



Usability Evaluation of a Virtual Reality Simulation System for Earthquake Preparedness Using the System Usability Scale Method

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Abstract

This study aims to evaluate the usability level of the Virtual Reality (VR) simulation system for earthquake preparedness training at the Environmental Agency of East Java Province using the System Usability Scale (SUS) method. The testing was conducted with nine respondents who performed two task scenarios in the simulation and subsequently completed the SUS questionnaire. The analysis covered three main aspects of usability: effectiveness, efficiency, and user satisfaction. The results showed an effectiveness level of 100% (“Highly Effective” category), an average efficiency of 0.01758 goals/second (“Very Fast” category), and an average SUS score of 73.88, which falls into the “Acceptable” category with an adjective rating of “Good.” These findings demonstrate that the VR simulation has strategic potential as an effective and efficient interactive training medium for improving the understanding of earthquake evacuation procedures. Nevertheless, improvements are needed in interface consistency and in reducing the initial learning curve to optimize the user experience.

Introduction

Earthquakes are natural events caused by the shifting or collision of tectonic plates, fault activity, volcanic activity, or rock collapse, resulting in vibrations on the Earth's surface. These events are destructive and have the potential to cause significant impacts, including damage to infrastructure and loss of life. Indonesia, located in the Pacific Ring of Fire, is among the countries most vulnerable to earthquakes worldwide. This geological phenomenon is sudden and difficult to predict, as evidenced by data from the Meteorology, Climatology, and Geophysics Agency (BMKG), which recorded that East Java Province experienced an average of 28 significant earthquakes (magnitude >5 on the Richter scale) per year during the period 2018–2023. These conditions indicate that earthquakes have the potential to cause major damage and threaten human safety, making community preparedness through understanding evacuation and mitigation procedures essential to minimize impact and enable rapid and appropriate responses during disasters (Cahyo et al., 2023; Ferreira et al., 2025; Kusumastuti et al., 2022; Afrihyia et al., 2025; Khan et al., 2022; Chotib, 2024).

Conventional and interactive video-based earthquake preparedness training have several limitations that may reduce their effectiveness. In conventional training, such as lectures or simple physical simulations, the delivery of material is generally passive, making participants primarily listeners and observers without intensive direct involvement (Karkera et al., 2024; Zubair et al., 2024; Siregar, 2025; Sulashvili et al., 2024; Sagala & Cabales, 2025). This can lower information retention and practical skills, especially in emergency situations requiring

quick responses. Furthermore, conventional training is often constrained by limited resources, time, and space, preventing it from fully replicating the complexity and psychological pressure of real disasters. Meanwhile, interactive video-based training offers more engaging visualization compared to lectures, but remains largely one-way and does not provide participants with a fully interactive experience. Participants can only watch and respond to questions without truly experiencing the dynamics of a disaster situation. Both methods are limited in simulating rapidly changing field conditions, inducing stress, and requiring sudden decision-making, which reduces their effectiveness in building mental preparedness and emergency response skills (Sigar, 2025; Reale et al., 2023; Khorram-Manesh et al., 2025; Ahmadi et al., 2025).

Technological integration is increasingly applied in education and training across various fields, providing diverse options for educators (Eden et al., 2024; Alenezi et al., 2023; Kalyani, 2024; Hamzah et al., 2024). The ongoing rise in educational technology includes mobile learning (m-learning) via smartphones, augmented reality on tablets, and immersive experiences in simulation environments such as virtual reality. Virtual reality technology has been shown to positively impact skill development and improve operational efficiency. By simulating realistic work environments, VR allows professionals with limited experience to practice in safe conditions without the risk of injury or critical errors (Indarta et al., 2022; Yazdi, 2024; Kennedy et al., 2023; Yu et al., 2022).

Virtual Reality (VR) emerges as an innovative solution to bridge these gaps by creating realistic, risk-free earthquake simulation environments, thereby improving understanding of evacuation procedures (Hakim et al., 2025; Faiz et al., 2024; Torres-Agüero et al., 2025). Previous studies have extensively examined VR applications in simulating various types of natural disasters. For instance, (Editya, 2022) developed a VR-based flood disaster mitigation simulation, while (Kholis et al., 2022) studied the effects of VR simulations on disaster knowledge and preparedness among adolescents in Bugasur Kedaleman Village, Jombang Regency. Additionally, (Virgantara et al., 2022) developed VR-based disaster evacuation route simulations at Gontor Putri Campus 3. All research implementing VR-based training demonstrated higher engagement and better outcomes compared to conventional learning methods.

Despite its promising strategic potential, VR-based earthquake or other disaster preparedness training has several limitations. Although VR can provide immersive simulations close to real conditions, it requires specialized hardware and software that are relatively expensive, limiting accessibility for some institutions or individuals. Moreover, VR usage demands technical skills from both organizers and participants, which can pose challenges without adequate preliminary training (Alene et al., 2024; Mehra et al., 2025; Kent Cawley et al., 2024).

From a technical perspective, VR experiences may be constrained by graphic quality, realism level, and system responsiveness, which may not fully represent emergency situations in the field. Physical comfort is also a concern, as prolonged VR headset use can cause dizziness, nausea (motion sickness), or eye strain for some participants (Hein et al., 2023; Zielasko et al., 2024; Ramaseri Chandra et al., 2022). Additionally, VR generally focuses on pre-programmed scenarios, so unexpected variations in real-world disasters may not be entirely covered. These limitations could reduce participants' preparedness for complex and dynamic emergency situations. Operational effectiveness of VR simulations heavily depends on system usability, which encompasses three critical variables: efficiency, effectiveness, and user satisfaction. Therefore, comprehensive evaluation is a prerequisite before large-scale implementation. Previous studies, such as (Editya, 2022), have explored VR use for flood mitigation.

Usability is a measure of the extent to which a product, system, or service can be used by its users to achieve specific goals effectively, efficiently, and satisfactorily. According to ISO 9241-11, usability consists of three main aspects: effectiveness (the degree to which users achieve their tasks), efficiency (the resources, including time, used to achieve goals), and satisfaction (user comfort and acceptance of the system). Nielsen also identifies five components of usability: learnability, efficiency, memorability, errors, and satisfaction. In other words, usability emphasizes not only technical functionality but also the overall user experience in interacting with the system, enhancing comfort, productivity, and the likelihood of repeated use (Yulianti, 2024; Bawa, 2024).

The System Usability Scale (SUS) technique was chosen for this study as it is a standard tool for usability analysis. SUS provides an objective and systematically structured approach to measure the usability of a system. Its user-centered perspective ensures that evaluation results realistically reflect actual user situations. SUS offers advantages such as speed, ease of use, flexibility, and a single score that is easily interpretable.

Thus, virtual reality technology can be utilized as an interactive learning medium or simulation that provides an immersive experience, making users feel as if they are in a virtual world. VR can be used for training or orientation that requires visual illustrations for better understanding, such as Earthquake Preparedness Simulations. Furthermore, through the design and evaluation of VR-based Earthquake Preparedness Simulations, it is expected to promote high-quality education that is inclusive and equitable, while enhancing lifelong learning opportunities for all individuals.

Methods

This study employed the System Usability Scale (SUS) technique to assess usability, conducted through the completion of SUS questionnaires. The study sample consisted of nine participants who used the Virtual Reality-based Earthquake Preparedness Simulation and were asked to complete two predefined task scenarios. Upon completing the tasks, participants were instructed to fill out a questionnaire measuring their satisfaction with the simulation. The collected data were then analyzed using a quantitative approach, focusing on measurements derived from the usability evaluation results.

Effectiveness

Effectiveness analysis was conducted by measuring the users' task success rate. This metric quantifies the percentage of tasks completed accurately and fully according to predefined criteria. The purpose of this analysis is to assess the extent to which users are able to complete the assigned tasks effectively. The following presents the usability parameters that can be used to measure the success rate (Maulina, 2024).

$$SR = \left(\frac{S + (PS \times 0,5)}{T} \right) \times 100\%$$

Explanation:

SR : Success Rate

S : Success

PS : Partial Success

T : Task

The success of each task completion will subsequently be analyzed using the 1991 Research and Development Standard of the Ministry of Home Affairs as a guideline to assess the level of effectiveness (Maulina, 2024).

Table 1. Effectiveness Measurement Values

No.	Duration	Level
1.	< 40%	Very Ineffective
2.	40% - 59,99%	Ineffective
3.	69% - 79,99%	Moderately Effective
4.	≥ 80%	Very Effective

Source: Yulianti, 2024

Efficiency

Efficiency analysis aims to measure the duration required by users to successfully complete the assigned tasks, which can be expressed in minutes or seconds. The efficiency evaluation is conducted using specific usability standards that assess the time users spend completing tasks. This approach is known as Time-Based Efficiency, which is calculated using the following formula (Maulina, 2024).

$$TBE = \frac{\sum_{j=1}^R \sum_{i=j}^N \frac{n_{ij}}{t_{ij}}}{NR}$$

Explanation:

TBE : Time Based Efficiency

N : Total Number of Tasks

R : Number of Users

Where n_{ij} represents the outcome of task i by user j (with $n_{ij} = 1$ if the task is successfully completed, and $n_{ij} = 0$ if not), and t_{ij} denotes the time taken by user j to complete task i (if the task is not completed, the time is recorded until the user stops attempting it). Efficiency analysis relates to the amount of time required to complete tasks, thus reflecting the average speed or slowness of users in accomplishing the assigned tasks. This evaluation is derived from the duration of user interaction with the system, and the range of recorded durations can be described as follows.

Table 2. Time Behavior Duration Range

No.	Duration	Level
1.	1 - 5 menit	Very Fast
2.	6 - 10 menit	Fast
3.	11 – 15 menit	Slow

Source: Yulianti, 2024

User Satisfaction

User satisfaction can be analyzed through usability assessment using the System Usability Scale (SUS) questionnaire, which is administered after users complete the tasks. The SUS questionnaire consists of ten statements evaluated using a Likert scale. The Likert scale serves to measure the opinions, perceptions, or viewpoints of individuals or groups regarding a particular phenomenon. In this study, a five-point Likert scale was used, with the following ratings: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

Table 3. Likert Scale

No.	Scale	Value
1.	Strongly Disagree	1
2.	Disagree	2
3.	Neutral	3
4.	Agree	4
5	Strongly Agree	5

: Yulianti, 2024

The results of the SUS questionnaire will then be interpreted by comparing the obtained SUS scores with the applicable reference standards.

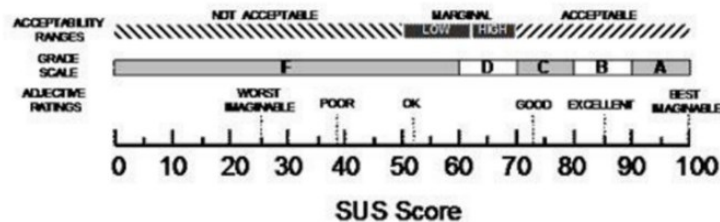


Figure 1. SUS Rating Scale

SUS scores will be presented using several evaluation standards, namely acceptability ranges, grade scale, and adjective ratings. Acceptability ranges indicate the level of user acceptance of the tested system. In the System Usability Scale (SUS), scores above 70 are categorized as acceptable, scores between 50 and 70 as marginally acceptable, and scores below 50 as not acceptable. The grade scale provides letter-based assessments, similar to the school grading system. Meanwhile, adjective ratings describe users' impressions when using the application, with the scoring scale structured like academic grading: 90–100 = A, 80–89 = B, 70–79 = C, 60–69 = D, and 0–59 = F. The adjective rating levels include Best Imaginable, Excellent, Good, OK, Poor, and Worst Imaginable, reflecting users' subjective experiences with the system (Ernawati et al., 2023).

Table 4. Adjective Ratings Levels

No.	Level	Average
7.	Best Imaginable	100
6.	Excellent	85,58
5.	Good	72.75
4.	OK	52,01
3.	Poor	39,17
2.	Awful	N/A
1.	Worst Imaginable	25

Source: Yulianti, 2024

Results and Discussion

The results and discussion of this study include effectiveness analysis, efficiency analysis, and the application of the System Usability Scale (SUS) method to measure user satisfaction. The findings will serve as a basis for expanding understanding of Virtual Reality-based Earthquake Preparedness Simulations and for improving user satisfaction with the system.

The next stage involves the development of task scenarios and the SUS questionnaire as testing instruments. The researchers designed two types of tasks with different levels of complexity: normal tasks and complex tasks. This study targets users who have never

participated in Virtual Reality-based earthquake disaster simulation training, allowing for an objective evaluation of effectiveness and learning experience.

Table 5. Task Scenario

No.	Level
1.	<p>Users access the initial interface, which displays information about potential symptoms during VR use. To proceed, users press the grip button on the controller while pointing it at the "Continue" option (1). Next, on the interface containing the "Play" or "Exit" options, users select "Play" by pressing the trigger button and pointing the controller at the option to start the simulation (2). Finally, users can navigate the evacuation route map from the starting point (2nd Floor) to the Assembly Point (Field) by pressing the grip button while pointing the controller toward the right or left arrows (3).</p>
2.	<p>The simulation consists of four sequential scenes:</p> <p>Initial Evacuation Scene (2nd Floor): Users are spawned in the 2nd Floor Room of the East Java Provincial Environmental Agency building. There are two earthquake response options: Hide under the table (correct) Run out of the building (incorrect) If the incorrect option is selected, the system displays an explanation of the mistake. Users must interact with the "Back" button to return to the starting location. The correct option (Hide under the table) must be selected and confirmed by pressing the trigger button on the controller.</p> <p>Evacuation to the Stairs: After the earthquake, users walk toward the stairs without additional interaction. They simply follow the directions indicated by the interface waypoint.</p> <p>Route Choice (1st Floor): On the 1st floor, users face two options: Exit the building toward the cafeteria (incorrect) Exit the building toward the field/assembly point (correct) The feedback mechanism is identical to Scene 1: selecting the incorrect option displays an explanation and returns the user to the previous location until the correct option is chosen.</p> <p>Simulation Completion (Assembly Point): After exiting the building, users proceed to the field/assembly point. Standing in the designated position serves as the indicator for completing the simulation.</p>

Source: Processed Data, 2025

Next, in designing the user satisfaction questionnaire, this study referred to the guidelines of the System Usability Scale (SUS). The questionnaire was developed to systematically assess the user experience and consists of ten statements representing various aspects of usability. The following table presents the list of SUS statements used as the instrument for collecting user satisfaction data.

Table 6. SUS Questionnaire

No.	Statements
1.	I think I would use this Simulation again in the future.
2.	I find this Simulation difficult to use.
3.	I find this Simulation easy to use.
4.	I would need assistance from others when using this Simulation.
5.	I feel that the features in this Simulation work well.
6.	I find many aspects of this Simulation inconsistent.
7.	I believe others would find it easy to understand how to use this Simulation.
8.	I find this Simulation confusing.
9.	I do not experience difficulty when using this Simulation.
10.	I need to familiarize myself with this Simulation before using it.

Source: Processed Data, 2025

The Data Collection

The data collection phase was conducted in a structured manner through three sequential stages: (1) an initial briefing before using the Virtual Reality device, aimed at providing an understanding of the procedures and objectives of the simulation; (2) the simulation session, in which participants performed the predefined task scenarios to evaluate their interaction and performance within the Virtual Reality environment; and (3) the completion of the System Usability Scale (SUS) questionnaire, which was used to systematically measure user satisfaction and experience. The following provides a detailed explanation of the activities carried out in each phase of the data collection process.

The Pre-Testing Briefing Session

The pre-testing briefing session for the Virtual Reality simulation serves to enhance participants' comfort and understanding of the simulation context. The briefing materials include: (1) the magnitude level of the earthquake simulated in the Earthquake Disaster Preparedness Simulation; (2) a general explanation of the Oculus Quest 2 device; (3) the control button configuration within the simulation; and (4) the interaction mechanisms with the user interface (UI) and virtual objects. This procedure helps reduce participant confusion while also increasing the validity of the testing results.

In the testing process, participants were given the opportunity to directly engage in the Virtual Reality Earthquake Preparedness Simulation until all stages were completed.

After completing the Virtual Reality simulation testing stages, all trial participants were required to fill out the System Usability Scale (SUS) questionnaire. The purpose of this questionnaire was to obtain a measurable overview of participants' perceptions regarding the level of usability of the system being tested. Through the SUS instrument, the collected data could be used to evaluate the extent to which the system met the aspects of effectiveness, efficiency, and overall user satisfaction.

Effectiveness Analysis

The effectiveness analysis was conducted based on the number of successful completions of each assigned task by the users. This analysis aims to assess the system's level of effectiveness through the task success rate indicator. The metric measures the percentage of tasks that can be completed accurately and entirely according to predetermined criteria. Therefore, the higher the success rate, the more effective the system is in supporting users to accomplish tasks. The results of this effectiveness test are presented based on the respondents' success rates in completing all structured tasks during the simulation.

Table 7. Test Results Based On Success

Respondent	Task	
	Task 1	Task 2
1	✓	✓
2	✓	✓
3	✓	✓
4	✓	✓
5	✓	✓
6	✓	✓
7	✓	✓
8	✓	✓
9	✓	✓

Subsequently, the measurement of the effectiveness level of using the Earthquake Preparedness Virtual Reality Simulation was carried out through the calculation of the Success Rate. This metric was calculated based on the percentage of tasks successfully completed by respondents in accordance with the completion criteria established in the testing protocol.

$$SR = \left(\frac{S + (PS \times 0,5)}{T} \right) \times 100\%$$

$$SR = \left(\frac{7 + (0 \times 0,5)}{7} \right) \times 100\%$$

$$SR = \left(\frac{7}{7} \right) \times 100\%$$

$$SR = 1 \times 100\%$$

$$SR = 100\%$$

Based on the measurement results, a success rate of 100% was achieved, which falls into the “Highly Effective” category. This finding demonstrates that the implementation of the Earthquake Preparedness Virtual Reality Simulation has reached an optimal level of operational effectiveness in supporting users’ mastery of disaster safety procedures.

Efficiency Analysis

In the efficiency analysis, time measurement was conducted by recording the duration required by respondents to complete structured tasks within the simulation. This method applies the Time-Based Efficiency standard, measured in seconds, where performance is calculated based on the ratio between the number of successfully completed tasks and the total completion time (in seconds).

Table 8. Test Results Based On Time

Respondent	Completion Duration (Seconds)		
	Task 1	Task 2	TBE
1	18	85	0,01942
2	22	65	0,02299
3	24	79	0,01942
4	41	91	0,01515
5	45	87	0,01515

6	26	70	0,02083
7	30	98	0,01563
8	30	81	0,01802
9	28	104	0,01515
Average Total TBE			0,01758

Based on the calculation results using the Time-Based Efficiency method, it was found that the time required by users to complete the first task was 0.03646 goals/second, while the second task was completed at 0.01253 goals/second. Accordingly, the average completion rate for all tasks was 0.01758 goals/second, which falls into the Time Behavior category at the Very Fast level. Therefore, it can be concluded that the efficiency analysis results indicate that the Earthquake Preparedness Virtual Reality Simulation demonstrates efficient performance in terms of the time required to complete the tasks.

User Satisfaction Analysis

The usability evaluation of the Earthquake Preparedness Virtual Reality Simulation involved nine respondents as the research sample. Each respondent was instructed to fully operate the simulation and subsequently provide assessments using the System Usability Scale (SUS) instrument. The following data presents a comprehensive evaluation of ten usability aspects, assessed based on the responses of all participants.

Table 9. SUS Questionnaire Recap Results

Respondent	Questionnaire Results (in Likert Scale)										Result
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
1	4	3	4	2	5	2	4	2	4	2	75
2	4	1	5	2	4	1	4	1	1	2	77,5
3	5	1	5	1	5	1	5	1	5	1	100
4	4	4	2	5	4	3	3	4	2	5	35
5	4	5	2	4	2	5	2	2	4	4	35
6	5	1	5	4	5	1	4	2	4	4	77,5
7	5	1	5	1	5	1	5	1	5	2	97,5
8	5	2	5	4	5	2	4	2	4	4	72,5
9	5	1	5	2	5	1	5	1	5	2	95
Total Result											73,88

Based on the results of the questionnaire completed by nine respondents, the System Usability Scale (SUS) score obtained had an average of 73.88. This result indicates that the user satisfaction level toward the Earthquake Preparedness Virtual Reality Simulation falls into the acceptable category, with an adjective rating of Good. However, the score is still at a grade C, indicating that users feel reasonably satisfied when using the simulation and consider the system to be fairly good in terms of usability. Overall, users feel comfortable using the system. Nevertheless, improvements in service presentation are needed to further optimize user satisfaction levels.

Based on the usability evaluation results of the Virtual Reality (VR) simulation system for earthquake disaster preparedness at the East Java Provincial Environmental Agency (DLH), the research findings were comprehensively analyzed through three critical usability variables. The following is a descriptive analysis of each aspect.

The efficiency aspect achieved an average Time-Based Efficiency (TBE) of 0.01758 goals/second, classified as "Very Fast." Task completion duration varied among respondents (Task 1: average 28.22 seconds; Task 2: average 84.44 seconds), indicating that the task flow design (waypoints, evacuation symbols) and controller-based interactions (joystick, trigger

button, and grip button) were optimized for quick navigation. Technical challenges, such as initial adjustment to VR devices, contributed to the variation in duration. However, overall, the system successfully minimized navigation confusion.

The system achieved a 100% success rate (classified as “Very Effective”). All respondents completed the tasks without critical errors, including selecting the correct mitigation actions (drop, cover, hold on), navigating the optimal evacuation route, and reaching the assembly point. This success was supported by a step-by-step scenario design that replicates DLH’s actual protocols and the high fidelity of the 3D building model, which reduced user disorientation, reinforcing Sigar’s (2025) findings on VR’s advantages over conventional training.

The System Usability Scale (SUS) score averaged 73.88 (classified as “Acceptable” with a “Good” rating). Questionnaire analysis revealed that users found the simulation easy to use and the features functioning well. However, feedback highlighted the need to improve interface consistency and address the initial learning curve, indicating the necessity to optimize the user interface to reduce confusion.

The VR simulation system meets high usability standards (ISO 9241-11) in the context of disaster preparedness training. Its combination of immersion, efficiency, and effectiveness makes it a strategic tool for enhancing preparedness in the East Java DLH environment, although technical refinements are needed for long-term optimization.

Conclusion

Based on the usability evaluation results of the Virtual Reality (VR) simulation system for earthquake disaster preparedness at the East Java Provincial Environmental Agency, it can be concluded that this system demonstrates a high level of usability across three main aspects. Efficiency is evidenced by an average Time-Based Efficiency of 0.01758 goals/second, categorized as “Very Fast,” indicating efficient performance in terms of task completion time. Effectiveness reaches a 100% success rate, classified as “Very Effective,” proving optimal operational effectiveness in supporting users’ mastery of disaster safety procedures. User Satisfaction achieved an average SUS score of 73.88 (Acceptable category with a “Good” rating), indicating that users were fairly satisfied and considered the simulation to have good usability. Overall, users felt comfortable when using this simulation, and respondents stated that Virtual Reality technology, particularly the earthquake disaster preparedness simulation, is beneficial, easy to use, and increases confidence in utilizing Virtual Reality technology in the future.

Suggestion

For future research, it is recommended that the application development include the addition of varied training scenarios, features with different earthquake intensity levels, and integration with various Virtual Reality devices to enhance the functionality, usability scope, and effectiveness of the application as a VR-based training medium. Furthermore, future studies should also involve more comprehensive usability variables, covering aspects such as errors, satisfaction, and user memorability, in order to gain a deeper understanding of the user experience and the quality of interaction with the simulation system, ultimately leading to more representative findings.

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