators at the level of the manager population

		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval	
									Lower	Upper
Emergency response	Equal V(X)	1.671	.204	1.644	38	.108	.775000	.471385	-.179269	1.729269
	Equal V(X) not assumed			1.644	34.747	.109	.775000	.471385	-.182212	1.732212
Site command and coordination	Equal V(X)	1.779	.190	2.432	38	.020	3.675000	1.511175	.615785	6.734215
	Equal V(X) not assumed			2.432	36.454	.020	3.675000	1.511175	.611520	6.738480
Incident analysis	Equal V(X)	1.120	.297	2.507	38	.017	1.225000	.488654	.235771	2.214229
	Equal V(X) not assumed			2.507	35.291	.017	1.225000	.488654	.233272	2.216728
Integrated decision-making capabilities	Equal V(X)	2.185	.148	2.731	38	.010	2.750000	1.007048	.711339	4.788661
	Equal V(X) not assumed			2.731	33.316	.010	2.750000	1.007048	.701884	4.798116

Source: Own elaboration based on SPSS 25.0

For both the medical and nursing subjects, the evaluation form consisted of four level one indicators: professional skills, communication and coordination skills, humanistic care skills and awareness of professional protection. In Table 4.7, we can see that the p-values for all four level 1 indicators are less than 0.05, and the differences between the experimental and control groups are statistically significant. In the humanistic care section, the differences between the two groups are relatively small, considering that this is a competency that is highly used by the group of nurses on a daily basis and is therefore less affected by the different simulation techniques in the case simulation session. On the contrary, we can find significant differences in the performance of the experimental group compared to the control group in the team communication and coordination section, and we can infer that the subjects were able to have a better interactive experience in the XR virtual environment, which allowed them to effectively carry out team communication.

When analyzing the physician group, we found a similar pattern to the nurses' group. In the section on resuscitation skills between the experimental and control group of doctors, Table 4.8 shows that there was no statistically significant difference, indicating that the professional skills of the subjects in the two groups were not significantly affected by the different environments in which they operated. However, the two groups reflected significant differences in terms of communication skills and awareness of professional protection, inferring that this was due to the immersion brought about by the virtual environment of the XR technology, thus enhancing the subjects' realistic responses.

The overall performance of the group of managers was better than that of the control group throughout the experiment (See table 4.9). In the first level of emergency response, the two groups did not show a significant difference in performance, considering that this indicator belongs to the preliminary preparation component of emergency management, which in the vast majority of cases has more clearly defined implementation steps and is mostly developed with the assistance of local emergency management authorities. Therefore, although the difference in performance between the two groups of managers was not significant under different experimental conditions. In the field command section, however, we can find that the experimental group received a higher rating. This indicator is designed to evaluate the intermediate part of the emergency management process, which is more flexible and uncertain, and requires managers to make decisions that are not only correct and scientific, but also time-sensitive. The experimental group using XR technology was able to obtain higher scores, which can be inferred from the fact that virtual reality technology is effective in improving the subjects' resilience and coordination skills.

In addition, the experimental group also received higher ratings in the comprehensive decision-making ability section. This part of the evaluation was made for the management performance of the managers during the whole emergency management process, indicating that the managers in the experimental group not only showed better management ability during the development of the

incident, but also had good analysis and summarizing ability after the incident, and the overall comprehensive decision-making ability had better performance compared to the control group under the traditional simulation conditions. It is inferred that this is due to the fact that XR technology provides more information and interaction during the case simulation, while allowing managers to gain more macroscopic decision-making perspectives based on a close to realistic environment.

(2) Further emergency management capacity assessment for managers

The Hazard Vulnerability Analysis (HVA) was introduced in this study in order to better measure the overall performance of the experimental subjects in emergency management and the awareness of team management in response to emergencies, and to examine the managers' perception of the team's ability to cope with disasters in different situations from four dimensions. The HVA not only reflects the managers' risk assessment of each type of emergency, but also the managers' focus in making different decisions for different situations in the emergency management process.

In this study, an HVA survey was conducted on 20 participants in the role of manager and a group of experts was organized to evaluate the reasonableness of each manager's HVA analysis on a five-point Likert scale: 1 - strongly disagree, 2 - disagree, 3 - partially agree, 4 - agree and 5 - strongly agree.

Table 4.10 HVA Group Statistics

	Experiment/Control	N	Mean	Std. Deviation	Std. Error Mean
HVA	Experiment	10	4.15	.745	.167
	Control	10	3.50	1.192	.267

Source: Own elaboration based on SPSS 25.0

Table 4.11. HVA Independent T test

		Levene's Test		t-test for Equality of Means						
								Std. Error	95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Difference	Lower	Upper
HVA	Equal V(X)	9.344	.004	2.068	38	.046	.650	.314	.014	1.286
	Equal V(X) not assumed			2.068	31.881	.047	.650	.314	.010	1.290

Source: Own elaboration based on SPSS 25.0

From Table 4.10, it can be found that the mean value of the expert group scores obtained by the experimental group is higher than that of the control group, indicating that the expert group approves of the HVA analysis given by the experimental group more than that of the control group. It is also

noted that the standard deviation of the two groups is slightly different, and the standard deviation of the experimental group is smaller, indicating that the scores are less discrete, indicating that the scores given by the experts are relatively concentrated and more consistent.

To find out whether the differences in scores between the two groups of subjects were statistically significant, an independent samples t-test was conducted, and Table 4.11 was obtained. The variance of the two groups of subjects was flush and the two-sided p-value was less than 0.05, indicating that the differences in scores between the two groups were statistically significant. Therefore, it can be inferred that the XR technology can effectively improve the overall performance of managers and enhance decision-making ability in the session of case simulation.

(3) Cost analysis

NFYY, as a public hospital, operates on a public benefit basis and has access to policy and financial support provided by the government. However, with the changing healthcare policies in China in recent years, public hospitals need to operate autonomously and be self-financing (GOSCPRC, 2022). Emergency management training activities, such as the one carried out in this project, are a long-term investment that will not yield substantial economic benefits in the short term, so it is important to consider not only the efficiency of the training but also the cost of the training when designing the various training activities, as this is the only way the project can be implemented.

The experimental group and the control group established during the study of this project used different training methods and incurred different costs during the course of the project. After completing all the RCT experiments, the costs incurred by the two groups were quantified and averaged per person per session, as shown in Table 4.12.

Table 4.12 Cost analysis

	Fixed assets costs	Design life	Depreciation rate/Year	Depreciation rate/Month	Depreciation amount/Month	Additional consumables
Experiment	70,000 CNY	6 year	16%	1.38%	972	3.5 CNY/person
Control	40,000 CNY	3 year	33%	2.77%	1,111	13 CNY/person

Source: Own elaboration based on SPSS 25.0

From a cost control point of view, the lower cost of the exercise will facilitate the overall management of the hospital and the implementation of the emergency exercise. Analysis of the costs of the two types of exercises, we can find that the experimental group using XR technology was more expensive to purchase than the conventional equipment used in the control group, but it is also worth noting that the equipment in the experimental group had a higher life expectancy than the control

group. The conventional simulated dummies used in the control group were more severely worn out during use and had a greater monthly depreciation. In addition, we found that other additional costs incurred during the exercise were much lower in the experimental group than in the control group. It can be argued that the XR equipment used in the experimental group has a lower cost of use than the simulated dummies used in traditional drills. In addition, in a traditional emergency drill, the human and overhead costs are higher than in the experimental group due to the need to organize multiple participants in the process. Therefore, XR technology can provide a more economical training method while helping the experimental subjects to obtain better training results, which is of great relevance to hospitals of public interest.

CHAPTER 5

Implementations & Recommendations

5.1 Application of XR technology in emergency management

5.1.1 Virtual reality technology development and applications

With the continuous development and iteration of information technology, system simulation technology, based on control theory, mathematical theory and computer technology, has integrated a variety of new technologies and increasingly diversified application areas and technical forms. Virtual reality, as a form of graphic simulation, is increasingly being used in the military, architecture, education and medicine, thanks to more realistic, fully immersive aural effects and richer interaction designs.

Simulation-based training has shown promise and is gaining acceptance as a means of improving training efficiency (Hancock, 2009). A large number of virtual reality applications have emerged in the fields of medical education, special skills training and disaster relief exercises. VR technology is increasingly becoming the future direction of education with its high degree of realism, short training cycles and trial-and-error-accessible educational models. With the continuous development of microelectronics technology in recent years, the computer RAMDAC (Random Access Memory Digital/Analog Convert-or) conversion rate has been greatly enhanced (Ling Y, 2019), and virtual reality technology is no longer limited by the image processing of computers, and while being able to simulate more realistic scenes (Chuah, 2020). The ability to simulate large scenes with grand scale and complex details has been significantly improved, which has greatly broadened the application scenarios of virtual reality technology (Daniel et al., 2018).

Virtual technology has spawned many different types of technology while meeting different types of needs. We are witnessing the increasing use of Augmented Reality (AR) and Virtual Reality (VR) displays, as well as new Mixed Reality (MR) displays, which include AR and VR. virtual reality technology typically uses head settings that block visual stimuli from the real world. AR allows the user to see the real world, but overlays virtual elements. He combines the two, including both aspects of the real and virtual worlds. And Extended Reality (XR) is the umbrella term for these three different types of simulation.

XR technologies are increasingly being used in large-scale event simulations as they enable virtual scenario building on top of having greater advantages for large scenarios and for simulating environments of high complexity. These technologies promise to reduce some of the costs associated with expensive training, particularly where spatial information is important, such as in mining simulations, earthquake relief, and in the more granular areas of aviation. XR training can eliminate

some of the risks inherent in high level training by placing individuals in simulated environments rather than in real world hazardous situations. XR training promises to reap more than just complement the benefits of traditional training protocols. Whether or not it is a time-saving, cost-saving measure, the benefits of its existence may still outweigh the potential drawbacks.

The benefits of XR technology are being further explored in terms of large scale scenario reproduction (Gironacci, 2020). The emergence of XR technology provides a possible solution to this dilemma. XR technology not only allows users to enter complex scenarios that are close to reality, but also allows them to exchange information with other participants through interactive design, thus enabling management decisions to be simulated and providing a platform for, for example, emergency rescue management, disaster prevention, etc. (Moser et al., 2020). The XR technology not only allows users to enter complex scenarios that are close to reality, but also to interactively design and communicate with other participants, thus enabling management decisions to be simulated, for example for emergency management, disaster prevention, etc.

5.1.2 Emergency management developments

According to historical data from CRED (Centre for Research on the Epidemiology of Disasters), the number and severity of disasters around the world has increased in recent decades. This fact applies not only to natural disasters, but also to wars triggered by geopolitical crises that challenge the survival of mankind in a time of increasing globalization. Despite the many advances in science and technology that have been made in modern times, the number of casualties from disasters has not decreased significantly with the development of science and technology, but rather has tended to increase. This has placed greater demands on emergency management of disasters.

It is very difficult to prevent disasters from occurring at the source, and it takes a long time to invest and manage them, but if effective management and rescue is carried out before and after a disaster occurs, it can significantly reduce the number of casualties and damage to property. The World Health Organization has looked at historical data and found that scientific and effective emergency management programs are effective in reducing casualties in all types of disasters.

Emergency management is essentially a complex, multi-disciplinary and multi-agency management activity. In many common disaster emergency management scenarios, there are often multiple rescue forces involved, including but not limited to: medical rescuers, fire and rescue personnel, police, government personnel and public interest personnel from various public interest organizations. Given the complexity of disaster scenarios, effective rescue has always been a core area of research in the field of emergency management. However, due to the uncertainty of many disasters, the only way to improve the response to real emergency management scenarios is to develop

appropriate emergency plans in advance and to use emergency drills. This makes the development of emergency management mostly dependent on the experience accumulated from previous disaster events. Although many disasters are recurring and have a certain commonality and predictability, for disaster events that have not occurred before but have the potential to occur, emergency management can often only be achieved by establishing a theoretical simulation framework and then verifying the effectiveness of the developed emergency management framework through simulation exercises. As most sudden public events occur in complex scenarios with a large number of injured people in complex situations, this poses a great challenge for emergency management simulation exercises. Due to the inability to recreate realistic disaster scenarios, most drills currently can only be enhanced by limited means, such as the use of projectors and dummy casualties to enhance the realism of the drill. However, emergency management drills in this traditional sense are unable to recreate disaster scenarios and the process is not sufficiently immersive, often resulting in a failure to recreate the sense of urgency and randomness in disaster scenarios. As a result, emergency management plans developed under the traditional model rely more on past rescue experience.

Emergency management has received increasing attention from more and more countries and scholars in recent years, and the development of this field has gained more direction. The ability of virtual reality technology to build 3D scenes has provided new ideas for the development of many industries, and this is also true for emergency management. Caballero and Niguidula, (2018) applied virtual reality technology to disaster risk management and emergency preparedness and obtained a good user experience. Virtual reality technology provides a new solution to the problem of poor realism and low immersion in traditional emergency drills and has been fully applied in the field of emergency management. Worldwide, a growing number of scholars are investigating how the two can be more effectively combined to advance emergency management.

5.1.3 Integration of emergency management and virtual reality in a digital twin perspective

Digital twin theory provides a strong theoretical model to guide the integration of virtual reality technology and emergency management. The earliest conceptual model of the digital twin can be traced back to the University of Michigan Industrial Industry Lecture, presented by Dr. Greaves in 2002. DT is a dynamic mapping of physical entities in a virtual world that can provide support for the extension and upgrade of physical objects through the use of attributes, rules for the behavior of simulated and real situations in virtual models for interactive virtual and real feedback, data fusion analysis, decision operations such as iterative optimization (Lim 2019). The core elements of DT include physical entities, virtual models, services, data and connectivity. This mirror space simulation enables

effective simulation to predict the state as well as developmental changes of research objects in real physical environments. Guided by the digital twin theory model, this project constructed a mirror space simulation of public emergencies through XR technology for emergency management simulation exercises. Through randomized controlled trials, it was found that the XR-based simulations were effective in improving the overall performance and emergency management capabilities of the experimental subjects.

This project experimentally verified the effectiveness of XR technology in the field of emergency management simulation. The experimental group adopted the XR technology for case simulation, while the control group adopted the conventional simulation route. The expert group conducted a full-cycle quantitative evaluation of the two experimental groups, according to the developed evaluation scale. When comparing the final scores of the two groups, it was found that the mean score of the experimental group was higher than that of the control group, and this difference was statistically significant. This indicates that the experimental subjects outperformed the control group to a certain extent in terms of both their professional skills and their resilience in the XR virtual reality environment. With the assurance that the other experimental conditions were consistent, we can conclude that it was the XR technology that brought about this change. Considering the characteristics of XR technology, it is easy to see that this virtual reality technology is able to provide a more realistic virtual environment, and diverse interactions, than conventional simulations. While providing a better platform for simulation exercises, it enhances emergency management capabilities in potential future emergencies, thus reducing the probability of casualties in real events, as hypothesized by the digital twin model. Further analysis reveals that the effectiveness of the application of XR technology in emergency management case simulations is reflected not only in the data of the experimental subjects, but also in the design of the theoretical framework of the whole case.

(1) Innovation in emergency management simulation pathways

In this case, the XR virtual technology and the large field of view construction technology are innovatively used in the simulation process, combined with the traditional high-precision simulator, to build a highly realistic, interactive, low-cost and repeatable case simulation environment. Providing a vehicle for emergency management simulation exercises: Based on this simulation environment, the problem of poor decision-making and management in traditional case simulations has been innovatively solved. Emergency managers will interact with the virtual environment in their command and decision making in the field and receive feedback from the environment in a real emergency. This allows the emergency management mechanism to be scientifically validated in a near-realistic context.

(2) Standardized emergency management

Emergency management is difficult to standardize to some extent due to the multidisciplinary involvement and complexity of the event. In practice, it is mostly a matter of individual cities or

emergency management units carrying out the corresponding top-level design of emergency management in accordance with the guidance documents of their country or the World Health Organization. As many emergencies have a certain geographical character, this is to some extent an advantage in terms of local adaptations. However, on the other hand, this model has led to a wide gap in the emergency management models and concepts of individual localities, which is not conducive to emergency control at the macro level. The XR emergency management case simulation system can be modularized to provide standardized case simulations for different emergencies. This standardized approach will not only help to achieve consistency in emergency management concepts, but will also help to promote good emergency management frameworks and improve the emergency management capabilities of different regions at a national level.

(3) Emergency management simulation with convertibility

The core of a case simulation is the ability to provide translatable improvements to existing mechanisms or models. Only when the case design is anchored in the actual problem can targeted improvements be obtained in the exercise session and can be effectively transferred to the practice session, which is an organic expression of efficiency in case simulation.

This project achieves a high level of case convertibility in the combination of XR technology and emergency management. The case design of this project is based on the shortcomings of emergency management in the current emergency management segment and carries out the case design from the homogeneous pain points that exist in emergency management. The three major pain points of inadequate mechanisms, lack of standardization in management, and lack of practical experience are covered. Therefore, through the XR simulation exercise in advance, even in real emergencies with different contents, the experimental subjects are equipped with certain theoretical guidance and handling experience for the management of emergency situations, which undoubtedly has practical significance for emergency management rescue to reduce casualty rates.

(4) Building a constant crisis awareness

Unlike traditional case simulations, this project is able to present a more realistic rescue performance with the help of XR technology. While conventional simulations often present rescue effects through data such as the survival rate of the casualty, this project presents the casualty in a virtual environment in a different state in response to the different measures taken by the subject, making the rescue more realistic. This effect enhances the seriousness of the case simulation and strengthens crisis awareness while allowing the experimental subjects to be more immersed.

In addition, unlike traditional emergency drills that require large amounts of human and material input, this case relies on XR technology to build an event scenario and non-core participants, which controls the cost of the case simulation and reduces the difficulty of organizing the case simulation on the basis of the participation of multiple parties, ensuring that the case simulation can be repeated

many times and effectively implementing the normalization of emergency management. The establishment of a permanent crisis awareness will not only improve the effectiveness of emergency management case simulations but will also enable the first response to be carried out in the event of a real case.

5.2 Improvements in the effectiveness of XR technology for emergency management training

For emergency management simulations, the traditional simulation training model is difficult to simulate, and the training outcomes are unsatisfactory due to a series of problems such as limited resources and low simulation levels. A single simulation path for emergency management cases can no longer meet the needs of emergency response capabilities under new challenges, so this project constructs a new emergency management case simulation system based on the digital twin model with the help of XR technology and conducts an empirical project. The data from the validity experiments, combined with the objective performance of the trainees and the real feedback from experts, show that this new hybrid simulation model is effective in emergency management training and can solve many problems in the traditional education model. The experiments and follow-up surveys have shown that the XR technology has improved the effectiveness of emergency management training in the following ways.

5.2.1 Improving subjectivity and learning curve

Emergency management case simulations based on XR technology can help to improve the learning curve of emergency management knowledge and decision-making by enhancing user motivation. This model allows for a high degree of freedom of exploration while enabling rich interactive feedback design. The unique case simulation approach breaks away from the traditional simulation approach and is a new way of learning for the user.

While the subjects gained a greater sense of immersion through the virtual environment, the effective interaction with the virtual objects greatly enhanced their sense of engagement. Although a small number of participants experienced 3D vertigo, the majority of subjects found this 'game-like' approach to be fun. The overall performance of the experimental group was more active and positive than that of the control group, which shows that this model is a good solution to the problem of boring exercises in traditional simulations, while effectively stimulating the subjects' interest and keeping their subjective motivation at a high level. This change is of great significance for decision making simulations in emergency management, as it will push the subjects to change the intrinsic drivers of the case simulation. Traditionally, the main driver of a case simulation is to identify problems by testing the emergency plan through drills. However, in the case simulation environment with XR technology,

the subject is highly motivated and equipped to explore, and is therefore able to shift from testing plans to actively identifying and exploring problems, which will effectively help in the development and formation of emergency management capabilities.

In addition, the experimental group showed higher levels of motivation as well as higher levels of concentration. In addition to helping to improve the efficiency of the case simulation, the high level of concentration could potentially help in improving the learning curve. The experimental results demonstrated in this trial suggest that the XR technology is perfectly suited for routine training in emergency management competencies. From the results of the experiment, there was a significant difference in the occupational performance of the subjects with relatively low years of experience in the field in the two experimental conditions. This suggests that the XR technology is beneficial for conducting initial and mid-term competency training and that applying this model to the training of regularized emergency response competencies will undoubtedly significantly improve the traditional learning curve and shorten the talent development cycle.

5.2.2 Strengthen clinical thinking and enhance resilience

In real emergency management scenarios, management and medical care are intertwined, and XR technology can effectively help managers improve their strain while strengthening the clinical skills and thinking of medical workers.

The traditional clinical teaching model focuses on both theoretical learning as well as clinical practice, but both theoretical learning and clinical practice are processes of learning about disease in the prograde direction, which tends to lead to a solidified mindset in trainees, resulting in a lack of resilience in real clinical scenarios. Clinical thinking is a reverse process that requires the analysis of symptoms and signs before moving on to disease. The clinical thinking required of healthcare workers in emergency management is even more demanding, requiring rapid judgement of injuries and accurate treatment decisions in a short period of time. Injuries arising from disaster scenarios are often variable and complex, requiring doctors to be extremely adaptable. This is also true for managers. In conventional case simulations, managers are faced with unexpected situations in which they make decisions, with the narrator giving information about changes in the event, which somehow loses the suddenness and urgency needed for emergency drills and reduces the effectiveness of the simulation.

The XR virtual reality technology is able to construct a large number of virtual casualties through 3D simulation and interactive design and can set different types of traumas to the casualties. Also in the process, the experimental group is faced with a variety of sudden illness triggering mechanisms for the casualties in the simulated environment, the experimental subjects often need to deal with a variety of sudden scenarios, and the virtual casualties are able to give real feedback according to the doctor's operation. With this mechanism, the complexity of the casualty's injuries in a real disaster

scenario is reproduced to the greatest extent possible. For the managers of the experimental group, their ability to respond to emergencies was fully exercised. With the support of XR technology, the case simulations were accompanied by randomly occurring critical events and a variety of changing field conditions such as weather and traffic. Instead of a single change in conditions, the managers were confronted with a comprehensive scenario that evolved and their emergency management skills could be fully demonstrated.

From the results of the experiment, the experimental group performed better than the control group in terms of coordination and communication skills and overall decision-making ability.

5.2.3 Optimizing the decision-making model and enhancing global awareness

The emergency management simulation based on XR technology can further improve the emergency response management mechanism and enhance the management level of managers. XR provides a vehicle for emergency management simulation exercises, and based on this simulation environment, the problem of poor decision-making and management aspects of traditional case simulations is solved.

The emergency manager's command and decision making in the field is interacting with the virtual environment and receiving similar feedback to that of a real emergency event. This allows the emergency management mechanism to be scientifically validated in a situation close to the real one. The simulation is also a full-cycle simulation of the entire emergency management process, allowing for quantitative statistics on the deployment of supplies and personnel, providing more effective information for managers to make macro-management decisions.

Emergency managers wearing virtual reality headsets are able to observe and review every aspect of the emergency response from a "God's perspective", and can observe the entire emergency response process from non-subject groups, such as the emergency fire brigade, government commanders and social groups, as well as carry out disaster vulnerability analysis and root cause analysis from the overall perspective of the incident to further explore specific problems in the emergency response mechanism and implementation process, so as to improve the emergency management mechanism in a targeted manner and effectively enhance comprehensive emergency management capabilities.

The difference in management decision making between the experimental and control groups shows that XR technology is indeed effective in improving the management skills of managers. The experimental group performed better than the control group in the integrated decision-making section, especially in the information communication and decision-making sections. In addition, in the post-event HVA analysis section, the managers in the experimental group also received higher ratings, showing that the experimental group, with the help of XR technology, had a more thorough understanding of the whole emergency management event and were able to give a more detailed and

scientific post-event analysis. This will help managers to feel the macro impact of different decisions on the emergency management scenario, thus helping them to enhance their global awareness and improve their management in the emergency management process.

This project has revealed that managers in the XR environment will be confronted with the need to make scientific decisions and rationalize the use of resources in the face of changing emergency management and deployment in the field. This will improve the current emergency management mechanism in three ways. Clarifying emergency response authority and responsibility, optimizing plans to break down communication barriers, and establishing clear organizational management structures.

In addition, with the continuous development of technology, the application of information technology in emergency management scenarios has formed a trend, and XR can build a simulated information decision-making environment for managers, empowering emergency management with information technology, cultivating managers' ability to extract key information and comprehensive processing of complex information, thus effectively enhancing emergency management capabilities and resilience against emergencies It also helps to reduce losses during disasters.

5.3 Recommendation

Emergency management is a complex, multidisciplinary, and multi-agency management activity (Kapucu & Garayev, 2011). Emergency management has received increasing attention from more and more countries and scholars in recent years, and the development of the field has gained more direction (Rauniyar et al., 2023). The aim of this project is to explore the portability of XR technology in the field of emergency management, and ultimately to experimentally validate the application of XR technology. Considering the characteristics of XR technology, it is easy to see that this virtual reality technology can provide a more realistic virtual environment and a variety of interactions than conventional simulations and can keep the costs within reasonable limits (Zwoliński et al., 2022). In summary, XR technology can enhance the initiative of trainers and achieve better training results (Gironacci, 2020); improve the learning curve and shorten the training cycle; strengthen the clinical thinking during first aid and improve the resilience in various emergency situations; optimize the decision-making model and emergency planning, thus enhancing the overall awareness of managers. Therefore, we recommend that medical institutions or emergency management units can apply XR technology in their daily emergency management activities.

In applying XR technology to emergency management activities, we have found that although this new model applies different techniques, it is also essentially a process of learning and constant revision, so a single simulation exercise does not get to the root of the problem, and several routinised simulations are needed to enhance the effectiveness and strengthen the capabilities. It is therefore

very much a question of how to ensure the sustainability of new and effective simulations once they have been found. The project suggests three ways to ensure its sustainability: in order for case simulations to be carried out on a regular basis, not only a strict regulatory system but also a regular training program is needed; in addition to scientific regulation, the improvement of emergency management capabilities requires humane incentives to stimulate the inner drive of each participating group; a quality control and feedback mechanism should be developed to improve the script design of the case through the feedback of the experimental subjects to make the exercise more realistic.

With the help of XR technology, combined with a regular exercise model, emergency management exercises will become easier to carry out and will effectively improve the emergency management capabilities of each unit, especially for the managers of the emergency management activities. The design of the case content, like any emergency, is not fixed, so we recommend that when applying XR technology to emergency management activities, it is important to design the most appropriate case content, taking into account the local context, so that the advantages of XR technology can be used most effectively.

CHAPTER 6

Conclusion and further research

6.1 Conclusion

According to CRED's historical data, the frequent occurrence of disasters around the world in recent decades has posed a challenge to human survival, so how to effectively avoid or reduce casualties and losses has become a major research hotspot. The World Health Organization (WHO) has found through historical data that scientific and effective emergency management exercises can effectively reduce casualties and losses from various disasters. With the development of technology, people's lifestyles have changed, but at the same time emergencies have become more complex and uncontrollable, and the traditional training model of drills is no longer adequate for this situation. In addition to the objective development requirements, each country has different policy requirements for the construction of emergency management, as does the Chinese government. In China, public hospitals are the most important part of the emergency management response process, and the development of hospital emergency management capacity has become a reflection of the hospital's overall capability. In this research context, therefore, this project hopes to find a way in which emergency management capacity can be effectively developed.

In public emergencies, there are often large numbers of casualties and complex injuries, as well as complex scenarios with many potential hazards. How these elements are reproduced in an emergency management exercise is therefore an important factor in the efficiency of the exercise. The traditional drill model is based on simulated dummies and the scenario can only be recreated by limited means to enhance immersion, which makes the training less effective. If large scenarios and casualties can be effectively recreated, the immersion in emergency management drills can be effectively enhanced, thus validating the emergency plan in an environment close to the real situation. XR virtual reality technology is increasingly being used in large-scale event simulations, as it offers the advantage of being able to build virtual scenarios and simulate large and complex environments.

As virtual reality technology continues to develop and iterate, many scholars have applied it to areas such as skills training. Alcañiz et al. (2018) found that VR technology was effective in improving managers' leadership skills. Maura and Son (2022) found through a literature review that VR could help with emergency management scenario development and the rehearsal of related activities. Ferreira et al. (2021) found that the application of VR and AR technologies to team management was effective in improving the managerial skills of managers. Virtual reality technology is not only widely used in the field of skills training but has also shown high applicability in the training of management skills. XR technology is a combination of VR, AR and other technologies used in a single case, combining the advantages of each technology to better build complex scenarios and support multi-person

collaboration. It is foreseeable that the use of XR technology in emergency management training activities could be useful, but to what extent, is it more effective than the traditional drill model, is it universal and can it be replicated in healthcare organizations?

With this in mind, this project designed a randomized controlled trial exploring the merit of applying XR technology to emergency management based on digital twin theory. This project chose to carry out the research design with the theoretical support of digital twins because, according to digital twin theory, simulating physical models in real environments by means of digital informatics can provide simulations and predictions for complex physical environments. With such theoretical support, it is foreseeable that XR technology can provide assistance in the development of emergency management plans. In order to investigate the effectiveness of applying XR technology to emergency management, this project has designed an RCT superiority experiment to compare the effectiveness of the traditional emergency management exercise model and the application of XR technology to improve emergency management capabilities. As emergency management is a multi-functional activity, medical and nursing staff were also included in the experiment to better evaluate the performance of the emergency team. In terms of quantitative evaluation, this project also achieved functional evaluation for each type of experimental subject by establishing expert evaluation groups and setting up evaluation scales.

Upon completion of the RCT, a comparison of the superiority results showed that the experimental group using XR technology had significantly better overall scores in emergency management activities than the control group. The XR technique was found to be effective in improving the performance of managers and other health workers in the emergency management process, while the virtual simulation approach provided a scientific training environment for emergency management in a real environment. In the post-event questionnaire for the experimental group, the vast majority felt that XR technology provided a more realistic experience, with greater case immersion, and that the technology was effective in improving their performance. There were also some experimental subjects who found the XR technology to be vertigo-inducing and not easy to use. In the group of nurses, we found that the experimental group received higher ratings in team communication; in the group of doctors, the experimental group received higher ratings in awareness of occupational protection; in the group of managers, the experimental group outperformed the control group in most indicators, with a clear advantage over the control group in field command as well as overall decision-making ability. In addition, in the evaluation of the managers' HVA analysis reports, the group's HVA reports were more favorable to the experimental group.

To conclude, XR technology does improve emergency management activities and is more effective than the traditional model in developing emergency management skills, and it helps to increase the initiative of trainees, thus improving the learning curve and shortening the training cycle. The rich

interactions strengthen trainees' clinical thinking and enhance their resilience in complex environments. Emergency management activities are characterized by a high degree of uncertainty and the decisions made by managers need to be not only correct and scientific, but also time sensitive. The virtual environment simulated by XR technology can provide managers with an effective exercise platform that provides a more realistic virtual environment and diverse interactions than conventional simulations, enhancing emergency management capabilities in potential future emergencies and thus reducing the probability of casualties in real events, as hypothesized by the digital twin model. With the help of XR technology, the managers not only showed better management skills during the development of the event, but also good analytical and summarizing skills after the event, and overall, better decision-making ability compared to the control group under traditional simulation conditions. It is clear that XR technology provides more information and interaction in the case simulation process, and allows managers to gain more macroscopic decision-making perspectives based on a realistic environment, thus effectively optimizing the decision-making model and enhancing the managers' global awareness.

In addition to demonstrating the effectiveness of XR technology in emergency management through quantitative experimental data, this project was also found to be instructive in theoretical aspects of emergency management through further analysis. XR technology has innovatively provided a model that is different from traditional emergency management exercises and offers a different direction for the future development of the discipline. With the help of XR technology, it is possible to present a more realistic representation of the rescue, an effect which, while allowing the experimental subjects to be more immersed, increases the seriousness of the case simulation and helps to build a permanent awareness of the emergency management crisis. In addition, thanks to this information technology, the standardization of emergency management can be further enhanced, helping to promote emergency management plans. Given that emergency management activities in China are mainly carried out in public hospitals, which operate in the public interest, the economic cost of applying this new technology becomes an essential consideration. By comparing the cost of use and depreciation rates of the different models, this project found that XR technology has a more manageable cost compared to the traditional exercise model. This means that emergency management drills using XR technology are highly replicable and can provide an effective way for more hospital managers to improve their emergency management capabilities, which is important for safeguarding people's lives and property during various emergencies.

Through the research of this project, we suggest that medical institutions at all levels can apply XR technology when conducting emergency management exercises, but it is important to note that the process should be designed to fit the local geographical characteristics and the living environment of

the emergency case, so that the local situation can be adapted to the local situation, and only in this way can the effect of XR technology be maximized.

6.2 Further research

It has been found that the application of XR technology to emergency management simulations, guided by the digital twin theory, has significant results and can improve emergency management capabilities in many ways. The XR virtual case simulation, although using different technologies, is essentially a learning and revision process, so a single simulation does not solve the problem at its root, and several regular simulations are needed to improve the results and enhance effectiveness and strengthen capabilities. From another point of view, the normalization of emergency management simulations is inevitable. The uncertainty of emergencies makes it impossible to avoid risk, but regular simulations can reduce the risk in the face of emergencies. Therefore, after finding new ways of effective simulation, it is well worth exploring how to ensure its sustainability, and this project suggests that it can be implemented in the following three ways.

(1) Regulatory mechanisms combined with regular training

For the simulation to be carried out on a regular basis, not only is a strict regulatory system needed but also a regular training course. In terms of supervision, this case proposes a dual supervision mechanism of the emergency management center and the hospital, whereby the hospital's functional department, such as the emergency management office, supervises and conducts random checks on the hospital's emergency management, ensuring that the relevant emergency supplies are in place and that emergency personnel has clear authority and responsibility to undertake relevant tasks in the event of an incident. It is also recommended that the emergency management center, which is responsible for organizing case simulations, be included as a supervisor, that regular emergency response assessments be conducted for the core personnel involved in emergency response activities, and that emergency response courses be conducted on a regular basis, with training based on the syllabus and a 'modular' training program, so that all types of personnel can be proficient in a short period of time and improve the effectiveness of their training.

(2) Personalized incentives

In addition to scientific supervision, the improvement of emergency management capabilities requires humane incentives to stimulate the inner drive of each participant group. In addition to this, the emergency management center can conduct quarterly emergency response competitions to select the best performers and integrate them into the senior emergency management team. This will create a strong sense of honor and a sense of belonging for those involved. In addition, a questionnaire was

included throughout the case simulation to optimize the case and increase the level of participation of the participants.

(3) Quality control feedback mechanism

After the case simulations have been regularized, this project considers that the design aspect of the simulated cases, based on references to the literature and first-hand information from each emergency hospital, can use the actual feedback from the participants during each simulation as another design reference. At the end of each case simulation, the emergency management center responsible for holding the case simulation will conduct a questionnaire for all participants to investigate the content of the case design, the way in which the case was examined and evaluated, and the rationality of the key events, and take relevant comments in a targeted manner to continuously adjust the case and form a set of effective quality control feedback mechanisms, thus guaranteeing the effective implementation of emergency rescue.

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Appendices

Appendix A. Questionnaire for the evaluation of XR technology-based simulation cases

Dear Healthcare Workers:

Greetings! First of all, thank you very much for your participation in this case simulation exercise and for your support in providing emergency management for our hospital. The purpose of this questionnaire is to understand the opinions and suggestions of the medical practitioners who participated in the case simulation, so that the case can be optimised to further improve the comprehensive emergency response capability and quality of care in our hospital.

The questionnaire is anonymous and your comments will be kept confidential. Please make sure that you fill in your real feelings based on your experience in the case simulation.

Thank you again for your participation in this case simulation!

1. Your gender is： [Single choice] *

○ Male

○ Female

○ Prefer not to say

2. The section you are working in is： [Fill in the blanks] *

_____

3. Your job title is： [Fill in the blanks] *

_____

4. How immersive do you think the case simulation using XR technology are? (The greater the level of immersion, the closer the surroundings are to a real disaster scenario) [Single choice] *

○ No sense of immersion	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Excellent immersion

5. What do you think is a reasonable level of critical event setting in this case? [Single choice] *

○ Extremely irrational and out of touch with reality	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Very reasonable and Consistent with the real situation

6. What do you think is the adequacy of the relevant items and logistical staffing during this case simulation? (including but not limited to: first aid supplies, exercise support, etc.) [Single choice] *

○ Extremely inadequate, lack of exercise materials	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Very adequate and well prepared for all

7. What do you think of the professional performance score for nursing staff in your medical team? (If you are a nursing staff member, please rate yourself) [Single choice] *

○ Poor overall performance	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Excellent overall performance

8. What do you think is the professional performance score of the specialist in your medical team? (If you are a specialist, please rate yourself) [Single choice] *

○ Poor overall performance	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Excellent overall performance

9. What do you think of the professional performance score for managers during the emergency response? (If you are a manager, please rate yourself) [Single choice] *

○ Poor overall performance	○1	○2	○3	○4	○5	○6	○7	○8	○9	○ Excellent overall performance

10. Do you think there are any obvious advantages or shortcomings in this simulation? If so, please provide further clarification. [Fill in the blanks] *

_____

_____

_____

11. Do you think that case simulations with XR technology can effectively improve your performance in emergency management scenarios?[Fill in the blanks] *

_____

_____

_____

Appendix B. Critical event design elements

（**Critical Events**）	（**Objectives**）	（**Targeted Responses**）
Emergency Management and Response (prior performance of managers)	1. Upgrading emergency response capabilities; 2. Optimizing emergency response plans;	1. be able to obtain key information such as the nature, size, intensity, and number of tasks based on available information, submit it to the leadership for approval, and initiate the response plan 2. medical team extraction group, according to the case situation flexible development of a reasonable emergency rescue personnel with the plan 3. medical team assembly, before the case simulation to ensure the successful assembly of personnel and materials
Event 1. On-site firefighting teams as well as traffic police teams multiple rescue forces in disarray, no on-site command staff, a large number of casualties chaotic distribution.	1. Determine on-site command authority and responsibility, resource allocation and rescue plan development; 2. Coordinate the rescue forces, obtain the latest information on rescue and adjust the rescue plan; 3. Direct individual rescue forces to carry out casualty examination and classification, and carry out rescue in an orderly manner;	1. arriving at the simulated site, quickly develop a plan based on the site situation and arrange to carry out rescue; 2. record key information about the rescue process; 3. maintain communication with other rescue forces on site to obtain overall casualty situation fluency; 4. quickly confirm site management authority and responsibility, and clarify rescue tasks;
Event 2. There was a large number of wounded at	1. How to rationalize the rescue plan when medical resources are crowded within a short period of time; 2. On-scene casualty management and emotional reassurance;	1. real-time grasp of the back hospital load before the rescue is carried out, and according to the rescue situation at the scene, timely application for assistance from the nearest hospital; 2. depending on the rescue conditions at the scene

the scene, some of whom were in critical condition, and the overall patient compliance at the back hospital had reached its limit and could not accommodate more patients.		as well as the rescue team, open a temporary hospital for temporary emergency treatment according to the level of injuries;
Event 3. A large number of dead people's remains appeared at the accident site, the surrounding onlookers were agitated, the collapsed building showed precursors of secondary collapse, and rescue work could not be carried out normally.	1. Delineating in advance the area where the remains of the deceased person are to be placed for closed management; 2. Managing to safeguard the personal finances of the deceased person and the surrounding environment; 3. Keeping an eye on the site environment and being alert to secondary collapse of buildings;	1. the development of relevant details for the disposal and placement of the remains of a large number of deceased persons in the emergency plan; 2. cordoning off the rescue site in coordination with other rescue forces; 3. setting up the emergency rescue area in an open area with dedicated personnel to assess and monitor the status of the collapsed building;

Appendix C. Expert Authority Questionnaire

Instructions for completing the form:

In the "Basis of Judgement and Degree of Influence" column, please first self-assess the degree of influence (large, medium or small) of each basis of judgement on your decision and tick "✓" in the corresponding column, only one influence can be ticked for each option. Please read it carefully and complete it without omission. Thank you for your cooperation. (Remark: the level of the hospital is shown in the column, e.g. Grade IIIA, Grade IIIB)

Basic information							
Name		Gender		Age		Highest Education	
Work experience (years)		Position/Title		Hospital class		Specialist positions	

The basis for your judgement of the hospital's emergency management and the extent of its impact			
Basis of judgement	Lage	Medium	Small
Practical experience			
Theoretical analysis			
Reference to national and international data			
Visual Experience			

How familiar you are with emergency response related work					
Familiarity level	Very familiar	More familiar	Moderately familiar	Not really familiar	Not at all familiar
Self-Assessment					

Appendix D. Managerial Professional Conduct Evaluation Form

Managerial Professional Conduct Evaluation Form					
Managers		Name_____ Department _____ Education _____ Years of experience _____			
Assessment content		Assessment criteria	Score	Problems	Points scored
Before the event	Emergency response	Be able to obtain key information about the nature, size, intensity and number of tasks based on the scenario given in the case, and submit it to the leader for approval to activate the response plan.	5		
		Medical team draw groups, with flexibility to develop a reasonable mix of emergency responders depending on the case.	5		
		Medical team assembled to ensure successful assembly of personnel and supplies before the case simulation takes place.	5		
During the event	Carrying out the rescue	Upon arrival at the simulated site, a plan was quickly drawn up based on the situation and arrangements were made to carry out the rescue.	5		
		Documenting key information about the rescue process.	5		
	Site command and coordination	Maintain communication with other rescue forces on the scene to obtain overall casualty fluency.	5		
		Rapid confirmation of site management authority and responsibility and clarification of rescue tasks.	5		
		Communicate with back hospitals in real time and make relevant emergency arrangements.	5		

		Rationalise on-site resources and sort and evacuate patients as soon as possible.	5		
		Reasonable arrangements for the remains of a large number of people who have died.	5		
		On-site crisis management to prevent secondary injury incidents.	7.5		
After the event	Summary	At the end of the rescue at the scene, a record of the rescue should be made up and summarise.	5		
	RCA/HVA Analysis	Conduct root cause analysis afterwards and further optimise the emergency plan based on the results of the data.	7.5		
Integrated decision-making capabilities	Communication skills	Ability to communicate effectively with medical mission teams and implement rescue plans.	5		
		Communicate with the front and back in a timely manner to ensure a smooth flow of rescue information.	5		
	Decision-making	Clear decision making and clear lines of authority and responsibility.	7.5		
		Decision-making instructions are issued promptly and in a timely manner.	7.5		
		Predictive management of on-site decisions.	5		

Appendix E. Professional conduct evaluation form for nursing staff

Professional conduct evaluation form for nursing staff					
Nurses	Name_____ Department _____ Education _____ Years of experience _____				
Assessment content	Assessment criteria		Score	Problems	Points scored
Clinical thinking Nursing Competencies	Injury assessment	Ability to identify and risk assess acute and critical care scenarios	5		
	First aid knowledge	Proper observation and management of trauma patients	2.5		
		Correct handling of fractured patients	2.5		
	Nursing 12 items	Nursing 12 relevant operations normative	10		
	Specialist care implementation	Provide specialist knowledge of the patient's condition, knowledge of possible complications and implementation of preventive measures	10		
Communication and coordination skills	Communication skills	Ability to communicate effectively with patients	5		
		Timely communication with doctors and managers to ensure smooth flow of rescue information	5		
	Collaboration models	Work well with doctors in the team and communicate without barriers	10		
		Timely response to the doctor's rescue programme and all support	10		
		Ability to work efficiently with other rescue forces to advance rescue plans	10		
Human care competencies	Focus on patient privacy		5		
	Appropriate psychological support for patients		5		

Awareness of occupational protection	Use of medical defence equipment in emergency situations	5		
	Proper disposal of medical waste	5		
	Be aware of environmental conditions on site and avoid high wind areas	10		

Appendix F. Professional conduct evaluation form for specialist physicians

Professional conduct evaluation form for specialist physicians					
Physician		Name_____ Department _____ Education _____ Years of experience _____			
Assessment content		Assessment criteria	Score	Problems	Points scored
Resuscitation capabilities	Resuscitation knowledge and operational skills	Ability to identify and risk assess acute and critical care scenarios	2.5		
		Proper observation and management of trauma patients	2.5		
		Correct handling of fractured patients	2.5		
		Be able to use a simple resuscitation capsule, defibrillator and perform tracheal intubation correctly	10		
		Proper implementation of relevant specialist emergency measures	10		
	Inspection and assessment	The SALT injury classification area, overall classification and individual assessment is correct and rapid	10		
		Provide correct primary patient assessment for clinical and decision-making purposes	2.5		
		Secondary assessment after dealing with life-threatening injuries	2.5		
	Patient	Scientific and rational arrangements for	5		

	Management	patient transfer and evacuation			
		Develop a mass fatality emergency response plan	2.5		
Communication and coordination skills	Communication skills	Ability to communicate effectively with patients	5		
		Communicate with teams and managers in a timely manner to ensure smooth flow of rescue information	5		
	Collaboration models	Work well with nurses in the team and communicate without barriers	5		
		Timely determination of rescue plans and rational deployment of resources	5		
		Ability to work efficiently with other rescue forces to advance rescue plans	5		
Human care competencies		Focus on patient privacy	5		
		Appropriate psychological support for patients	5		
Awareness of occupational protection		Use of medical defence equipment in emergency situations	5		
		Proper disposal of medical waste	5		
		Be aware of environmental conditions on site and avoid high wind areas	5		

Appendix G. Hazard Vulnerability Analysis (HVA)

Category	Risk events	Possibility of occurrence	Level of severity						Relative risk（%）	Risk ranking
			Casualties	Property damage	Service Impact	Emergency preparedness	Internal reaction	External response		
Natural disasters										
Technical incidents										
Personnel injuries										
Hazardous substances										