An Immersive Virtual Field Experience Structuring Method for Geoscience Education

Rafael Kenji Horota, Pedro Rossa, Ademir Marques Jr., Luiz Gonzaga Jr., *Member, IEEE*, Kim Senger, Caroline Lessio Cazarin, André Spigolon, and Maurício Roberto Veronez

***Abstract*—Digital outcrop models (DOMs) have facilitated quantitative and qualitative studies in digital and virtual environments of source and reservoir rock analogs important to the oil industry. The use of immersive virtual reality (iVR) to extend field experiences has motivated several research groups to develop software integrating iVR techniques with tools to interpret and derive geological information from DOMs. This virtual approach can also contribute to the development of geological and spatial thinking skills taught in the classroom and during field trips. The immersive virtual field trips (iVFTs) can provide students access to outcrops and additional data restricted to field learning activities while allowing additional interactions impossible in the field. iVFTs have been developed recently; however, the structuring of iVFTs for geology classes has not been presented in a way that inexperienced iVR users can make use of such systems. In this scenario, our work proposes a method to structure an iVFT using georeferenced data containers and the virtual reality software Mosis LAB while evaluating users' perceptions during an iVFT study case. The evaluation using technology acceptance model questionnaires showed that users were positively impacted by the observational iVFT experience, effectively supporting e-learning, and class field learning activities and preparations. This approach allows field trip experiences in less accessible study sites, especially in less favorable conditions like the ones during the Coronavirus 2019 pandemic where many geoscience departments had their field trips hampered.**

***Index Terms*—Digital outcrop model (DOM), education, field learning, immersive virtual field trip (iVFT), immersive virtual reality (iVR), virtual reality.**

I. Introduction

GEOSCIENCE field trips focus on studying outcrops, such as cliffs, quarries, mine faces, road cuts, and other prominent topographic rocky features that can be observed, analyzed, and sampled *in situ*. Commonly located in remote areas and/or with difficult access, these exposures are critical to exemplify and properly derive relevant geological information. In addition, the access to outcrops is directly related to the terrain, climate, transportation costs, maintenance, and accommodation of personnel. It can also offer safety risks and difficulty in obtaining representative data in traditional studies, especially when it is necessary to acquire a large volume of data and integrate it into a digital database [1]. Meanwhile, recent technological developments have enabled the acquisition and manipulation of georeferenced 3D digital outcrop representations, i.e., digital outcrop models (DOMs), through remote sensing and computer vision techniques such as digital photogrammetry based on structure from motion (SfM) and multiview stereo algorithms or laser scanning [2], [3].

The use of DOMs has increased considerably in recent decades, with the first general application in the petroleum industry developed by Bryant et al. [4]. They explore how data acquired digitally from the Puerco River basin in New Mexico could be used to assist in the interpretation and modeling of sedimentary environments in the Boonsville gas field in northern Texas. They demonstrate the use of 3D outcrop data to analyze the architecture and internal geometry of geobodies, by allowing geoscientists to make direct comparisons between outcrop and subsurface data, thus proposing the use of outcrop analogues as explicit controls in modeling subsurface reservoirs.

The work of Bryant et al. [4] set the stage for a digital transformation in the field of geosciences. This revolution includes the use of differential global positioning system, laser rangefinders, and total station surveys [5], [6], up to the current digital outcrop modeling approaches based on LiDAR and digital photogrammetry, which have allowed the recognition and interpretation of geological features within a realistic 3D computational scenario [2], [3], [7], [8], [9], [10]. These studies applied different techniques to extract information from DOMs, either through the use of generated attributes, manual interpretation, or the development of automated approaches.

Besides the geosciences and industry applications, the use of these technologies offer means of teaching and learning the fundamentals of geosciences in field activities in the form of virtual field trips (VFTs), being these of the utmost importance in undergraduate courses [11].

There are several reasons why instructors choose to implement VFTs in their courses. These include budgetary cuts, increasing class sizes, mobility restrictions, emphasis on

Manuscript received 31 March 2021; revised 26 December 2021, 1 August 2022, and 5 September 2022; accepted 8 September 2022. Date of publication 15 September 2022; date of current version 17 February 2023. This work was supported by Petróleo Brasileiro S.A. and Agência Nacional do Petróleo, Gás Natural e Biocombustíveis under Grants 4600556376 and 4600583791. *(Corresponding author: Rafael Kenji Horota.)*

Rafael Kenji Horota and Kim Senger are with the Department of Arctic Geology, The University Centre in Svalbard, 9170 Longyearbyen, Norway (e-mail: khorota@edu.unisinos.br; kims@unis.no).

Pedro Rossa, Ademir Marques Jr., Luiz Gonzaga Jr., and Maurício Roberto Veronez are with the X-Reality and Geoinformatics Lab, Graduate Program in Applied Computing, Unisinos University, São Leopoldo 93022-750, Brazil (e-mail: prossa@edu.unisinos.br; adejunior@edu.unisinos.br; lgonzaga@unisinos.br; veronez@unisinos.br).

Caroline Lessio Cazarin and André Spigolon are with the CENPES-Petrobras Research Center, Rio de Janeiro 20031-912, Brazil (e-mail: cazarin@petrobras.com.br; andrespigolon@petrobras.com.br).

Digital Object Identifier 10.1109/TLT.2022.3207089

spending department's financial resources on technological upgrades, and the growing movement to develop distance learning solutions. Instructors envision this new technological approach as a way to provide access to field trips [12], [13], [14], [15] and keep up with institutional directives. Furthermore, some have sought to create more inclusive classroom environments as fieldwork can represent physical obstacles, especially for those with mobility restrictions who otherwise could not participate in these field activities [16], [17]. In addition, unpredictable weather conditions like in the circum-Arctic environments, or sanitary risks like the global Coronavirus 2019 (COVID-19) pandemic can be addressed by VFTs [18].

A. Virtual Field Trips

Field trips offer the opportunity to study natural phenomena in open systems [19]. These field studies are defined by Lonergan and Andresen [20], as any environment where supervised teaching and learning takes place through first-hand experience outside the limitations and context of the classroom [20]. Traditionally, teaching–learning in the field has been an integral component of geoscience curricula, where students learn the technical fundamentals during initial geology disciplines and improved their field skills during field trips to advanced disciplines, field courses, and summer camps [21].

On the other hand, VFTs are defined as a collection of resources designed for effective teaching and learning that simulates a conventional field trip in the form of a computer or web-based digital fieldwork. They are called virtual because no physical visit to the place of interest takes place. However, the VFTs must be developed attending explicit learning objectives, with a glossary related to the region, images, video clips, and questionnaires [22]. In this way, students can learn at their own pace and, thus, be able to perform, in a virtual way, basic field exercises that are normally structured in between a spectrum of participation ranging from observation to hands-on fieldwork [23].

Traditional VFTs vary in quality and approach of what is presented [22], which includes VFTs based on a series of maps, text, 2D images, audio, videos, and even spherical panoramic photos in the form of an itinerary activity like an excursion, such as the *Virtual Field Tour* offered by the Virtual Library of Australia's Geology,[1] or the Arizona State University *Virtual Field Tour*[2] [24], [25].

In essence, VFTs aim to represent the real-world environment through digital data and without the cost of being "there" physically [1], [26], [27]. However, according to Hurst [28], even though these so-called VFTs allow the exploration of outcrops and sites through digital data, they are not the same as a first-hand visit since the abundance of details and the notions of geometry and size are dimmed by 2D interfaces of computer screens.

Recent studies [29], [30], [31], [32] introduce immersive VFTs (iVFTs) and evaluate its capabilities and impact on geoscience education. However, some limitations can be found as in the work of Forsberg et al. [29] who proposed an iVFT for geoscience learning using CAVE technology that limits the immersion by offering fixed points of view when showing images on the wall. The work of Zhao et al. [30] provides a framework for analysis of point clouds and hyperspectral data providing a great set of interpretation tools; however, the model visualization and model types limit the immersion by not offering visuals similar to the actual sites. The work of Zhao et al. [31] carried a comprehensive study on the application of iVFTs and comparisons with VFT and field trips *in situ*. They indicated open opportunities like the field of view expansion and the addition of free movement and interactivity proposed by Klippel's taxonomy [32] to provide an advanced VFT.

Considering these limitations, the main objective of this article is to propose an iVFT structuring method based on georeferenced data containers (GDCs) over an immersive virtual reality (iVR) software called Mosis LAB, while evaluating its applicability to geoscience education and fieldwork.

II. Mosis LAB: System Overview

Mosis LAB is an iVR application that simulates a virtual laboratory providing new forms of interacting with georeferenced data, either 2D or 3D, presenting a more robust architecture than the prior version, namely VROffice [33]. MOSIS LAB is built on the Unity 3D[3] game engine, that combined with HMD hardware (e.g, HTC Vive[4] and Facebook Oculus Rift S[5]), offers state-of-the-art human–machine interactions using user experience and user interface design principles that favors comfort and ease of use (see Fig. 1).

Mosis LAB does so by immersing the user in a digital environment where the user can move and adjust the position and dimension of objects in the surrounding endless space. However, as it lacks conventional input systems (e.g., physical mouse and keyboard), these files are accessed and manipulated through diegetic concepts like providing stimulus and environment responses without breaking the virtual world's logic and immersion while handling the GDCs, attenuating the learning curve of new users, and ensuring a more productive experience (see Fig. 2) [33].

To guarantee this level of immersion and usability, interactions using hand-like interface controllers were developed based on the widely known and studied gestures applied on touchscreen devices (e.g., smartphones and tablets), such as scroll, pinch, and slide (see Fig. 2) [34].

III. Georeferenced Data Containers

The GDC is an iVR computational diegetic file concept structured to group different digital data formats acquired at a given location or from other sources, where the user can choose which files she/he wishes to group in a single geographical point over a georeferenced 3D model (e.g., a DOM,

[1] http://www.ausgeol.org
[2] https://vft.asu.edu/
[3] https://unity.com/
[4] https://www.vive.com/us/
[5] https://www.oculus.com/rift/

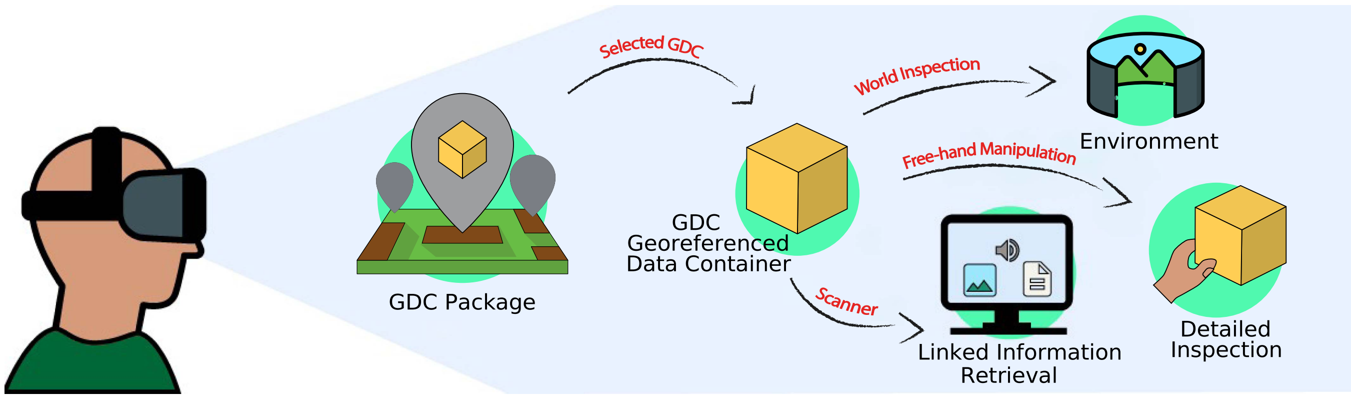


Fig. 1. Mosis LAB system overview adapted from the prior VROffice system overview.

Fig. 2. Mosis LAB workspace environment, displaying the center table with the "Open panoramic" and "Scanner" diegetic interactive objects, the half-transparent board, and the shelf that holds the miniaturized file representations, on the back wall.

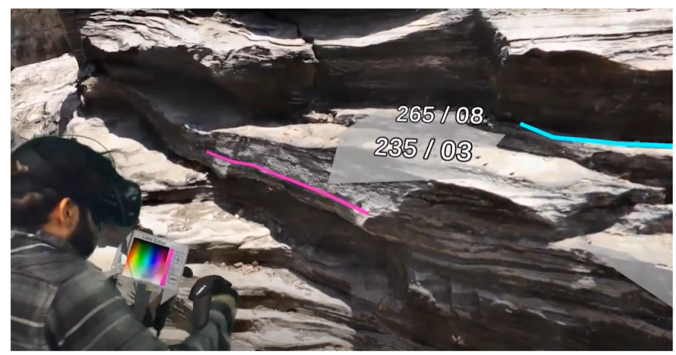


Fig. 3. Mosis XP/iXP iVFTs participatory concept in a mixed reality visualization.

a digital elevation model, a digital surface model, etc.) [33]. The GDC architecture supports the grouping of different file formats used to perform data interpretation and correlation dynamically. The files can be accessed and manipulated while using the 3D iVR space. This allows handling a 3D model and simultaneously, e.g., listening to an audio file, while also looking over images and texts, linking information of the same context (geographic location) at the same time.

In cases when multiple GDCs are needed for an iVR experience, those are grouped and organized in a GDC package. A GDC package is an object centralizer that uploads all data to the system; in addition to the GDCs, it holds a.json file describing and giving access to each GDC data. The GDC Package is stored in a.zip file, which can be generated independently of the application, thus allowing the GDC Package to be created by the user from his files and opened by the system at run time.

IV. Proposed iVFT Implementation

Based on the works of Kent et al. [23], [35] and Arrowsmith et al. [36], we have conceptualized two possible iVFT methods, one observational, and other participatory according to the definition present in the work of Kent et al. [23].

The observational approach works a "Cook's Tour" style [35], where the students are exposed to geological concepts through high-resolution visual information in different scales of the studied outcrop region, simulating field trips of the introductory geoscience-level courses [36].

The participatory approach aims to simulate and test fieldwork activities [23] similar to what has been used by the petroleum industry in studies of outcrop analogues [1]. This type of iVFT consists of inserting the user in a full-scale DOM, where the user can be trained and evaluated while performing guided activities on a virtual outcrop model (VOM) using a software like the Mosis XP [37] (see Fig. 3).

Owing to the broader requirements of definitions of objectives by the instructors when organizing a participatory iVFT, and to limit the scope of this article, this approach will be studied in future works, while this article will focus on the observational concepts to facilitate the reproducibility of the planning, acquisition, and organization of field data steps and its structuring in an iVR software (Mosis LAB).

The proposed workflow (see Fig. 4) aims to assist users willing to create their iVFTs, by considering that it is not expected for a geologist or education professional to know how to program an iVFT, but it is required to know how to present the information one seeks to transmit logically. However, the knowledge of remote sensing techniques for field data acquisitions and processing is required to obtain data.

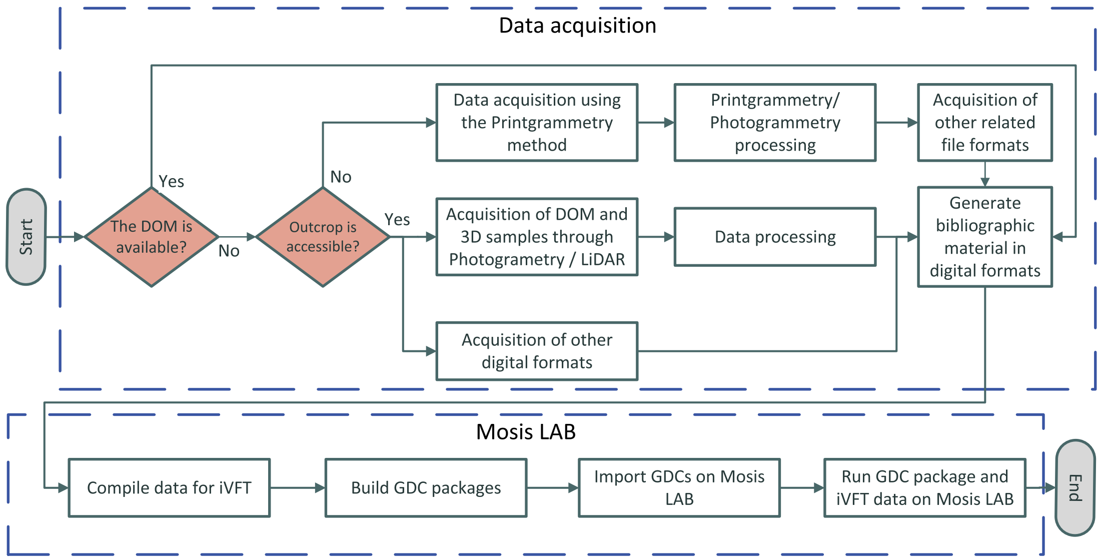


Fig. 4. iVFT structuring method for geoscience field learning considering expositional concepts.

This workflow starts by questioning if a DOM is available, necessary to anchor other data; then, it guides the acquisition and organization of the data to fully explore the iVFT concept on Mosis LAB software later exploring other file acquisition and software data necessary. These files and data related to the geological site studied are described shortly below.

A. DOM, VOM, or 3D Outcrops?

DOMs, also known as VOM, are 3D realistic digital representations of outcrops that are subject to inspection, manipulation, integration, and extraction of geological information in a virtual environment. Early definitions of DOMs [5], [38] point out the requirements to fully represent the structure of the outcrops, defining them as 3D digital models composed of points in a computational space with X, Y, and Z coordinates structured as point clouds or textured triangulated meshes.

The DOM digital data file is the most important file in an iVFT structured to teach or to present geological concepts, as it is critical to anchor GDC objects to geolocalize file information, connecting data to its original source. These 3D digital outcrop representations can either be acquired on the field or downloaded for instance from Sketchfab[6] or databases such as Svalbox.[7] Complementary to the traditional SfM workflow, we also proposed in a recent work [27] an alternative to generate 3D models from images from Google Earth called Printgrammetry, which evolves from the work of Chen et al. [39], that proved a viable alternative to obtain models from inaccessible areas due to cost and logistics.

B. Digital Rock Sample

Rock samples are important geological assets as they can be used to describe the rock properties of the outcrop, and they can be digitized and made into an interactive VR rock and mineral identification exercise [40], [41], [42]. Its digital reconstruction follows a similar procedure as the outcrop models using the digital photogrammetry workflow but with images acquired in the laboratory.

C. Spherical Panoramic Images

Spherical panoramic images are 360° spherical images that allow the visualization of all the surroundings around a nodal point, centered on the position of a remotely piloted aircraft (RPA), mobile app, or 360° dedicated camera, and can be converted into an interactive panoramic image, navigable in 360°. This technique allows a wide visual perspective of the landscape, allowing a vantage point when acquired by RPAs as similar perspective is impossible to obtain by a satellite, conventional plane, or by an observer on the ground.

D. Additional Files Used in the iVFT

The proposed iVFT structuring also considers essential learning materials like audio academic reference files, videos, additional images, and explanatory texts that will guide the user while learning the geological context of the region.

The audio and video files can be used to introduce and exemplify certain aspects of the studied location, highlight subtle geological features, or present prior geological knowledge to the student. The 2D image files can represent maps and photographs from different periods, while a catalog of images from a region can provide historical changes in vegetation and erosion over the years.

E. GDC Package Generation

After acquiring all necessary data for the iVFT, the user needs to create and structure GDCs packages before using them in the Mosis LAB software by accessing the GDC Package Generator available on the website https://package.mosis.vizlab.cc.

[6] https://sketchfab.com/
[7] http://www.svalbox.no/

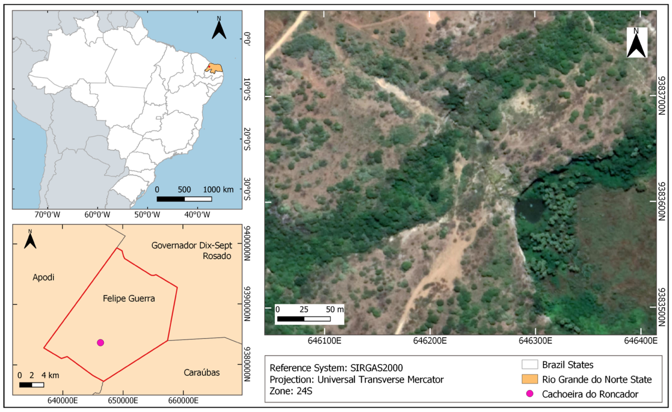


Fig. 5. Localization map of Cachoeira do Roncador outcrop.

The iVFT file import begins by following the instructions at the website when filling the form from top to bottom. The process continues by guiding the user creating and naming a main GDC package for the iVFT and including the DOM files that will anchor the other GDCs by declaring the geographic border limits values of the imported DOM model and texture. In the next steps, a set of GDCs can be included by adding a name, description, and geographic coordinates for each GDC.

To finally experience the iVFT, the user should use HDM iVR systems such as Oculus Rift and HTC Vive accompanied by a compatible personal computer with the minimum requirements suggested by the HMD manufacturer and the SteamVR application.[8]

V. iVFT Prototype Study Case

The proposed iVFT prototype used in this article is presented below detailing the data necessary to guide a proper understanding of the geological aspects of the studied region. This detailing starts by describing the geological settings in which the DOM (the central element of the iVFT) was acquired. This primary element can represent other types of environments and sites like construction areas, historical monuments, biomes, etc., however, the studied geological site is used to limit the scope of this article and to evaluate the acceptance and overall perception of geology students and professionals.

A. Case Study Geological Setting

The Cachoeira do Roncador outcrop is a rocky exposure along the course of an intermittent river in the Brazilian semi-arid biome *caatinga*, in the municipality of Felipe Guerra/RN, Brazil (see Fig. 5). This region of study is a succession of two outcropping cliffs walls of approximately 10 m high, spread horizontally about 100 m from one to another, resulting in three baseline platforms of carbonate rocks. This outcropping region belongs to the Jandaíra Formation (Apodi Group, Potiguar Basin) [43], which is composed of bioclastic and intraclastic *mudstones* and *grainstones* [44], postdiagenetic carbonate tuffs, rocks generated by the dissolution of carbonates at room temperature, that also occur in Quaternary ages. This formation marks the upper portion of the Apodi Group and has characteristics of deposits such as carbonate ramps in a shallow sea environment.

[8] https://store.steampowered.com/app/250820/SteamVR/

B. Field Data Acquisition

Fieldwork to acquire the 3D model of the target outcrop used different methods of data acquisition. Field planning steps considered Google Earth data, additional databases for aerial satellite images, and previous surveys that could aid the field trip planning to acquire the most recent 3D landscape features of the Cachoeira do Roncador. These data were used to build a map of the study region, with information on the geologic disposition and type of the outcrop, coordinate grid, distribution of control points, and relief. This information helped us to plan the acquisition of the DOM, considering the weather and security conditions in the field.

The outcrop acquisition to obtain a 3D model employed the RPA image acquisition and digital photogrametry SfM processing as proposed by Westoby et al. [2], [45]. Additional activities to retrieve outcrop data were also planned to collect plugs and samples for laboratory analysis and 3D modeling, to capture spherical panoramic images, and to obtain audio and video recordings (for field descriptions).

In the field, the aerial photogrammetric survey was carried out using an RPA DJI Mavic 2 and georeferenced using a Global Navigation Satellite System Real-Time Kinematic. Given the outcrop extension and relief, the aerial photogrammetric survey was divided into several flights allowing to map vertical and horizontal features of the outcrop.

In addition to the acquisition ground control points (GCPs) using GNSS to georeference the 3D models, we acquired the coordinate locations of six spherical panoramic images (terrestrial and aerial) and additional video recordings, to register the GDCs anchoring positions.

Rock samples were also collected and named according to the following code: CR-19-000-a. The initial CR is the abbreviation for Cachoeira do Roncador; the number 19 indicates the year 2019; the numbers that follow the year indicate the number of the sample, which was increased by 1 for each new sample.

C. Mosis LAB File Import

The processed field data obtained from the digital photogrammetry (point clouds, textured triangulated models, and orthophotos), added to the georreferencing data of the samples, 2D and spherical panoramic images, audio and video files, and supplementary bibliographic materials were used as basis for the construction of the iVFT prototype of Cachoeira do Roncador outcrop (see Fig. 6).

These data are separated into folders based on their respective position including bibliographic materials (texts and images) that contribute to the geological understanding of the study region highlighting the desired geological concepts the learners need to observe. Thus, these files were uploaded to

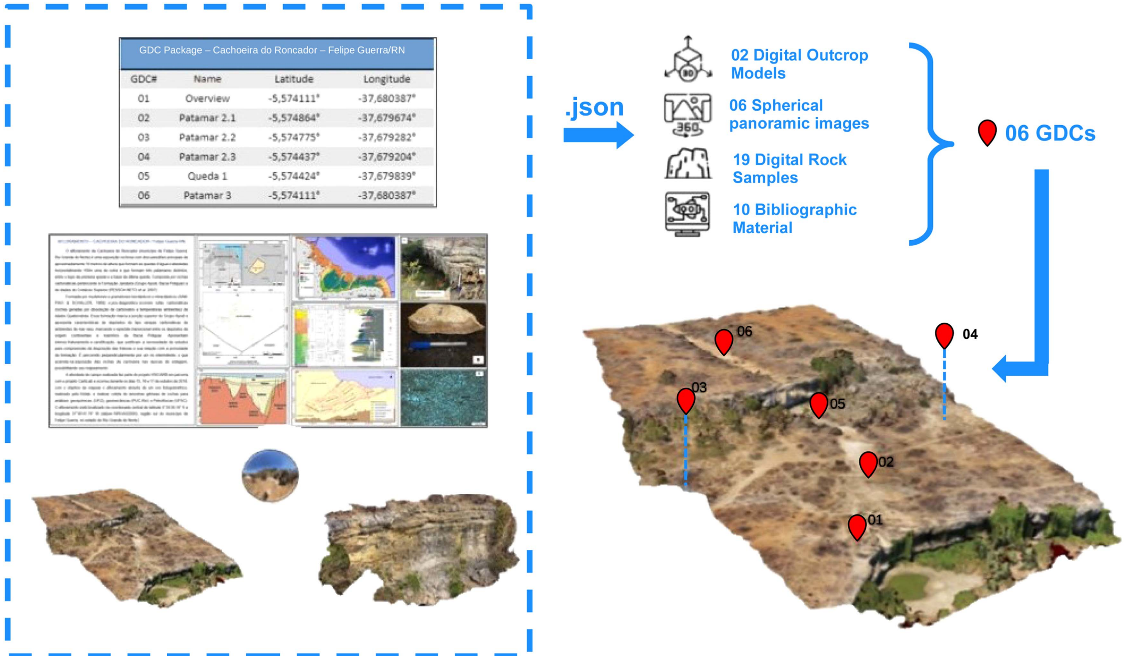


Fig. 6. GDCs coordinates, GDCs positioning over the DOM, and number of file elements used for the iVFT of Cachoeira do Roncador.

the GDC Package Generator that generated compressed files (the GCPs) for later import on the Mosis LAB Software through its respective.json file (see Fig. 6).

The GDCs imported in the Mosis LAB allows many forms of visualization and interaction with objects within the iRV environment, providing dynamic, and responsive interactions that adapts to the available data in each container.

The proposed iVFT of Cachoeira do Roncador was experienced by the users through an Oculus Rift S HMD, and an MSI computer with an Intel i7 sixth generation with 64 GB of RAM and a GTX1080 dedicated graphics with 8 GB of video RAM.

D. iVFT Experience and Evaluation

The iVFT of Cachoeira do Roncador was tested with geoscientists and geology undergraduates at the 1st Petrobras Internal Congress on Geology and Geoengineering, and at the University Center of Svalbard (UNIS) when performing demonstrations of the Mosis Software Suite, from November 26, 2019, to November 29, 2019, and from February 27, 2020, to February 28, 2020, respectively. The technology acceptance model (TAM) questionnaire was applied to 80 test users of the iVFT during the presentations of the Mosis LAB software.

The TAM methodology proposed by Davis et al. [46] is an adaptation of the theory of reasoned action (TRA) model. However, the TRA model was modified by Davis et al. [46] due to its wide scope, to create models of acceptance in information technology. The created TAM model is based on two theoretical constructs: perceived utility (PU) and perceived ease of use (PEU), suggesting that both mediate the effects of external variables, such as system characteristics, development process, training, and intention to use.

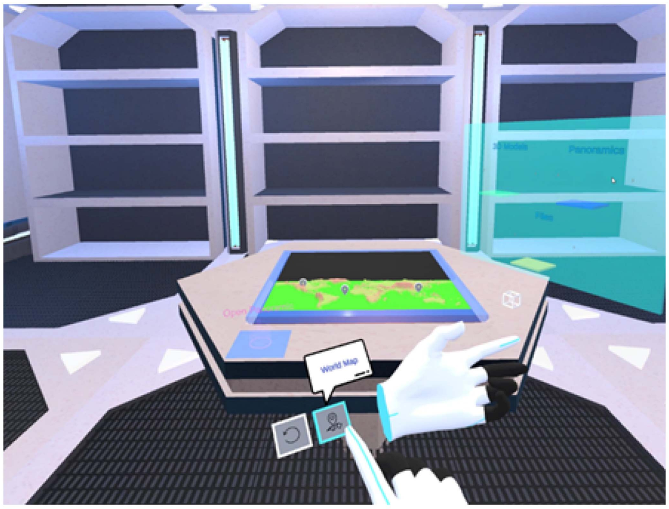
Davis et al. [46] define PU as the degree to which a person believes that the use of a particular system can improve its performance, whereas PEU is the degree to which a person believes that the use of an information system will be effortless. It suggests that individuals will use some technology if they believe it to provide positive results. The TAM is a behavioral model, and it can only refer to issues directly related to the user perceptions of a system; therefore, the theoretical constructs should be developed to capture personal opinions and deal with assumptions about third parties (people or institutions). This model is useful to identify why users do not accept a particular system or technology and, consequently, implement the appropriate corrective steps [46].

The used TAM questionnaire used the Likert scale, which is a psychometric response scale that measures the user's level of agreement or disagreement by providing directions on the respondent's attitude toward each statement. The number of levels on a Likert scale varies, five being the most used, while others may contain between four and ten levels always chosen by the researcher.

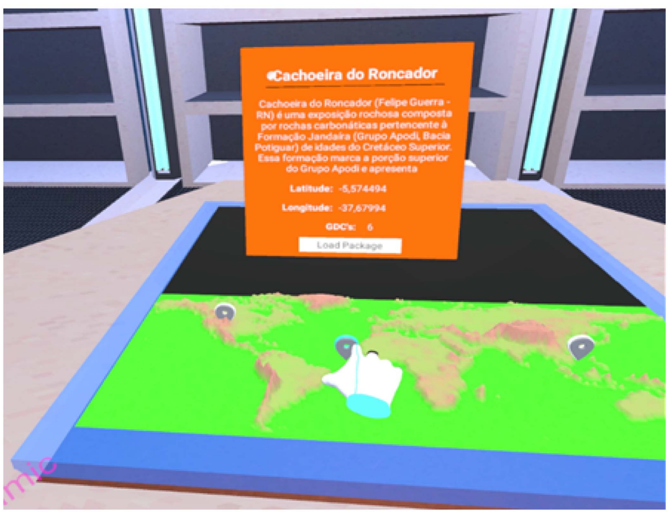
The TAM questionnaire employed was built to analyze four items (education level, occupation, and familiarity with VR, and age) in addition to other 18 items that formed the theoretical constructs: PU, PEU, perceived immersion (PI), perceived presence (PP), and behavioral intention (BI). The proposed questionnaire was built using the Likert scale from 1 (strongly disagree) to 7 (strongly agree).

VI. Results

The first result of this article is the iVFT creation itself based on observational concepts as presented in Section IV, being supervised by a professor. Regarding the iVFT creation, this is

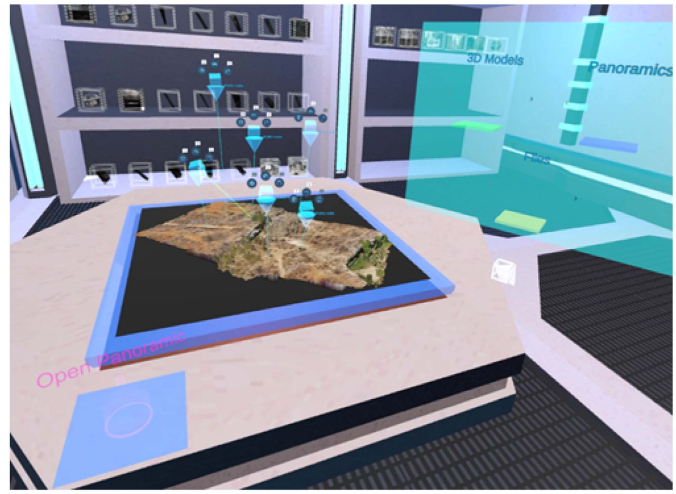


(a) Selecting tool on left wrist.

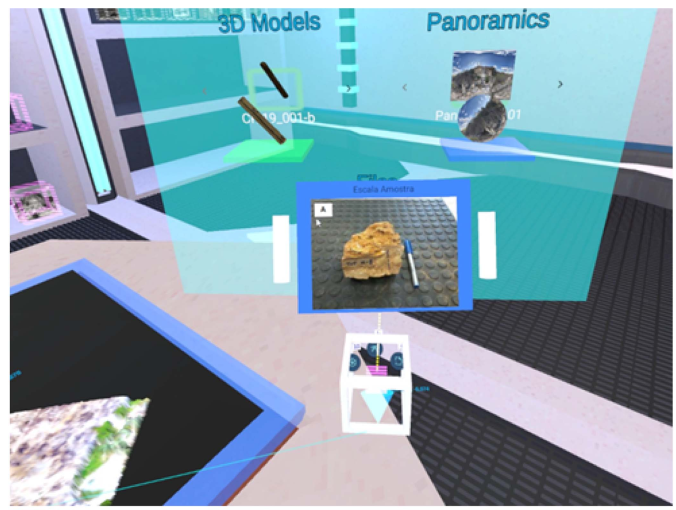


(b) Visualizing GDC information.

Fig. 7. iVFT GDC *Package* selection.



(a) Main DOM visualization and available GDCs in blue.



(b) Visualizing and handling the GDC content.

Fig. 8. Visualizing and handling the GDCs during the proposed iVFT considering the users' point of view.

an easy procedure; however, with multiple small details to follow given the complexity of the iVFT and scope, this procedure can be more demanding. This is due to the attention needed when planning the iVFT beforehand as the students can have different outcomes through the learning process, scenery also encountered in traditional classes and field trips, with the caveat that the iVFTs can be new to both geoscience professors and students.

A. User Experience Within iVR

With the iVFT composed by its respective GDCs loaded in Mosis LAB, we then proceed with the user experience and acceptance evaluation. Within the iVR system using the Mosis LAB, the user gets the impression of being teleported to an immersive virtual environment as expected, finding himself immersed in a virtual laboratory, with virtual hands (guided by the controllers) to interact with the environment. This is illustrated in Fig. 7(a), where the user can see in his/her left wrist options to load a global map, and refresh or close the application.

By pressing the global map loading button on the left wrist with the virtual finger, the user loads a 3D model of the world map on the virtual table. In the 3D model, it is possible to identify the approximate location of all *GDC Packages* previously created and loaded in the Mosis LAB. Then, the user can select the desired GDC Package (the Cachoeira do Roncador in this case) and read the information contained therein before loading it into the system [see Fig. 7(b)].

The system then loads the iVFT and the user can see that all the files stored in the GDCs present in the *GDC package* of the iVFT of Cachoeira do Roncador are now filling the shelf on the back. It is possible to note that the 3D model on the table was replaced by the DOM of Cachoeira do Roncador. The additional GDCs are placed as "holographic" blue boxes previously positioned containing the respective files for its locations [see Fig. 8(a)].

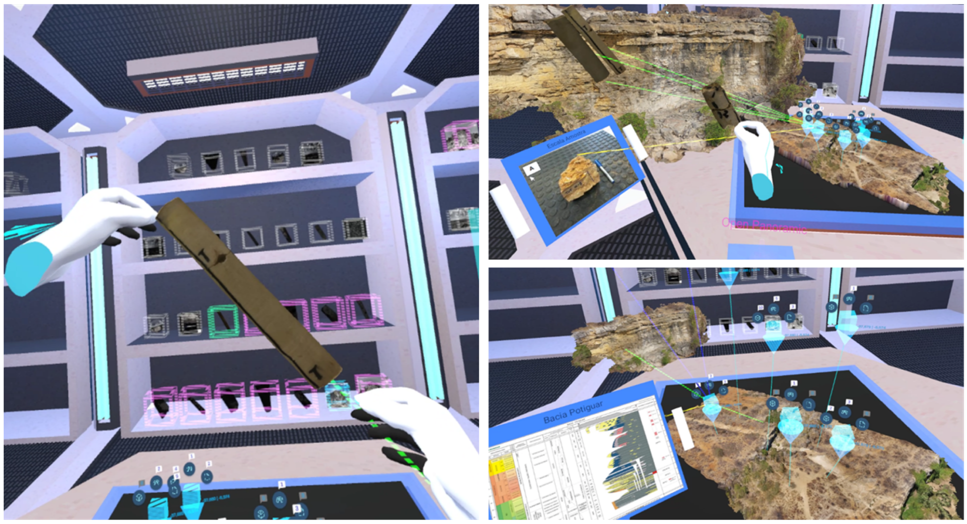


Fig. 9. Data manipulation and correlation within the VR space.

Fig. 10. Spherical image view of the studied outcrop and object manipulation within the same environment.

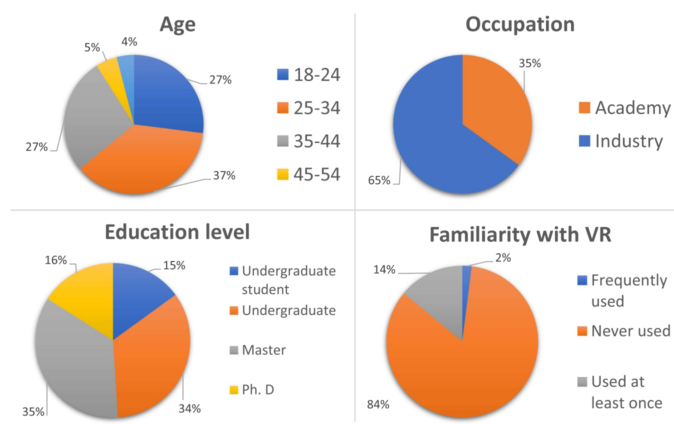


Fig. 11. Participant profile.

The user can manipulate these GDCs and access the files contained therein, placing the desired GDC inside the white diegetic cube under the greenish panel (floating right panel). After that, when releasing it inside the cube, the GDC files are loaded to the panel, which, when selected, materialize its content for manipulation [see Fig. 8(b)].

3D objects in the virtual environment can be handled, scaled, and positioned anywhere in the virtual space of the room (see Fig. 9), making it possible to correlate information and to build the geological knowledge of the region with the support of supplementary bibliographic materials included in the system.

To provide a greater sense of presence and immersion in the outcrop, spherical panoramic images, represented in three dimensions by a miniature 3D sphere (see Fig. 10), were included. The user can view them in the first person and even access them by carrying 3D sample objects through the panoramic image viewer. To return to the virtual laboratory, the user can end the spherical panoramic image display by selecting the return button on his left wrist.

The user can experience the outcrop from terrestrial panoramic images as well to facilitate the viewing of rock structures, sample acquisition points, lithological limits, and contact relations in the outcrop scale, while having an overall perception of the geomorphology and macroscopic structures of the region from aerial panoramic images extending the real field possibilities in this mesoscale view (see Fig. 10).

B. Evaluation

For better analysis of the acceptance results, we segmented the TAM questionnaire responses into two overlapping groups' data. The first considers the familiarity with VR, highlighting the different responses between users familiar with VR and those not familiar with VR. The second group identified for analysis considers users from the academy (professors/students/researchers) or industry, mainly geologists and other scientists in the petroleum industry. Fig. 11 shows how the data are segmented according to these groups and concerning age and education level.

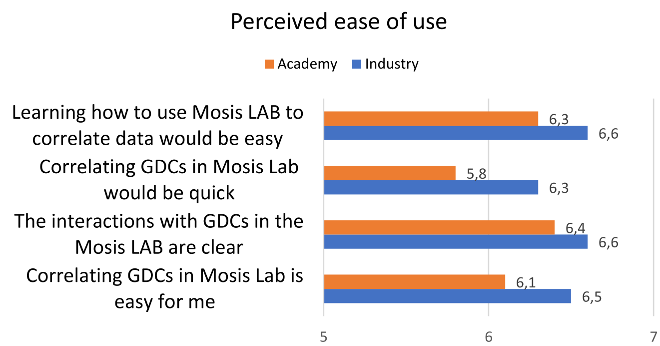


Fig. 12. Perceived ease of use.

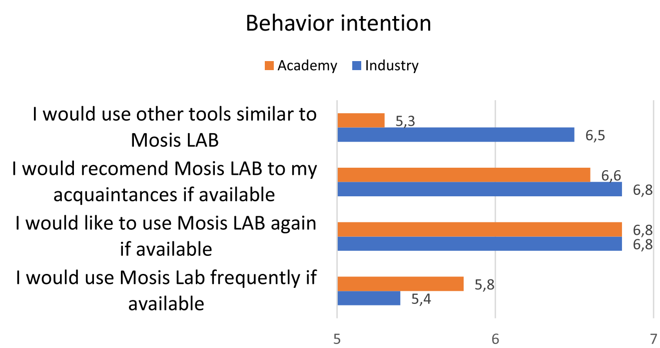


Fig. 13. Behavioral intention.

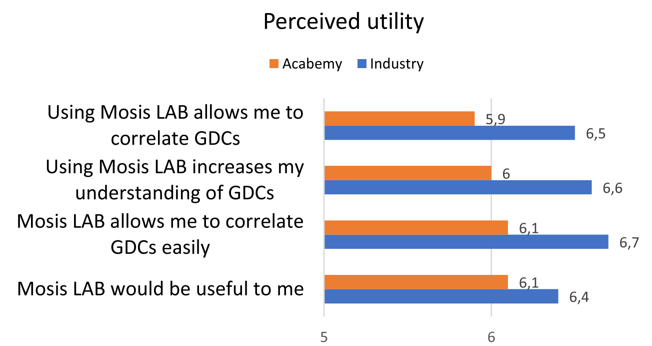


Fig. 14. Perceived utility.

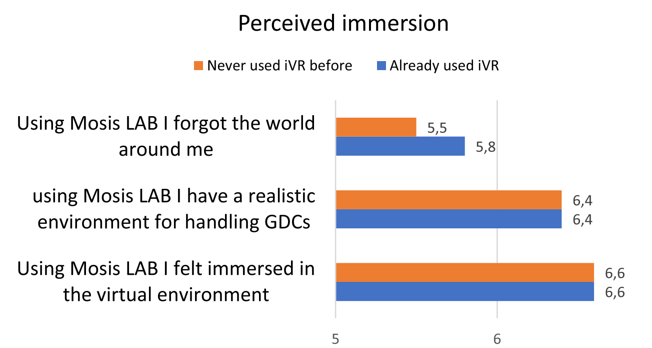


Fig. 15. Perceived immersion.

Figs. 12–14 show the PEU, BI, and PU regarding Academy and Industry participants. Considering Fig. 12 for PEU, most respondents strongly agree that the iVFT of Cachoeira do Roncador makes it possible to correlate geological information easily and clearly through the interactions developed, requiring little effort to learn how to correlate such information.

Considering the results in Fig. 13 for BI, we observe that industry professionals would be more inclined to make use of iVFT for education and sharing geological information of their study sites routinely and would use the app again if available. Considering Fig. 14 showing results for PU, the participants from the industry again scored higher for the questions presented. We believe that this is due to the greater field experience that these participants have, making it easier for them to correlate the Mosis LAB usage with the day-to-day tasks, while for the academy participants, this notion is incipient or nonexistent.

For the items PI and PP, the question results for the participants that used an iVR system before and those that used it for the first time are presented in Figs. 15 and 16, respectively. It was noticed that the iVFT of Cachoeira do Roncador through the use of HMD enabled a high degree of immersion in the virtual environment, both for those who had never used iVR systems as for those who had already experienced iVR devices, as shown in Fig. 16. Likewise, the sense of presence in another environment was even higher as almost all the respondents strongly agreed that they felt in another location, as shown in Fig. 15, especially when they accessed the panoramic spherical images, as reported by users.

Considering that the participants from UNIS used the Mosis LAB during the test class, we can highlight that the students interacted more with static information (text and images) than

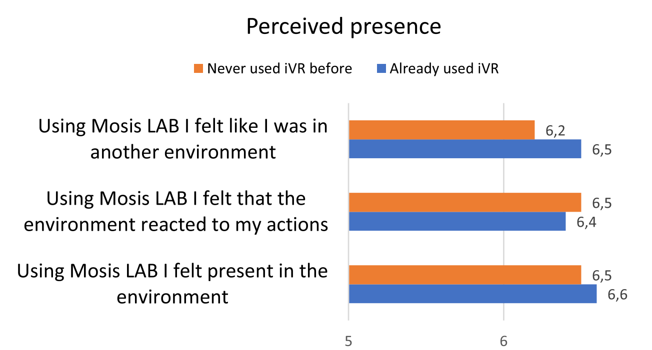


Fig. 16. Perceived presence.

they would in class or on a field trip as the interactions with the GDCs bring a new ludic layer that is not possible to replicate in the real environment.

VII. Considerations

The advancement of technologies and digital resources, as well as their impacts on society, have produced changes in our way of life and, consequently, affect education at all the levels. Difficulties like long distances between students and schools, lack of accessibility, and environmental and health hazards like endemic and pandemic healthy issues (e.g., COVID-19) [47] have demanded new ways of building and reconstructing knowledge, for example, with new forms of teaching and learning through the use of digital and virtual resources. That is a new scenario for education, which focuses on the pedagogical and technological use of computer-based and virtual reality in numerous initiatives and methodologies. From this perspective, the presence of virtual reality in universities needs to be intensified, especially to expose students to a wide range of experiences.

Despite the iVR potential to be a tool of fundamental importance, it fails in some cases [48], [49]; however, as seen in prior studies and in this presented work, it brings exceptional results [47], [48], [49], [50]. To evaluate this approach, this article employed the TAM model to evaluate the technological acceptance and overall perception of the proposed iVFT to the geoscience community. The results show that users from both industry and academia were positively impacted by the field experience in iVR, allowing them to correlate geological information with easiness and thoroughly, improving their understanding of a study region never visited before by them.

Therefore, the results corroborate with the general hypothesis of this research, concluding that the iVFT can extend field access to field activities, through an iVR data manipulation approach. The BI of the users was determined by the PU and PI constructs. It is worth mentioning that the PU has high influence on the BI, which legitimizes the results obtained by Davis et al. [46], once again proving the direct effect of the utility perceived in the intended use and reaffirming this construct as the most relevant in assessing the acceptance of systems.

Regarding the proposed work method, we systematically sought to structure the different elements that can contribute to the iVFT experience in a workflow that facilitated its reproducibility and, in the same way, the creation of numerous iVFT by instructors who may use this method in their field activities. This was only possible due to the characterization of the challenges inherent in field trips (restricted mobility, difficulties in access, etc.), recently aggravated by the budgetary restriction policies applied at universities around the world, and the COVID-19 pandemic. This theme will continuously be addressed since the nature of fieldwork geoscience education is changing rapidly, and new technologies and the continued financial pressures imposed on departments will continue to drive the development and integration of iVFTs.

This will lead to new research on this topic as the universities and industry will seek to extend access to geoscience education and training, considering that the real difference in the technology used to simulate a field trip is immersion and interactivity. In this landscape, students will have first-person experiences and make decisions and interactions with proper feedback, while learning outcomes are yet to be analyzed. Meanwhile, students and teachers have the possibility to create and share their virtual objects (DOM and digital sample models) and experience through a framework that facilitates knowledge sharing. Thus, the limits of using iVR in an educational environment are not in the technology itself, but in how it is used to teach and how students learn.

Although full iVR is certainly more immersive than the use of web browsers or the not iVR, a broader study highlighting its additional educational benefits in geosciences is yet to be carried out [49]. For comparison, the work of Zhao et al. [31] carried out a preliminary study in this sense; however, as pointed out by the authors the number of iVFT users was much smaller than the control groups, and the iVFT experience was confined by the actual physical space of the traditional field trip, while our method and software allow free movement over the outcrop studied.

Instructors and professors highlighted the need of additional pedagogical resources that could be incorporated in the proposed iVFTs, e.g., guided questionnaires or treasure hunt activities; however, these resources should be provided by the instructors themselves in future iVFTs using our proposed framework. For the professionals and students experiencing the iVFT, the immersive approach simulating a real scenery brought positive impressions due to the high interactivity provided by the proposed iVFT combined with the Mosis LAB software; however, a greater evaluation of pedagogical aspects is still needed.

In summary, the contributions of this article are as follows: 1) the workflow for iVFT creation and structuring; 2) the presentation of data acquisition steps necessary when creating an iVFT for geology classes; 3) an iVFT use case of a real studied geology scenario; and 4) users' acceptability and perception evaluation when using the proposed iVFT. Future works will expand the presented concepts creating a participatory iVFT, which will enable the integration of other learning techniques and field activities while evaluating additional teaching and learning gains of the iVFTs.

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Rafael Kenji Horota received the Geology and M.Sc. degrees in applied computing from Unisinos University, São Leopoldo, Brazil, in 2020. He is currently working toward the Ph.D. degree with the University Centre in Svalbard, Longyearbyen, Norway.

He is also a Geologist with the University Centre in Svalbard. His research interests include virtual field environments and its applications in immersive virtual reality for field education and research on geosciences and photogrammetric field data acquisition using unmanned aerial vehicles and embarked sensors applied in geological analysis.

Pedro Rossa received the master's degree in applied computing from Unisinos University, São Leopoldo, Brazil, in 2020.

He is currently a Digital Games Technologist with Unisinos University. He is a former Researcher and a Laboratory Manager with the Vizlab | X-Reality and GeoInformatics Lab, Unisinos University, where he is currently a Full Game Developer.

Ademir Marques Jr. received the M.Sc. degree in computer science from São Paulo State University, São Paulo, Brazil, in 2016, and the Ph.D. degree in applied computing from Unisinos University, São Leopoldo, Brazil, in 2022.

He is currently a Researcher with the Vizlab | X-Reality and GeoInformatics Lab, Unisinos University, working on machine learning and pattern recognition for data analysis, image processing, and geostatistics in geological data.

Luiz Gonzaga Jr. (Member, IEEE) received the M.Sc. and Ph.D. degrees in electrical engineering from the State University of Campinas, Brazil, in 1996 and 2005, respectively.

He was a Lecturer and Professor Unisinos University, São Leopoldo, Brazil, where he cocreated and coheads the Vizlab | X-Reality and GeoInformatics Lab. His research interests include computer vision, real-time computer graphics, graphics processing unit programming, and immersive visualization with a strong interest toward geoinformatics applications.

Dr. Gonzaga is a Member of the IEEE Computer Society, the Association for Computing Machinery (ACM), and the ACM Special Interest Group on Spatial Information and Special Interest Group on Computer Graphics and Interactive Techniques.

Kim Senger received the Ph.D. degree in geology from the University of Bergen, Bergen, Norway, in 2013.

He is currently an associate professor of Structural Geology with the University Centre in Svalbard, Longyearbyen, Norway. His research interests include using emerging technologies to enhance both geoscience teaching and research, as well as workflows related to the quantitative interpretation of virtual outcrop models.

Caroline Lessio Cazarin received the M.Sc. degree from the Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, and the Ph.D. degree from Brasília University, Brasília, Brazil, in 2015 and 2021, respectively, both in geology with focus on hypogenic karst.

She is currently a Geologist specialized in karst processes and carbonate reservoirs with the Petrobras Research Center, Rio de Janeiro, Brazil. Since 2013, she has been working in coordination and management of R&D projects. Her research interests include fractured and karstified reservoirs, flow simulation, and digital and virtual outcrop models.

André Spigolon received a degree in geology and the M.Sc. degree in regional geology from the University of Brasília, Brasília, Brazil, in 2000 and 2003, respectively, and the Ph.D. degree in geology from the Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, in 2014 in collaboration with the American Geological Survey (USGS).

He is currently a consultant in geology with Geochemistry Management (GEOQ), General Management of Research and Development in Innovation, Exploration, and Production, Centro de Pesquisas e Desenvolvimento da Petrobras (PDIEP/CENPES), where he is a Consultant in the coordination, management, and technical dialogue of internal R&D projects and terms of cooperation with national universities and foreign research institutions in multiclient projects. He is a Specialist in organic-geochemistry and basin analysis, with an emphasis on the source rocks characterization, oils and gases, as well as kinetic and organic facies modeling.

Maurício Roberto Veronez received the M.Sc. and Ph.D. degrees in transportation engineering from the São Carlos School of Engineering State University, University of São Paulo, São Paulo, Brazil, in 1998 and 2004, respectively.

He was a Lecturer and a Professor with Unisinos University, São Leopoldo, Brazil, where he cocreated and coheads the Vizlab | X-Reality and GeoInformatics Lab. His research interests include global navigation satellite systems, remote sensing, digital imaging, and immersive visualization with a strong bias on geoinformatics applications.