Simulation and Visualization of Volcanic Phenomena Using Microsoft Hololens: Case of Vulcano Island (Italy)

Ali Asgary, Costanza Bonadonna, and Corine Frischknecht

***Abstract*—This article describes an interactive holographic visualization of volcanic eruption application for Microsoft HoloLens device. The aim of the project is to use this technology to visualize different eruptive phenomena on an active volcano for public education, emergency training, preparedness planning purposes, and raising awareness among tourists. We have selected La Fossa volcano on Vulcano island (Italy) as a case study and, thus, the application is named HoloVulcano. Unity game engine and Microsoft Visual Studio were used to develop the HoloVulcano augmented/virtual reality visualization application. The current version of HoloVulcano visualizes volcanic phenomena typically associated with unrest (fumaroles) and explosive eruptions (e.g. eruptive plumes, ejection of ballistic blocks, bombs, and pyroclastic density currents). The eruption types are developed based on existing literature using Unity game engine's particle systems component. HoloVulcano is a Microsoft HoloLens device application. Wearing the HoloLens, users can interact with the application through voice, gazing, and gestures and view different volcanic phenomena from different sites and angles on the island. HoloVulcano can be used by emergency managers and teachers for training, emergency exercises, and public education.**

***Index Terms*—Holovulcano, microsoft hololens, modeling and simulation, virtual reality (VR), visualization, volcanic phenomena, Vulcano island.**

Managerial Relevance

The HoloVulcano application developed in this article allows emergency managers to visualize various possible eruption scenarios and volcanic phenomena that can be used for 1) emergency management training and exercises; 2) public education, and awareness raising. Using HoloVulcano emergency managers can better understand and examine different eruption types and their potential impacts and plan for emergency evacuation and response scenarios. Emergency managers can also use HoloVulcano as a public education and awareness raising tool to educate residents and tourists about different volcanic phenomena and possible types of eruptions of the volcano that they live nearby or visiting. Enhanced public education and awareness can influence people and tourists' behavior and subsequent actions during actual emergency situations.

I. Introduction

VISUALIZATION plays a significant role in public safety and disaster and emergency training, education, preparedness planning, and response management [1]–[3]. They provide valuable easy to comprehend information to end users that include scientists, emergency managers, students, and general public. Virtual and augmented reality visualizations and animations are one of the most recent approaches to natural and technological hazards visualization and they can be used for hazard and risk communication at various levels in the society [4]–[6]. Virtual reality (VR), augmented reality (AR), and mixed reality (MR) are some of the most recent trends in visualization technologies. AR applications allow users to see the real world with layers of digital contents. MR visualizations help users to see the real, physical world, and objects but also see and interact with virtual objects using voice, keypads, gestures, and gazing [7]. AR and MR are significant innovative concepts and applications because:

1) they provide powerful, contextual, and situated learning platforms for different types of education and training activities;
2) they enable visualization and exploration of complex real-world phenomena and the interconnections that exist between them [7];
3) they facilitate situational awareness by providing rich context aware surroundings and computing environment for decision making, operations and effective teamwork [8]–[2]–[9].

AR and MR are among the key emerging technologies for education and training in recent years. According to Mekni and Lemieux [10], they allow us to "visualize complex spatial relationships and abstract concepts, experience phenomena that is not possible in the real world, interact with two- and three-dimensional (3-D) synthetic objects in the MR, and develop important practices that cannot be developed and enacted in other technology-enhanced learning environments" (p 209).

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Moreover, the combination of the increase in the power and decrease in the size of computers has created a new era for the development of lighter and safer wearable and mobile AR and MR enabled devices [11]. As the AR and MR technologies are becoming mature and well established, more advanced and popular applications are also developed for the devices [12]. Furthermore, their usability and social acceptance are increasing, and their limitations are reduced.

AR and MR have demonstrated successful applications and specialized niches in a number of sectors, including manufacturing, public health and medicine, construction, transportation, entertainment, education, defense, and public safety and security [13]–[16]. Public safety as well as disaster and emergency management are emerging as new and growing application areas for the AR and MR technologies [6], [17]–[20]. These technologies are being developed and used in public safety and emergency management mainly to

1) enhance situational awareness for first responders and decision makers in emergency operations centers (EOCs);
2) plan for emergency response and interventions in complex systems and environments;
3) enhance emergency responders' ability to navigate in degraded visual conditions due to fire, chemical releases, and extreme weather phenomena,
4) visualize large-scale emergency scenarios for training and emergency exercises when using real-world and functional trainings are costly and unsafe, and
5) emergency public education and communication when the public can better comprehend the nature of hazards and their impacts.

Recent studies and experiments show that, for example, virtual 3-D animations that reconstruct geohazards and volcanic processes make scientific results more understandable to a wide audience [21]. End users, such as students and trainees, find virtual 3-D animations and AR visualizations as interesting and efficient tools in knowledge transfer [22]. Moreover, experience shows that knowledge transfer from scientists to the public can be enhanced using modern visualization techniques such as VR and AR, which are particularly more attractive to the new generations [22].

Volcanic eruptions have caused many disasters worldwide and a large fraction of the world population is still living in proximity to volcanic hazards [23]–[25]. Studies show that about 47 million people are living within 5 km of active volcanos. This number increases to 58 million within 10 km, 200 million within 30 km radius and more than 750 million within 100 km of about 1378 active volcanos [26]. For example, Indonesia has the largest population within 100 km of active volcanos (179 million), followed by the Philippines and Japan (approximately 100 million each, based on the 2010 population data) [26]. Many volcanic eruptions occur every year that require mass evacuation, followed by significant human, economic, and environmental impacts. According to the global disaster database EM-DAT [27], from 1900 to 2018, a total of 245 volcanic disasters have been reported worldwide with 96 306 fatalities, 11 760 injures, and 6 408 600 affected.

This article presents details of a Microsoft HoloLens application developed for simulation and visualization of volcanic phenomena that can be used for emergency management training, public education and awareness raising. The rest of this article organized as follows. Section II provides some background information about the Vulcano Island in Italy covering its volcanic history, hazards, vulnerability, and the rational for the HoloVulcano application. Section III describes the details of the HoloVulcano application development process which includes methodology and outcomes. Section IV explains some of the current and future use cases for the application. Finally, Section V concludes this article.

Fig. 1. Vulcano Island [28].

II. VULCANO ISLAND

Vulcano is one of the seven Aeolian islands in the south of Italy, with an area of about 23 km^2. It is composed of four main developed areas: Vulcanello, Porto, Lentia, and Piano (see Fig. 1). Porto is a mix of commercial, tourism, and residential activities, while Piano is the main residential place with the majority of permanent residents; Vulcano has a Carabinieri, a diesel and a solar power generation stations, three helipad facilities, one main port (Porto Lavante) and two smaller ports (Porto Ponente and Gelso) [28]. The rapid growth of the island in recent years in terms of accumulation of assets and people has increased the risks and highlighted the importance of emergency management and public education. Vulcano island, whose subaerial activity started between 135 and 120 ka years ago [29], consists of four main volcanic edifices: Vulcano Primordiale, Lentia, La Fossa cone and Vulcanello (see Fig. 1). La Fossa, a 391-m high quiescent volcanic cone, represents the most current active system on the island, which was characterized by five different activity periods [30]. The last eruption of La Fossa cone (1888–90) consisted of a long-lasting Vulcanian cycle [30] (Fig. 2). Nonetheless, subplinian eruptions have also been observed in the stratigraphic record of the last 1000 years [31], [32]. Since the last eruption of La Fossa cone, the population has no direct experience with volcanic eruptions and their associated potential hazards. Therefore, public education and awareness-raising among the permanent and temporal residents of the island (seasonal workers and tourists) are very important for risk mitigation and emergency preparedness. The application of innovative communication tools such as AR, VR, and MR could help to transfer knowledge and enhance public awareness.

Fig. 2. Eruption of the La Fossa in Vulcano 1888-1890 [56].

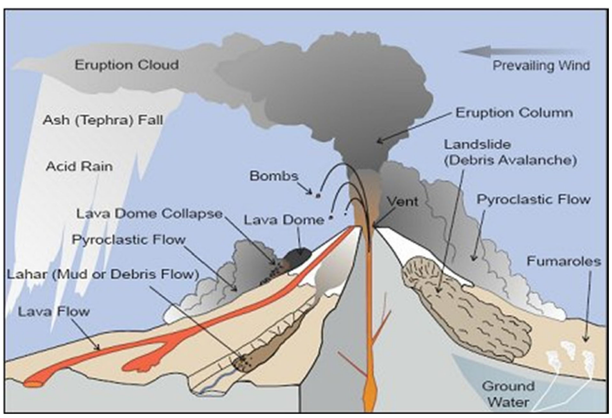

Fig. 3. Volcanic hazards [57].

Fig. 4. Background activity of the La Fossa cone.

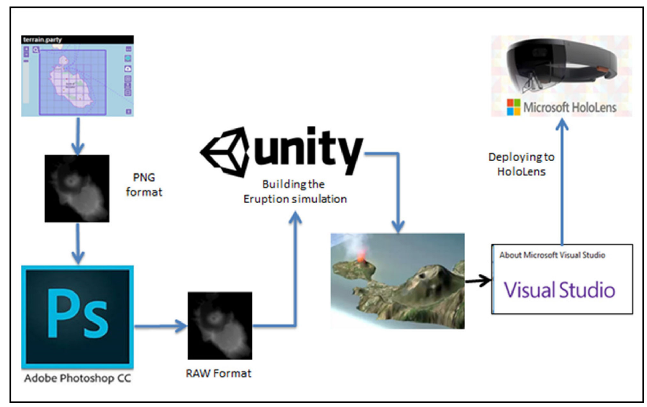

Fig. 5. Process of developing HoloVulcano.

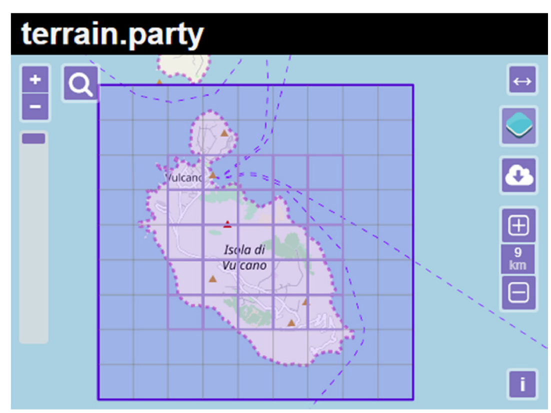

Fig. 6. Extracted elevation area from the terrain.party.

III. Volcanic Hazards and Eruption Types

A. *Volcanic Hazards*

Lava flows, ballistic projectiles, tephra falls, pyroclastic density currents (PDCs), lahars, earthquakes, ground deformation, tsunami, gases are among the key hazards associated with volcanic eruptions [33] (see Fig. 3). Some of the main hazards, especially those that are used in the HoloVulcano application are described in further details in this section.

Lava flows and PDCs are considered to have a high destructive potential [33]. Both lava-flow and PDC deposits have been observed on the island of Vulcano [30]. Tephra is the most widespread of all volcanic hazards causing variable damage to various economic sectors, eco-systems, and built environments [31], [33].

Another important hazard associated with volcanic eruptions is the ejection of ballistic projectiles (i.e. blocks and bombs). Depending on their size and temperature, ballistics can be harmful for people and cause various damages including roof perforation and fires [34].

A volcanic eruption can generate a large amount of loose unconsolidated debris, which, if mixed with water (from rainfall or melting of snow or ice), can produce lahars, which have a variable impacting potential on buildings and infrastructures [33].

B. *Eruption Types of La Fossa Cone*

HoloVulcano aims to visualize the background level observed at Vulcano, potential unrest conditions as well as several types of eruptions including short-lived Vulcanian explosions, long-lasting Vulcanian cycles, and subplinian eruptions of La Fossa volcano. The background level is the current state of La Fossa where intensive degassing is observed near La Fossa cone (see Fig. 4) and in some areas near Porto.

Unrest conditions correspond to a state where degassing, seismic activity, deformation, and temperature are higher than the background level [35], [36]. Unrest can last for a variable amount of time and may or may not lead to an eruption [37]. However, seismic activity, deformation, degassing, and secondary hazards

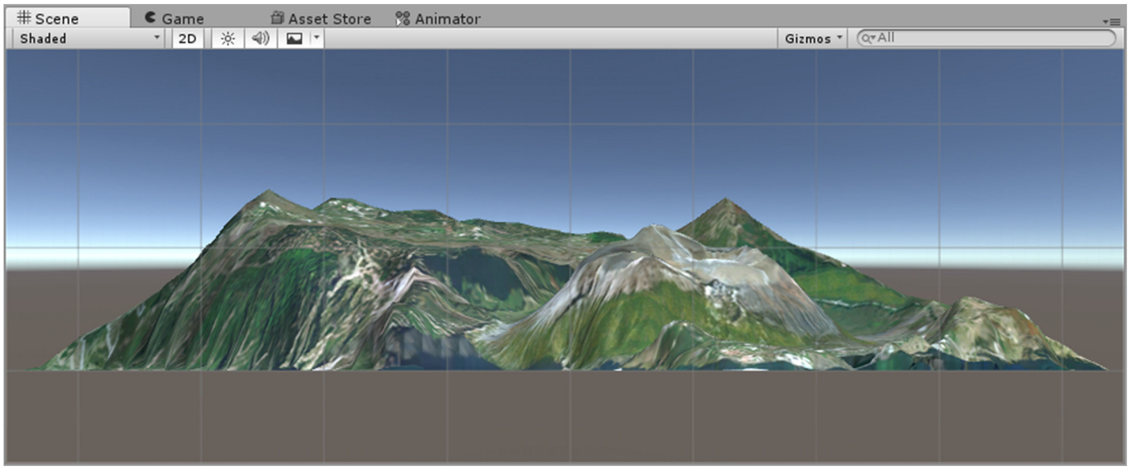

Fig. 7. 3-D model of Vulcano Island developed in Unity.

such as landslides, rockfalls, and tsunamis could be harmful to people and properties during the unrest conditions [38].

Vulcanian eruptions are transient explosions of viscous magma that typically result from the fragmentation of a plug or from the rupture of a lava dome [39]. Vulcanian explosions could occur as individual events (short-lived) or as long-lasting cycles of discrete events mostly associated with tephra dispersal, ejection of ballistic bombs and blocks and, sometimes, PDC generated by plume collapse.

Plinian and subplinian eruptions are typically larger and of longer duration than Vulcanian explosions [40]. However, similarly to Vulcanian explosions, Plinian and subplinian eruptions are associated with eruptive plumes, tephra dispersal and sedimentation, ejection of ballistic bombs and blocks and, PDCs but of larger extent.

IV. Application Development

La Fossa cone on Vulcano island has been chosen as a case study to develop the HoloVulcano application because it is an active volcano with the potential to erupt again and affect local population even in the case of an unrest phase [36]. However, the selected unrest phase and eruption types have no relation to potential future eruptions and are only using to demonstrate the capability of the HoloVulcano application (Vulcanian explosion, subplinian, and effusive eruptions). Fig. 5 shows the overall process of developing the HoloVulcano application for Microsoft HoloLens.

Terrain Party (www.terrain.party) was used to extract the elevation data for Vulcano Island. Terrain Party allows users to extract elevation data in PNG format that can be used for 3-D terrain modeling (see Fig. 6). TrainParty uses a number of sources for the elevation data including ASTER (30-m resolution), Scankort Denmark DTM (1.6-m resolution), SRTM3 v4.1 (30-m resolution), SRTM30+ (900-m resolution), and USGS NED (10-m resolution). It also generates a merged dataset, consisting of ASTER (30 m), USGS NED (10 m), and SRTM (30 m). We used the merged elevation output that blends the three images.

The terrain party output needs to be converted to RAW format to be used for terrain modeling in the Unity Game Engine. Adobe photoshop was employed to convert the PNG elevation data from Terrain Party to the RAW format. The RAW elevation file was then imported and added to a terrain object in unity to make the 3-D model of the Vulcano Island. The terrain model can be textured using existing satellite imagery or unity's texture editing tools. In this version of HoloVulcano, a google map satellite image that is produced by Digital Globe in 2018 was used to texture the 3-D terrain model (see Fig. 7).

Unrest phase and eruption types were then defined and added to the 3-D model using various tools in the unity and third-party unity assets that were imported to the unity. For the most parts, unity's particle system component was used to simulate and visualize different eruption types. This system is capable of 3-D and realistic simulation of many types of dynamic natural (e.g., waterfall, rainfall, fog, etc.), biology, and technological phenomena (e.g., building and forest fire, smoke, etc.) [41]–[42]–[43], [44], [45].

Particle system is basically a technique in computer simulation and graphics that uses many very small sprites, 3-D models, or other graphic objects to simulate complex systems, natural phenomena, or processes that are difficult to create with conventional rendering methods [46]. Using a particle system, it is possible to create and destroy a desired number of particles, change their size, color, velocity, density, shape, gravity, noise, emissions, etc. Most of these parameters can take random values between two constants or random values between the two curves. Because particles can be influenced by the effects of gravity and winds, they are widely used for simulating many natural phenomena.

Fig. 8 shows the visualization of background conditions at La Fossa. Unity particle system was used to visualize normal degassing (i.e., fumaroles with background level degassing).

The unrest state is an extension of the background condition with higher emission rates of fumaroles (see Fig. 9).

Fig. 10 shows an eruptive plume associated with a Vulcanian explosion (i.e., a mixture of gas and tephra rising in the atmosphere). Snapshots of the subplinian eruption are shown in

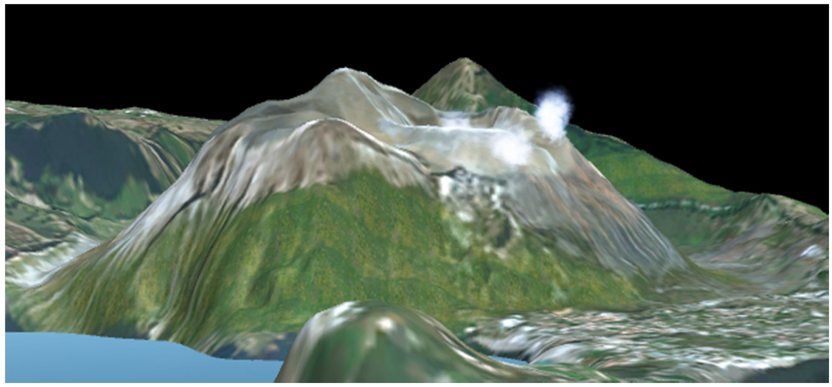

Fig. 8. Visualization of background activity of La Fossa cone (i.e., fumaroles with background intensity).

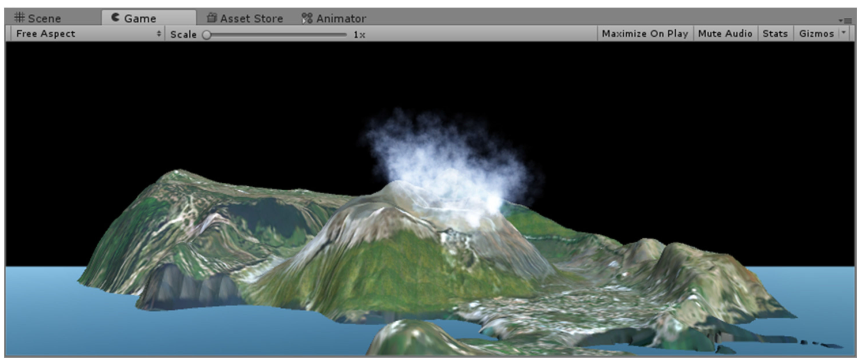

Fig. 9. Visualization of unrest state of La Fossa (the text on the top right is the menu. Users can use voice to navigate in the application and choose desired types).

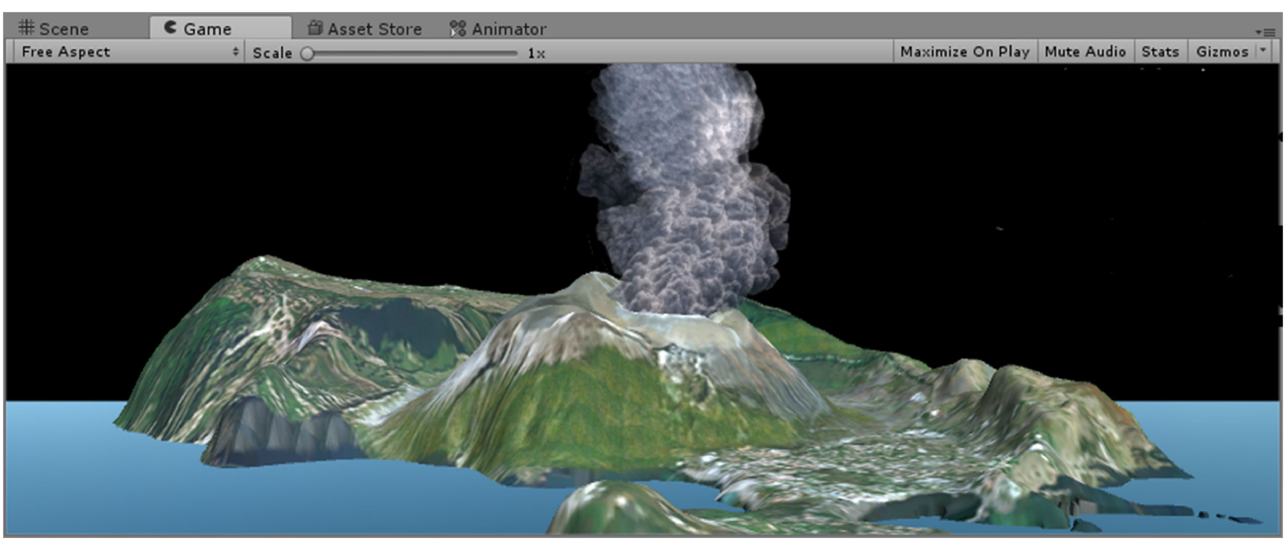

Fig. 10. Simulation and visualization of a short-lived Vulcanian eruption of La Fossa characterize by an eruptive plume.

Fig. 11. They include visualizations of PDCs, tephra fallout, and ballistic projectiles.

HoloVulcano also has the capability to visualize lava flows. As an example, Fig. 12 shows a lava flow at La Fossa cone associated with an effusive eruption.

Users can navigate in the application and interact with the HoloVulcano using voice and air taps. A menu helps users to select eruption types and desired viewing location (from north, east, south, west, top, etc.). Users can also use voice command to move backward, forward, left, and right and observe the volcano from different points.

The visualization application built in the unity environment is then opened in Microsoft Visual Studio to build and deploy the application in Microsoft Hololens device. Hololens is a

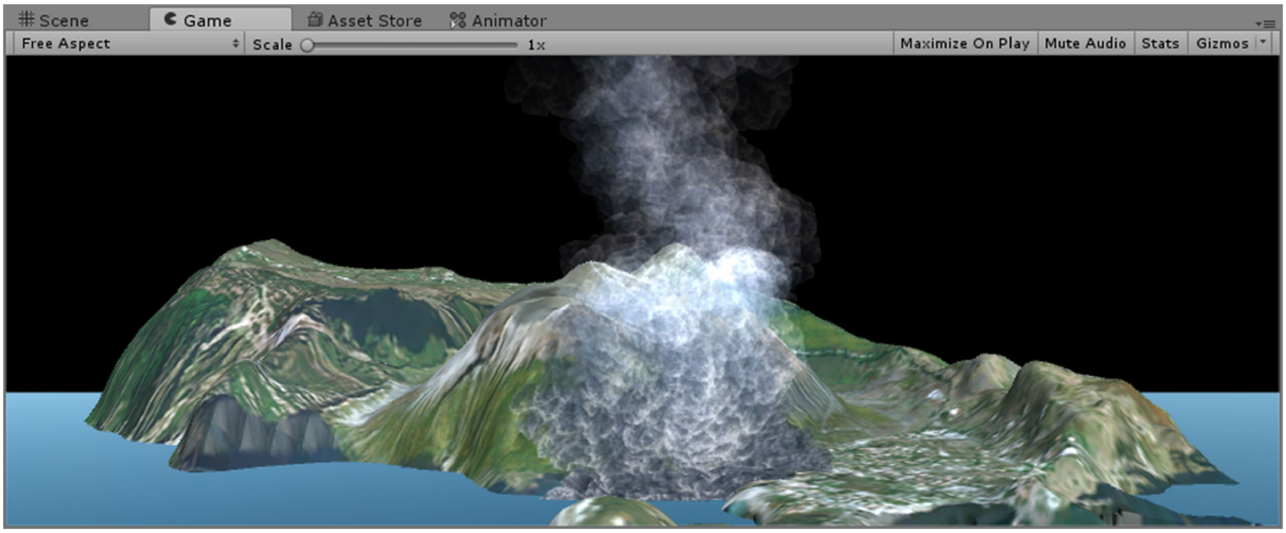

Fig. 11. Simulation and visualization of a subplinian eruption with PDCs.

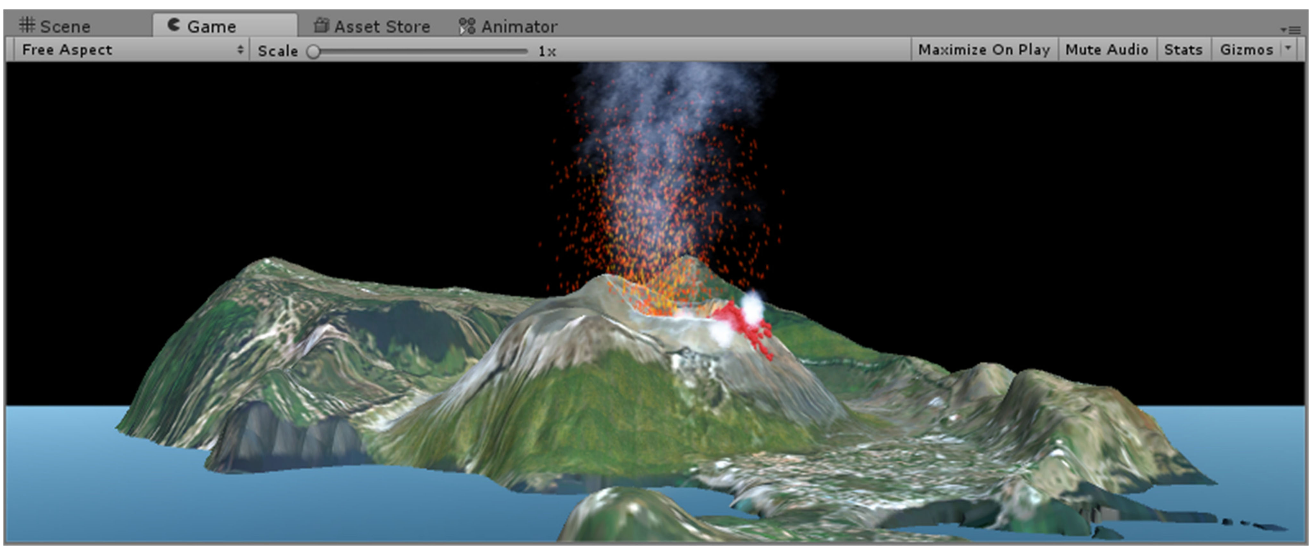

Fig. 12. Visualization of a lava flow at La Fossa cone (effusive eruption).

Fig. 13. Microsoft Hololens kit.

self-contained, relatively lightweight wearable system [47] that allows users to interact with holograms through voice, gaze, and air tap (see Fig. 13). Hololens operates with Windows 10 [48].

HoloLens is powered by an Intel Atom processor, Wi-Fi connectivity, 3-D spatialized sound, a depth, and color camera. It includes a 120° spatial sensing system and a see-through screen [49] and a holographic processing unit that combines real-world and holographic data and, therefore, demonstrates enhanced integration capabilities compared to other AR devices [49]. While there are various AR and VR devices that can provide similar functionalities, Hololens was used in this application mainly because of its computing power, immersive feelings for the users, and allowing users to interact with the holographic objects.

V. HoloVulcano Use Cases

HoloVulcano application can be used in disaster and emergency training and exercises, public education, awareness raising, and risk communication among the residents and tourists. These cases are discussed in this section.

Fig. 14. Table top exercises with CERG-C participants on Vulcano Island (May 2018).

Fig. 15. Demonstration of HoloVulcano in table top exercise with CERG-C participants (May 2018).

A. *Emergency Exercise and Training*

As for many other fields, training of the current and future emergency managers is one of the main applications of the AR technologies. As discussed earlier, visualization-based learning is very effective in disaster and emergency management. It promotes the development of experience without having an actual disaster situation. Learners can be trained without any risk to them and others. AR visualizations can be enhanced to provide details of emergency scenarios with virtual human and economic losses. Moreover, trainees will benefit from a virtual 3-D view of the scene, which will help them with a better spatial understanding of the situations. As an example, the HoloVulcano has been tested and implented in the volcanic module of the CERG-C program (found online[1]) to train researchers and practitioners in the management of volcanic crisis (Figs. 14 and 15).

AR and MR technologies are expected to have increased applications in education [50]. The more interactive the applications are the more interesting they will be for learners.

[1][Online]. Available: http://www.unige.ch/sciences/terre/CERG-C/

These technologies facilitate learning through entertainment, deep-understanding of the complex concepts, interaction with virtual objects, and real-time feedback [51]. AR and MR visualizations enable teachers to explain complex and significant scientific information (such as volcanic processes and eruptions) to students in a much easier and attractive and safer methods. As applications can be tailored to meet different profiles of users, HoloVulcano could, therefore, also be used by the school located on Vulcano island, as part of an activity on understanding their natural environment.

B. *Public Education and Awareness Raising*

AR and MR technologies are expected to have increased applications in education [50]. The more interactive the applications are the more interesting they will be for learners. These technologies facilitate learning through entertainment, deep-understanding of the complex concepts, interaction with virtual objects, and real-time feedback [51]. AR and MR visualizations enable teachers to explain complex and significant scientific information (such as volcanic processes and eruptions) to students in a much easier and attractive and safer methods. As applications can be tailored to meet different profiles of users, HoloVulcano could, therefore, also be used by the school located on Vulcano island, as part of an activity on understanding their natural environment.

C. *Volcanic Tourism*

AR and MR can have huge applications in the tourism industry. Already, several tourism-related HoloLens applications, particularly for historic and cultural sites, have been developed [52]. These solutions are used to enhance tourists' experiences of places that they visit. Volcanoes are among the most popular tourist destinations. Studies show that annually more than 130 million tourists visit nine major volcanos including Fuji-Hakone in Japan, Mt. Teide National Park in Spain, Yellowstone National Park in the United States, Tongariro in New Zealand, and Vesuvius in Italy [53]. Volcanos attract tourists because of their spectacular views and adventure activities [54]. Research also shows that increased volcanic activity draws more tourists to volcanic sites [55].

While very interesting and impressive, there are health and safety risks associated with volcano tourism [56]. As such, it is very important that tourists are educated on health and safety issues associated with volcanoes as well as on what to do in case of an eruption. Applications like HoloVulcano can be used by tourists visiting Vulcano island in order to gain a better understanding of the volcano various behaviors. For example, the INGV visitor center (can be found online.[2]) on Vulcano island could be equipped with AR devices with HoloVulcano application to inform the visitors.

D. *Other Volcanoes*

The HoloVulcano application can be adapted for other volcanos, particularly those with similar eruption types and hazards. Application developers can change the 3-D elevation file of the island and change the eruption types and parameters for the selected island.

[2][Online]. Available: http://www.ilvulcanoinforma.it/en/1/home

VI. Conclusion

HoloLens is an MR tool with significant potentials for disaster and emergency and public safety applications. Visualizing disaster and emergency visualization scenarios in MR format presents a new level of realism. As more and more low cost and compact wearable MR hardware are becoming available, new and interesting applications are developed and used in public safety and emergency management field.

HoloVulcano is an MR application that visualizes various volcanic phenomena that can occur at La Fossa volcano for emergency management training, public education, and raising awareness. While the effectiveness of this application has not been fully tested yet, it is believed that the application can provide a new way of visualizing volcanic eruptions and volcanic emergency scenarios that can enhance learning and training and improve preparedness and risk understanding.

More features will be added to the current application to make it more scientific, interactive, and educational. For example, additional features will be added that enable users to set different values for different parameters of each eruption type.

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