Enhancing Geoscience Communication: Building Virtual Reality Field Trips with the Outcrop Digital Model at Varvito Geological Park of Itu (Brazil, SP)

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Abstract. This article presents an innovative approach to Geosciences education through the development of a Digital Outcrop Model (DOM) combined with virtual reality. Fieldwork has long been a valuable didactic resource for teaching geological processes and rock outcrop analysis. In this study, a photogrammetric survey was conducted on the rhythmite in the "*Parque Geológico do Varvito,*" and the data was used to create a three-dimensional model. The model was optimized for real-time rendering and adapted to a virtual reality environment. Based on existing literature, a didactic itinerary was designed, allowing users to explore the rhythmite outcrop while receiving educational guidance from teachers on sedimentary formation. The goal is to encourage the use of digital models and gamification techniques to enhance Geosciences teaching, offering an immersive and engaging learning experience for students to understand complex geological processes. The immersiveness of virtual reality aligned with the rhythmite DOM demonstrated to be an engaging solution for Geosciences communication, by supporting virtual fieldworks and accessibility.

Keywords: virtual learning environment · virtual reality in education · photogrammetry · Paraná Basin

1 Introduction

Virtual reality (VR) technology is an advanced human-computer interface that has the capability to simulate realistic virtual environments [1]. It offers users the opportunity to navigate and interact within these environments from various angles and scenarios, providing a highly immersive and interactive experience [1]. VR technology can provide a significant contribution to education, applicable in both remote and in-person teaching settings. The concept of virtual geovisualization holds immense potential across geology,

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sparking discussions about its relevance in teaching geological aspects [2, 3]. The field work is crucial to geological knowledge, and the most meaningful approaches are related to the sense of vision [32].

An effective method to enhance didactic aspects within VR is through the implementation of virtual field trips [4]. By combining the visualization of rock outcrops with the immersive experience of virtual reality, students and the general public can engage in investigation and exploration during geological fieldwork. Collecting three-dimensional qualitative information from outcrops becomes essential in various geological segments, proving invaluable for teaching and illustrating geological processes [5].

Through virtual field trips, students can have an experience and understanding of geological phenomena without being physically present at the outcrop locations. This innovative approach enables educators to present complex geological concepts in an interactive and visually captivating manner. By merging technology and Geosciences education, virtual reality not only fosters active learning but also opens doors for more accessible and inclusive learning and communication opportunities.

Based on this context, this work presents a methodological approach for virtual field trips using principles of photogrammetry for the visualization of rock outcrops. The current approach uses images taken by unmanned aerial vehicles (UAV) to create optimized meshes through simplification and retopology. The *Parque Geológico do Varvito*, located in the city of Itu, in São Paulo State, Brazil, was chosen as a use case for the creation of the digital outcrop model (DOM), which would be visited during a virtual field trip.

So that the DOM could be rendered in real-time rendering, two applications were created using C++ language for users to interact with the model: one for Android, designed for VR, and the other for the Windows Desktop version.

Exploratory tests were conducted during the Educational event 'Unicamp Portas Abertas (UPA) 2022,' organized by Universidade Estadual de Campinas, to collect feedback from potential users. UPA is an ideal place for testing this program, as it showcases scientific research developed at the university for elementary and high school students. The tests were carried out in an exploratory, rather than systematic, manner. In future research endeavors, you will have the opportunity to design experiments with a more targeted focus on addressing specific questions, rather than prioritizing application development. The feedback from users was carried out in an exploratory, rather than systematic, manner. For future research, it will be advantageous to conduct experiments with a more precise focus on addressing specific issues, instead of giving priority to application development.

2 Related Work

2.1 Digital Outcrop Model and Virtual Field Work

The outcrops can be scanned and represented by 3D digital models generated from photogrammetric or laser scanning methods [6]. These digitally-generated models are known as Digital Outcrop Models or DOM [6]. The possibility of having the outcrop inside the classroom allows a great optimization of time and money, in addition, it can bring more educational support for vulnerable students. Digital outcrop models can be generated based on photogrammetry surveys, optimized to be visualized in real-time on Android or Windows applications.

In photogrammetric surveys, a significant collection of photographs is employed, which can be acquired using an airborne platform such as a drone or directly with a surface camera (short-range photogrammetry) [7]. Both methods generate a point cloud consisting of 3D spatially positioned points, which must be aligned within the same coordinate system.

Subsequently, the DOM is generated through the 3D interpolation of the point cloud data. This process involves reconstructing the surface and features of the outcrop by connecting the points and creating a continuous representation of the geological features.

By utilizing photogrammetric techniques, the DOM provides a detailed and accurate digital representation of the outcrop, enabling geoscientists and educators to explore and study geological formations in a virtual environment. This approach facilitates the integration of fieldwork data into educational settings, offering an immersive and accessible learning experience for students [4].

The 3D interpolation of the collected points can be generated using a regular network of points or an irregular triangular network (TIN - Triangulated Irregular Network) [8]. A regular lattice of points is a continuously and regularly connected triangular network [8]. Triangular networks are commonly used in mesh generation for representing surfaces, terrains, and geological formations [9]. According to Li [10], the mesh texture can be projected onto the digital outcrop model through five different orthogonal projection mapping methods. Orthogonal projection is the figure formed in a two-dimensional plane, coming from points projected in space [11].

The digital model created by the photogrammetry technique can be inserted into virtual reality software developed inside a graphics engine for games [12]. A graphics engine for games was used as a tool to develop software for interacting with digital outcrops in a much freer and more versatile way compared to web viewers, its documentation was consulted as support during the development.

Virtual reality can be used to simulate different scenarios and also reproduce the physical environment. The generation of an immersive Virtual Field Trip (VFT) can bring a more expository context to the classroom [13], Silva [14] explains that a more expository approach to teaching can enhance the understanding of theoretical content presented in the classroom.

Expository fieldwork has been essential for teaching and forming geological knowledge, and the practical activity is based on the contact with the object of study, the outcrop [15]. Walking through geological time and the formation of an outcrop in VFT can require imagination, the use of an investigative look at details can give important aspects for the interpretation of the outcrop [16]. The VFT can give a simplified path and expand the student's cognitive possibilities using paleoenvironment simulations [17].

2.2 The Didactical Importance of "*Parque Geológico do Varvito*"

The *Parque Geologico do Varvito* (PGV) is a municipal park created in 1995 in the area of a local former quarry. The *Parque Geologico do Varvito* is listed by the State of São Paulo Council for Historical, Archaeological, Artistic and Tourist Patrimony (CONDEPHAAT) as cultural and geological heritage. Since then, the *Parque Geológico* *do Varvito* has received about 500 thousand visitors, according to the Itu City Hall site [33].

The outcrop situated within the *PGV* displays distinct layers of siltstone and fine sandstone; those layers correspond to the geological dynamics associated with meltwater fluvial systems [21]. The presence of these layers provides valuable insights into the sedimentary processes that occurred in the past, specifically related to the flow of meltwater within fluvial (river-related) systems. The clarity of these layers contributes to a comprehensive understanding of the geological history and environmental conditions in the region.

The term “varvite” refers to a specific type of sedimentary rock formation, while “rhythmite” represents a geological phenomenon characterized by the repeated alternation of distinct layers, often involving sandstone and shale, in the context of varvites and rhythmites [19]. Initially classified as varvite, the rhythmites found in Itu have been redefined as clayey shale rhythmites, these rhythmites consist of alternating layers of clayey shale and finer sandstones to siltstones, often containing fallen clasts [20]. Notably, these layers exhibit a distinct parallel plane lamination pattern, this reclassification reflects a refined understanding of the Itu’s region geological characteristics and composition of the rhythmites [20].

Mendes [22] described the seasonality of these rhythmites as an outcome of glacial influence on the sedimentation process. According to this interpretation, during the summer melting period, the resulting water, being denser, would flow into the lake, giving rise to currents carrying turbidity. These turbidity currents would be concentrated near the lake bottom. This seasonal pattern contributes to the distinct layering observed in the rhythmites, as they represent alternating deposits formed during different climatic conditions.

This dynamic transports and deposits coarser fractions to the bottom and subsequently decants finer fractions in winter [23]. In the varvite of Itu, the repetition has pairs of strata (>1 cm) or layers (<1 cm) of light and dark colors, where the light layers correspond to summer and dark layers to winter [24]. The existing layers of sediment on the varvite outcrop are clearly depicted and sufficiently detailed to facilitate an informative explanation regarding sedimentological processes and the formation of rhythmites.

2.3 Education and Expository Didactic Teaching

To create a didactical experience, we used the thoughts of the brazilian education philosopher Paulo Freire, who aimed to offer meaningful training to students [34]. Paulo Freire emphasized the importance of engaging students in a way that resonated with their lived experiences and fostered critical thinking, his approach sought to empower learners by facilitating active participation, dialogue, and reflection, transcending traditional teaching methods [25].

Engaging students with a broad and diverse range of topics, perspectives, and methodologies not only expands their intellectual horizons but also nurtures adaptability and open-mindedness, it prepares them to navigate the complexities of an ever-changing world, fostering a deeper understanding of the interconnectedness of various subjects and realities [26].

Expository classes serve to complement the classroom theory, but effective teacher mediation remains vital to manage the student-knowledge relationship [14]. Gillings [17] suggests that Virtual Reality can be employed to enhance expository classes. Brandão [27] contends that formal education constitutes the phase in which educational knowledge is imparted in alignment with pedagogical principles. This process engenders conducive environments for learning to thrive, resulting in the formulation of methodologies rooted in the student-teacher dynamic.

Non-formal education pursues its objectives through an interactive process where the approach centers around achieving its goals through a dynamic interchange of information and training [28]. Non-formal education often occurs through interpersonal relationships and the exchange of knowledge, leading to a reversal in the traditional flow of information [29].

In summary, formal education takes place within structured academic settings with predefined curricula, while non-formal education revolves around learning during the process of social interaction and engagement [30]. The two educational models are not designed to replace each other but are intended to complement each other in the student's overall learning process [31].

Compiani & Carneiro [18] discuss the application of fieldwork for didactic purposes within geology encompasses a comprehensive classification of field activities based on various parameters. Based on these studies, the geological field trips could be classified as illustrative, inductive, motivational, formative and investigative. The main objectives of the fieldwork activities encompasses subjects as modes of learning, teacher-student relationships, the questioning about the actual scientific models and the logic of the learning process.

3 Methodology

3.1 Virtual Field Trip Creation

This section outlines the primary steps taken to develop and present the immersive virtual field trip at the Parque Geológico do Varvito. The methodological steps can be delineated across three primary stages: first, conducting a survey using photogrammetry techniques; second, processing the DOM and preparing the virtual field trip; and third, conducting tests with participants.

A fieldwork was made on *Parque Geológico do Varvito*, where a UAV captured overlapped images to execute the photogrammetry workflow after. The pictures were processed to create a tridimensional digital mesh, after this the digital model is optimized in order to produce a real-time render. The digital outcrop model of this article was generated using photogrammetry methods and later it was optimized to be rendered in real-time inside an Android and Windows application.

Using the graphical engine Unreal Engine, two softwares were developed using nodes and C++ programming language in order to create a virtual field trip in the *Parque Geologico do Varvito* and a simulated paleoenvironment of a glacial lake environment, one software was coded into a virtual reality using an android system for Oculus Quest 2. The other software developed inside the Unreal Engine was built for Windows Desktop.

A series of steps are outlined to provide further details regarding the methodological advancements of the research:

Fieldwork: A fieldwork expedition was conducted at *Parque Geológico do Varvito*, capturing overlapping images using a drone. These images were then used as input for the photogrammetry workflow.

Photogrammetry Workflow: The captured images were processed using photogrammetry techniques to generate a three-dimensional digital mesh. This digital model represented the geological features of the location.

Optimization: The digital model obtained from photogrammetry was optimized to ensure real-time rendering capability. This optimization enhanced the efficiency and performance of the virtual experience.

Software Development: Two separate software applications were developed using the Unreal Engine. These applications were created using a combination of node-based and C++ programming language. One software focused on creating a virtual field trip experience in *Parque Geológico do Varvito*, while the other simulated a paleoenvironment of a glacial lake.

Platform Compatibility: The software designed for virtual reality was tailored to run on an Android system specifically for the Oculus Quest 2 headset, providing an immersive VR experience. The other software developed within the Unreal Engine was intended for Windows Desktop use.

3.2 Itinerary for Geosciences Teaching

To enhance the educational value of the virtual field trip and promote effective learning in the sedimentology of Varvito, a well-structured itinerary should be developed. It guides users through key geological concepts and processes associated with Varvito formation.

3.3 Exploratory Tests for User Feedback

Conduct user testing sessions with students using the virtual field trip software. After the experience, collect feedback from users regarding the educational value of the simulated fieldwork. Utilize a rating system and a questionnaire to assess the helpfulness of the virtual field trip in enhancing their understanding of Geosciences, particularly sedimentology concepts related to Varvito.

By following these steps, the study successfully achieved its objective of creating an immersive and interactive virtual field trip experience, allowing users to explore the geological aspects of Parque Geológico do Varvito and the simulated paleoenvironment of the glacial lake.

3.4 Fieldwork to Apply the Photogrammetry Technique

The geological park "*Parque Geológico do Varvito*" is located in the city of Itu, São Paulo, Brazil, at latitude coordinates 23° 16′ 4″ S and longitude 47° 19′ 13″ W, approximately 60 km from Campinas.

The data collection was made in the outcrop area of the park to create a detailed digital outcrop model (DOM) of the park's geological formations using the photogrammetry methods. To capture the necessary images, a DJI Mavic Air unmanned aerial vehicle was used, piloted by Dr. Henrique Candido de Oliveira (see Fig. 1). In total, 238 sequential photos were taken, capturing the outcrop from frontal or oblique angles, while an additional 107 photos were captured in a vertical view.

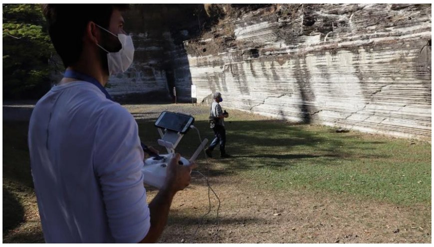

Fig. 1. Doctor Henrique Candido de Oliveira piloting the aerial vehicle in the *Parque Geológico do Varvito.*

Once the image data was collected, it was imported into the Agisoft Metashape Professional software, version 1.8.2. Within the software, the standard photogrammetry processing steps were carried out. The Workstation machine used for this process was equipped with an Intel(R) Core(™) i7–9700 K processor, 80 GB of RAM memory, and an Nvidia GeForce RTX 2060 GPU. These powerful hardware specifications enabled efficient and accurate data processing during the photogrammetry workflow.

The mesh produced by the software contained a substantial number of faces and vertices, specifically 94,430,344 faces and 47,383,505 vertices (see Fig. 2). This level of complexity made the mesh significantly heavy and impractical to perform integrated into real-time rendering software. As a result, it became evident that the model required post-processing work to optimize its structure and reduce its complexity.

Optimizing the model was imperative to enhance its suitability for real-time rendering and other performance-critical applications. The post-processing procedures encompassed a meticulous reduction in the count of faces and vertices, meticulously safeguarding the intrinsic details and overall model accuracy. This strategic optimization endeavor yielded a mesh of diminished weight and enhanced manageability, facilitating seamless integration and swift rendering within real-time software ecosystems.

After applying automated simplification and manual retopology to the model, the newly generated optimized mesh displayed 200,000 faces and 104,817 vertices, representing a remarkable 99.78% reduction in complexity compared to the original mesh.

3.5 Programming the Applications

To build an interactive platform in both virtual reality and Windows desktop versions, the graphics engine used was Unreal Engine 5.0.3 from Epic Games. This powerful engine supported the creation of immersive experiences for both virtual reality and

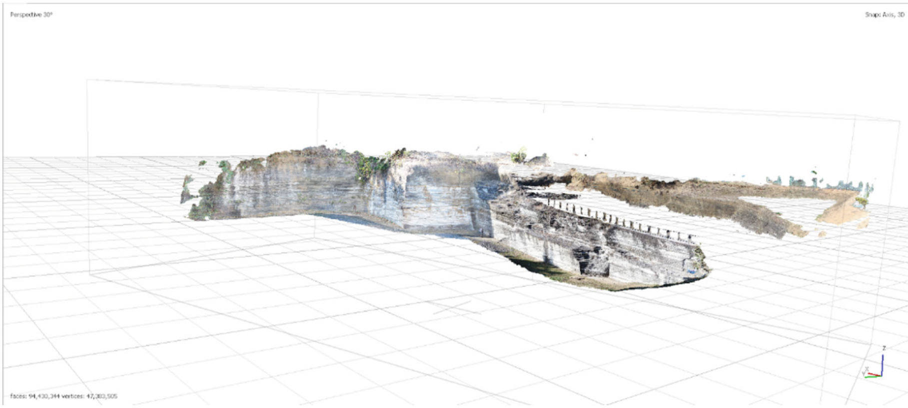

Fig. 2. Outcrop 3D mesh generated by photogrammetry method.

traditional desktop environments. To facilitate the integration with Android devices and specifically target the Oculus Meta Quest 2 hardware, an Android mobile application was made. This Android application would eliminate the need for a computer, once the Oculus Meta Quest 2 already has an internal system to run android applications.

To develop a captivating fieldwork experience through virtual reality, gameplay mechanics for movement and visualization inside the Oculus Quest 2 were made. This was achieved by leveraging the power and versatility of the C++ programming language.

C++ is widely used in game development due to its efficiency and ability to directly access hardware resources, which is crucial for providing a seamless and immersive experience in virtual reality. By utilizing C++, the development could optimize performance and ensure smooth movement and visualization within the virtual environment. They programmed various interactions, such as walking, running, and exploring the fieldwork area, to mimic real-world movements as closely as possible. Additionally, the team implemented visualizations of geological data and features, enabling users to examine and study the park's geological formations and structures in detail.

Through careful programming and leveraging the capabilities of C++, the team created a compelling and immersive fieldwork experience that allowed users to explore the Varvito Geological Park as if they were physically present, enhancing the overall engagement and educational value of the virtual reality application.

For educational purposes, a glacial lake environment was simulated for the users, as shown in Fig. 3. The simulation included several characteristic aspects of a glacial environment, enhancing the realism and educational value of the experience. Notable features added to the paleoenvironment simulation included striated rocks, fallen pebbles, a glacial lake, and glaciers. To create this virtual paleoenvironment, the development team utilized resources from quixel.com/bridge, a web source that provides three-dimensional models specifically designed for real-time rendering in graphics engines. These models were freely available, allowing the team to access a wide range of high-quality assets, thereby streamlining the development process and ensuring a visually stunning and authentic representation of the glacial lake environment.

By incorporating these realistic features and leveraging pre-made 3D models from quixel.com/bridge, the virtual simulation delivered an immersive and informative experience for teaching purposes. Users could explore and interact with the glacial lake environment illustrated on the Fig. 3, gaining insights into the geological processes and unique characteristics associated with glacial regions.

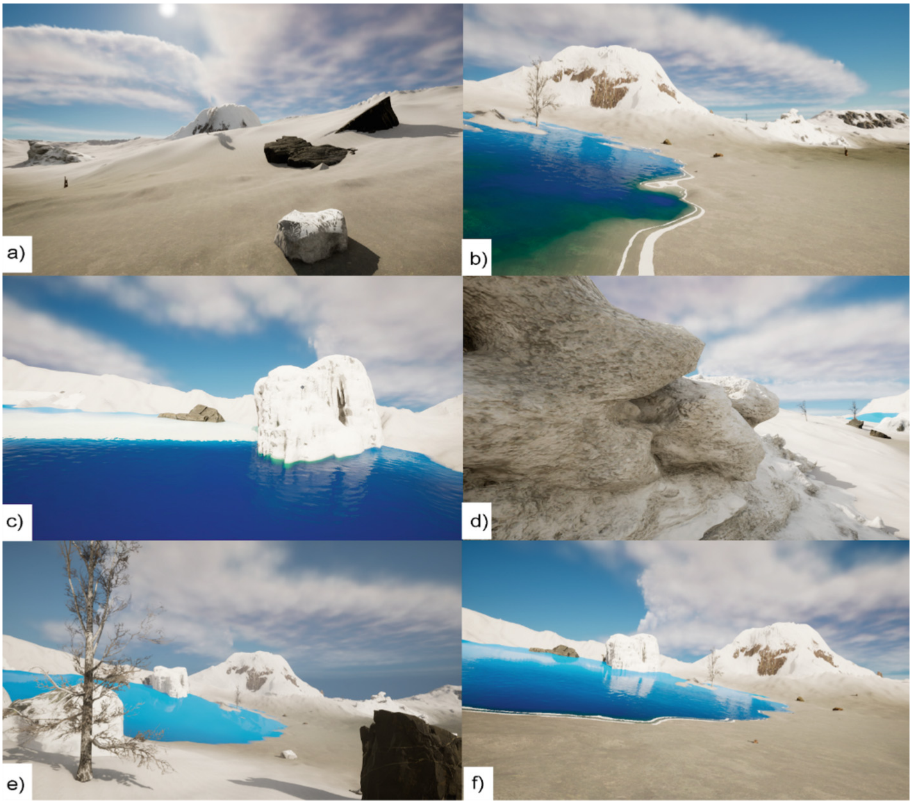

Fig. 3. (a) A section of the meticulously recreated glacial ecosystem within the simulation. (b) A replicated environment segment situated adjacent to the tranquil glacial lake. (c) A representation of a glacial lake adorned with towering glaciers. (d) A rocky landscape simulated with the intricacies of the snow formations. (e) A panoramic vista capturing the expansive surroundings, with the glacial grooves. (f) A simulated portion of the outcrop, recreated to showcase the closest proximity to the eroded region.

3.6 Exploratory Tests for User Feedback

To enhance the educational value of the virtual field trip and promote effective learning in the sedimentology of Varvito, a well-structured itinerary was developed. It aims to guide users through key geological concepts and processes associated with Varvito formation.

A didactic script was carefully developed to test the application's effectiveness in teaching about rhythmites and their formation. The primary goal was to explain the key features of the rhythm in the Itu park. The script was designed to provide users with a comprehensive understanding of the geological formations and processes involved in the geological formation.

After implementing the didactic script into the virtual reality application, a quiz was elaborated for the user. This quiz was designed to understand how immersive and helpful the learning experience was. The incorporation of the digital outcrop model, along with the utilization of virtual reality makes the subject matter more accessible and understandable for students and enthusiasts in the field. User feedback would help identify strengths, weaknesses, and areas for improvement, thus ensuring the application's educational value and promoting a deeper understanding of geological concepts.

The virtual fieldwork project was presented during the 17th edition of the Unicamp Portas Abertas (UPA) program held on 28/08/2022. The UPA program's main goal is to introduce high school students to the public university and assist them in making informed decisions about their future courses for the entrance exams. During UPA 2022, more than 500 visitors had the opportunity to explore the Unicamp Institute of Geosciences (IG) (see Fig. 4).

Fig. 4. User testing the software application during the UPA 2022.

A script was prepared for the visitors to the IG, offering two distinct experiences: one through virtual reality and the other using third-person playable desktop software. Both experiences were centered around the concept of the paleoenvironment and utilized the digital outcrop model. In the virtual reality experience, users could immerse themselves in the outcrop environment of *Parque Geologico do Varvito*. Through the use of VR technology, they were able to interact with the outcrop, examine rhythmite, and look at the fallen pebbles, all of which are characteristic features of the outcrop (see Fig. 5). This context offers an opportunity for a deeper understanding of geological concepts in an engaging and interactive manner.

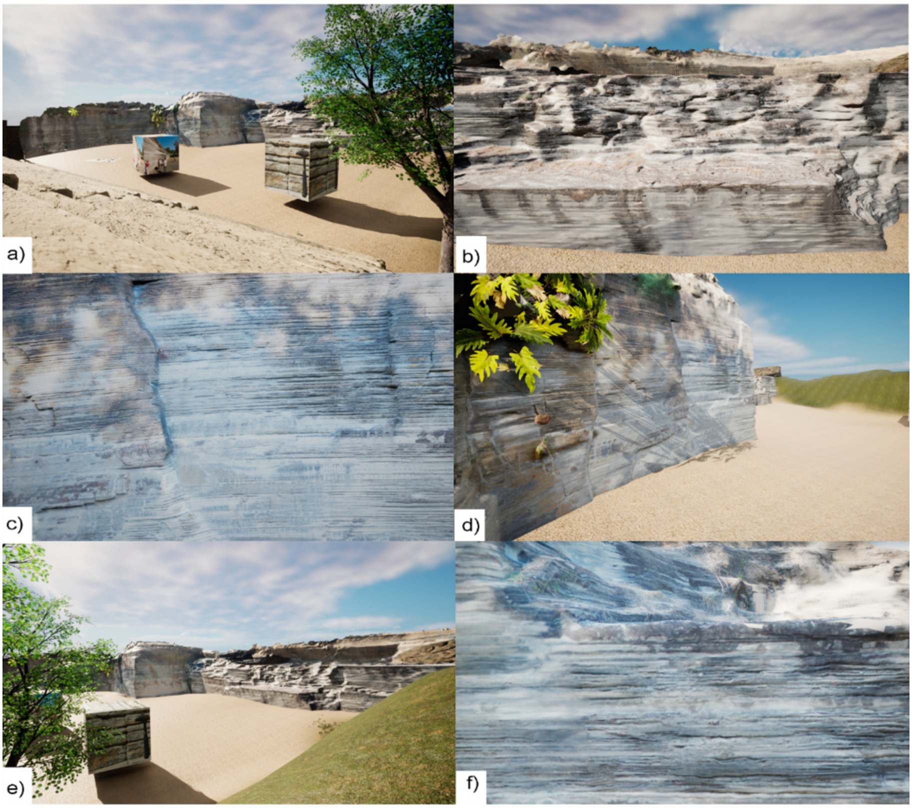

Fig. 5. (a) Peripheral image of the *PGV* simulation. (b) Outcrop inside the virtual environment, with evident erosion features in the thinnest layers. (c) Enlarged outcrop wall, with darker and lighter layers represented in the texture. (d) Simulated portion of the outcrop where the fallen pebble is located. (e) A broader view of the DOM. (f) Simulated portion of the outcrop, eroded part closest view.

The second experience, in the form of a third-person playable desktop software, provided users with a unique perspective on the paleoenvironment. Players could navigate the environment and experience it from a different viewpoint, interacting with the virtual world and engaging with the rhythm physical samples provided by IG. The primary cause for the development of a desktop iteration was in tandem with the VR counterpart, leveraging its enhanced processing capabilities. This synergy facilitated the dynamic interplay between the map housing the digital outcrop model and the map incorporating paleoenvironmental data.

To assess the effectiveness of the VR experience in teaching sedimentological processes at the varvite outcrop, users participated in a questionnaire. This questionnaire focused on three primary questions, where 0 means a bad experience and 10 corresponds a great learning experience:

1. "From 0 to 10, how was your experience playing the game?" (see Fig. 6).
2. "From 0 to 10, how much did you understand about rhythmite?" (see Fig. 7).
3. "From 0 to 10, was the game important for understanding the local geology?" (see Fig. 8).

We have gathered valuable feedback and suggestions from users, which can be leveraged to enhance the model and its educational concept. These suggestions, alongside positive feedback, included requests for a higher level of immersion within the application and increased rendering details.

4 Results and Discussion

The development and optimization of the DOM, combined with the development of the applications utilizing a graphics engine, has proven to be effective to allow real-time rendering. Based on the rates assigned by users and qualitative feedback collected during the UPA 2022 event, the experience received highly positive responses as a didactic support for Geosciences. The users' feedback indicated that the project successfully enhanced their understanding of Varvito and local geology in an engaging and interactive manner.

A total of 49 randomly selected users tested the virtual field trip, participating during a drop-in event. The questions posed to the users primarily aimed to assess the level of immersion and the quality of their experience in terms of comprehending and interacting with the varvito digital outcrop model, particularly from the perspective of elementary and high school students. In response to the question "From 0 to 10, how was your experience playing the game?", an impressive average score of 9.4 was recorded. This high rating indicates the enthusiasm and positive reception among users when engaging with academic geology content through a technological and gamified approach. The gamification tool had the potential to incorporate elements of interactivity and engagement, aligning with the principles elucidated in Lima's framework for non-formal education [30].

In the question "From 0 to 10, how much did you understand about rhythmite?", the average score was 8.44. While this score slightly dropped compared to the user experience rating, it suggests that users might have faced challenges in fully grasping the content. This feedback is relevant in terms of improving the design of the learning activity. This could be attributed to the event's bustling environment, making it difficult to provide optimal didactic support.

However, in the final question "From 0 to 10, was the game important in understanding the local geology?", the average score increased again to 9.37. This rise in average scores could be attributed to the immersive nature of the software, enhancing users' cognitive ease and investigative engagement. The visual and interactive aspects of the environment seem to have tapped into a potential that not only illustrates theoretical concepts but also sparks users' curiosity and encourages exploration.

The standout aspect, according to user opinions, was the interplay between the outcrop and the paleoenvironment. This aspect of versatility can be correlated with the interactive elements of Virtual Reality, as elucidated by Zheng [1]. This dynamic helped users visualize and comprehend the intricate processes of rhythmite deposition and formation. Qualitative feedback from users also offers valuable suggestions for refining the model and enhancing its educational proposition. Overall, the study underscores the potential of gamification and immersive technology in enriching geology education and piquing students' interest and understanding.

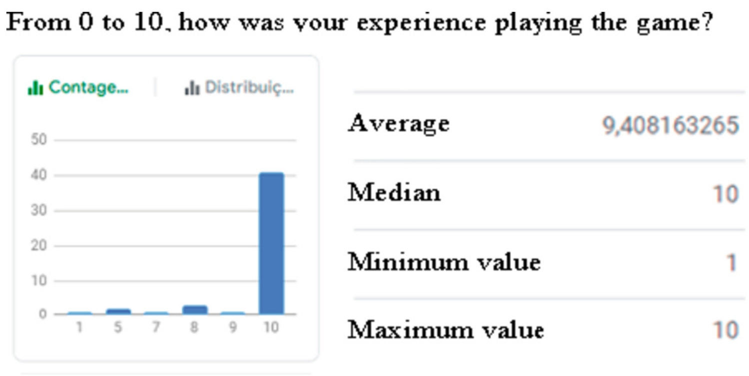

Fig. 6. Graph prepared according to feedback about the game experience from users who tested the application at UPA 2022.

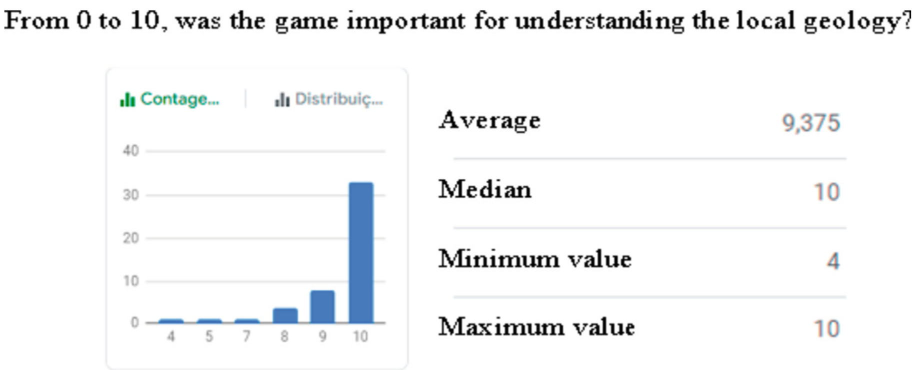

Fig. 7. Graph prepared according to feedback about the geological understanding from users who tested the application at UPA 2022.

The numerical ratings provided by the users allowed for a quantifiable assessment of their experience, comprehension, and the game's educational impact from the user perspective. The scores from 0 to 10 indicated the level of satisfaction and understanding users felt during the virtual reality and third-person playable desktop software experiences.

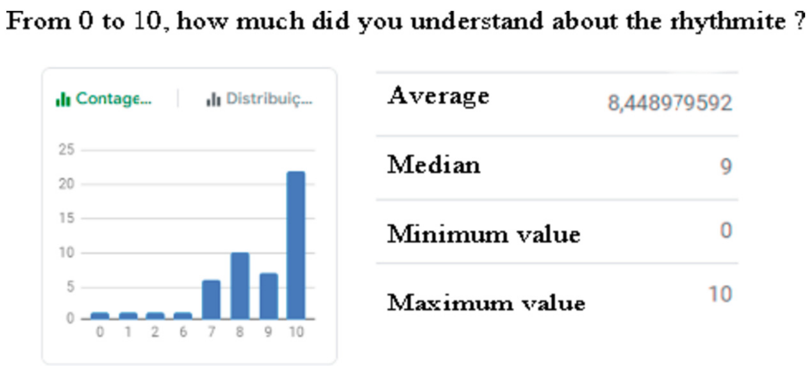

Fig. 8. Graph prepared according to feedback about the understanding of the outcrop from users who tested the application at UPA 2022.

Based on the gathered data, the majority of users awarded high grades, indicating a positive and enjoyable experience while playing the game. The interactive nature of the simulation likely contributed to this positive feedback. Additionally, users reported a significant increase in their understanding of outcrop and local geology, as evidenced by the high scores provided in response to the second question.

Moreover, the users recognized the game's importance in facilitating their understanding of local geology, demonstrating the educational value and effectiveness of the project. Overall, the positive grades and qualitative feedback collected from users at the UPA 2022 event support the initial objective to create a virtual field trip for teaching Geosciences. The interactive and immersive experiences provided by the virtual reality and desktop software left a strong and positive impression on the participants, fostering curiosity and knowledge about the field of Geosciences.

Based on the users opinions, the dynamics between the outcrop and the paleoenvironment emerged as the most significant highlight. This aspect played a crucial role in helping users visualize and comprehend the rhythmite deposition and formation process. Integrating the outcrop data with the virtual paleoenvironment allowed users to bridge the gap between real-world geological formations and their virtual representations. This approach facilitated a deeper understanding of the geological processes involved in rhythmite deposition and how they translate into the formation of the outcrop. This empirical endeavor has paved the way for the establishment of an exceptionally immersive pedagogical setting, aligning with the concepts explored by Klippel [4]. But now specifically tailored to the mechanisms governing the formation of sedimentary rhythmites.

This teaching model, centered around VFT, exhibits significant potential for enhancing both expository and interactive classroom sessions, ultimately leading to improved student engagement and learning outcomes, as posited by Silva [14]. As per Gohn [28], a significant facet of informal teaching lies in its emphasis on socialization and the heightened adaptability of its implementation. Leveraging cost-effective surveys and increased flexibility in its application, the highly motivating VCVi model holds promise for expanding the reach of geology education across diverse segments of society.

The VFT can fulfill several roles with regard to -field trip learning [34]. As far as this experiment is concerned, they are mostly illustrative and motivational, integrating the experience into the motivating field established by Compiani, Mauricio and Carneiro [18]. They are student-centered activities where knowledge comes through interactions with the object of study, aiming to stir up curiosity and induce knowledge. We understand that this is, at the moment, the main function of this type of activity. In the future, with the development of technology, other roles may be added.

The interactive nature of the experience further enriched the learning process. Users could explore the outcrop area and compare it with the virtual representation of the paleoenvironment, thereby gaining insights into the geological features and their spatial relationships. This interactive dynamic provided a more comprehensive perspective, fostering a holistic understanding of the subject matter.

5 Closing Remarks

By following the methodological steps, the study successfully achieved its objective of creating an immersive and interactive virtual field trip experience, allowing users to explore the geological aspects of *Parque Geológico do Varvito* and the simulated paleoenvironment of the glacial lake.

The "Varvito Digital" project at UPA 2022 successfully facilitated an educational and immersive learning experience for visitors. Through innovative technologies and interactive simulations, the project aimed to foster interest in Geosciences and encourage students to explore the field further in their academic pursuits.

The didactical results were highly encouraging, users with no prior knowledge of geology showed increased interest and curiosity after experiencing the simulation. The digital fieldwork cannot replace traditional field trips, but it can effectively supplement and extend the learning experience, allowing students to revisit and interact with outcrops that have been previously visited.

Furthermore, its accessibility and cost-effectiveness make it an excellent tool to reach social strata outside the academic environment. By reducing costs and increasing application flexibility, digital fieldwork has the potential to bring geology education to various layers of society, promoting interest and understanding in Geosciences. In conclusion, the experience proved to be a promising didactic tool for teaching Geosciences, providing an engaging and accessible approach for users to explore and understand geological concepts in the current context. By addressing the observed weaknesses and leveraging teacher feedback, virtual fieldwork can continue to evolve and become an even more effective and valuable resource for Geosciences education. For future research, the focus could shift towards more specific educational and didactic subjects, adopting a more systematic approach.

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