

# Performing submarine field survey without scuba gear using GIS-like mapping in a Virtual Reality environment.

Jérémie Billant  
*Université Côte d'Azur, CNRS,  
Observatoire de la Côte d'Azur,  
IRD, Géoazur  
Valbonne, France  
jeremy.billant@geoazur.unice.fr*

Nuno Gracias  
*University of Girona  
Girona, Spain  
ngracias@eia.udg.edu*

Júlia Bozzinio  
*University of Girona  
Girona, Spain  
jbozzinobastit@gmail.com*

Klemen Istenic  
*University of Girona  
Girona, Spain  
klemen.istenic@gmail.com*

Frédérique Leclerc  
*Université Côte d'Azur, CNRS,  
Observatoire de la Côte d'Azur,  
IRD, Géoazur  
Valbonne, France  
leclerc@geoazur.unice.fr*

Aurelien Arnaubec  
*Ifremer  
La Seyne-sur-Mer, France  
aurelien.arnaubec@ifremer.fr*

Javier Escartin  
*IPGP CNRS UMR 7154  
Paris, France  
escartin@ipgp.fr*

Rafael Garcia  
*University of Girona  
Girona, Spain  
rafa@silver.udg.edu*

**Abstract**— Geomorphological and geological studies of the seafloor benefit today from both ROV exploration and from acquisition of high resolution bathymetric data. Although both represent significant improvements to study submarine domains, the understanding of the studied objects is made more difficult than on land given the limited visual perception provided by the ROV camera due to the attenuation of light in the water and the need to use artificial illumination. Likewise, mapping can be performed using GIS software for digital elevation models and its derivatives (e.g. slope or shade raster), mostly in a 2D map view only. So, the submarine studies lack the field survey stage performed in classical onshore works that allows clear visualization and appreciation of the studied objects.

Our aim is to develop a solution allowing the visualization of Digital Elevation Models (DEM) and 3D models derived from Structure-from-Motion (SfM) within a virtual reality environment, and to use these data for geomorphological and geological analysis. For this, we use an Oculus Rift headset, Touch controllers, and the Unity game engine, with GIS-like interaction capabilities.

The free and open Unity package that we are developing allows, at this stage, data visualization and working at a 1:1 scale in a georeferenced system. The user can therefore move freely within a 3D immersive environment that includes custom topographic data. For quantitative observations, we develop tools (ruler, compass) allowing measurements similar to those performed during geomorphological or geological field work. We also add the possibility to map objects. Digitizing in 3D is achieved with a laser pointed towards the data, providing great precision. The user can thus create pseudo shapefiles using the same three graphic primitives, and that are compatible with standard GIS software. Beside these functionalities, we also implement a spatial user interface displaying help and information and a teleportation tool preventing motion sickness.

The users that have tested this solution are enthusiastic and agree that it helps to better appreciate and understand the shape

and geometry of the studied objects. It was also used to present and explain 3D models of outcrops to master students. Further developments will port the solution for other headsets, facilitate the data import (e.g., standard file formats for 3D objects and DEMs), create and manage of multiple layers of shapefiles, and include multiplayer online gaming capabilities to allow remote co-working with colleague(s) at other distant locations, or a whole classroom.

**Keywords**—Virtual Reality, GIS, Geosciences

## I. INTRODUCTION

The recent advances in data acquisition (aerial imagery, multibeam bathymetry, Lidar, and photogrammetry) produce increasingly accurate models of our environment, that can reach millimeter resolution. The Earth sciences based on topographical analyses benefit significantly from these improvements, and detailed and accurate mapping of natural objects can now be performed from a desktop using GIS software. The usefulness of the analyses made using these existing tools is not contested, but even if several software propose 3D data visualization, the view through a screen cannot offer the same appreciation than direct observation of the scale, shape, and geometry of the studied objects, and of the spatial relationships between them for a qualitative survey. Offshore studies are particularly affected by these limitations. Indeed, regional-scale analyses can only be performed using indirect observations (multibeam bathymetry, backscatter and side-scan sonar imagery) whereas high-resolution observations are performed using Remotely Operated Vehicles (ROV) mounted with cameras that can only offer a limited and narrow view field due to the lack of ambient light, in addition to other constraints (e.g., turbidity, backscatter). Although SfM techniques are now frequently applied to ROV videos and make it possible to create tens meter wide 3D models of submarine structures and outcrops [1][2], our appreciation of these objects is still limited by the 2D-

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3D visualization we can make of them through a computer screen.

Developed for the first time within the 70s at the Utah University by Daniel Vickers [3], the R&D of the Virtual Reality (VR) was then and is still nowadays mainly supported by and used in the videogame industry. However, the potential of the VR for research and teaching was noted by numerous researchers [4][5][6] including geoscientists [7][8][9][10][11]. Currently, one of the most advanced project using VR for geosciences is the Keckcaves which already proposed useful tools for mapping [12] and Lidar data processing [13]. However, visualization at a 1:1 scale is missing within these solutions and they were limited to the use of whole dedicated room until recent upgrade.

Despite the keen interest of the geosciences community for the virtual reality, no free tool is yet available that allows to import data from different sources, with standard DEM digital formats, and to map the objects within a VR environment at the user scale, using a VR headset, and export the mapping results for further analysis. Therefore, we initiated the development of a new solution presented hereafter in order to facilitate topographic data analysis from any sources.

## II. SETUP

### A. Hardware

We choose to develop our solution for the Oculus Rift (Fig. 1) and Oculus Rift S because those virtual reality headsets provide a good performance for their relatively affordable cost and are associated with controllers that can offer many possibilities for our purpose. Both headsets are equipped with a tracking system (Fig. 1) allowing movement with 6 degrees of freedom which means that translations and rotations of the headset within the real world can be reproduced within the virtual environment. The Touch controllers (one for each hand, Fig. 1) are tracked the same way, which means that position and rotation of the user's hands can also be reproduced within the virtual environment. Controllers both contain one clickable thumbstick, three buttons and two triggers (i.e. a button sending an input depending on how far the user pressed in) allowing a wide range of interactions at each moment of the utilization of the software.

Because virtual reality implies to render a 3D scene twice (one per eye), the user's computer needs sufficient specifications. According with the manufacturer of the Oculus Rift, minimum specifications are a NVIDIA GTX 1050Ti GPU, an Intel Core i3-6100 CPU and 8 GB of RAM. However, in our case, we want to render heavy datasets (DEM and 3D models with resolution of a few decimeter and millimeter respectively) without degrading the data and losing precision, which implies that this configuration is insufficient. For example, despite the use of a computer with better CPU (Intel Xeon E3-1505M v6), better GPU (Radeon Pro WX 7100 Graphics) and four times more RAM, we still experience slow-down for the heaviest 3D models. Consequently, we recommend the use of a higher performance computer to take full advantage of the software we are developing and presenting below.



Fig. 1. Oculus Rift headset with two sensors used for localization and the two Oculos touch controllers. The Oculus Rift S is similar except that it use embed camera for headset localization instead of external sensors.

### B. Software and data importation

We develop our solution using the Unity game engine (<http://unity.com/>). It is a software-development environment used to create video games. We use a game engine as it provides already the tools and pipelines dedicated to the rendering, physics networking, and memory management, and therefore allows focusing on the development of the wanted functionalities. The Unity game engine has the advantage of being user-friendly, allowing the development of new functionalities using personal C# scripts, while benefitting from a large user community sharing information. Moreover, Oculus provides tools and packages allowing quick integration of the Oculus Rift within Unity.

Currently, the topographic data are imported within Unity as a mesh; raster data are converted to mesh using ad-hoc scripts, and compiled via Unity together with the GIS-like tools we developed. One should note that the Unity game engine uses 16-bit mesh buffers and 32 bit floats. This means that one single mesh cannot be composed of more than ~64k vertexes and that coordinates of the objects can only have seven significant digits leading to round coordinates when using true geographic coordinates (projected or not). To counter these limitations, >64k vertexes meshes are split in smaller parts and data are shifted to be centered on the game engine coordinates origin. This offset is recorded inside a local file in order to correct the coordinates within the software in real time. A future version of our solution will avoid this preparation stage (see Ongoing development).

## III. CURRENT FUNCTIONNALITIES

### A. Visualization and user interface

Our solution allows the visualization of 3D models and topographic data at a 1:1 scale in a 3D immersive environment (Fig. 2). This way, the user can fully appreciate the scale, shape and geometry of the studied objects as well as their spatial relationships (e.g. following a tilted discontinuous feature along a relief).

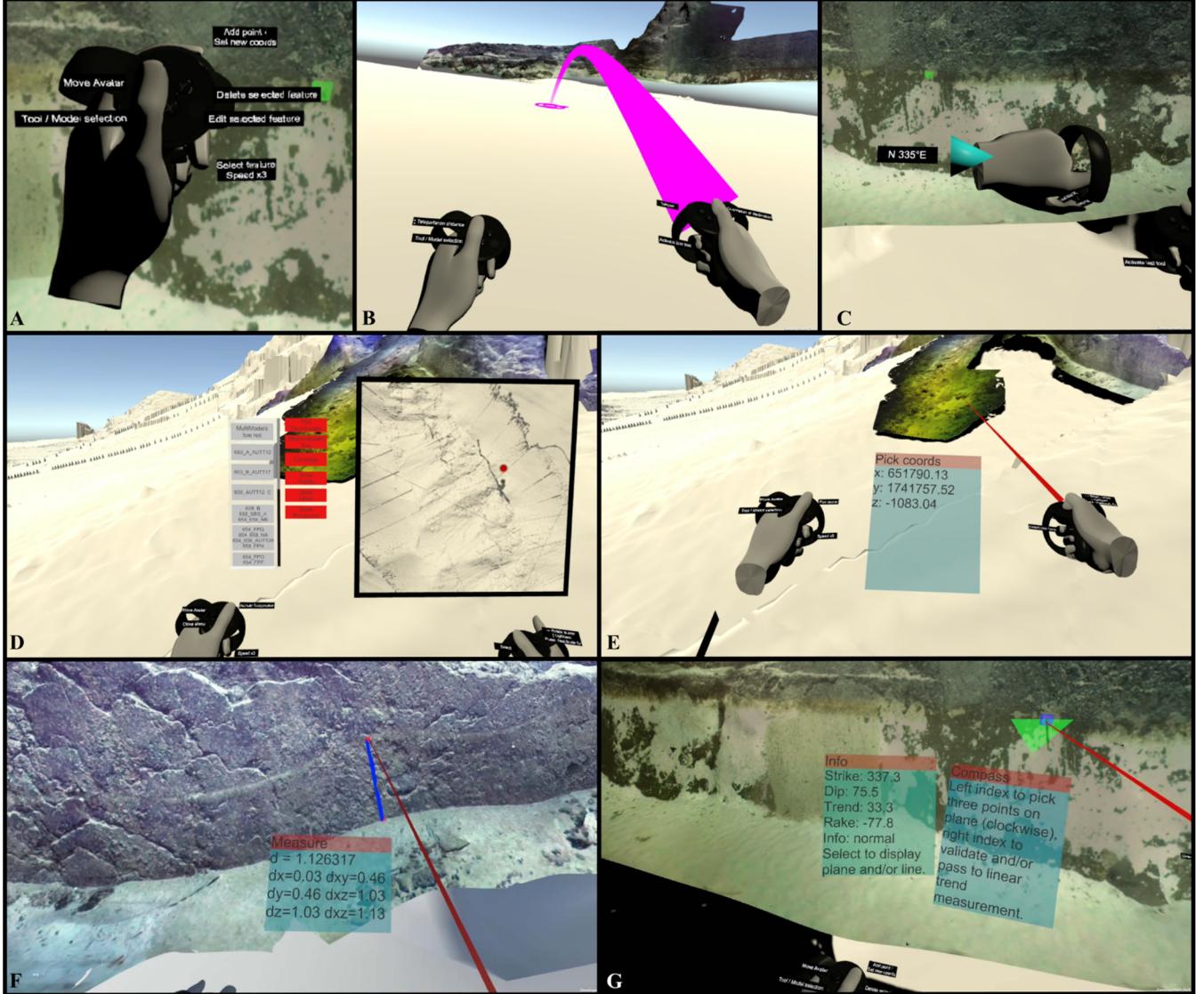


Fig. 2. A-Controls display. B-Teleportation tool. C-Quick compass view. D-Menu with tool' selection and localisation map. E-Coordinates Picking. F-Ruler. G-Plane and line measurement tool.

Within the software, the user has an avatar which allows displaying his/her hands and the controllers that he is holding. Controls related to each thumbstick, buttons and triggers are also displayed in real time (Fig. 2A) which allows new users to easily use the software. A more detailed explanation about the usage of the tools is also displayed when they are activated.

#### B. Navigation and localization help

The user can move freely within the environment using the two thumbsticks. Controls are similar to those found in video games. When on the ground, the left thumbstick allows walking forward, backward and on the side, whereas the right one allows clockwise and anticlockwise rotation. By clicking on the right thumbstick, the fly is activated and the users can also move freely upward and downward using the right thumbstick. Finally, one trigger button manages the multiplication factor applied to the initial velocity and so permits acceleration in order to cover long distances.

One of the main problems with virtual reality is motion sickness that some users may feel when they are moving within the virtual environment. In order to prevent this, we added a teleportation functionality. When activated, the user points the controller toward a position of the environment, and is then teleported to this place by pressing a trigger (Fig. 2B). Such a movement does not trigger motion sickness because there is not a different signal between the eyes and the inner ears.

Navigating in a huge dataset environment can result in similar problems as those found while performing a true field survey: the user can be lost or disoriented. We so implemented a quick compass (Fig. 2C) that the user can consult by looking at its watch as well as a map, that can be consulted throughout the menu and that indicates its position within the environment (Fig. 2D).

### C. Measurements

Three measurement tools are currently implemented. These tools use a virtual laser pointer commanded by the user hand that permits to point toward the object of interest. The intersection between the laser and the object can then be used to select a point (by pressing left trigger) on the topographic data, as it would be done with a mouse in standard GIS software.

The first tool simply permits to quickly access a point's coordinates and elevation (Fig. 2E).

The second tool is a ruler. The user selects two points between which the total distance as well the distances along each Cartesian axis and projected on the xy, xz and yz planes (Fig. 2F).

The third and last tool allows measuring strike (azimuth of a horizontal line within the plane dipping rightward) and dip (angle between top of the plane and the horizontal) of a plane and/or trend of a line (Fig. 2G). These measurements constitute the basic but fundamental measurements geologists are performing in the field in order to describe geological objects in space. To measure planes, the user selects three points on it, clockwise in order to orient the normal to the plane. For the trend, two points are needed, the first one being the origin and the second one defining the direction of the line. If both a plane and a line are identified (e.g. a fault plane presenting striae, or a foliation presenting a lineation) they can be measured and associated, and a rake is also computed (signed value indicating pitch and direction of movement within a plane) which defines a whole fault kinematics measurement for instance. Finally, an attribute (like a name, or ID) can be added to the measurements, like in the mapping functionalities (see below).

### D. Mapping

Mapping is made the same way that it is done within a GIS software (Fig. 3). First, the user selects the graphic primitive that he wants to use, i.e. 3D point, 3D line or 3D polygon. Then he can select a point or several nodes to form lines or polygons using the same laser pointer used in the measurement tools (Fig. 3A). When the definition of the geometry is finished, and validated by the user, a virtual keyboard (open and free VRKeys asset by The Campfire Union) is displayed and permits to add an attribute value to the shape (e.g. name, ID, Fig. 3B). Then, the created features can be deleted or edited by modifying node's position. 3D geometries associated with their attribute (Fig. 3C) can be saved as three different files, one per graphic primitive (Fig. 3D).

### E. Data export and compatibility with GIS software

The software generates four CSV files: one for each 3D geometry and one for plane and line orientation measurements. The point, line and polygon CSV files embed geometries in Well Known Text (WKT) format within the true coordinate system of the dataset and the attribute value is saved as a text field. This format permits the user to read and write on the dataset within a standard GIS software (Fig. 3D).

The plane and line measurement file also embed a WKT geometry (3D point, coordinates of the first plane's vertex or of the first line's vertex) and an attribute value. However, each measurement is also associated with the strike, dip, trend and

rake values as well as an additional geometry field defining the geometry of the plane and line for their reconstruction within the VR environment. These files are also readable and writable within a GIS software. However, editing them will not allow modifying geometry fields dedicated to VR, therefore modifications will not be visible within the VR environment. The main purpose of this file is to export the measurements to fault kinematics plotting and inversion software.

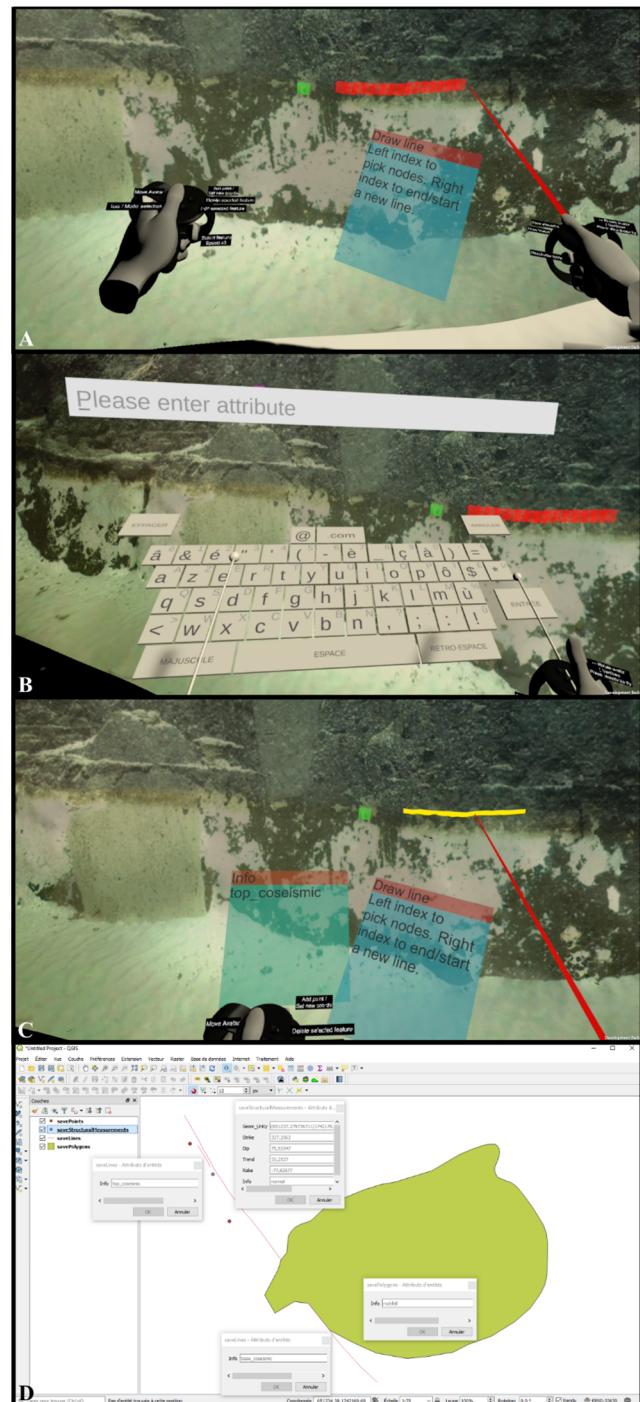


Fig. 3. A-Features drawing. B-Virtual keyboard for attribute's input. C-Interrogation and selection of an existing feature. D- Data from VR mapping opened within QGIS.

## IV. USE CASES

### A. Research

We present thereafter an ongoing study in which our software is used and in which classic survey is difficult to perform.

The 40 km long submarine normal Roseau Fault is responsible for the Mw6.3 2004 earthquake that damaged Les Saintes archipelago [14][15][16] in Guadeloupe (French West Indies). This earthquake triggered a 3.5 m run-up tsunami that flooded the nearby island coasts [14][17][17] indicating that the rupture reached and offset the seafloor. A first survey in 2013 (ODEMAR cruise [18]) operating an ROV (Victor 6000, Ifremer) documented a vertical coseismic displacement of 0.9 m at one site, as well as near-fault hangingwall cracking [19]. The Subsaintes survey (2017) [20] was therefore performed to acquire high resolution (1m) multibeam bathymetry data over the cumulative scarp, and systematic video surveys along the scarp base in order to fully characterize the surface rupture of this submarine earthquake. Videos were used to build 3D models of outcrops with millimeter resolution using photogrammetry.

In this study, we mapped this rich dataset in the VR environment using the tools we have developed (e.g. Fig. 2 & 3). In the 3D models, we identified and mapped the top and base of the coseismic ribbon (part of the fault scarp uplifted by the vertical displacement generated during the earthquake) visible at the base of the cumulative fault scarp. Mapping was performed with the laser tool, as 3D lines. By exporting the 3D lines, we were able to constrain the coseismic slip vector in several places along the fault [21]. The 3D visualization of the outcrops in VR allowed us to detect visually other markers of vertical offset, above the coseismic ribbon, witnessing the past few earthquakes. We also imported the high-resolution multibeam bathymetry, in order to analyze the morphology of the cumulative scarp and we mapped several features (dejection fans as polygons, canyons or scarps as lines), some of them are related to mid-term seismic cycle.

The complete analysis of this rich dataset, facilitated by the use of VR, will allow us investigating the rupture history and scarp evolution of the fault over different timescales.

These first uses of our software reveal that this solution has several advantages compared to standard 3D visualization or GIS software. The navigation on/around the dataset is fluent and data can be observed easily at different scales and angles. Moreover, morphological mapping is always a tricky task within GIS software because the user maps mainly slope breaks identified using shaded DEM, slope raster and/or contour levels. Within VR, the slope breaks are clearly visible and our mapping tools allows to easily point and map them. Finally, it permits analyses that approach those performed during field surveys even in areas that are unattainable otherwise.

### B. Teaching

We used our software to present the coseismic rupture of the Roseau fault to Master students of the Université Côte d'Azur Master program 3G, in the framework of a class of Active Tectonics. The first obvious advantage is that in some areas like

metropolitan France that deforms at very slow strain rate [22], it is quite unlikely that a student can see during his/her university course a real coseismic rupture. Here, it was possible to present different morphologies of the rupture (fault plane with coseismic ribbon, opening cracks, scarp on top of a blind fault) and several markers of slip on the fault (coating on the fault plane, striae and corrugations) and to discuss with them as if we were in the field.

These data were first presented through a classical medium (photographs within powerpoint presentation), then the students were invited to investigate the outcrop with the VR. A large part of the students admitted during the VR visualization that they did not think that the coseismic slip could be that high (it is locally  $>2$  m), and that the fault scarp could be that vertical. This kind of comments indicates that physical values presented or indicated on figures remain quite abstract as long as they are not directly observed. Therefore, VR can be very useful to help the students appreciate geological objects that cannot be directly observed in the field. Furthermore, VR can be developed in many ways for teaching purposes.

## V. ONGOING DEVELOPMENT

The current version of our solution is already functional and allows performing morphological and geological analysis routinely. However, we are still developing several functionalities that we consider necessary to get a more functional and user friendly software.

The first is to take advantage of the online gaming facility provided by the game engine to allow colleagues working together on the same dataset. Indeed, using a VR headset implies that only one user on the workplace can benefit of the VR environment even if his colleagues can watch what was he is seeing on the computer's screen. Such functionality will have two important advantages. It will allow collaborative work among colleagues even when some participants are remotely located (group telepresence). It will also allow engaging a whole classroom to perform virtual field courses and training.

Also, we plan to facilitate data importation by scripting the current data import process which will remove the need to use the Unity game engine for the user. This import facility should cover some of the standard and better used file formats (e.g., grd, geotiff, etc.). Moreover, the user will be able to choose to display or not some data, as it is done in standard GIS software, as well as to create and manage several pseudo-shapefile layers with custom attribute values.

Concerning the user experience, we plan to add left-handed controls and the possibility to reduce the field of view by masking peripheral vision during movement in order to limit motion sickness. Indeed, although teleportation is already implemented, this solution cannot be applied if the user is flying and/or need to move over a long distance. The field of view reduction is a technique already implemented in several VR applications (e.g. Google Earth VR) which seems efficient [23].

Finally, the software will be ported to at least one different platform, such as the upcoming Valve Index headset. This headset will be complemented by the addition of two Knuckles controllers which offer as many inputs as the Oculus touch controllers.

## VI. CONCLUSION

While recent development of techniques allows imaging the Earth and planets' surfaces (even the seafloor) and calculating digital elevation surfaces, the development of VR facilities can be used to make the fullest use of these rich datasets. In this paper, we presented our recent advances in the development of an application allowing analysis of topographical models and mapping compatible with GIS software as well as the planned development to complete it. Future developments and the release of our solution should benefit researchers not only in Earth Sciences, but in any science based on these data (e.g. biology and the mapping of coral communities, geography). In particular, we note that this tool is particularly efficient with 3D models of submarine outcrops where classic field survey cannot be performed.

Our first uses reveal that performing morphological and geological analysis in a 3D immersive environment is gainful because it allows a good appreciation of the scale and geometry of the studied objects. Mapping of the morphological features is made easier by the fact that slope breaks can be clearly visualized.

Finally, this tool is also efficient for teaching, and can provide examples to students of sites that are distant, inaccessible (offshore, extra-terrestrial) or unsafe (roadside, cliff, paleoseismic trenches) sites, benefiting from the exchange platforms of topographic data like OpenTopography [24][24], e.RocK [25] or the SEANOE (SEA scieNtific Open data Edition, Ifremer) data publisher.

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