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Research on Virtual Scene Development and Multi-Role Collaborative Simulation Training of Post-Earthquake Natech Accidents for Undergraduate Emergency Majors

Bo Yang *, Shuaikun Ma

University of Emergency Management, School of Emergency Technology and Command, Langfang, Hebei, 065201, China
*** Corresponding author:** Bo Yang (Email: boyang@ncist.edu.cn)

Abstract: Technical accidents triggered by natural disasters—such as gas leaks and explosions in buildings following an earthquake—are characterized by sudden onset, distinct chain reactions, a narrow response window, and high demands for coordination. They serve as crucial scenario resources for undergraduate students in emergency management to understand the risks of compound disasters and mechanisms for multi-agency coordinated response. In response to the requirements for the finalization of the project "Research on the Construction of a Practical Training System for Undergraduate Emergency Management Students Based on Typical Accident and Disaster Virtual Scenarios," this paper focuses on post-earthquake Na-tech accidents in buildings. By integrating accident case studies, virtual reality technology, and emergency response plan teaching requirements, it develops a practical teaching plan comprising "accident chain analysis—virtual scenario modeling—multi-role collaborative drills—data recording and evaluation feedback." The study first maps out the chain reaction process involving seismic disturbances, building damage, gas pipeline failure, gas accumulation and leakage, and subsequent explosions and fires; second, it uses Unity 3D to construct virtual scenario resources, including post-earthquake buildings, hazard sources, rescue forces, and interactive triggers; third, it establishes roles such as commanders, search-and-rescue personnel, medical responders, public security and traffic police, and domain experts, forming a collaborative drill process that includes task assignment, execution feedback, consultation and adjustment, and debriefing and optimization; Finally, the study analyzed the scenario's value in supporting the project's final deliverables from the perspective of the "Four Categories, Five Levels, and 4R Phases" framework. Research indicates that this approach can transform static, text-based contingency plans into dynamic, interactive, and recordable practical teaching processes. While reducing the risks and costs associated with high-risk scenario drills, it enhances students' understanding of accident chain mechanisms, emergency response plans, job responsibilities, and collaborative rescue procedures. It can serve as a key component of the virtual scenario case library for typical accidents within the practical teaching system for undergraduate emergency response programs.

Keywords: Na-tech Incident; Post-Earthquake Buildings; Virtual Reality; Practical Instruction; Multi-Role Collaboration.

1. Introduction

A Na-tech incident refers to a compound disaster event in which natural disasters—such as earthquakes, floods, and typhoons—trigger failures in technical systems, which in turn lead to technical accidents such as fires, explosions, leaks, and the spread of toxic substances. Compared to single natural disasters or single industrial safety accidents, Na-tech incidents [1]are characterized by long trigger chains, strong coupling of disaster elements, rapid risk propagation, and complex emergency response requirements. Post-earthquake gas explosions in buildings are a relatively typical type of Na-tech accident in urban environments [2]. Earthquakes can cause structural damage to buildings, deformation of underground pipelines, loosening of valves, and gas leaks. If inspection, security measures, ventilation, valve shutdown, and evacuation are not carried out in a timely manner, leaked gas may accumulate in enclosed or semi-enclosed spaces. Upon contact with an open flame or an electrical spark, an explosion may occur, leading to secondary structural damage and casualties[3].

From the perspective of emergency management and practical training, the challenge in responding to post-earthquake Na-tech incidents [4]in buildings lies not in individual response techniques, but in the continuous assessment and multi-agency coordination across different stages of the incident chain. In the early stages of an incident, it is necessary to rapidly complete post-earthquake inspections, locate hazard sources[5], and identify risks to personnel; as the incident progresses, it is necessary to establish security perimeters and containment zones, conduct gas detection, shut off valves and seal leaks, extinguish fires and cool down affected areas, and carry out search and rescue operations; once the incident is under control, on-site assessments, medical evacuations, restoration of transportation, and post-incident debriefings and optimization must be conducted. Traditional emergency drills often rely on physical venues and scripted procedures; while these help familiarize personnel with their job responsibilities, they fall short in terms of simulating high-risk incidents, demonstrating dynamic risks[6], facilitating multi-role interactions, and recording process data[7].

The project "Research on the Construction of an Undergraduate Practical Training System for Emergency Response Based on Virtual Scenarios of Typical Accidents and Disasters" proposes establishing a "four-category, five-tier" virtual simulation-based practical teaching system for typical accidents and disasters, centered on academic specializations such as emergency technology and management, emergency management, disaster prevention and mitigation science and engineering, and data science and big data technology (emergency informatization)[8-10]. It

also aims to align practical instruction with the four components of the 4R crisis management theory: Reduction, Readiness, Response, and Recovery. The post-earthquake Na-tech building incident involves not only natural disaster triggers but also gas facility failures, explosions, fires, and coordinated rescue operations, effectively demonstrating the project's characteristics of complex disaster scenarios, virtual simulation development, and multi-role collaborative drills.

Based on this, this paper builds upon previous research on VR visualization drills for post-earthquake Na-tech accidents in buildings and further restructures the approach from the perspective of supporting project completion. It transforms accident simulations and rescue drill designs into typical virtual scenario resources for undergraduate practical training in emergency response. The focus of the research is no longer limited to "how to build the system," but rather extends to addressing how these virtual scenarios can serve the project's research objectives, how they can be integrated into course practical components, how they can support the assessment of students' practical skills, and how they can be developed into replicable outcomes for project completion[11-15].

2. Project Orientation and Research Framework

2.1. Project Completion Requirements and Scenario Definition

The development of virtual scenarios for typical accidents and disasters serves as a key vehicle for building a practical training system. The goal is not merely to produce a number of 3D scenes for demonstration, but to establish a comprehensive teaching system comprising "resource modules—competency levels—emergency response phases—curriculum application—evaluation and feedback." The post-earthquake Na-tech building accident scenario is highly representative within this system: on the one hand, it falls under the category of secondary and derivative risks from natural disasters—a focus of the Disaster Prevention and Mitigation Science and Engineering program; on the other hand, it involves gas safety, equipment application, and on-site response in emergency technology and management, as well as contingency planning, command and dispatch, and collaborative drills in the Emergency Management program.

Therefore, this paper identifies the post-earthquake Na-tech accident scenario in buildings as one of the core scenarios in the project's "Repository of Case Studies and Models for Typical Accidents and Disasters." This scenario supports five levels of application: basic training, course experiments, comprehensive design, professional skills training, and competition innovation. In the basic training phase, it is used to develop an understanding of accident chains; in the course experiment phase, for operating virtual platforms; in the comprehensive design phase, for translating contingency plans into practical procedures; in the professional skills training phase, for multi-role collaborative drills; and in the competition innovation phase, for scenario expansion, model optimization, and the design of evaluation metrics.

2.2. Research Framework

The research framework of this paper is shown in Figure 1. The overall approach begins with project requirements and uses a post-earthquake Na-tech accident in a building as a typical scenario, focusing on four key aspects: accident mechanisms, scenario resources, multi-role drills, and evaluation feedback. First, through literature and case studies, the accident chain is identified to clarify the logical relationships among seismic disturbances, building damage, gas leaks, explosions and fires, and emergency response; Second, the accident chain is transformed into virtual scenario resources, including the spatial environment, disaster effects, rescue forces, task triggers, and data logging; third, a multi-role collaboration process is designed to simulate the division of tasks and information feedback among command, search and rescue, medical, traffic police, and expert teams; finally, educational applications, evaluation metrics, and supporting materials for project completion are developed.

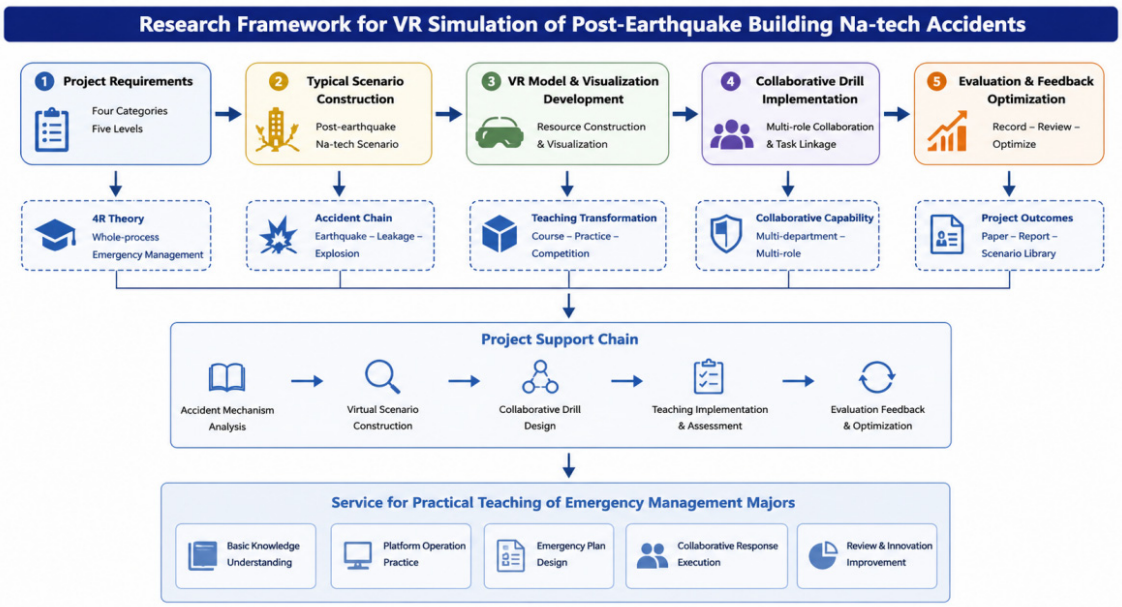


Fig 1. A Project-Oriented Research Framework for Virtual Scenarios of Post-Earthquake Buildings Using Na-tech.

Table 1. Correspondence between the Na-tech scenario of post-earthquake buildings and the project goals.

Project Requirements	Corresponding Content	Output Formats	Supporting Role
Accident & Disaster Scenarios	Post-quake gas leak/explosion Natech scenarios	Scenario cases, accident chains, model resources	Supports scenario & model libraries
"4-Category" Practical Resources	Disaster mitigation, emergency mgmt & tech, IT cross-application	Course-task mapping table	Supports specialty group resource sharing
"5-Level" Ability Training	Basic cognition, course experiments, comprehensive design, professional drills, innovative expansion	Practical task chains	Supports progressive training models
4R Stage Division	Reduction, Readiness, Response, Recovery	4R task mapping	Supports full-process emergency teaching
Evaluation & Feedback	Process records, role evaluation, review & improvement	Evaluation index system	Supports teaching effect validation

3. Analysis of the Na-tech Accident Chain in Post-Earthquake Structures and Its Application in Education

3.1. Characteristics of Typical Cases

The Na-tech accident at the post-earthquake building was not caused by a single failure, but rather was the result of the combined effects of natural disaster disturbances, inherent defects in the facilities, gaps in daily management, and delays in emergency response. Take the “August 13” post-earthquake gas explosion in Gaomi, Shandong, as an example: seismic disturbances exerted external impacts on aging gas pipelines, while hidden hazards—such as substandard pipe wall thickness, insufficient clearance from sewage pipes, and tree root intrusion—reduced the technical system’s resistance to disturbances. After the earthquake, the company failed to conduct comprehensive inspections, and potential leaks were not detected in a timely manner, ultimately leading to gas accumulation and an explosion. Although the triggering conditions differed in cases such as the “June 13” gas explosion in Shiyan, Hubei; the “July 16” liquefied hydrocarbon fire and explosion at Shida Technology in Rizhao; and the “December 3” gas explosion at Jingri Dongda in Beijing, they all reflect common issues such as facility vulnerability, confined spaces, inadequate inspection and maintenance, and failure to properly fulfill primary responsibilities.

From an educational perspective, the value of case studies lies not in simply recounting the sequence of events, but in transforming the causes, hidden hazards, and chain of responsibility outlined in accident investigation reports into scenario-based tasks that students can understand and apply. For example, pipeline wall thickness failing to meet standards can be transformed into the identification of vulnerable facilities; the absence of post-earthquake inspections can be transformed into uncompleted inspection tasks; confined spaces can be transformed into areas prone to gas accumulation; and poor interdepartmental coordination can be transformed into delayed task feedback. Through this transformation, typical case studies can evolve from classroom text materials into practical resources that can be practiced and evaluated.

3.2. Mapping the Accident Chain to the 4R Stages

Post-earthquake Na-tech incidents in buildings can be divided into five consecutive stages. The first is seismic triggering, manifested by ground shaking, soil displacement, and structural vibrations; the second is structural damage, manifested by cracks in walls, damage to beam-column joints, localized collapse, or deformation of ancillary facilities; the third is failure of technical systems, manifested by damage to gas pipelines, valves, connections, or storage devices; fourth is the leakage and accumulation of hazardous substances, manifested as rising gas concentrations, poor ventilation, and the presence of ignition sources; fifth is the occurrence and spread of secondary accidents, manifested as explosion shock waves, fire spread, people trapped, and the spread of toxic fumes. If effective measures are taken at any critical stage—such as post-earthquake inspections, concentration monitoring, valve shutdowns, cordoning off the area and evacuation, and fire suppression and cooling—the accident chain can be interrupted.

By aligning the accident chain with the 4R crisis management theory, a clearer framework for teaching objectives can be established. The Reduction phase emphasizes risk mitigation, with key tasks including the renovation of aging pipelines, inspections for potential hazards in gas facilities, and verification of safety distances; the Readiness phase emphasizes preventive preparedness, with key tasks including the development of contingency plans, the establishment of post-earthquake inspection protocols, the pre-positioning of emergency resources, and training exercises; The Response phase emphasizes emergency response, with key tasks including assessing emergency calls, establishing security perimeters and evacuating the area, shutting off valves and sealing leaks, firefighting, search and rescue, and medical transport; the Recovery phase emphasizes recovery and reconstruction, with key tasks including on-site assessment, incident debriefing, revision of emergency plans, and restoration of resources.

4. Virtual Scene Resource Construction and Visualization Plan Conversion

4.1. Composition of Scene Resources

The core of virtual scene construction lies in integrating accident progression models, spatial environments, and rescue missions into an interactive system. This paper uses Unity 3D as the primary development environment and focuses on constructing six types of resources related to post-earthquake gas explosions in buildings: spatial environments,

disaster phenomena, character objects, emergency response procedures, interaction triggers, and data logging.

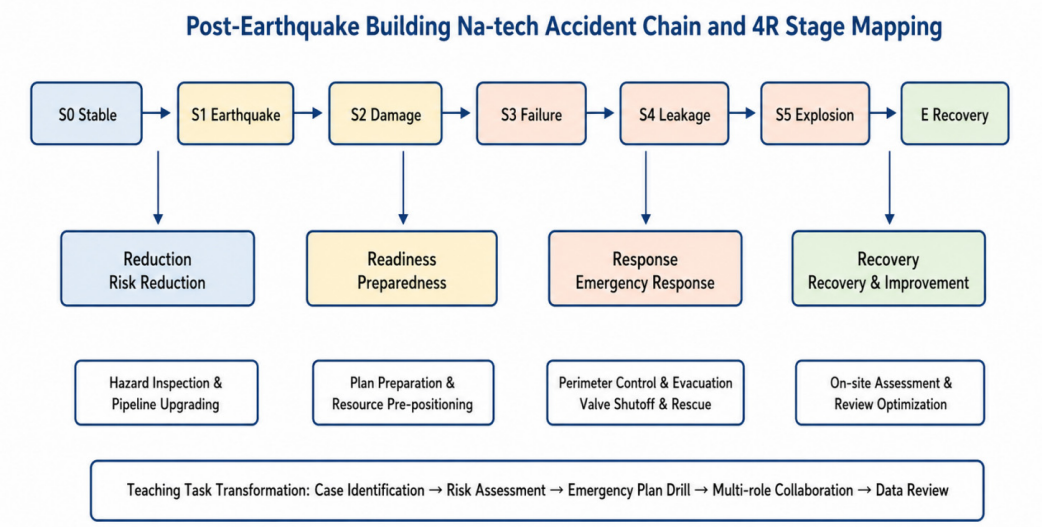


Fig 2. Mapping of the Na-tech Accident Chain in Post-Earthquake Structures to the 4R Stages.

Table 2. Accident Chain - 4R Stages - Mapping Table of Teaching Tasks.

Accident Phase	4R Stage	Virtual Scenario Presentation	Student Task	Capability Goal
Pre-quake hazards	Reduction	Aging pipelines, confined spaces, hazard tagging	Identify risk points	Risk identification
Earthquake trigger	Readiness	Building shaking, cracks, warning alerts	Activate emergency plans	Response readiness
Gas leak	Response	Leak points, concentration zones, danger boundaries	Detection, valve shutoff, cordoning	On-site disposal
Explosion & fire	Response	Blast shockwaves, flames, smoke, trapped personnel	Firefighting, SAR, medical evacuation	Collaborative rescue
Accident control	Recovery	Site cleanup, damage assessment, data playback	Review & debrief, revise contingency plans	Summary & improvement

The spatial environment includes post-earthquake buildings, surrounding roads, residential areas, gas valves, temporary medical stations, and rescue assembly areas; disaster phenomena include building cracks, leak points, smoke, flames, the epicenter of the explosion, and the boundaries of the danger zone; character objects include commanders, search-and-rescue personnel, medical responders, public security and traffic police, and domain experts; emergency response procedures include receiving the alarm, assessment, response, handling, and recovery; Interaction triggers include task prompts, route guidance, status feedback, and action buttons; data logging includes timestamps, task status, collaboration feedback, and evaluation results.

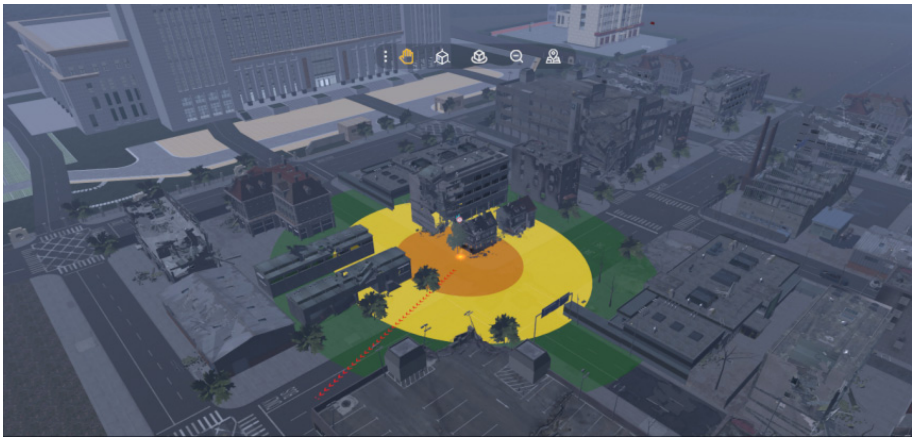


Fig 3. Virtual scene rendering of the Na-tech accident in the aftermath of the earthquake for building construction.

This paper does not view virtual scenarios as mere displays of 3D models, but rather emphasizes the correspondence between "accident mechanisms—scenario elements—rescue operations." For example, the gas leak point should be linked to the location of the pipeline rupture, the position of the valve, and the areas of structural damage; the delineation of the danger zone should be linked to the extent of the leak, ignition sources, and the distribution of personnel; and rescue routes should be linked to road conditions, cordoned-off areas, and temporary first-aid stations. Through these correspondences, students can understand the risk rationale behind each operation within the scenario, rather than mechanically

executing preset actions.

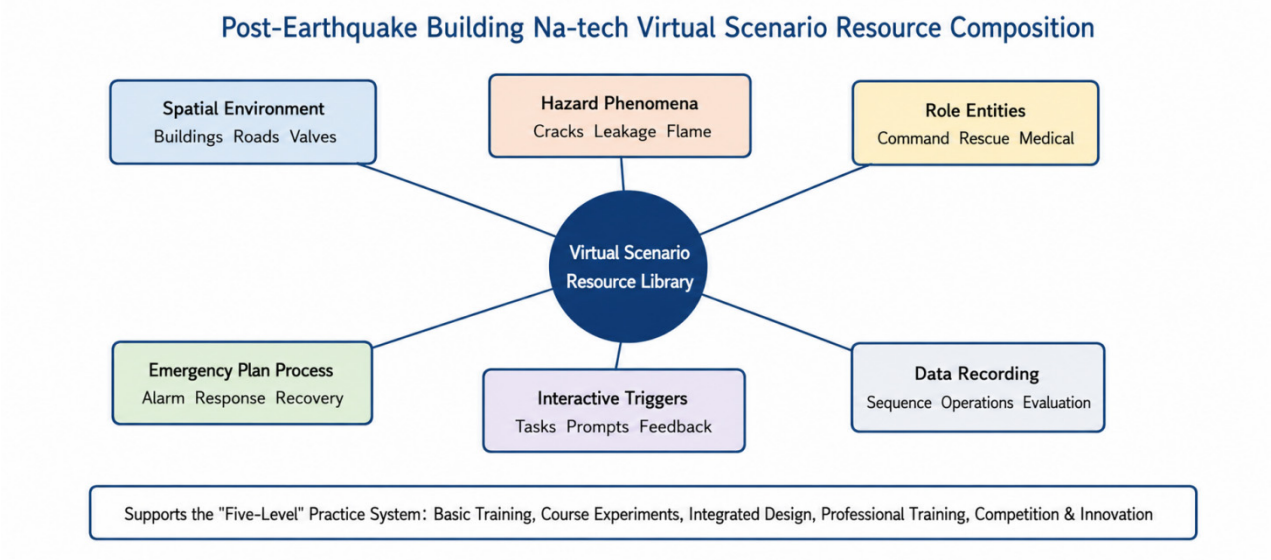


Fig 4. Composition of Na-tech Virtual Scene Resources for Post-Earthquake Buildings

Table 3. Virtual Scenario Resource Module and Teaching Function.

Resource Module	Main Content	Teaching Function	Corresponding Course Phase
Spatial Environment	Buildings, roads, residential areas, valves	Build on-site spatial cognition	Basic training
Disaster Phenomenon	Cracks, leaks, flames, smoke	Understand accident chain evolution	Course experiments
Role Objects	Command, SAR, medical, traffic police, experts	Train post/role responsibilities	Professional skills training
Contingency Workflow	Alarm receipt, response, disposal, recovery	Convert written contingency plans	Comprehensive design
Data Records	Time, operations, feedback, evaluation	Support review & improvement	Competition innovation

4.2. Visualization of Contingency Plan Conversion

Traditional written contingency plans typically cover accident reporting, response activation, resource allocation, on-site handling, medical assistance, information reporting, and post-incident recovery. However, during training and drills, issues such as overly abstract procedures, unclear role responsibilities, and difficulty in determining the proper sequence of actions often arise. This paper breaks down written contingency plans into five categories of elements—"event, role, task, trigger condition, and feedback result"—and maps them onto virtual scenarios. The commander's tasks include receiving and assessing the emergency call, activating the response plan, allocating resources, and adjusting the response strategy; search and rescue personnel are responsible for entering the scene, detecting gas leaks, shutting off valves, and rescuing trapped individuals; public security traffic police are tasked with establishing a cordoned-off area, closing roads, and ensuring rescue access routes remain open; medical personnel are responsible for triaging injuries and transporting patients; and subject matter experts are responsible for risk assessment and providing technical recommendations.

When designing visual emergency response plans, it is important to consider the sequence and constraints between different tasks. Gas leak response cannot simply follow a linear process of "detection—fire suppression—rescue"; instead, it must be dynamically adjusted based on the leak concentration, ignition sources, personnel locations, and ventilation conditions. If the leak area has not yet been fully inspected, entering it prematurely or using non-explosion-proof equipment may exacerbate the incident; if the cordoned-off area has not been fully established, a large gathering of people may increase the risk of secondary injuries. Therefore, the simulation system should restrict unreasonable operations through measures such as task locking, risk alerts, and feedback confirmation, and guide participants to complete the response in accordance with the logic of the contingency plan.

5. Design of Multi-Role Collaborative Exercises

Effective emergency response emphasizes unified command, division of responsibilities, and coordinated action. The response to a Na-tech accident in a post-earthquake building involves multiple stages, including disaster assessment, hazard control, search and rescue, medical aid, traffic control, and expert consultation; no single role can accomplish this independently. Therefore, this paper outlines a multi-role coordinated rescue drill process, categorizing participants into five groups: commanders, search and rescue personnel, medical personnel, public security and traffic police, and domain experts. Within a unified scenario, each role receives tasks, carries out operations, and reports feedback, engaging in continuous interaction through the platform.



Fig 5. Multi-role coordination rescue drill effect diagram.

The drill process is divided into four phases. The first phase is task assignment, during which the system provides the accident background, earthquake intensity, building damage, leakage risks, and initial personnel distribution, and the commander assigns tasks based on the situational map. The second phase is execution and feedback, where search and rescue personnel enter the hazardous area to conduct gas detection, shut off valves, extinguish fires, and search for and rescue people, while experts assess the risk of gas dispersion based on detection data, and the commander dynamically adjusts response resources. The third phase is consultation and adjustment: traffic police cordon off the hazardous area and maintain rescue access routes, while medical personnel set up temporary first-aid stations and triage the injured; all roles provide timely feedback on changes in risk. The fourth phase is debriefing and evaluation: the system records task completion status and key timelines, and participants conduct a debriefing focusing on response duration, information transmission, operational standards, and coordination effectiveness.

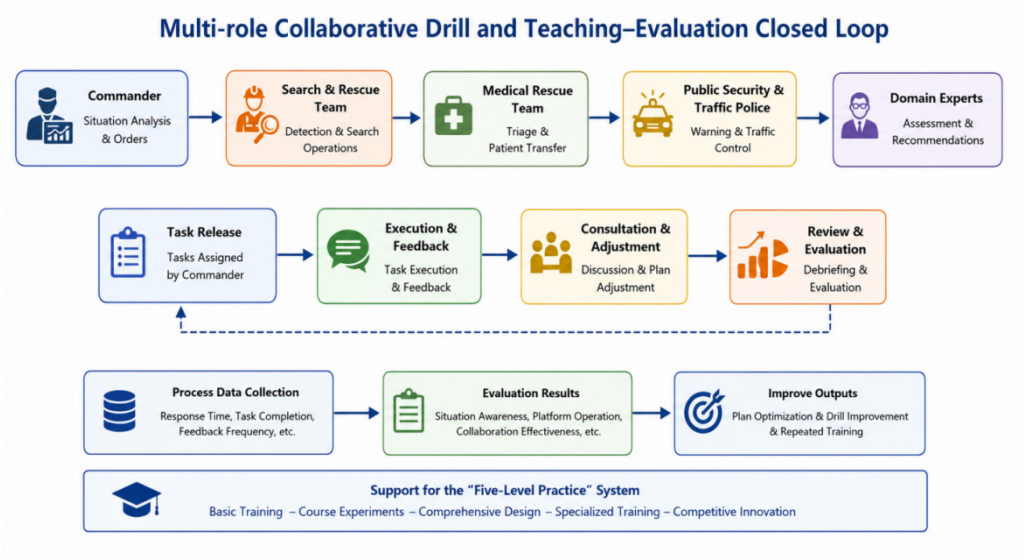


Fig 6. Multi-Role Collaborative Drills and a Closed-Loop Teaching Evaluation System.

Table 4. Multi-role Collaborative Rescue Task Matrix.

Role	Main Responsibility	Key Tasks	Collaborative Partners	Evaluation Focus
Commander	Unified command	Situation assessment, task allocation	All roles	Rationality of decision-making
SAR Personnel	On-site disposal	Detection, valve shutoff, SAR, firefighting	Command, medical	Standardisation of operations
Medical Rescue	Triage & evacuation	Injury triage, first aid, medical transfer	SAR, traffic police	Timeliness of rescue care
Police & Traffic	Cordon & traffic control	Set up cordons, maintain open channels	Command, SAR	Effectiveness of control
Domain Experts	Technical assessment	Risk assessment, plan optimization	Command, technical staff	Feasibility of suggestions

6. Teaching Implementation and Evaluation Feedback

6.1. Ways to Integrate Emergency-Related Practical Training into Undergraduate Curricula

This virtual scenario can be integrated into multiple practical teaching components of undergraduate emergency response courses. During the course introduction phase, instructors use typical accident case studies and accident chain diagrams to help students understand the complexity of Na-tech accidents; During the platform operation phase, students use the VR scenario to identify structural damage, leak points, danger zones, and rescue resources; during the contingency plan design phase, students convert written contingency plans into role-based tasks and drill scripts; during the collaborative drill phase, students assume different roles to carry out command, search and rescue, medical care, security, and expert consultation; during the debriefing and evaluation phase, the system generates reports on task completion and process records, and instructors organize

students to analyze the rationality of the contingency plan, the efficiency of collaboration, and the sequence of response actions.

Compared to the "Four-Category Classification" practical resource module of the project, this scenario offers strong cross-disciplinary adaptability. For students majoring in Emergency Technology and Management, it can be used for training in gas accident response, equipment deployment, and on-site safety techniques; for those majoring in Emergency Management, it can be used for training in contingency plan development, response grading, and resource dispatch; for students majoring in Science and Engineering of Disaster Prevention and Mitigation, it can be used for training in the analysis of secondary disaster chains caused by earthquakes and risk assessment; and for students majoring in Data Science and Big Data Technology (Emergency Informatization), it can be used for training in scenario data management, situational visualization, and exercise record analysis.

Table 5. Correspondence Table between Course Practical Sections and Ability Cultivation.

Practical Level	Teaching Content	Scenario Tasks	Capability Goal	Evaluation Materials
Basic training	Case cognition	Identify accident chains & hazards	Risk awareness	Classroom Q&A
Course experiments	Platform operations	Call up scenarios, tag risk zones	Platform application	Lab records
Comprehensive design	Contingency conversion	Design role tasks & workflows	Scheme design	Drill scripts
Professional training	Collaborative drills	Multi-role disposal & feedback	Emergency disposal	Process records
Competition innovation	Scenario expansion	Optimize models & evaluation indexes	Innovative application	Achievement display

6.2. Design of Evaluation Metrics

The evaluation system should take both process and results into account. Process evaluation focuses on whether participants have completed tasks at each stage as required, while outcome evaluation focuses on whether the incident was effectively controlled, personnel were safely evacuated, security measures were appropriate, and information was shared in a timely manner. To support the demonstration of practical teaching effectiveness during project completion, this paper suggests establishing evaluation indicators based on five dimensions: scenario recognition, platform operation, response execution, collaborative communication, and debriefing and improvement. This indicator system is applicable not only to practical teaching in higher education but can also serve as a reference for gas safety training and local emergency drills.

It should be noted that the exercises and validation in this paper primarily rely on virtual scenario simulations, process verification, and expert consultations, and have not yet yielded quantitative experimental results based on a large-scale sample of participants. Therefore, the relevant evaluations remain limited to validity analyses at the levels of plan validation and educational application. In the future, data from multiple cohorts of students or emergency responders could be collected to compare the effects of different training methods on response speed, task completion rates, and the quality of coordination, thereby enhancing the reliability of the evaluation results.

Table 6. Visualized Drill Evaluation Index System.

Primary Indicator	Evaluation Content	Evaluation Method	Suggested Weight
Scenario Cognition	Identification of hazards, accident chains & risk zones	Q&A & tagging	20%
Platform Operation	Role movement, task reception, status feedback	Process records	15%
Disposal & Execution	Detection, valve shutoff, firefighting, SAR, medical evacuation	Task completion	30%
Collaboration & Comm	Command transmission, info feedback, consultation & adjustment	Multi-role peer assessment	20%
Review & Improvement	Problem analysis, plan optimization, report writing	Debriefing report	15%

7. Significance and Value

This paper is not only a technical application paper focusing on Na-tech accidents in post-earthquake buildings, but can also serve as supporting material for typical achievements in the final report of an educational reform project. First, the paper clearly defines a core scenario that can be incorporated into the project's "Repository of Case Studies and Models for Typical Accidents and Virtual Disaster Scenarios," namely, the scenario of a gas leak and explosion in a post-earthquake building. This scenario exhibits typical characteristics such as being triggered by a natural disaster, technical system failure, the spread of secondary disasters, and multi-agency rescue coordination, thereby embodying the essence of the project's "Virtual Scenarios for Typical Accidents and Disasters."

The paper links the development of this scenario to the "four-category" academic specializations, ensuring that the scenario resources serve not just a single course but a cluster of courses across specializations such as Emergency Technology and Management, Emergency Management, Science and Engineering of Disaster Prevention and Mitigation, and Emergency Information Technology. Through this approach, scenario resources are transformed from the output of a single graduation project into shared teaching resources for a cluster of majors, meeting the project's requirements for openness, sharing, and widespread application.

The paper integrates virtual drills with the "five-tier" practical skills development framework, dividing student competency development into five stages: foundational training, course experiments, comprehensive design, professional skills training, and competition-based innovation. This forms a practical task chain that can be incorporated into both the main body and appendices of the report. This task chain helps the final project report demonstrate that the project outcomes are not merely technical demonstrations, but practical teaching achievements with a clear logic of instructional organization and competency development.

The thesis embeds the 4R crisis management theory into the incident chain and drill process, ensuring that scenario-based teaching covers the entire process of risk reduction, prevention and preparedness, emergency response, and recovery and improvement. This approach aligns with the design requirements in the project proposal—which called for constructing practical teaching phases based on the 4R theory—and also strengthens the thesis's relevance to the project and its value in supporting the project's completion.

8. Discussion

The value of this paper lies primarily in three aspects. First, it combines the chain reaction mechanism of post-earthquake Na-tech accidents in buildings with the construction of VR simulation scenarios, thereby preventing virtual scenarios from focusing solely on visual presentation while neglecting the underlying accident mechanisms. Second, it transforms traditional text-based emergency response plans into visual, interactive, and recordable task workflows, shifting emergency response training from "reading the plan" to "applying the plan." Third, it introduces the concept of multi-role collaboration into virtual drills, strengthening task coordination among command, search and rescue, medical, traffic police, and expert teams, and providing an organizational approach for emergency response training in complex incidents that more closely mirrors real-world scenarios.

In terms of practical application, this solution can serve three scenarios. First, practical teaching for emergency response majors at universities. Students can use virtual scenarios to understand the mechanisms of Na-tech accidents, contingency plan procedures, and job responsibilities, addressing the limitation of classroom instruction in which high-risk scenarios are difficult to replicate. Second, training for gas companies and urban operations and maintenance units. The system can be used for specialized training in post-earthquake inspections, valve shutdowns and leak containment, on-site security cordoning, and public evacuation. Third, drills and simulations for local emergency management departments. Through multi-role collaboration processes, the system can test the suitability of emergency response plans, coordination mechanisms, and resource allocation schemes.

However, the research still has limitations. First, current scenarios primarily focus on gas explosions, with insufficient coverage of other Na-tech incidents such as hazardous chemical leaks, power failures, and water pipeline ruptures. Second, disaster evolution within the scenarios remains dominated by rule-based triggers and visual representations; there is room for improvement in coupling with refined models of fluid diffusion, structural damage, and explosion shock waves. Third, support from practical training data is still needed for multi-user concurrency, intelligent role behavior, and the calibration of evaluation metric weights. In the future, the system's dynamic simulation capabilities and realism can be enhanced by integrating digital twins, AI agents, and multi-source sensor data.

9. Conclusion

This paper focuses on post-earthquake Na-tech accidents involving gas explosions in buildings. To meet the needs of undergraduate practical training in emergency response and the completion of educational reform projects, it proposes a virtual reality-based accident simulation and multi-role collaborative rescue visualization drill plan. Research indicates that post-earthquake Na-tech accidents in buildings exhibit distinct chain-reaction characteristics, with key processes including earthquake triggering, building damage, facility failure, gas leaks, explosions and fires, and emergency response. Translating this accident chain into a virtual scenario helps enhance students' and participants' intuitive understanding of complex disaster risks.

The Unity 3D-based scene-building method integrates the building environment, hazard sources, rescue resources, role-based tasks, and contingency plan procedures into a unified interactive space, addressing the lack of dynamism and visualization inherent in traditional text-based contingency plans. By assigning roles such as commanders, search-and-rescue personnel, medical responders, public security and traffic police, and domain experts, a collaborative closed-loop system can be established that encompasses task assignment, execution feedback, consultation and adjustment, and post-exercise debriefing and optimization, thereby enhancing the organization and educational value of the drills.

Overall, the visualization-based drill solution proposed in this paper is characterized by safety and controllability, low cost, ease of organization, the ability to review and analyze results, and scalability. It can serve as a representative scenario outcome within the project "Research on the Construction of an Emergency Response Undergraduate Practical Training System Based on Virtual Scenarios of Typical Accidents and Disasters," supporting the scenario case library, model library, practical teaching evaluation system, and final thesis outcomes. Future research should further expand the range of Na-tech accident scenarios, strengthen the coupling between physical models and real-time rendering, refine the exercise data collection and evaluation metrics system, and promote the development of virtual simulation exercises toward digital twin, intelligent, and combat-ready capabilities.

References

[1] Pilone, E., Demichela, M., & Camuncoli, G. (2022). Na-Tech risk: A new challenge for local planners. Chemical Engineering Transactions, 90, 223–228.

[2] Zhang, S., Xu, D., Shen, G., et al. (2020). Numerical simulation of Na-Tech cascading disasters in a large oil depot. International Journal of Environmental Research and Public Health, 17(22), 8620. https://doi.org/10.3390/ijerph17228620.

[3] Bahamid, A., & Mohd Ibrahim, A. (2022). A review on crowd analysis of evacuation and abnormality detection based on machine learning systems. Neural Computing and Applications, 34(24), 21641–21655. https://doi.org/10.1007/s00521-022-07594-4.

[4] Brignone, M., Santamato, F., Ravina, M., et al. (2025). NaTech database and methodologies for its risk assessment: A review.

Natural Hazards, 121(17), 19565–19590. https://doi.org/10. 1007/ s11069-025-07698-9.

[5] Butnariu, M., & Bonciu, E. (2022). Assessment of some hazards associated with dangerous chemicals. In Environmental biotechnology (pp. 1–37). Apple Academic Press.

[6] Marzo, E., Busini, V., & Rota, R. (2015). Definition of a short-cut methodology for assessing the vulnerability of a territory in natural–technological risk estimation. Reliability Engineering & System Safety, 134, 92–97. https://doi.org/10.1016/j. ress. 2014. 10.008.

[7] Lan, M., Gardoni, P., Weng, W., et al. (2024). Modeling the evolution of industrial accidents triggered by natural disasters using dynamic graphs: A case study of typhoon-induced domino accidents in storage tank areas. Reliability Engineering & System Safety, 241, 109656. https://doi.org/ 10.1016/ j.ress. 2024. 109656.

[8] Cha, M., Han, S., Lee, J., et al. (2012). A virtual reality based fire training simulator integrated with fire dynamics data. Fire Safety Journal, 50, 12–24. https://doi.org/10. 1016/j. firesaf. 2012. 04.003.

[9] Wen, Z., Li, J., & Wang, Z. X. (2024). Research on urban disaster emergency management mechanisms and rapid response system construction. Journal of Environmental and Building Engineering, 1(2).

[10] Yu, G., Shi, L., Wang, Y., et al. (2023). A collaborative emergency drill system for urban tunnels using BIM and an agent-based model. Sustainability, 15(18), 13533. https:// doi. org/ 10.3390/su151813533.

[11] Thakur, C. (n.d.). Regulatory frameworks for natural hazard risk management in industries. In Navigating natural hazards risk assessment management: Enhancing disaster resilience through risk analysis and IIoT innovations (p. 237).

[12] Antonioni, G., Bonvicini, S., Spadoni, G., et al. (2009). Development of a framework for the risk assessment of Na-Tech accidental events. Reliability Engineering & System Safety, 94(9), 1442–1450. https://doi.org/10. 1016/j.ress. 2009. 04. 005

[13] Petrova, E., & Bostenaru Dan, M. (2020). Preface: Natural hazard impacts on technological systems and infrastructures. Natural Hazards and Earth System Sciences, 20(10), 2627–2631. https://doi.org/10.5194/nhess-20-2627-2020

[14] Marzo, E., Busini, V., & Rota, R. (2015). Definition of a short-cut methodology for assessing the vulnerability of a territory in natural–technological risk estimation. Reliability Engineering & System Safety, 134, 92–97. https://doi.org/10.1016/ j.ress. 2014. 10.008

[15] Petrova, E. (2008). Natural hazards as pre-conditions of technological disasters in Russia. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 2(4), 250–258. https://doi.org/10.1080/17495180802327751.