

# OLERDOLA'S CAVE, CATALONIA, PAST AND PRESENT: A VIRTUAL REALITY RECONSTRUCTION FROM TERRESTRIAL LASER SCANNER AND GIS DATA

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## ABSTRACT:

Terrestrial laser scanning technology is one of the most important revolutions in surveying: it is a fast, accurate, and cost-efficient method of gathering three-dimensional data for use in 3D models and mapping; it can be widely used in many interrelated fields, such as engineering constructions and 3D measurements, owing to its prominent characteristics of high efficiency and high precision, moreover laser scanner images can also be used in virtual reality applications which can be used to study complex three dimensional data and to explore human interaction with results that are still in digital format. The example presented in this paper, the Cave of *Olèrdola*, is an ideal environment to test and to develop interactive applications in a complex urban scale model, which will allow exploring possible reconstructions and its comparison to its present day situation.

In this case study it's possible to demonstrate the potentiality of the integration between two systems: a fast accurate 3D modeling from Terrestrial Laser Scanner and GIS data, and its real-time visualization in a virtual reality environment. The choice of using a Terrestrial Laser Scanner to survey the test site was due to its complexity; irregular slope, difficult accessibility and, as consequence, in measuring its conformation with traditional topographic methods.

A one day campaign was necessary to acquire the laser scanner raw data (point clouds) and the photos with which the 3d model has been created by registering and optimizing the point clouds, creating and editing a polygonal model and texturizing the result with high resolution photos. The digital terrain model of the context was generated by ortho photos and GIS cartography, to complete the laser scanner model and to recreate a realistic environment.

This final 3D model was introduced in Alice, visualization software produced by the Virtual Reality Centre (CRV) from the UPC. Alice was developed with the idea that the best way to accelerate development in a new medium such as VR is to provide tools that allows people without highly technical backgrounds to create program for it. A user is able to interact with the virtual reconstruction using a mobile portable workbench; which allows position tracking and stereo viewing.

## 1. INTRODUCTION

In every day practice, virtual 3d modeling ends being a theoretical interpretation of reality. Nonetheless, there are some heritage buildings with a high complexity where this interpretation cannot be done with conventional information; construction plans or simple measurements. There is simply not enough metric data for the construction of an accurate 3d virtual representation. These cases demand another technology to be implemented, one capable of collecting enough metric data for a true virtual interpretation. Laser scanners offer a sophisticated alternative to the traditional data collection methods, with very high resolution and accuracy. It consists of automatic high speed data capture of complex surfaces and often inaccessible environments. With the recent developments in 3D scanner technologies, it is now possible to acquire and create accurate models of historical and archaeological sites in small periods of time. As a contact less technique, the scanned laser light doesn't cause any change on the surface, it can be used in surfaces with different shapes and sizes, and the 3D record can be used later and remotely, for study, documentation, demonstration and reproduction, with no more relation to the real object. In this way, unrestricted access to these sites, which is highly desirable from both a research and a cultural perspective, is provided.

All these advantages suggested the use of the laser scanner application for the 3d modeling of Olerdola's cave (Fig. 1). The cave, with a size of 150 meters long by 20 meters high, where two main chambers are recognized, is located 60km west from Barcelona, presents difficult accessibility, is still in the process of excavation, shares a complex geometry and offers the possibility to test, in a large scale context, laser scanner data combined with GIS data. The goal of the project consists in the digital reproduction of the cave and its surroundings in a fast and accurate way, in an interactive 3d environment where the archaeologist can envision a virtual restitution of different construction hypothesis of the ancient buildings.

In this paper three different technologies are presented: Terrestrial laser scanner for the digitalization of the cave, GIS technology for overall context modeling, and Alice-UPC software used in a portable workbench for visualization purposes. Technologies advantages and disadvantages during the modelling and visualization process are discussed.



Figure 1. Location and general overview of Olerdola's cave.

## 2. WORKFLOW FOR GENERATING THE 3D MODEL OF OLERDOLA'S CAVE FROM LASER SCANNER DATA

The complicated shape of Olerdola's cave and of its surrounding, the absence of any previous survey and the need to reconstruct the 3D geometry in a brief period of time, suggests the use and combination of two different techniques: laser scanner for surveying the Cave and GIS data for creating a DTM of its surroundings. In this chapter the workflow used to perform the 3D reconstruction of the place from laser scanner data, is described and discussed analyzing each step (Fig.2)

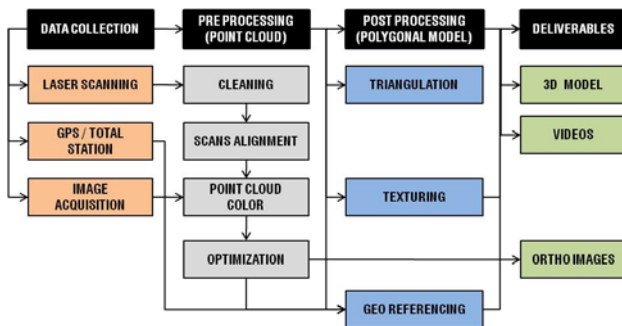


Figure 2. Laser scanner Workflow

### 2.1 Data Collection

The measurement system used for the Olerdola's Cave project is a RIEGL LMS Z420i Laser-Scanner equipped with a calibrated Nikon D100 6 Mega Pixel digital camera mounted solidly on top of the scanner. Recording was made in only one field day. A total of 28 scan positions where taken (Fig. 3), each scan position was made approximately every 10 meters, at a 0.1° resolution with a 80° by 180° field of view, in order to have 1,5 million points per scan. 70 calibrated images where taken in order to add color to the point cloud model. No registration targets where used, because all scan positions alignment were calculated via software (see paragraph 3.2 for more detail). Reducing data collecting time simplifies post processing noticeably; especially on sites where there are work in progress and climate conditions vary considerably.

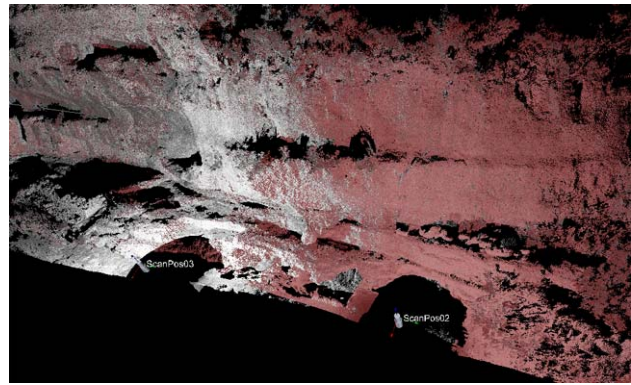


Figure 3. Two scan positions in Olerdola's cave survey.

The context model was generated using free available GIS data from the Cartographic Institute of Catalonia (ICC) webpage. From points coordinates: E 391433.5, N 4573411.5 (ED50 UTM 31N), Longitude: 1° 42' 7.319" Latitude: 41° 18' 10.83" (ETRS89 Geodetic) a 1:5.000 scaled topographic (sheet 139-65) and ortho image (sheet 278-130) was downloaded.

### 2.2 Data Pre-Processing

Laser scanning pre-processing was made in only three days: one day for cleaning unwanted data and aligning scan positions, another for fixing colour of the images, and the third for optimizing the resolution of the point cloud model. The raw point cloud model, contained 46,3 millions points (X,Y,Z,i,R,G,B) with a 790Mb file size. The final point cloud model was optimized to a 1cm resolution, and was reduced to 22,6 million points and a 198Mb file size only. Three software were used to perform these operations: Riegl Riscan Pro for cleaning and colouring the point clouds, Innovmetric Polyworks for aligning scan positions without topographic references points (an algorithm permits a best-fit alignment of the point clouds), and Raindrop Geomagic for global point cloud optimization (for reducing the number of points to a specified density).

### 2.3 Exploitation of 2D information from a 3D point cloud model

Before creating a 3D polygonal model of the cave, the global point cloud was introduced into Pointools software. This visualization software allows real time inspection for large point cloud data sets, standard CAD formats for data comparison, and other useful information extraction such as: videos, simple measurements, and specially, scaled true ortho images (plans, facades and sections) where point size rendering effects and pixel size resolution can be controlled to achieve best image quality results. Figures 4 shows two good examples of a 100 pixel/cm color image with a 1 point/pixel resolution to properly represent a 1:100 scaled image. Shadows simulated by points normal and controlled by the position of the light, helps to understand the complexity of the model's geometry and surfaces. Finally, scaled images can be introduced in a CAD platform for standard vectorization.

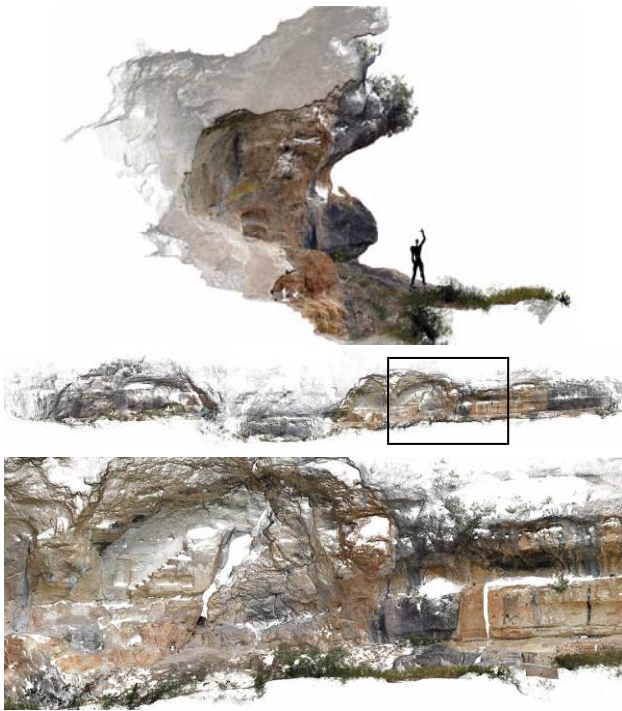


Figure 4. True ortho images from point cloud model.

## 2.4 Point cloud meshing

Even if, a useful information can be obtained from an optimized and coloured point cloud, polygons are usually the ideal way to accurately represent the results of measurements, providing an optimal surface description.

Triangulation converts the set of raw 3D points into a triangulated surface. Principal aims of triangulation (meshing) process are:

- Convert the point-based data into a visually more intuitive representation (especially when mapped with reflectance or texture data)
- Reduce the amount of data (some information is loss in the process)
- For subsequent interactive processing (e.g. when extracting surface measurements or ortho photos or for visualization purposes and animations)

From the optimized point cloud a 45 million polygons triangulated model was reached. In order for this mesh to truly represent reality, optimized model was reduced to a 4 million polygons model (Fig.5). Geometric details lost in this process are added through the mesh via texture.

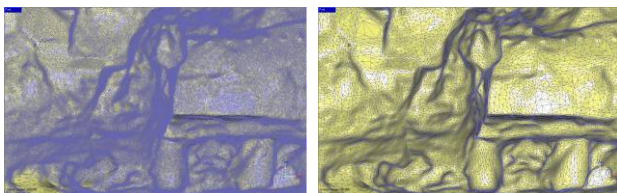


Figure 5. Polygon optimization: 9% of original model.

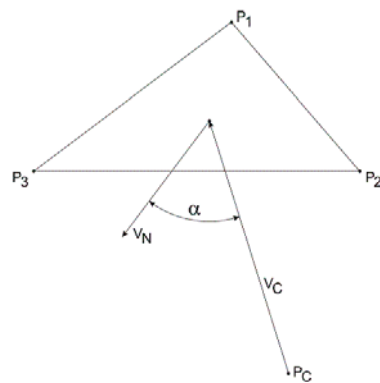
## 2.5 Texture application

Triangulated data can be textured with the high resolution images taken by the digital camera which leads to a nearly photo realistic model; essentially the purpose of texture processing is to integrate the 3D measurements from the laser scanner with 2D information taken with an external camera. In order to project a 3D point into an image and thus assign a color value, the software needs to know internal and external camera parameters. The internal camera calibration parameters depend on: the lens itself (even the same type of lens will lead to a different set of parameters), the setting of the focus, and the setting of the aperture; furthermore we need information about the position and orientation of the camera for every image to apply the color of a pixel to a 3D surface, it means that the mathematical relation between laser scanner and digital camera must be defined. Usually the camera, when ordered with the scanner, is delivered with internal calibration information. Along with the precise internal camera calibration, a mounting calibration guarantees a reliable correspondence of image and scan data: RiScan Pro provides the orientation and position information "automatically" in case the camera is mounted on top of the scanner. Thanks to internal and external calibration, an easily and automatically texture of the mesh it's possible.

The texturing procedure takes every triangle and tries to find the optimal image to texture it. The image has to meet several criteria such as smallest distance between camera position and centre of triangle, visibility of the triangle in image (no other objects between camera position and triangle) and smallest angle of view.

It's possible to choose a filter which removes all images where the angle "alpha" between the triangle normal and the ray of sight is larger than the given value. The higher the angle "alpha" is the less pixels of the image can be mapped on the triangle and thus the worse the quality of the texture will be (Fig.6).

Figure 7 shows the final textured model, once 140 high resolution images were applied to the optimized mesh model and exported as a VRML file to Autodesk 3D Max.



$P_i$	Edge points of a triangle
$V_n$	Normal vector of a triangle
$P_c$	Position of the camera
$V_c$	Ray of sight
$\alpha$	Angle between $V_n$ and $V_c$

Figure 6. RiscaPro texturing parameters.



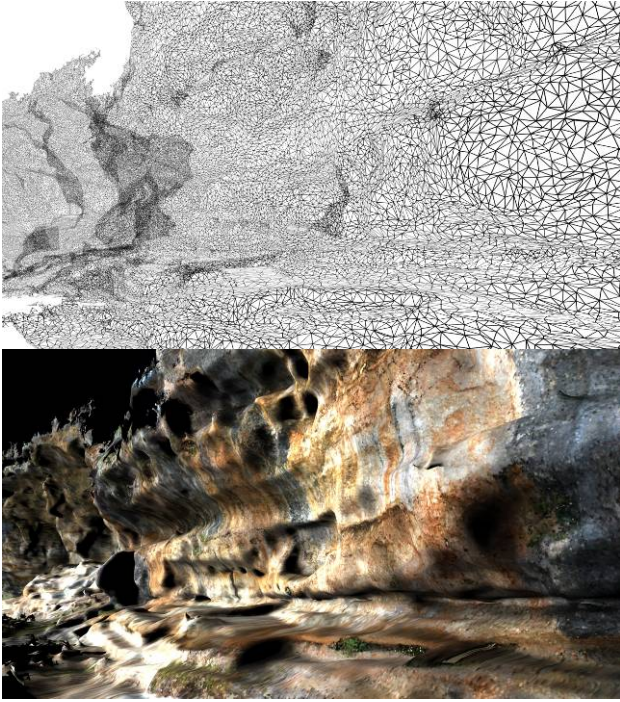


Figure 7. Mesh and textured model

### 3. VIRTUAL RECONSTRUCTION OF OLERDOLA'S CAVE AND ITS SURROUNDINGS

#### 3.1 GIS Application

Terrain models can be easily created with different available CAD packages. Therefore, GIS application not only provides the same solution, but also allows the possibility of introducing different analysis information to the virtual 3d model.

Using ESRI ArcScene a TIN model of the surrounding area of the cave was generated from the contours lines file downloaded from the Cartographic Institute of Catalonia.

Height values produced from the TIN model were given to the 1:5.000 scaled ortho image of the area of interest to generate a textured 3d model. Accuracy in maintaining the geo referencing of the aerial image is guaranteed with this process. Final model was exported as a VRML file to 3d Max package.

Viewshed, slope, or hillshade analysis can be added to the model with the same process, thus allowing different levels of information, for intelligent and interactive data interpretation.

Figure 8 is an example of a viewshed analysis, where visibility from the cave is represented in pale green and out of sight area is displayed in dark green. Crossing and comparing this information with different available data is a useful tool for experts. For instance archaeologists, use crossed-source information when historical reconstruction hypothesis need to be proven.

Context modelling benefits also from other aspects from GIS application: not only accurate georeferenced data is available online and lightweight models can be easily and rapidly generated, but also any GIS data can be represented, managed and visualized in the final virtual reality environment (roads, trees, buildings, etc.) allowing simulation, inspection and design verification.

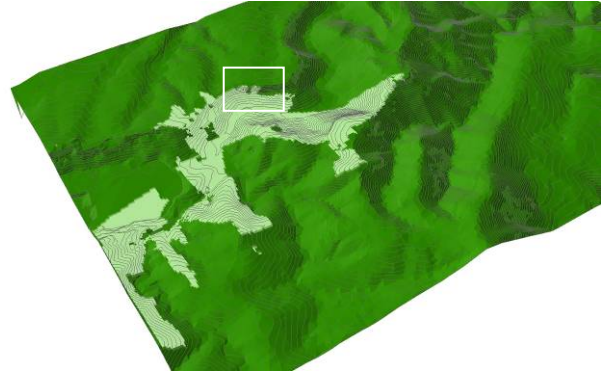


Figure 8. GIS viewshed 3D model.

#### 3.2 Overall Virtual Reconstruction

In order to realistically visualize Olerdola's landscape, several issues had to be addressed; in particular, the way to combine terrain meshes, texture images and laser scanner data for producing a full visualization with good engine performance without compromising valuable information loss. The overall model was generated by merging the TIN created with ArcScene and the 3D cave model generated by laser scanner in Innovmetrics Polyworks (Fig. 9): merging of the objects was possible without GPS control points thanks to the performing alignment algorithms of the software based on two steps: first a procedure that computes approximately an alignment transformation from a set of N tiepoint pairs, selected interactively and then an iterative algorithm that computes an optimal alignment by minimizing the 3D distances between surface overlaps in a set of 3D Images acquired from unknown viewpoints. Algorithm multiplies each 3D image transformation matrix by the incremental transformation matrix that best improves the image alignment with respect to the other 3D images with each iteration. This incremental matrix is computed using a linear least-squares technique, and results from averaging the best alignment parameters of each image point.

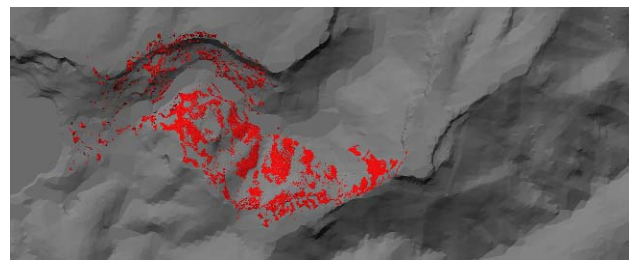


Figure 9. Laser scanner and TIN registration, final model.

Using the transformation matrix obtained, the laser scanner model was geo referenced to the terrain model in 3D Max Software. With this software the model thus obtained was handled and render parameters adjusted.

Virtual Reality Center's 3D Max plug-in was necessary to export an appropriate PD3 file to introduce the model in the VR platform ALICE.. This file format, as VRML, separates textured image from the geometric information, thus the image is exported with a RGB file extension, in order to maintain vertex color information correspondence to the vertex mesh model.

## 4. THE OLERDOLA'S CAVE IN A VIRTUAL REALITY PLATFORM

### 4.1 UPC's Virtual Reality platform

Virtual reality equipment was developed by the UPC's Virtual Reality Centre and is composed of Alice's visualization software and a portable workbench as hardware.

Alice is a 3D engine used for the visualization and interactive validation of complex virtual environments. ALICE allows the combination of different 3d models formats. It is a fully oriented interactive inspection platform for 3D complex models which require advanced interactive techniques. The software focuses on industrial design applications, architecture and heritage, virtual museums and medicine. Alice incorporates sophisticated algorithms for image rendering and complex modeling management to offer a scalable solution which allows real-time navigation of 3d models in a wide range of equipments and platforms. Code is available as a library for developers as Microsoft Foundation Classes, so it can be used in applications which required a specific user.

Solutions offered are:

- High-quality visualization thanks to the use of different algorithms and other high-end technologies.
- High range of navigation options accessible trough classic interactive hardware or using different tracking devices.
- Stereoscopic vision from different virtual reality hardware: 3d glasses, head mounted displays, CAVE, PowerWall and Workbench.
- Space referenced sound
- Collaboration workspace
- Plugin for importing VRML97 (WRL), AutoCAD (DXF), y 3DStudio MAX 4.0(MAX) files



Figure 10. Portable low-cost workbench.

Workbench (Fig. 10) is composed by a standard PC, two DLP SVGA projectors for stereo viewing, and a 1,40m by 1,0m screen. The low-cost workbench needed to solve three common problems: first, to be moved to any particular location; second to be shown to a group of people instead of being single user; and third, position in virtual environment needed to be easily located for tracking purposes. First issue was solved building a foldable equipment in order to be transported in a standard car trunk. Second issue was solved using a large screen size, for this a mirror was installed in the workbench to minimize its size. Third, tracking was solved by installing mouse sensors in each of the two main wheels, which once calibrated with the Alice software transforms the movement of the real object to a known virtual position. This tracking device is valid only for X and Y coordinates in a 7 meter perimeter area.

### 4.2 Virtual Reality vs. Reality

Based on archaeologist hypothesis and drawings (Fig.11), reconstructed theoretical model was created in traditional CAD software. This 3d model needed many dimensional adjustments when hypothesis ideas were compared with the accurate laser scanner data. Final model derived from the best interpretation between hypothetical use and real measurements (Fig.12). File export from Max software to ALICE virtual reality platform was the same used in paragraph 3.2. The final model, introduced in Virtual Reality platform, permits a global and interactive visualization of the three elements: the context (created from GIS data), laser scanner model and archaeologists reconstruction. In order to verify this reconstruction hypothesis, the portable workbench offers a tool to open a virtual window in the real site. Workbench was translated to a nearby place with views to the site in order to confront 3d digital model and possible reconstructions hypothesis with reality. A real time 3D stereo comparison can be made for a group of people which can cooperatively work with different virtual data information on site.

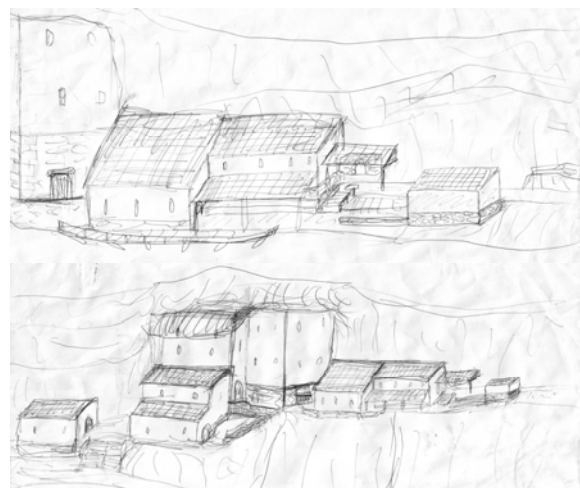


Figure 11. Archaeologist hypothesis and drawings.



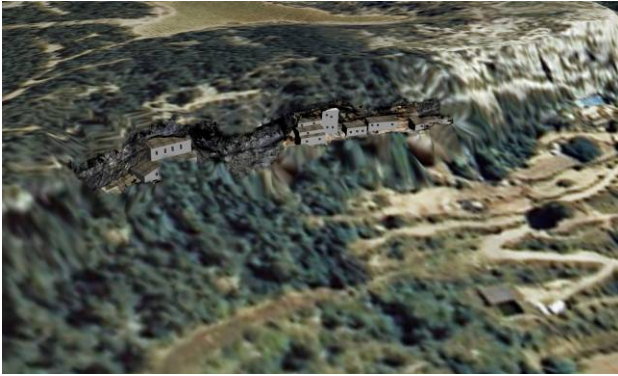


Figure 12. Final 3D model and reconstruction hypothesis

## 5. CONCLUSIONS

Terrestrial laser scanning offers different advantages in the 3d modeling of complex surfaces, appropriate point density is needed for different level of detail and scales:

- Laser scanning is a valid alternative where traditional survey techniques doesn't give enough information for complex 3d models environments, even if accessibility from all aspects is needed to scan it fully. Data collection is fast and accurate.
- Free target scanning using software for alignment, allows data collection in desirable periods of time.
- Large number of points found in a point cloud consist a valuable archive file.

However, meshing post processing of laser scanning data is not a standard process, is still significantly time consuming, needs specialised hardware and professional users need to control several different 3D modelling expensive packages. Also, accuracy lost in this process cannot be exactly controlled. One possible solution could be the development of tools able to introduce a dense coloured high resolution point cloud in the Virtual Reality platform: post processing time might be considerably reduced and all laser measurement is maintained. On the other hand, GIS technology enriches the 3d virtual environment, allowing different standard analysis to work interactively with the virtual model. Another advantage is that there are many free available databases online, which can be used to adequately represent the context. More possibilities of exploiting GIS data in Virtual environments need further studies to be tested at different level of detail and scales.

The final virtual application composed of workbench and ALICE software allows laser scanner and GIS data real-time visualization, and permits a first-class interaction between different users and complex data by easy position tracking. Flexibility of data integration must be improved and high resolution visualization can be implemented. This work in progress project opens new future scenarios, in which a more portable and easy to use device can be applied and an augmented reality application can be developed.

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