Visualization of Volcanic Landform with Augmented Reality

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ARTICLE INFO

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ABSTRACT

Visualization of volcanic landforms with digital elevation model (DEM) data on the GIS desktop computer has limitations regarding access to the software display function and its use outside the room. This obstacle can be overcome by combining GIS and mobile augmented Reality. However, using digital elevation model data and satellite imagery in augmented reality software has not been widely explored. This study shows a practical way of integrating geospatial data with mobile augmented reality software. This research aims to create an augmented reality prototype to visualize virtual volcano objects. DEM data and satellite imagery create 3-dimensional (3D) objects and provide texture characteristics of volcanic landform objects. Visualization of volcanic landforms is done through an augmented reality (AR) application prototype on an Android smartphone. The experimental results show that augmented reality technology effortlessly combines DEM data and land features from satellite imagery. Evaluation of a smartphone device's manufacturing and installation stages shows results with a "successful" status. Through follow-up testing nine times, the AR prototype showed positive performance in all aspects of distance, angle, and lighting. The final test scenario in the form of responses regarding the application from other users obtained an average value of the "Good" category of 92.8%. In conclusion, these results indicate that the system built can be used in learning. However, further research requires more diverse test scenarios to see how far this application prototype can be used in various conditions.

INTRODUCTION

Spatial Visualization of volcanic landforms in a three-dimensional (3D) model using augmented reality (AR) technology in teaching morphology is essential for several reasons. First, the object of the volcanic landform is a location that is difficult to visit in person, so making a virtual model in the real world is necessary. Second, volcanic landforms are spatial objects with complex reliefs generally depicted with two-dimensional (2D) maps. In 2D maps, landform reliefs are presented with line features representing elevation content (contours). According to (Krüger et al., 2022), giving spatial objects in 3D will be more effective than 2D representations. Several studies also show that 3D Visualization makes it easier to understand the thing being modeled compared to the appearance of 2D objects (Akpan & Shanker, 2018; Li et al., 2023; Revolti et al., 2023). Augmented reality (AR) technology allows users to interact with virtual 3D objects that appear in the real world (Fenais et al., 2019). Another reason is the support of AR software that is easily accessible and implemented on mobile devices, thus

enabling the Visualization of objects in different ways (Freitas et al., 2020).

Meanwhile, GIS technology can represent objects on Earth through spatial data. The availability of free spatial data allows 3D models of volcanic landforms to be processed with GIS technology. Therefore, combining GIS and AR technology can provide new experiences in utilizing spatial information (Hedley, 2018).

The study of augmented Reality as a visualization tool for 3D objects has developed in various fields such as medicine, military, education, and engineering. In the medical area, (Sushereba & Militello, 2020) developed a device in the form of a virtual patient as a tool for medical students to study the patient's condition. (Wang et al., 2020) developed an AR prototype to imagine how to maintain military equipment. AR devices are also used as teaching aids that provide new student experiences, as researched (Pramono & Setiawan, 2019). The process of running the machine and its parts was displayed with an AR application by (Aziz et al., 2020). The objects visualized in these studies are limited to non-geographical things.

Geographic entities have attributes related to location. Therefore, GIS technology is needed to represent these entities in specific data formats. There are several studies involving geospatial data with Visualization using AR. For example, research by (Revolti et al., 2023) proposed AR technology to visualize water, gas, and sewage pipes in spatial data to maintain their utilization. The same is done by (Li et al., 2023), who utilize AR and spatial data to manage subsurface pipeline facilities. The use of AR technology to visualize geographic objects in learning is carried out by (Pratama et al., 2021). However, previous studies have not explored the use of remote sensing data to display virtual 3D objects on AR devices. In this study, the authors offer the service of digital spatial data in the form of a Digital Elevation Model (DEM) and high-resolution satellite images that can be obtained easily. Both data are used to build a 3D model of volcanic landforms and implemented on mobile AR devices.

This paper intends to complement previous studies based on several arguments. AR is a growing interactive design technology, allowing 3D virtual content to be integrated with the real world. The availability of easy-to-obtain GIS data is an alternative for building a representative virtual range of 3D objects. Combining these two technologies allows interactive Visualization of 3D virtual volcanic landforms in the real world. Mobile devices are the choice for implementing AR applications due to the increasing use of smartphone devices in learning. According to the Global Education Census report, as many as 42% of students worldwide use smartphones in the classroom (CAIE, 2018).

Considering the background of the previous issue, this study aims to create a 3D model of volcanic landforms and to build an AR application prototype for visualizing volcanic landforms. The 3D landform model is derived from DEM by limiting it to three volcanic feature locations. DEM data is readily available and easily obtained via an addon to the 3D graphics software, BlenderGIS (Domlysz, 2022). The 3D model of the landform becomes the input data for making AR applications. The prototype design process utilizes AR software. The form combination of spatial data with AR technology produces an AR application prototype that displays a virtual 3D volcanic landform in the real world through a smartphone device.

RESEARCH METHODS

This research can be classified as experimental research involving development and evaluation. The research framework is shown in Figure 1.
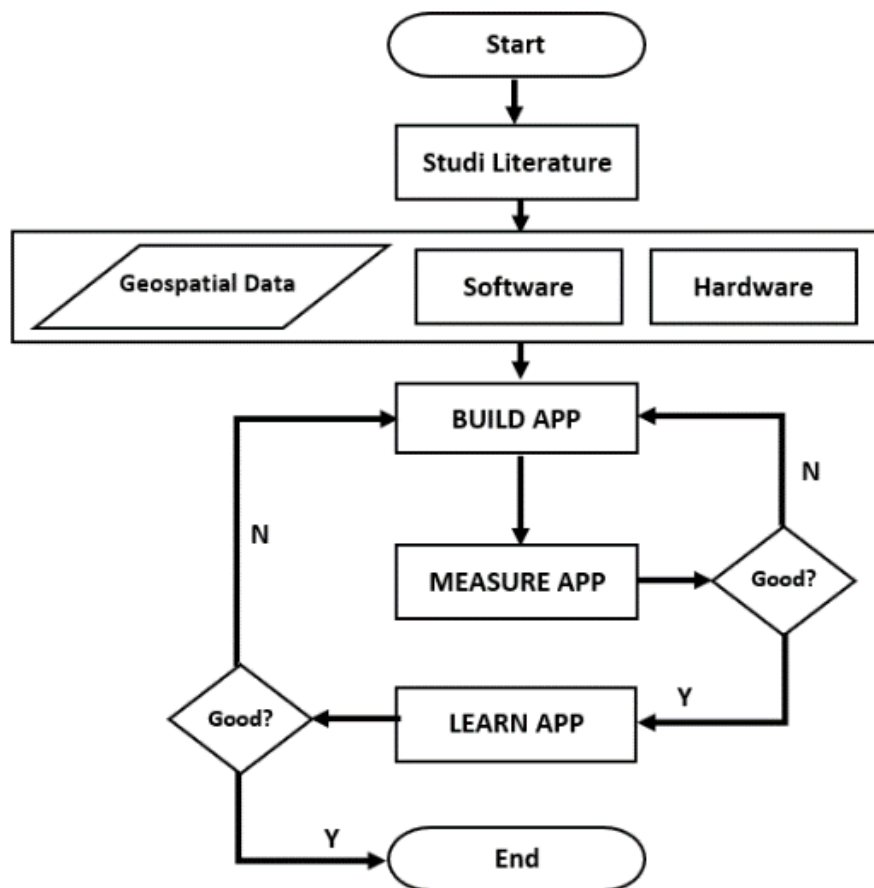
Figure 1. Research Framework (Source: Personal Documentation, 2023)

The final product was a mobile AR application developed using a prototype method, as done by (Lahay & Mohamad, 2020). The selection of this method is based on cost considerations and time to complete the research. According to (Glassman et al., 2018), manufacturing products using the prototype method is cheap, the turnaround time is fast, and it can be evaluated immediately. Therefore, this research implemented a prototype method with the Build-Measure-Learn cycle model developed by (Ries, 2015), also used by (Berry, 2019).

Data requirements, technical implementation, hardware, and software are identified early. This activity was in the form of literature studies related to AR technology through searches and online discussions. The process at the Build stage was to create a 3D model of volcanic landforms and image target (marker). The AR software implemented the technical design to produce a prototype application. The

Measurement Phase was carried out to evaluate application performance. Evaluation results became input for prototype improvement. Limited scale trials are the final stage to study user response regarding the application.

RESULTS AND DISCUSSION

A 3D visualization of volcanic landforms through an AR application on a smartphone has been created. This AR application can project 3D objects in a natural environment through smartphone devices. The exploratory process of using digital elevation models and augmented Reality consists of three aspects, namely, (1) 3D modeling of volcanic landforms, (2) Augmented Reality Applications, and (3) Testing.

3D Modeling of Volcanic Landform

Based on the literature review, making a 3D volcanic landform requires hardware, software, and data, as shown in

Table 1. (Blender, 2021) software was selected to create a 3D volcano landform. This tool is free and open-source software. It can run on the Windows 10 operating system. The Blender application interface is shown in Figure 2.

Table 1. Required Hardware and Software

No	Data/Software/Hardware	Function	Stage
1.	Digital Elevation Model	3D modeling of landforms	Build
2.	Satellite Imagery	to create object texture	Build
3.	Windows 10	operating system	Build
5.	Blender 2.83	3D graphic modeling software	Build
6.	Unity	augmented reality development tools	Build
7.	Vuforia Engine	software development kit	Build
8.	Laptop HP AMD A6-9220, Ram 8 GB	installation of operating systems and other software	Build
9.	Smartphone	application testing	Measure
10.	Lux Light Meter Pro	measuring illuminances	Measure
11.	Angle Meter	measuring angle	Measure
12.	Roll meter	measuring distance	Measure
13.	Tripod	support the camera	Measure

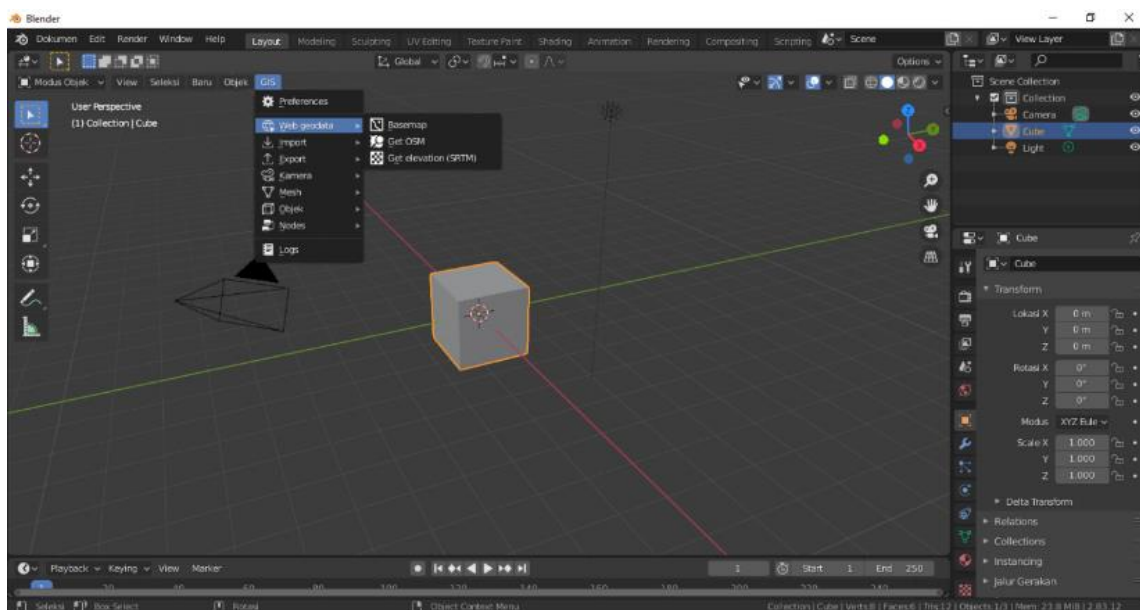(Source: Data Processing, 2023).

Figure 2. Blender interface and GIS menu (Source: Personal Documentation, 2023)

On the Blender application interface, there is a pre-installed BlenderGIS Addon. This tool has a function to import satellite imagery and other geographic data through the GIS menu. An internet connection is required to perform this task. In addition, BlenderGIS allows the creation of 3D views through digital elevation model data. Two types of digital geographic data used in this study are digital elevation models and satellite imagery. The satellite image display as a base map is shown in Figure 3.
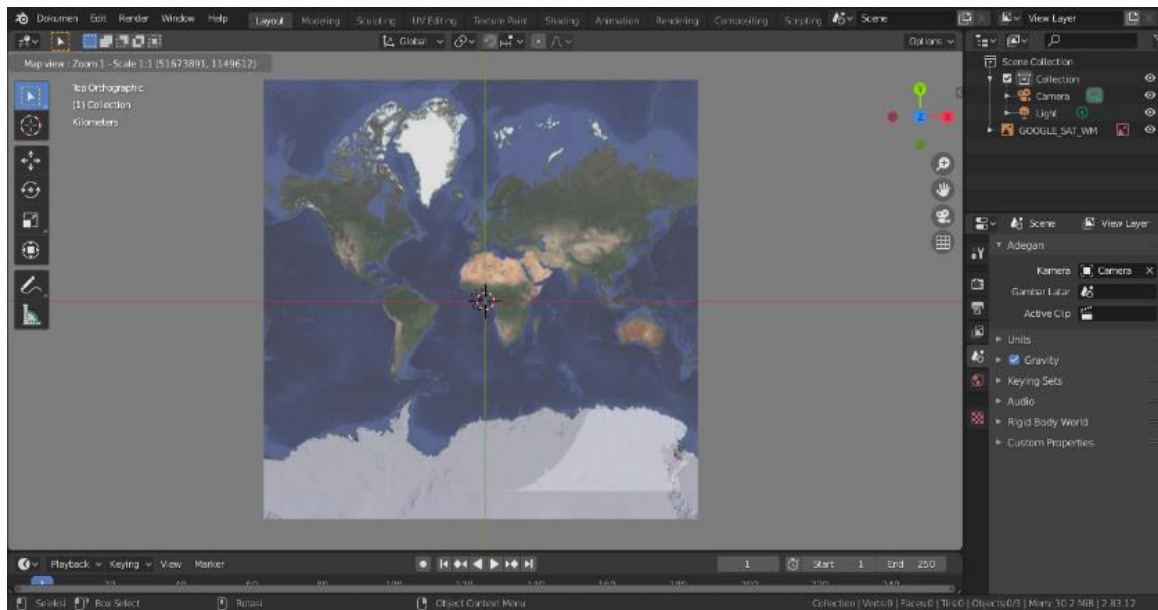
Figure 3. Satellite Image Data as a Base Map (Source: Personal Documentation, 2023).

These two data become the essential material to form a 3D object model. This satellite data is processed in the next stage according to research needs. Some processing processes are area cutting and 3D modeling of volcanic landforms. The image data processing process for one of the landforms is shown in Figure 3.

Figure 4 shows one of the 3D models of the Agung volcano landform in the Blender application. Making a 3D model of the landform begins with determining the area of the Agung volcano from the base map in Figure 3. The location is determined by zooming in (zoom in) and cutting the desired area (cropping), as shown in Figure 4a. The landform object in Figure 4a is still in the 2D model. The display settings (viewport shading) selected for the lighting mode are solid and flat textures.
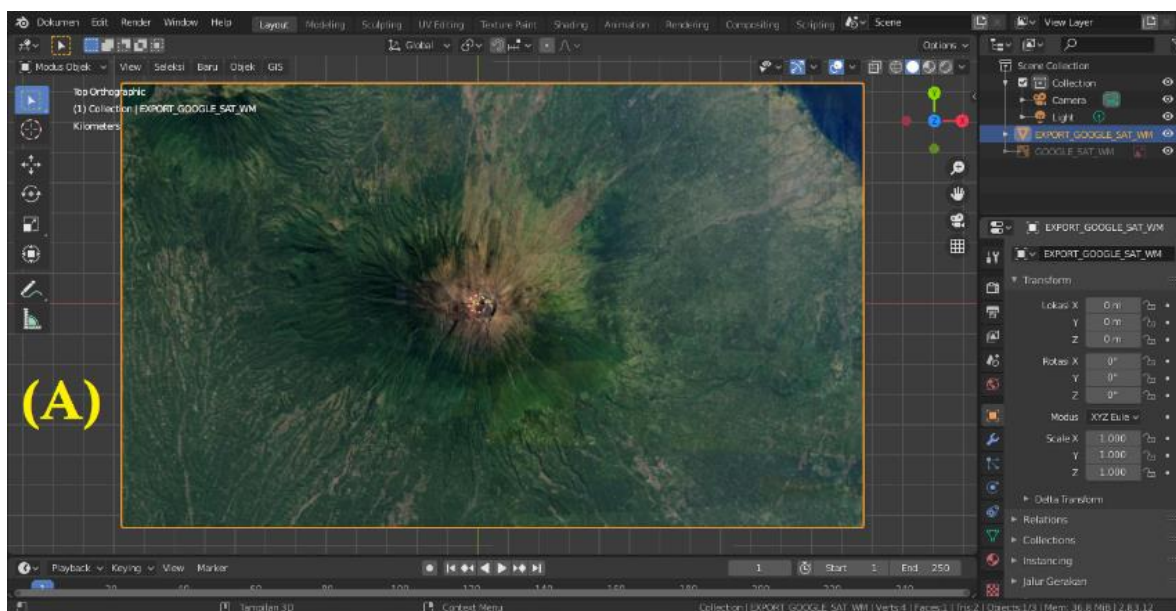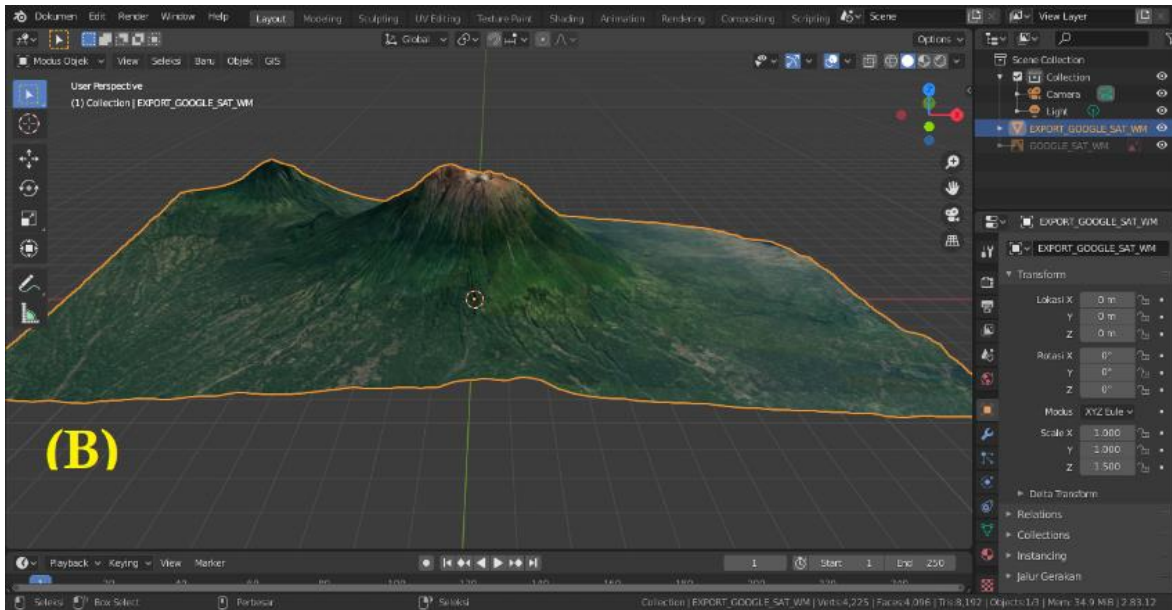
Figure 4. 3D Model Design in Blender, (a) 2D Landform Display, (b) Landform Display After Adding DEM Data (Source: Personal Documentation, 2023)

The texture appearance of the volcanic object uses satellite image data sourced from the Google Satellite service. The transformation of landform objects into 3D objects is made using 30m Shuttle Radar Topography Mission (SRTM) data. This data can be accessed on the Get Elevation (SRTM) menu in the Blender application (see Figure 2). The view of the 3D landform object is shown in Figure 4b. Files generated from Blender can be directly used in Unity applications to create AR applications.

Augmented Reality (AR) Application

Unity (Unity, 2021) and Vuforia Engine (Vuforia, 2021) were selected as software to create an AR Android application prototype for a mobile device. Both of these software programs are available online and freely accessible. As the leading platform, Unity has a supportive interface, features, and library environment for developing AR applications. Vuforia is an AR application development support package for marker recognition.
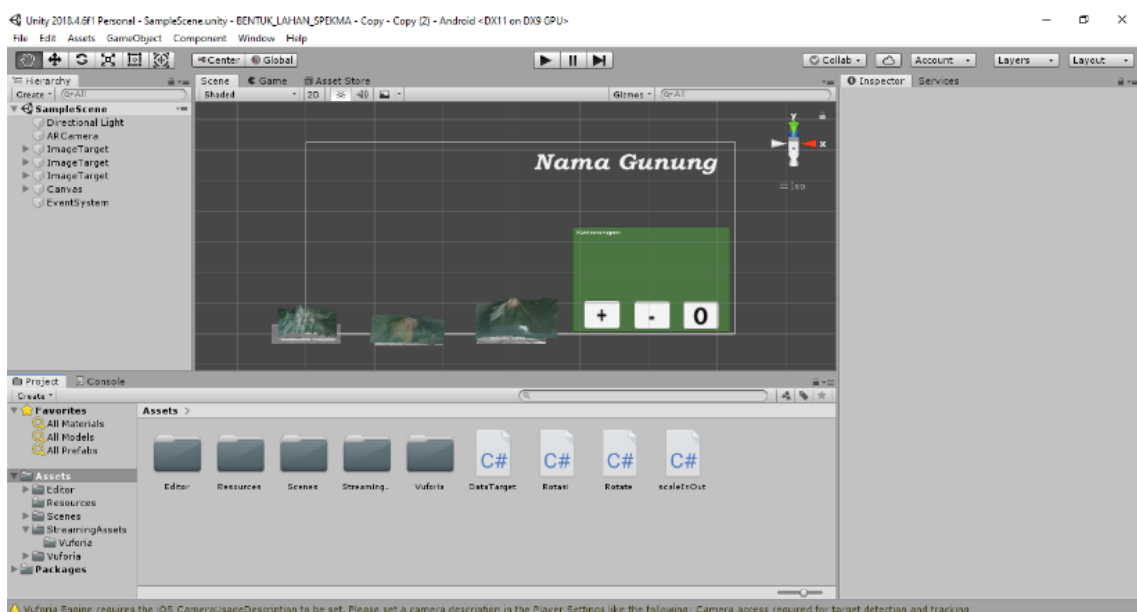

Figure 5. Volcano Landform 3D object in Unity Editor (Source: Personal Documentation, 2023)

Figure 5 shows the Unity software interface environment. This screen capture shows three landforms and markers inserted into the target image. Each landform is associated with a registered feature in the database or a License Key in the Vuporia SDK. Database creation is done through the https://developer.vuforia.com/ page. This study chose a mountain image as a marker, as shown in the image. The quality used is shown in Figure 6. The compilation result on the Unity software is a marker-based AR application with the .apk extension installed on a smartphone device.

Figure 6. Image Markers (Source: Personal Documentation, 2023)

Testing

This aspect is intended to see whether the function of the application is running as expected. If there is an error, it will be corrected immediately. The application testing stage is carried out in three steps; the first evaluation is done when making the application on a computer/laptop. Second, trial installation on one mobile device continued for several other smartphones of different types. Finally, test the app's capabilities with other users. In the first stage, the aspects tested are marker detection by the application and application package building. The test results show conformity with what is expected, as shown in Table 2.

Table 2. First-Stage Test Results

No	Testing	Scenario	Expected	Result
1	Marker Detection for Mount Agung objects	Pointing the computer camera at the marker	• Displaying 3D Objects • Displaying Text • Rotating	Succeed Succeed Succeed
2	Marker Detection for Mount Kelud objects	Pointing the computer camera at the marker	• Displaying 3D Objects • Displaying Text • Rotating	Succeed Succeed Succeed
3	Marker Detection for Mount Kerinci objects	Pointing the computer camera at the marker	• Displaying 3D Objects • Displaying Text • Rotating	Succeed Succeed Succeed
4	App Creation	Build and run the app	Android apps with an extension on the app	Succeed

(Source: Data Processing, 2023).
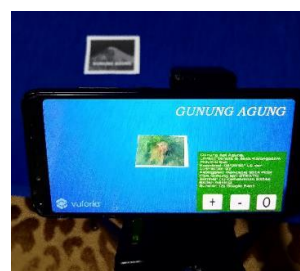
a.   b.

Figure 7. Testing on One of The Mobile Devices (Source: Personal Documentation, 2023)

The second test produced an application prototype, which was then installed on a mobile device. The trial of installing the application on one mobile device and several other types of smartphones was carried out after it was confirmed that the first trial stage was successful.

Figure 7 shows the trials carried out on one of the mobile devices. This prototype begins with a text that says "*Arahkan marker ke kamera, untuk menampilkan bentuk lahan gunung api*" as shown in Figure 7a. This condition occurs when there is no marker to be detected. If the quality is successfully seen, the system will respond by displaying a 3D volcanic landform and a description of the object being tracked (Figure 7). The text information in the green box contains a brief description of each volcanic object. This text is in the form of the object name, location, coordinates, height of the volcano, and type of volcano. In addition, in this green box area, three buttons function to zoom in (+), zoom out (-) and rotate (o). A simulation of using these buttons can be seen at the link: https://youtu.be/i6iArXh9GKU.

Testing is continued by installing the application on various smartphone devices with different Android operating system versions. The overall test results are shown in Table 3.

Table 3. Second-Stage Test Results

No.	Smartphone type	Result
1.	Xiaomi Redmi Note 8 ver. Android 10	Succeed
2.	Xiaomi Redmi 6A ver. Android 11	Succeed
3.	Oppo A53 ver. Android 10	Succeed
4.	Vivo Y91 ver. Android 8	Succeed
5.	Xiaomi Redmi 9C ver. Android 10 Q	Succeed
6.	Realme C6 ver. Android 10	Succeed
7.	Realme C33 ver. Android 12	Succeed

Source: Data Processing, 2023

The testing process did not experience any problems operating the application on the various types of smartphones. Overall, test results on mobile devices are as expected. The test status "Succeed" in Table 3 means that the application is appropriately installed on the smartphone device and can be run. Second, smartphone cameras can detect markers well, as indicated by the appearance of volcanic landforms and their text on the smartphone screen based on the detected features.

Figure 8 shows the application test results on a Xiaomi Redmi 6A Android 11 version of the smartphone type. The smartphone camera can detect the three markers and virtually display three volcanic landform objects in 3D.

Figure 8. Landform visualization on smartphones for three mountain locations
(Source: Personal Documentation, 2023)

The next stage of this second test is to create a test scenario based on the distance, angle, and lighting aspects. The test results are shown in Table 4. These three essential aspects affect application performance when detecting markers (Syahputra et al., 2020). Test scenarios

are not carried out separately for each element. However, the test is carried out by involving all three components simultaneously. Measuring the distance between objects and the smartphone camera is done with a meter roll. Aspects of the angle taken by the camera are calculated using the angle meter software.

Likewise, the state of the light when the Lux Light Meter Pro software measures shooting. The nine times test results show that the three target images were appropriately detected. In other words, the object displayed on the smartphone screen is stable and quickly seen.

Table 4. Testing Based on the Distance, Angle, and Lighting Aspects

No	Distance (cm)	Angle (degree)	Illuminance (lux)	Mount Agung	Mount Kelud	Mount Kerinci
1.	25	45	5			
2.	25	45	30			
3.	25	45	90			
4.	25	45	260			
5.	25	45	700			
6.	40	45	500			
7.	50	45	400			
8.	60	60	400			
9.	55	45	120			

(Source: Data Processing, 2023).

The final testing step is to test the application's capabilities on ten other users, namely, students of the Geography Education Study Program, Universitas Negeri Gorontalo. This process begins by explaining the AR application, its installation, and its use. After the procedure, students were asked to complete a questionnaire containing seven simple questions. Student responses to the use of AR applications are described in Table 5. The average percentage of student answers obtained in the "Good" category was calculated as 92.8%. Based on these results, this AR device is feasible and follows the intended purpose.

Table 5. Survey Results About AR Applications

No	Question	Good	Fair	Poor	Total
1	App installation	9	1	0	10
2	Application display on a smartphone	9	0	1	10
3	Ease of using the app	10	0	0	10
4	Caption text	9	0	1	10
5	Object textures	10	0	0	10
6	Object rotation	9	1	0	10
7	Marker	9	1	0	10
	Total	65	3	2	70

(Source: Data Processing, 2023).

The AR application prototype that has been made follows the purpose and has several characteristics. First, the application can virtually display 3D volcanic objects in the real world. The result is in line with the opinion of (Azuma et al., 2001) that AR applications must interactively combine virtual 3D objects in the real world, as shown in Figures 7 and 8. Second, this application is classified as AR, which uses marker techniques to display virtual objects in the real world, as stated by (Alamsyah et al., 2023) and (Remolar et al., 2021). Visualizations like this are categorized as Tangible AR (TAR) (Hedley, 2018). In this study, the virtual object of volcanic landforms was visualized in the real-world environment using a trigger in the form of image markers. The shape of the volcanic landscape seems to be present together with the natural world seen on the smartphone screen.

This application prototype was designed for smartphone devices with the Android operating system. Several previous studies have demonstrated the development of AR applications on mobile devices, such as (Al Shuaili et al., 2020; Li et al., 2023; Phon et al., 2019). Smartphone is a technological device that supports augmented Reality apart from Head-Mounted Displays (Khoong et al., 2023), Smart Glasses (Koutromanos & Kazakou, 2023), Holographic Displays (Uribe et al., 2023). The increasing number of smartphone users in Indonesia (McKinsey, 2021) is an opportunity to develop AR applications on mobile devices. This device allows every user to access applications installed on smartphones easily. In addition, the camera support that is installed by default is an advantage of mobile devices.

Several previous studies have discussed the combination of GIS and AR technology, such as (Chitaniuc & Iftene, 2018; Fenais et al., 2019; Jansen et al., 2023; Pereira et al., 2018). However, the use of geographic digital data for modeling 3D objects has not been well explored in previous studies. The topography of the Earth's surface becomes the data needed to create a 3D model of landforms. This altitude data can be obtained from remote sensing satellite recordings available foverage Two types of remote sensing data used in this study are the SRTM produced by NASA and high-resolution imagery. Using geospatialdata in AR applications combination of GIS and AR, as indicated by (Fenais et al., 2019; Jansen et al., 2023). Support for 3D graphics editor software, Blender, is required to provide and process both data. Blender was chosen by ause tevice can model volcanic landforms like actual relief conditions (Vinković et al., 2021). In addition, this software is free and open.

The present study complements the way of presenting the shape of the Earth's surface in 2D through paper maps, especially in learning. Visualization of the surface relief of volcanic landforms through paper maps generally represented using contour lines. According to (Carrera et al., 2018), understanding the surface relief depicted in 2D requires interpretation skills. The presentation of 3D objects with the help of AR can help students better understand learning content, especially spatial objects (Koparan et al., 2023). The use of 3D models becomes a tool for abstracting the surface relief. AR technology can be a solution to provide new ways of

interacting with geographic features such as volcanoes. The device can include both 2D and 3D visualizations, which means that 3D virtual objects can be displayed side by side with 2D paper maps. Scenarios of presenting the shape of the Earth's surface can be done together so that paper maps and AR applications will complement each other. In further research, the implementation of AR applications in learning needs to be tested further so that more optimal AR devices can be produced.

CONCLUSION

This study shows that 3D Visualization of volcanic landform morphology can be done through a combination of GIS, AR, and smartphone technologies. The 3D modeling process takes full advantage of the digital data of the Earth's surface, which can be obtained free of charge in the BlenderGIS modeling tool. AR tools also provide tools for building prototype AR applications that can display landform morphology in other ways. In further research, testing must be carried out so that this device can be applied optimally in learning. Adding features that make it easier for users to interact with the content is also important.

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