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Development of an Augmented Reality Framework for Tabletop Exercises as Sustainable Disaster Preparedness Training

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ABSTRACT

Tabletop exercise (TTX) is a typical disaster preparedness training conducted among disaster responders to improve their readiness and respond effectively during disaster events. However, the current manual and conventional TTX lack interactivity and immersion throughout the exercise. Augmented reality (AR) technology is a promising technique that improves the realism and engagement of TTX. This study aims to develop an augmented reality framework for tabletop exercises as sustainable disaster preparedness training. A Rapid Application Development (RAD) model is selected for this project. It consists of four main phases for project development: (1) Requirement planning, (2) User design, (3) Construction, and (4) Cutover phases. The AR framework was designed to visualise a heavy rainfall scenario, enable interactive decision-making and deploy the AR content on mobile devices. As conclusion, although the pilot testing and evaluation of the AR framework, which will be conducted during the project's future work, are still pending, this study highlights the AR application's conceptual design and development process based on the Rapid Application Development (RAD) model. It addresses the potential implications of the AR framework for tabletop exercises.

Keywords: augmented reality; tabletop exercise; disaster training; disaster preparedness

1.0 INTRODUCTION

Tabletop exercise (TTX) is a discussion-based disaster preparedness training among key personnel discussing simulated disruptive events in an informal setting [1], [2]. TTX is a method to review, refine and assess the guidelines and policies of organisations or governments to respond to undesired situations during disaster events [1]. The participants discuss and analyse the issues through paced problem-solving until effective decisions are made [2]. It is the most common and effective form of disaster training for improving preparedness [3], [4]. TTX also ensures disaster plans, policies and procedures can be tested and validated to identify gaps, drawbacks, and strengths of materials [5]. In addition, the tabletop exercise is a comprehensive, sustainable, thorough, and economic strategy for disaster planning [6]. Besides that, participants receive the opportunity to practise disaster management skills such as communication, prioritising, teamwork, and delegation [7].

Disaster responders must participate in disaster preparedness training to improve their readiness and respond effectively during disaster events [8]. Besides that, TTX provides an exclusive opportunity to review the standard operating procedures (SOPs) and guidelines used by different organisations or agencies in a controlled collaborative setting through a comprehensive exploration based on the coordination and interaction among organisations during crises [9]. However, the current practice of TTX relies on manual and conventional methods where disaster scenarios and injections are presented using presentation slides, printed materials, and verbal communication. This method was less effective for participant scenario engagement since it lacked interactivity and immersion throughout the exercise [10]. Hence, it is suggested that the effectiveness of TTX can be improved by using modern computing technology such as augmented reality (AR). This technology is a promising technique close to reality since it employs computer-generated information to enhance the physical surroundings rather than creating a virtual world [11], [12]. Apart from increasing participant engagement, AR also overcomes the significant drawbacks of traditional disaster training by reducing costs and disruption during training. After decades of experimentation with AR for education and training, it has proven feasible and compact enough to be integrated into training settings via personal devices such as mobile phones or computers [13].

The adoption of augmented reality in disaster training is no longer foreign. It has been widely explored and implemented in various disaster scenarios such as fire, earthquake and first aid [14] which succeeded in improving the participants' skills development and engagement [15]. Adoption of AR on evacuation training provides a realistic environment by using real space with superimposed virtual contents that improve spatial awareness and emergency decision-making [16]. Furthermore, a study on evacuation training using an AR game for earthquake, fire, and chemical attack scenarios demonstrated high satisfaction of participants with the flexibility and applicability of AR for evacuation guidance and training [17]. Similarly, AR tools in the first aid training and evaluation system significantly improved participants' self-confidence in performing emergency care [18]. In addition, AR is more cost-effective than conventional training methods by eliminating the large-scale training setups that come with expensive material costs and reducing the travelling expenses of participants to the face-to-face training location [19]. The augmented content can be frequently updated based on the training needs and to maintain the quality of the training method [15]. Climate variability of Malaysia has been reported to associated with increase of disaster risk and increase in the frequency of the disaster events that occur annually conditions [20], [21]. Hence, a more adaptive and immersive training method is needed to be conducted to maximise the effectiveness of TTX training. Despite proven effectiveness of AR in disaster training, there has been little to no evidence of the adoption of AR into the TTX, which resulting in a significant gap in exploring new disaster preparedness training approaches. Thus, this study aims to develop an augmented reality framework for tabletop exercises as sustainable disaster preparedness training.

2.0 METHODOLOGY

A Rapid Application Development (RAD) model is selected as the most suitable model for this project due to its ability to create and deliver the project within a shorter timeline, which results in lower development costs. The benefit of this model is that it identifies problems with feedback from project members or clients during the early phase of the project [22]. The RAD model consists of four main phases for project development: (1) Requirement planning, (2) User design, (3) Construction, and (4) Cutover phases, as summarised in Fig. 1.

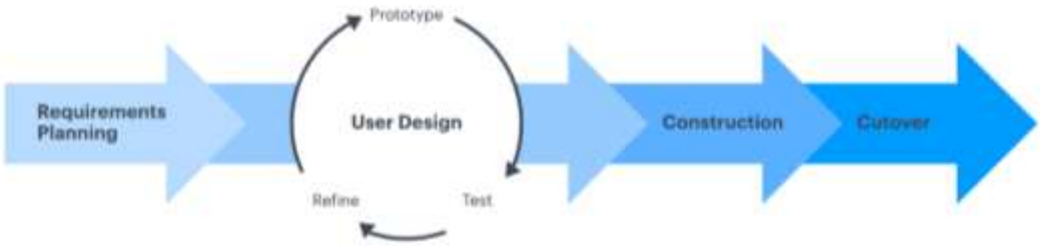


Figure 1: The RAD Model

2.1 Phase 1: Requirement planning phase

Several qualitative methods were conducted during this phase to gather comprehensive and context-specific requirements. The first method conducted was document analysis of published official policies, directives, and guidelines for disaster management in Malaysia including the Majlis Keselamatan Negara (MKN) Directive No. 20, National Disaster Management Agency Malaysia (NADMA) Directive No. 1, World Health Organization (WHO) Simulation Exercise Manual, and Federal Emergency Management Agency's (FEMA) The Homeland Security Exercise and Evaluation Program (HSEEP). These documents were selected and analysed using the READ approach to collect and analyse information from the documents [23] and the document analysis process was summarised in Fig. 2. Second, in-depth interviews were conducted with disaster experts in Malaysia to identify suitable scenarios for the tabletop exercise using augmented reality. In order to ensure relevance and analytical rigor, the disaster experts were selected among those with minimum of two years of professional experience in disaster management, prior participation in tabletop exercise training and direct involvement in disaster preparedness planning or operational response. Third, observations of the tabletop exercises organised by the disaster responding agencies in Malaysia such as the Royal Malaysia Police (PDRM), Fire and Rescue Department (JBPM), Malaysia Civil Defence Force (APM), Ministry of Health (KKM) and National Disaster Management Agency (NADMA) to gain various information of real-world insights on procedures, inter-agency coordination, and exercise structures that can be included in the development of disaster scenarios.

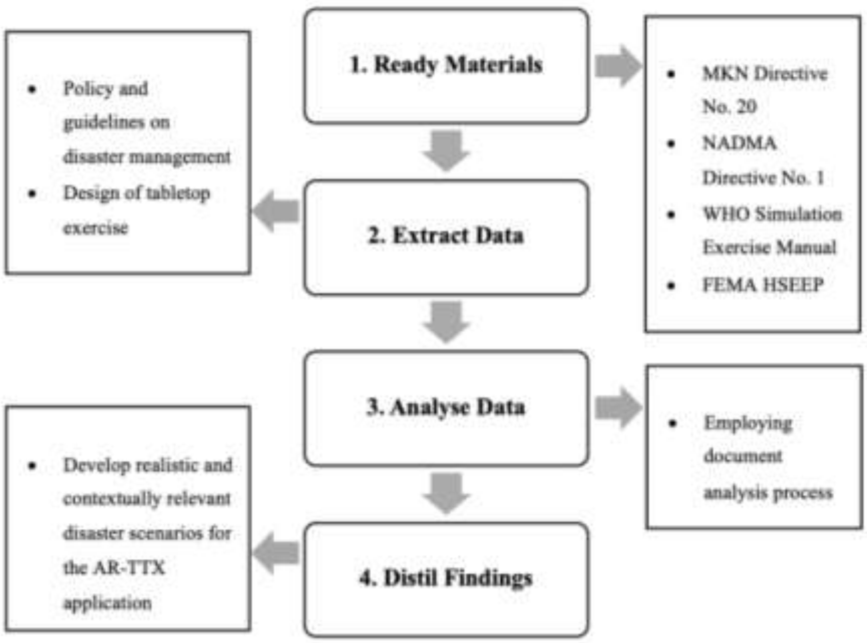


Figure 2: Document analysis using the READ approach

2.2 Phase 2: User design

Based on the findings gathered from Phase 1, the project members created a storyboard (Fig. 3) to conceptualise the AR-TTX application. Microsoft PowerPoint was employed to visualise the project's flow and development associated with the tabletop exercise contents, enabling early feedback from project team members. This phase ensured the application design was aligned with user expectations, training objectives, and real-life scenarios.

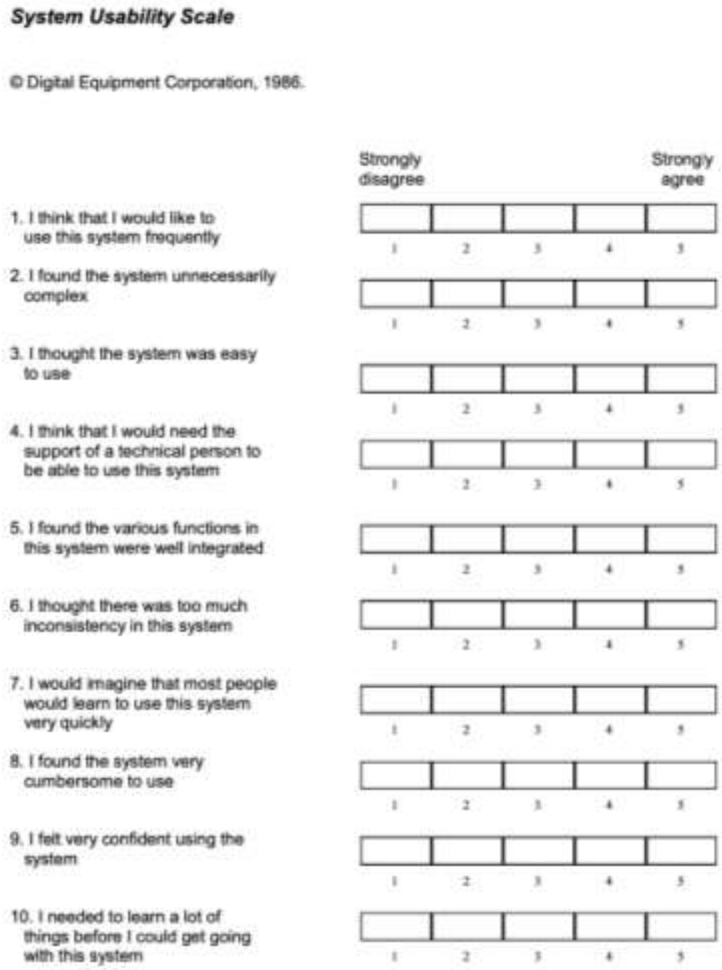
Figure 3: Storyboard designed using Microsoft PowerPoint

2.3 Phase 3: Construction

The storyboard constructed in Phase 2 served as a blueprint to guide the development of the project during Phase 3. The augmented reality application is developed using a powerful real-time 3D creation tool named Unreal Engine software on Windows 11. The resulting AR-TTX application was optimised for Android-based mobile devices (version 14.0 and above), allowing for accessible and flexible use on smartphones and tablets. The application was developed exclusively on Android devices due to resource availability during construction phase. Regular testing is conducted during this phase to ensure functional accuracy, user responsiveness, and compatibility with the intended devices.

2.4 Phase 4: Cutover

The final phase involved deployment, user testing, and evaluation of the completed AR-TTX application. The final product will be tested using the System Usability Scale (SUS), a validated and widely used usability testing tool due to its simplicity, reliability, and strong focus on usability [24]. The scale consists of 10 items rated from 1 point for strong disagreement to 5 points for strong agreement, as in Fig. 4. The SUS will be the primary tool used to determine the validity and usability of the augmented reality-based tabletop exercises for disaster preparedness training during Phase 4. A pilot study was conducted among 20 final year nursing students to evaluate the usability of AR-TTX application using the SUS. The method used in the pilot study have been comprehensively reported in the published study [25]. The application's suitability for deployment in actual disaster preparedness training will be significantly influenced by these upcoming findings.



System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Figure 4: System Usability Scale (SUS)

2.5 Ethical consideration

This study was approved by the author's university research ethics committee, the national medical research registers and the five disaster agencies (PDRM, JBPM, APM, KKM and NADMA) involved in the study.

3.0 RESULTS AND DISCUSSION

The final product was developed using the RAD model for augmented reality development for tabletop exercises. The heavy rainfall and flood scenario was developed based on information gained during Phase 1, as flood is among the most common disasters affecting Malaysia annually during the monsoon season [26]. Apart from the main scenario, several injections associated with flood situations were introduced throughout the tabletop exercise to test the ability of the disaster responders to respond according to the policies and guidelines used for disaster management in Malaysia.

3.1 Scenario visualisation

The content of this application focuses on a more realistic environment and enhances the participants' immersion throughout the tabletop exercises. The marker-less augmented reality is applied due to its more accurate and logical features, which require the camera to scan the flat surface to display the three-dimensional (3D) model above it, as compared to marker-based AR. The heavy rainfall 3D model (Fig. 5) was created in the project as the primary model for the tabletop exercises. Apart from that, another scenario associated with the main setting, such as the water release of the nearby dam (Fig. 6), was also included in this AR application.

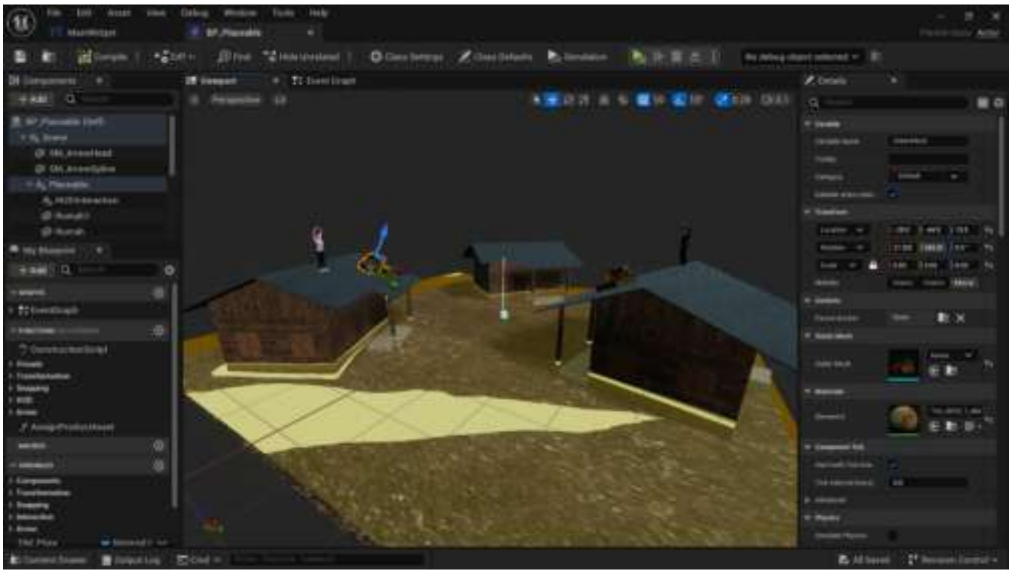


Figure 5: Heavy rainfall 3D model

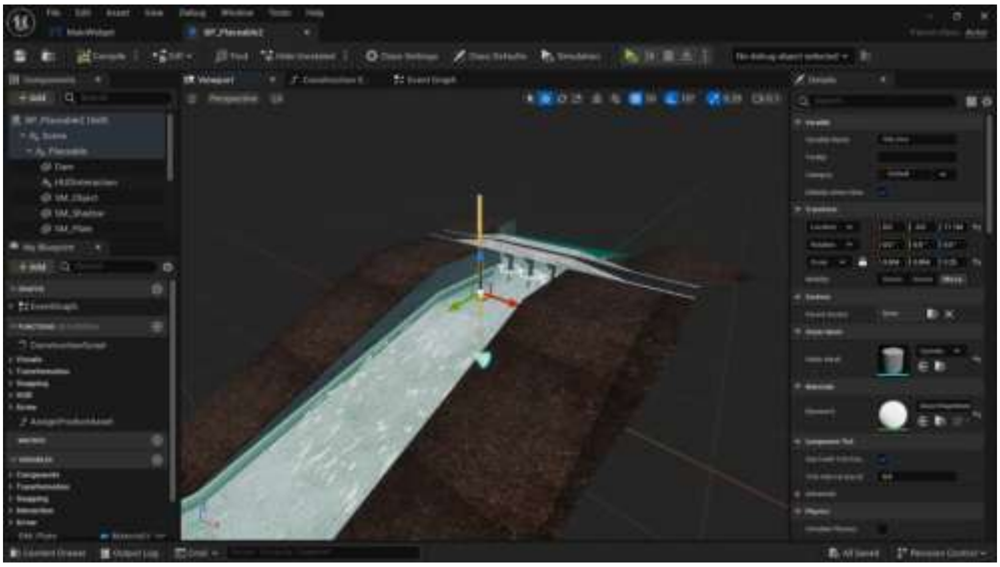


Figure 6: Dam water release 3D model

3.2 Interactive features

This application was developed based on the nature of discussion-based training among multiple agencies responsible for disaster management in Malaysia. Both national directives were analysed based on the main focus areas of the disaster management mechanism, prevention and mitigation, disaster response mechanism and rehabilatation (MKN, NADMA). There are several agencies were involved in disater and relief management, however, this study will on focusing on the five leading agencies of the PDRM, JBPM, APM, KKM and NADMA to be included as players or characters in this AR application. Hence, this project adopted a multiplayer system that synchronised all players' devices to provide real-time interaction in all scenes. This system can facilitate communication and coordination among the players [27]. For example, the scene where the APM agency needs help with the logistic supply, including a lorry and food supplies (Fig. 7), requires all four other agencies to respond to the request. The multiplayer system for the mentioned scene is constructed as shown in Fig. 8.

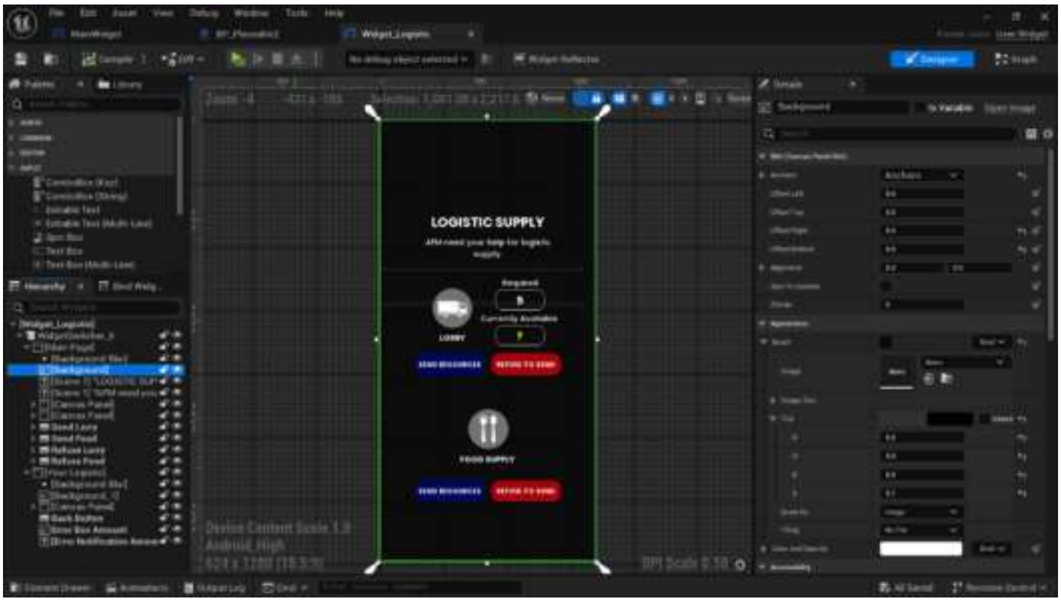


Figure 7: Scene of APM requests for logistic supply.

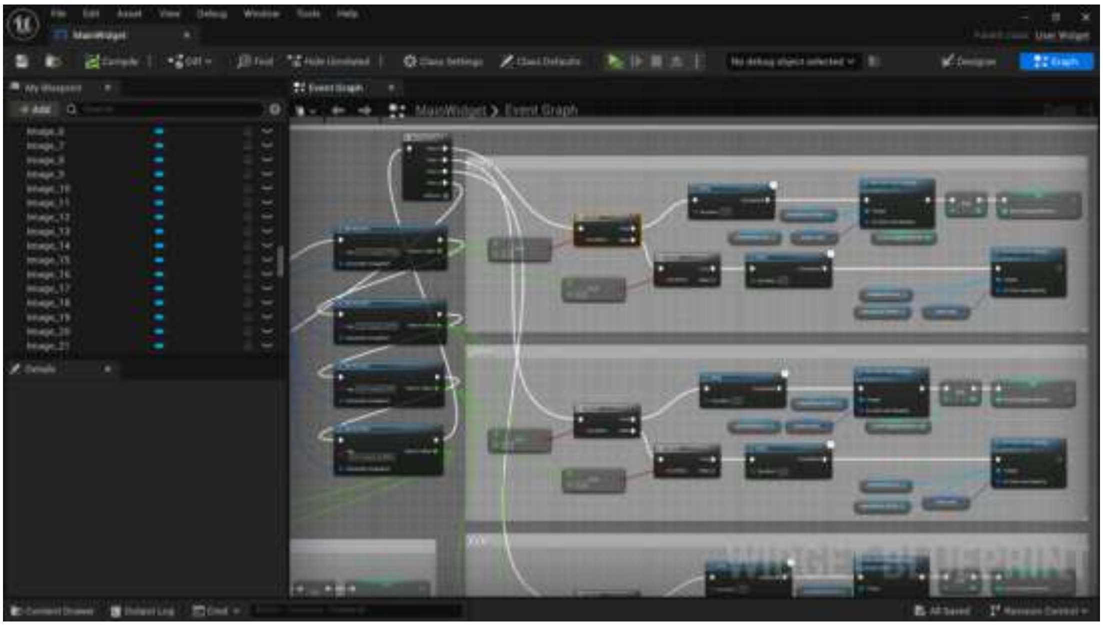


Figure 8: The multiplayer system for the APM scene requests logistic supply.

3.3 Deployment on devices

This AR application has been tested on Android devices. The AR features of 3D models from the Unreal Engine software are displayed on the mobile phone screen based on the input data from the device's camera. Touch screen was utilised to ensure the progress of the TTX scenes throughout the AR application. Fig. 9 shows the camera input for the AR component, highlighting plane detection of real-world scenarios as displayed on the screen. Meanwhile, Fig. 10 to Fig. 13 show some graphic interfaces from the AR application.

(a) (b)

Figure 9: Camera input for the AR component (a) Plan view on a flat surface (b) Close-up view through different angles

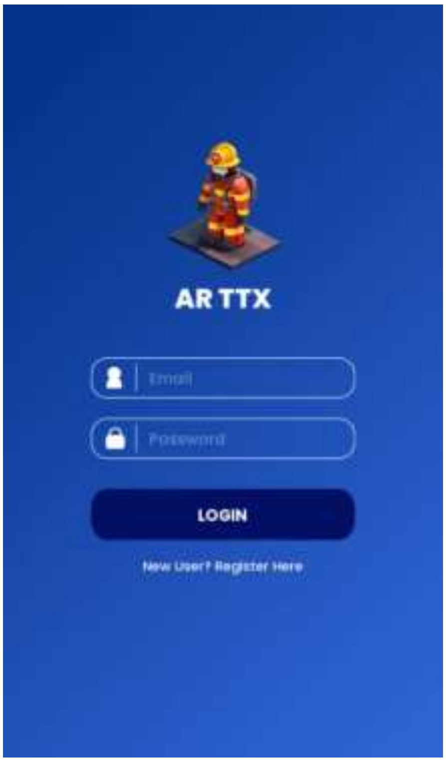


Figure 10: Registration and Login features for the participants

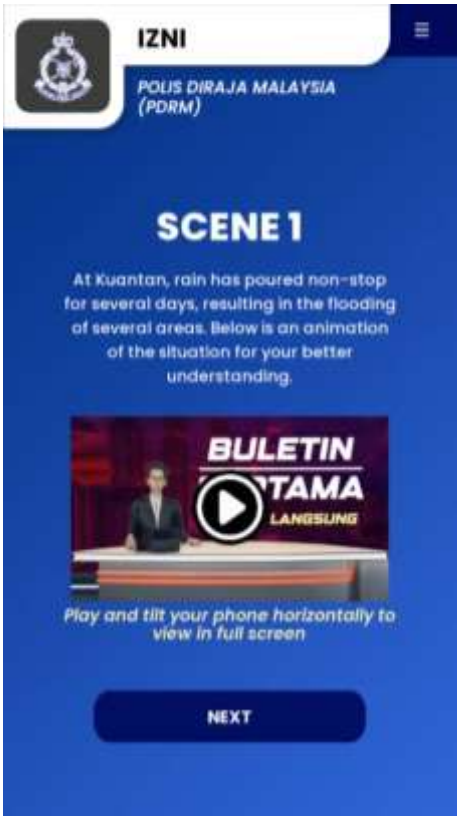


Figure 11: Scenario is introduced with 3D animations associated with the scene.

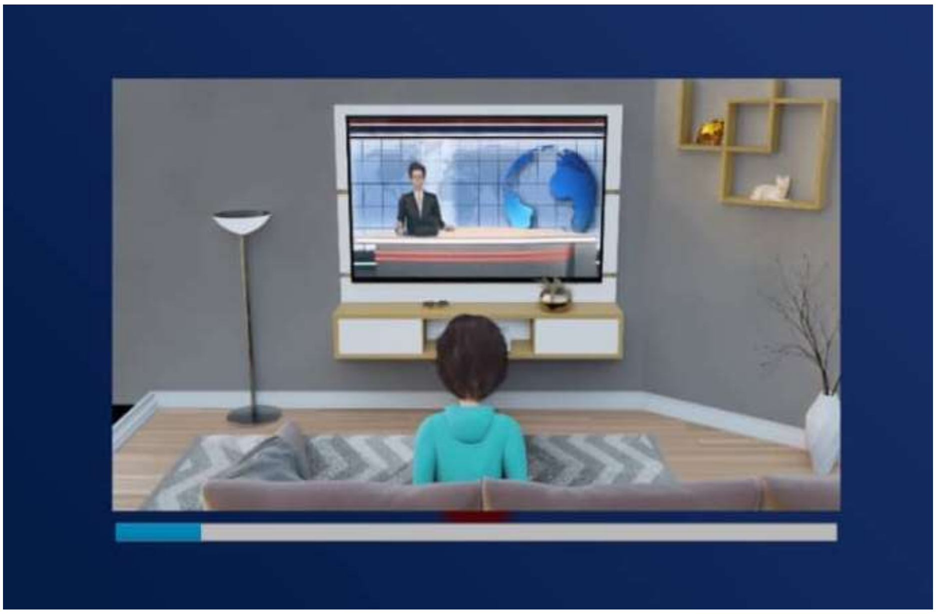


Figure 12: 3D animation of people watching flood news on television.

(a) (b)

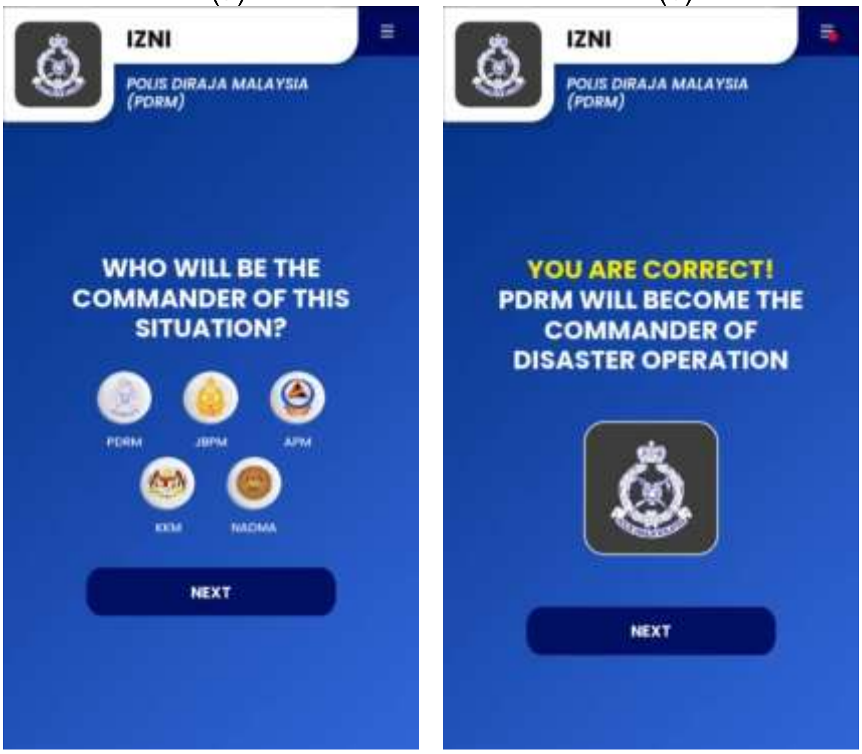


Fig. 13: (a) Question included during the tabletop exercise.
(b) The feedback given is based on the answer to the previous question.

3.4 Usability of AR-TTX application

The usability of the AR-TTX application was evaluated in a pilot study which the detailed results have been reported in [24]. The SUS scores were calculated using Brooke's calculation [25], the final SUS score was 58.38 which below the accepted usability threshold of 70. This result indicating further refinement is needed in the AR-TTX application as most of the participants were experiencing significant usability issues througout the pilot session. Despite low SUS score, the participants suggested this application was functional but not being fully optimised to maximise the usability for tabletop exercises as sustainable disaster preparedness training.

3.5 Limitations and recommendations

This AR application provides significant potential to improve the engagement of the participants or players through immersive visuals and to enhance decision-making in real-time interactions. However, this developed AR framework encountered some limitations in performance optimisation, including environmental dependency, where issues arise in detecting the physical environment due to a lack of distinct textures and lighting through spatial mapping. Besides, the AR content placement was unstable in this marker-less system, which caused the content to lose track and disappear from the screen. Hence, it is recommended to shift the marker-less AR system into marker-based AR system for the future project to overcome these limitations. It offers a more controlled environment by ensuring consistent content placement and enhancing the TTX experience [22].

4.0 CONCLUSION

This study presents a novel augmented reality approach for tabletop exercises to improve disaster preparedness training based on the RAD model which involves requirement planning, user design, construction and pre-evaluation phases. This study had great potential to produce engaging and interactive training methods that closely mimic actual disaster situations by enhancing the user engagement and practical disaster response skills. Future research should include more disaster-related agencies responsible in Malaysia to evaluate learning outcomes, decision-making accuracy and inter-agency coordination.

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CONFLICT OF INTEREST

Competing interests: No relevant disclosures.

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