



Web-Based Augmented Reality for Disaster Education and Mitigation in Buleleng Regency Supporting Climate Change Action

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ABSTRACT

Buleleng Regency faces high vulnerability to natural disasters due to its diverse topography and the increasing impacts of climate change, yet public disaster literacy remains low due to conventional and less interactive educational methods. This study aims to develop a web-based Augmented Reality (AR) media to enhance disaster mitigation understanding among the community. The research employs the Research and Development (R&D) method using the Multimedia Development Life Cycle (MDLC) model, encompassing concept, design, material collecting, assembly, testing, and distribution stages. The validity test by BPBD experts showed a very high validity score (1.00) according to Gregory's formula, while user response tests using the LORI instrument indicated positive feedback on content quality and interaction ease. The application presents an interactive map, 3D disaster simulations (floods, landslides, earthquakes, whirlwinds, tsunamis), and mitigation information. The conclusion indicates that web-based AR is effective as an attractive, accessible educational medium without installation, supporting SDG point 13 regarding climate change action.

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1. INTRODUCTION

Buleleng Regency, located in the northern part of Bali Province, Indonesia, possesses a unique geographical characteristic that ranges from highlands and mountains in the south to lowlands and coastal areas in the north. With an area of approximately 1,364.73 km², it is the largest regency in Bali, making it highly susceptible to various natural hazards [1]. The combination of tropical climate conditions, high rainfall, unstable soil structures, and proximity to seismic zones creates a complex risk profile [2]. Recent data from the Regional Disaster Management Agency (BPBD) of Buleleng Regency indicate a high frequency of disaster events, with 354 incidents recorded in 2022 and 308 incidents recorded by July 2023, including floods, landslides, strong winds, extreme weather, and earthquakes [3], [4]. These frequent occurrences not only cause physical damage to infrastructure but also disrupt social and economic activities, highlighting the urgent need for effective mitigation strategies.

Despite the high frequency of disasters, the current level of disaster literacy and preparedness among the local community remains suboptimal [5]. The BPBD of Buleleng Regency has implemented various disaster risk reduction and mitigation programs, including risk assessment and mapping, infrastructure mitigation and rehabilitation, and community capacity-building through outreach, education, and training [6]. However, these efforts often rely on conventional methods such as lectures, printed brochures, and static text-based materials. According to Widayati and Husain [7], the effectiveness of such traditional educational approaches is limited, particularly among the younger generation who are more accustomed to digital and visual media. Conventional disaster education methods that rely primarily on static and text-based materials may limit audience engagement and the effective retention of critical safety information. This limitation highlights the need for more interactive and accessible educational approaches that can deliver accurate disaster-related information and support disaster preparedness. Augmented Reality (AR) offers a promising approach by enabling disaster scenarios and safety procedures to be presented through immersive and interactive visualizations, potentially improving users' understanding and engagement with disaster preparedness content [8].

The rapid advancement of digital technology offers innovative solutions to bridge this educational gap, with Augmented Reality (AR) emerging as a promising tool. AR technology integrates virtual two-dimensional or three-dimensional objects into the real-world environment in real-time, creating an immersive and interactive learning experience [9]. In the context of disaster education, AR allows users to visualize complex disaster processes, such as the mechanism of a landslide or the spread of a flood, which are difficult to comprehend through text alone [10], [11]. By providing a visual and spatial understanding of disaster dynamics, AR can significantly enhance cognitive engagement and improve the retention of mitigation procedures, making it a superior alternative to traditional media.

This research aligns with the Sustainable Development Goals (SDGs), specifically Goal 13: Climate Action, which emphasizes the need to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters. One of the key targets of SDG 13 is to improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning [12]. By developing an accessible, web-based Augmented Reality (AR) application, this study contributes directly to the achievement of global sustainability goals, particularly those related to climate action, disaster risk reduction, and inclusive education. The proposed application provides an interactive learning environment that enables users to access disaster-related educational content through AR technology without requiring specialized devices or complex software installations. By presenting information in a more visual, immersive, and engaging manner, the application can improve users' understanding of potential disaster hazards, appropriate preparedness measures, and effective response strategies. This approach is particularly relevant in the context of increasing climate-related risks, where communities require accessible and understandable information to strengthen their capacity to anticipate and respond to environmental changes and disasters.

Therefore, this study proposes the development of a web-based Augmented Reality application for disaster education and mitigation in Buleleng Regency. The choice of a web-based platform ensures broad accessibility without the need for additional software installation, allowing users to access the content via smartphones easily. This article details the development process using the Multimedia Development Life Cycle (MDLC), presents the results of expert validation and user response tests, and discusses the potential of this technology in enhancing disaster literacy and supporting climate change adaptation efforts in the region.

2. RESEARCH METHOD

This study utilizes a Research and Development (R&D) approach, which is designed to produce a new product or improve an existing one through systematic stages of development and testing. The specific model employed is the Multimedia Development Life Cycle (MDLC), which consists of six sequential phases: Concept, Design, Material Collecting, Assembly, Testing, and Distribution [13]. The MDLC model was selected due to its suitability for developing interactive multimedia applications that integrate various media elements such as 3D graphics, audio, and user interface components [14]. This structured approach ensures that the final product is not only technically functional but also pedagogically sound and user-friendly. This method is documented in Figure 1.

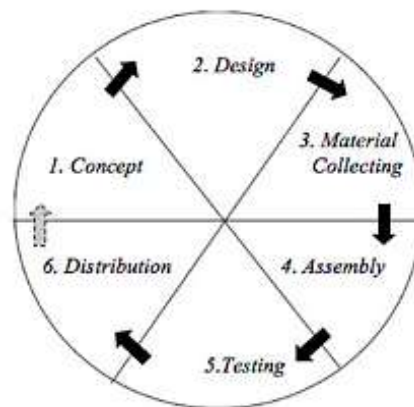


Figure 1. Multimedia Development Life Cycle

In the Concept phase, the researcher conducted a needs analysis through interviews with BPBD officials, field observations, and document studies of disaster reports. The analysis revealed a critical need for a media tool that could visually represent the dominant disasters in Buleleng, such as floods, landslides, and earthquakes. Based on this data, the concept for a web-based AR application was formulated, featuring an interactive map, 3D disaster simulations, and mitigation guidelines. The target audience was identified as the general public, with a special focus on the youth demographic, aiming to increase their understanding of disaster mitigation through visual and interactive means.

The Design phase involved the creation of system architecture and user interface (UI) prototypes. Functional modeling was performed using Use Case Diagrams and Activity Diagrams to map out user interactions, from launching the application to accessing specific simulation features [15]. The UI design was developed using Figma to create prototypes for the splash screen, main menu, disaster map, and simulation pages. Additionally, storyboards were created to plan the visual flow of the 3D animations, ensuring that the simulation of disaster events, such as the progression of a landslide, was logically structured and easy to follow.

During the Material Collecting phase, all necessary multimedia assets were gathered and prepared [16]. Three-dimensional objects for disaster simulations were modeled using Blender, including animations of soil movement, water flow, and structural damage. Graphic elements such as icons, AR markers, and backgrounds were processed using Adobe Photoshop, while audio narrations and sound effects were recorded or sourced from open libraries. All materials were validated for quality and relevance before proceeding to the assembly stage to ensure consistency in visual style and accuracy of information.

The Assembly phase involved the integration of all components into a functional web application [17]. The code was written using Visual Studio Code, utilizing JavaScript and the Three.js library for 3D rendering, and AR.js for marker tracking. The front-end interface was built using HTML and CSS based on the Figma designs. The 3D objects were imported into the system and linked to specific markers, allowing the simulations to appear in real-time when scanned by a smartphone camera.

Finally, the Testing and Distribution phases ensured the quality of the product through Blackbox testing, expert validation using Gregory's formula, and user response evaluation using the Learning Object Review Instrument (LORI), before distributing the application via a web URL and QR code [18], [19], [20].

3. RESULTS AND DISCUSSION

3.1. Development Results of AR Media

The development process resulted in a web-based application that implements Augmented Reality technology for disaster education [21], [22], [23]. The application successfully integrates five main modules: Disaster Map, Disaster Simulation, Disaster Mitigation, Developer Information, and User Guide. The Disaster Map feature displays an interactive map of Buleleng Regency with markers indicating disaster-prone

areas. The Disaster Simulation feature allows users to scan markers using their smartphone cameras to view 3D animations of floods, landslides, earthquakes, whirlwinds, and tsunamis. Table 1 below details the multimedia assets used in the development.

Table 1 . Details of Multimedia Assets in AR Development

No.	Asset Type	Description	Source/Creation	Format
1	3D Objects	Animation models of floods, landslides, earthquakes, whirlwinds, tsunamis	Self-made (Blender) & Sketchfab	.glb/.gltf
2	AR Markers	Images triggering the display of 3D objects	Self-made (Figma)	.png
3	Audio	Narrative guides and disaster sound effects	Self-recording & Freesound	.mp3
4	UI Graphics	Logos, menu icons, backgrounds, illustrations	Self-made (Photoshop/Figma)	.jpg/.png

Table 1 illustrates the components constituting the AR application, including three-dimensional visual objects, augmented reality triggers, audio elements, and graphical interfaces. The diversity of formats and sources indicates the complexity of multimedia integration required to create an immersive experience. The use of .glb/.gltf formats for 3D objects was chosen for their high compatibility with the Three.js library in a web environment, ensuring optimal rendering performance on mobile devices.

The disaster simulations are designed with specific durations and visual narratives. For instance, the landslide simulation begins with visualization of heavy rain in highlands, followed by soil sliding down due to water saturation, and ending with a large-scale landslide. This aims to provide a clear cause-and-effect understanding for users. The integration of 3D objects into the real environment via markers allows users to study disaster mechanisms from various perspectives, something difficult to achieve through conventional two-dimensional media.

3.2. Blackbox Testing and Expert Validity Results

Black-box testing was conducted to evaluate the functionality of the developed application based on several functional indicators, including the splash screen, menu navigation, marker scanning, and exit functions [24]. The results showed that all features functioned as designed without critical errors. The system was able to detect markers stably and display 3D objects and audio synchronization effectively. This proves that the technical aspects of the application met basic operational standards before being tested by experts and end-users.

Content validity was assessed by two experts from the Buleleng Regency BPBD, Mr. I Gede Mahendra (Disaster Analyst) and Mr. Yohanes Adi Saputro (Pusdalops Staff). Both experts evaluated aspects of content feasibility, visual suitability, and content presentation. Based on the assessment instrument, both experts gave a "Relevant" score (score 4) on all 8 assessment indicators. The validity calculation using Gregory's formula resulted in a value of 1.00, categorized as "Very High Content Validity."

Table 2. Gregory Method Content Validity Calculation Results

No.	Assessment Category	Number of Items	Description
1	Valid Agreement (Cell D)	8	Both experts rated as highly relevant
2	Difference of Opinion (Cell B & C)	0	No significant differences
3	Disagreement (Cell A)	0	No irrelevant ratings
Total Validity		1.00	Very High

Table 2 shows full agreement between the two experts regarding the quality of the application content. A validity value of 1.00 indicates that the disaster mitigation information presented in the AR application conforms to scientific standards and field needs. Input from experts, such as adjusting data with the latest BNPB Standard Operating Procedures, was revised to increase information accuracy.

Media experts also provided positive evaluations regarding visual aspects and interaction, although there were minor suggestions for improvement, such as adding audio to the interactive map and improving the consistency of 3D assets. These suggestions were followed up by the researcher to perfect the media quality before distribution.

3.3. User Response and Discussion

User response testing involved a sample of the general public using the LORI (Learning Object Review Instrument). The average rating results showed "Good" to "Very Good" categories in dimensions of content quality, motivation, and interaction ease. Users assessed that the 3D visual display made disaster mitigation learning more interesting and less boring than reading brochures. The ease of access via website without installation was also a plus value appreciated by respondents.

The application of AR in this context proved effective in overcoming the weaknesses of conventional education methods. Visualization of disaster processes such as tsunamis and earthquakes helps users understand the spatial and temporal dynamics of disasters. This aligns with the Reality-Virtuality Continuum theory where AR enriches reality with digital information, thereby increasing user understanding clarity [25]. Thus, this application functions not only as an information medium but also as a cognitive aid that strengthens long-term memory regarding safety procedures.

From the perspective of SDG support, this application contributes directly to goal 13 by increasing community adaptive capacity through innovative education. Web-based accessibility ensures that information can reach a wider layer of society, including those with storage limitations on their smartphones. This technological integration also encourages digital transformation in regional disaster management, opening opportunities for further development such as integrating real-time data from the BPBD disaster information system.

However, there are limitations in this study, namely dependence on internet connection for loading 3D assets for the first time and the need for sufficient lighting for marker scanning. Further development can lead to asset size optimization for offline performance and the use of markerless AR for higher flexibility. Overall, the results of this study affirm the great potential of web-based AR as a strategic solution to increase disaster literacy in disaster-prone areas like Buleleng Regency.

4. CONCLUSION

This study successfully developed an Augmented Reality (AR) based educational media through a web platform to increase disaster mitigation literacy in Buleleng Regency. Using the Multimedia Development Life Cycle (MDLC) method, the resulting application includes features such as an interactive map, 3D simulations of five dominant disaster types, and mitigation information. Test results show that the application has very high content validity (1.00) according to BPBD expert assessment and receives positive responses from users in terms of interest and ease of use. This development proves that the integration of AR technology in disaster education can overcome the limitations of conventional methods that are less interactive. Web-based applications offer high accessibility without requiring installation, making them suitable for widespread distribution to the community, especially the younger generation. The contribution of this research lies not only in the technological product but also in its tangible support for achieving SDG point 13 regarding climate change action through increased community adaptive capacity. For future research, it is recommended to develop markerless AR features so that users do not depend on printing physical markers, and to integrate real-time disaster data APIs from BPBD to automatically update risk map information. In addition, further research can measure the long-term impact of using this application on changes in community preparedness behavior through quasi-experimental methods.

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