VR-CivicGuard:
Enhancing Campus Civil Defense and Air Defense Preparedness through Immersive Virtual Reality Training

Hung-En Hsieh*, Jeng Wen Joshua Lean, Jin-Wei Chang, Yu-Ning Chen,
Pin-Yue Wang, Tsun-Hung Tsai, Min-Chun Hu

National Tsing Hua University, Taiwan

ABSTRACT

As drones and missile strikes become major threats in modern warfare, traditional civil defense training often fails to build the procedural memory required for survival. We present VR-CivicGuard, an immersive VR simulation that trains users in expert-informed air raid standard operating procedures. Developed through interviews with civil defense specialists, the system targets critical survival skills, including blast-mitigation posturing, emergency item collection, debris navigation, and drone evasion. A pilot study showed high usability and immersion, and participants trained with VR-CivicGuard significantly outperformed a control group. These findings highlight the effectiveness of expert-informed VR for civil defense training.

1. MOTIVATION & SYSTEM OBJECTIVE

Traditional civil defense training relies heavily on passive media like videos and brochures, which fail to instill the reflexive physical responses necessary for survival under duress. As modern threats like drone surveillance and missile strikes evolve, there is a critical need for training that builds procedural memory. VR-CivicGuard addresses this gap by providing an immersive simulation focused on expert-informed air raid Standard Operating Procedures (SOP). By reconstructing a high-fidelity "digital twin" of a campus environment, the system transforms theoretical knowledge into embodied, practical survival skills.

2. TECHNICAL IMPLEMENTATION & 3DGS WORKFLOW

The system is developed using Unity 6 and the Meta Quest 3 standalone headset, leveraging 6DoF tracking and hand-tracking for intuitive interaction. To ensure an authentic spatial scale for learning, we utilized 3D Gaussian Splatting (3DGS) to process handheld video scans of the physical campus. This point cloud data served as a high-precision reference for modeling physics-ready geometry in Blender. To maintain high frame rates on standalone hardware, a hybrid lighting strategy was adopted, combining baked lightmaps for static architecture with real-time lighting for dynamic explosions.

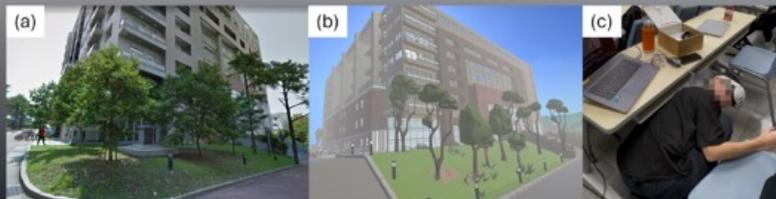Figure 1. In-game experience of VR-CivicGuard

Figure 2. (a) Real building (Source: Google Street View); (b) Scene reconstruction in our system; (c) Participant practicing postures.

3. Immersive Hazards & Interaction Design

To replicate the physiological hazards of an air raid, the simulation features a Dynamic Mesh Shattering System that simulates structural failures and fracturing glass caused by blast overpressure. Users must actively seek cover to avoid "Critical Injury" zones. Guidance is provided by a diegetic NPC companion (a cat), which utilizes a Finite State Machine (FSM) to lead users through safe paths and debris. Additionally, the system incorporates hostile drone patrols using Raycast-based algorithms, mandating strict adherence to concealment maneuvers and situational awareness.

4. Evaluation & Empirical Results

A between-subjects study (N=26) was conducted to evaluate the system's efficacy. VR-CivicGuard achieved an "Excellent" usability rating with a mean System Usability Scale (SUS) score of 85.19. The Igroup Presence Questionnaire (IPQ) results confirmed high immersion, particularly in Spatial Presence (M=4.12/6). Most importantly, the VR treatment group significantly outperformed the control group in knowledge acquisition, achieving an accuracy rate of 87.95 % compared to 66.41 % ($p < 0.001$). These findings suggest that expert-informed VR simulations effectively bridge the gap between theory and practical survival proficiency.
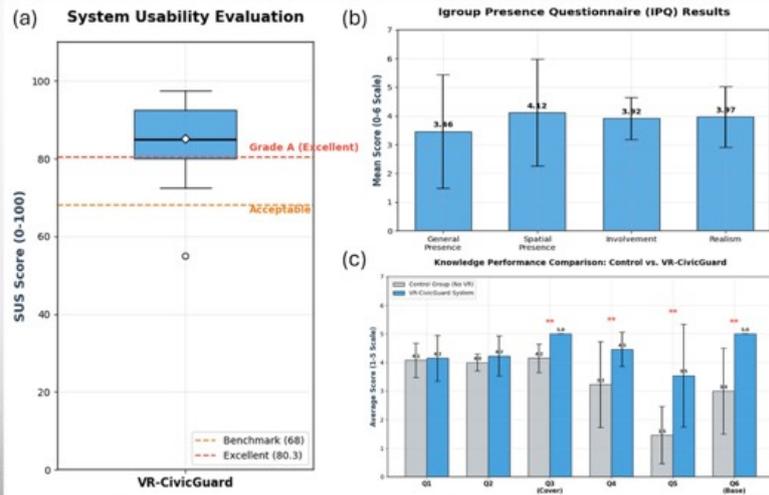

Figure 3. Evaluation results of VR-CivicGuard: (a) SUS boxplot showing excellent usability (M=85.19); (b) IPQ scores indicating high spatial presence and immersion; (c) Comparison of knowledge performance between the VR and Control groups ($p < 0.001$).

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