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THE CAVES OF NAICA IN 3D

ERMINIO PAOLO CANEVESE AND COLLEAGUES REPORT ON LASER SCANNING AND CLOUDCUBE FOR MEXICO'S NAICA CAVES

A new challenge started in May 2007 with the first official expedition to Mexico of the Naica Project, which involves researchers from ten universities, four companies and laboratories. In this multidisciplinary research project of international importance, Virtualgeo carried out the survey work with laser scanning technology of hypogeal caves covered with selenite crystals, then used the proprietary software CloudCUBE to manage and 3D model the point clouds. Here are the first results of the laser scanning survey of a spectacular "forest of crystals".

In a Mexican mine, there are several caves covered with selenite crystals, for which it was necessary to plan specific documentation strategies aiming at scientific research and divulgation. The Italian company Virtualgeo has verified the possibility to survey the caves as-built condition by laser scanning technology realizing, by means of the proprietary software CloudCUBE, the 3D digital model of the Cueva de los Cristales. The University of Bologna work team is applying to 3D data analysis and operative strategies.

Naica jewels

In Naica, a mining city in northern Mexico located 130 km south-east far from Chihuahua, nature offers a unique wonder in the world, not only for beauty but also for scientific significance. From 180 up to 300 meters deep into the mine, there are several caves covered with transparent selenite crystals. The Cueva del los Cristales (Cave of Crystals, see the picture below) and Cueva del las Espadas (Cave of Swords, see the banner image for this article) are the biggest among

the present caves. The caves include smaller cavities, among which the Ojo de la Reina and the Cueva del las Velas stand out. The caves are covered with selenite crystals, formed by plates merged into incredible shapes, creating the cavities toponymies. In the most spectacular cave, which is the Cueva del los Cristales, crystals are some 14 meters in length - a true forest of giant crystals.

The Naica Project

In May 2007, Virtualgeo took part in the first official expedition to the Naica mine, organized for the Naica Project by the Mexican company Speleoresearch & Films and the exploring team La Venta (Italy). The project involves researchers from universities and its purpose is to realize a multidisciplinary campaign of research and documentation of the caves. It is hoped that, from this research, it will be possible to explain the speleogenesis and minerogenesis processes as well as to propose hypotheses on how to preserve such a natural wonder and transfer its knowledge to the next generations.

The first results of the Naica Project were illustrated in December 2007 at the conference "Naica caves: exploration, documentation, research" organized by Prof. Paolo Forti in the Department of Earth and Geo-Environmental Sciences of Bologna University (Italy). Virtualgeo, a participant of the project, presented a report concerning the survey activities carried out with laser scanner in the caves as well as the outputs obtained from the elaboration of the acquired data. Moreover, it produced a structure equipped for stereoscopic visualization, by

means of which it was possible to “virtually” visit, in three-dimensions, the Naica caves.

3D laser scanning survey

In the frame of the investigations concerning the caves topography, Virtualgeo took part in the Naica Project to laser scan the Cuevas de los Cristales and de las Espadas. The survey campaign phase, carried out by Roberta Tedeschi, took place on May 2007 during the first official expedition to Naica mine.

The survey is aimed at documenting the as-built condition of the caves by constructing a high precision three-dimensional geometric database, including colour parameters, of the morphology and visual aspect of the caves and crystals. The 3D models obtained by laser scanner are directed at both scientific purposes, e.g. specialized “distance” study on caves and crystals, and information dissemination purposes, e.g. virtual and semi-immersive access, also stereoscopic, for the public; site advancement and promotion; hypotheses simulation and evaluation for preserving caves, etc.

The project team of the Department of Earth and Geo-Environmental Sciences of Bologna University is working on analysis connected with the three-dimensional data collected and operational strategies for the next 3D survey campaigns, and for the verification of data accuracy.

Morphometric acquisition of caves

On surveying hypogean cavities, problems are



3D laser scanning of the Cueva de los Cristales in Naica (Mexico)

connected with the irregular shape both of vertical and horizontal surfaces. Such surfaces are difficult to acquire (with a high detail level), measure, compare, visualize with traditional survey techniques. It is hard to identify a morphometric survey method that can be valid for all contexts, being increasingly automatic and fulfilling the requirements for each kind of application, minimizing measurement errors and reducing operative times and costs (both in the site and data elaboration phase), while increasing quality and quantity of acquired information.

Laser scanner surveying is a solution for speeding up surveys of large complex surfaces as well as for the density, precision and completeness of data compared to traditional topographic instruments. Compared to other hypogean cavities, the Naica caves have peculiar features making them difficult to survey regardless of the instruments used.

Prohibitive ambient

Survey operations in Naica caves were carried out in ambient conditions that were adverse

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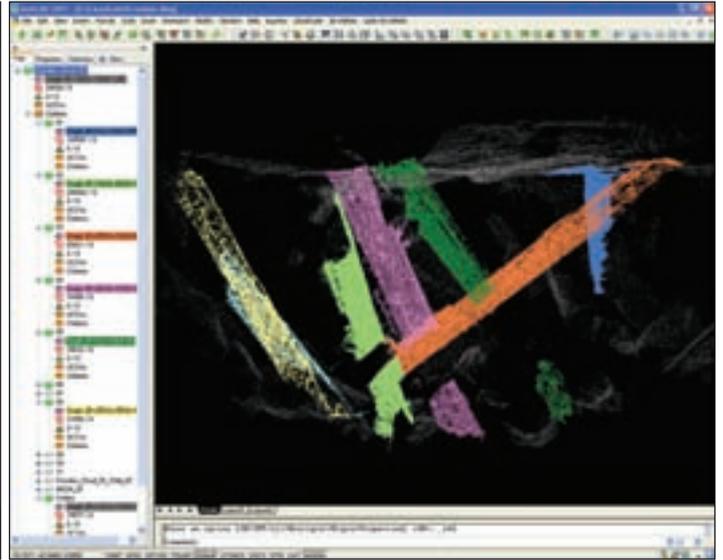
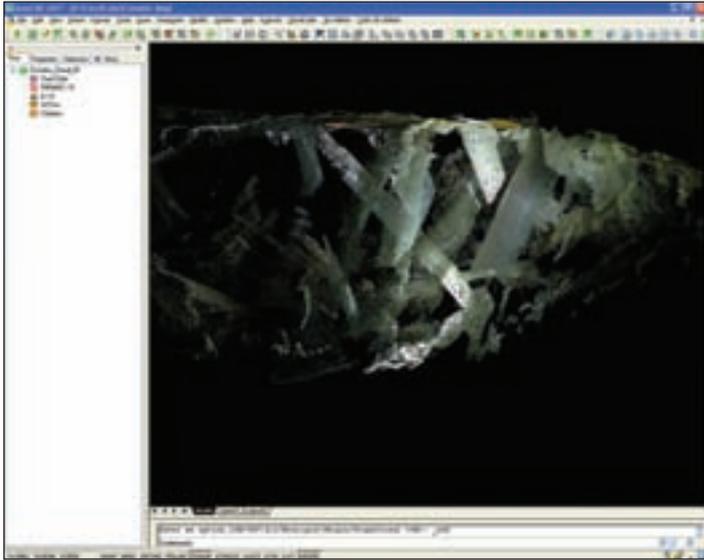


FIG 1. Cueva de los Cristales: visualization of the point cloud on AutoCAD® platform with Virtualgeo CloudCUBE software

FIG 2. Cueva de los Cristales: organization of the point cloud in sub-clouds, on AutoCAD® platform with Virtualgeo CloudCUBE software - each sub-cloud corresponds to a selenite crystal.

both for technicians' physiology and for laser scanning instrument functioning, e.g. 48°C temperature and humidity close to 100% in the Cueva del los Cristales. The laser scanner used is guaranteed by the producer from 5° up to 40°C of ambient temperature and, concerning the humidity degree, without condensation. Moreover, the equipment necessary for surveying (laptop, cables, power supply devices, etc.) had to be displaced and installed on an uneven floor covered with crystals.

The prohibitive microclimate, joined to the limited risky mobility among the crystals, affected the activity of technicians who could

work only wearing special suits and boots prepared by La Venta team for the whole expedition, after studying the requirements.

Acquired data

The laser scanner used for the survey of the Naica caves is based on "phase shift" technology. It measures the distance of the surveyed object "comparing" three pulses of different wavelengths reflected back to the scanner. Some technical data concerning such laser scanning instrument are listed in the Table 1.

In the Cueva de las Espadas and Cueva de los Cristales, four scans were effected, acquiring spatial coordinates and RGB colour values

of more than 43 million points - the latter thanks to the camera incorporated in the laser scanner, which took 40 pictures, 10 per scan. The total duration of all the survey operations in the caves was three hours in two working days, of which 15 minutes were taken for the scanning. The number of scans and the millions of points acquired by laser scanner, the amount of pictures taken by the integrated camera and the full "weight" of the digital data obtained from the survey campaign in Naica, divided for each of the two caves, are listed in Table 2.

Data post-processing

After registration of the Cueva de las Espadas scans, post-processing of the data acquired with the laser scanner in the Naica caves was performed with CloudCUBE, the software developed by Virtualgeo for managing and 3D modelling point clouds on an AutoCAD® platform. The work included the importation of the point cloud in AutoCAD® and, once the cloud has been visualized, it is carefully cleaned and filtered to remove noise and non-significant points. Concerning the Cueva de los Cristales, the output of such preliminary work is displayed in Figure 1.

The following phase focused on the Cueva de los Cristales and consisted in organizing the point cloud to obtain a basis rationally ordered according to the elaboration needs and survey purpose, on which it was possible to work optimizing time. Figure 2 shows, for example, how a point cloud was divided into sub-clouds, each corresponding to a single selenite crystal and differently coloured.

First outputs

The work proceeded to 3D model the morphology of the cavity and its giant crystals, exploiting the functionalities offered

Laser scanner	CAM2 LS 880
Range	0,6 meters – 76 meters
Measurement Speed	120.000 points/second
Systematic Distance Error	+/- 3 millimeters at 25 meters
Vertical Field of View	320°
Horizontal Field of View	360°
Scanning Time	2 millions of points in 20 seconds
Weight	14,5 kg
Camera	Nikon D70
Pixel	6,1 M

TABLE 1 – Technical data concerning the laser scanning instrument used by Virtualgeo to survey the Cuevas de los Cristales and de las Espadas in Naica.

	Cueva de los Cristales	Cueva de las Espadas
Number of scans acquired	1	3
Number of points acquired	13.180.893	30.032.525
Number of 2D images acquired	10	30
Amount of laser data acquired	1 gigabyte	3 gigabyte
Amount of 2D images acquired	45 megabyte	135 megabyte

TABLE 2 – Number of scans and millions of points acquired by laser scanner, amount of pictures taken by the integrated camera and full "weight" of digital data divided for each of the caves surveyed by Virtualgeo.

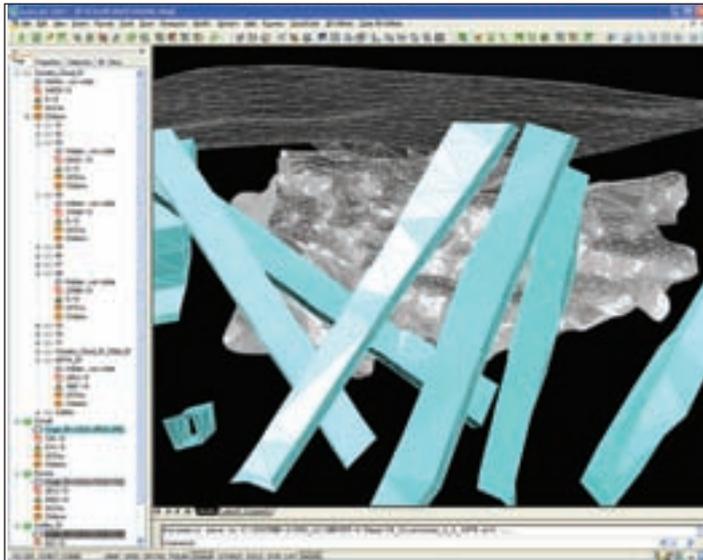


FIG. 3. Cueva de los Cristales: three-dimensional model of the cave and crystals, visualized in "shade" modality, obtained on AutoCAD® platform with Virtualgeo CloudCUBE software

by CloudCUBE software. The 3D surface model of the Cueva de los Cristales obtained with such software is visible, in shade modality, in Figure 3. From the cave 3D model, with CloudCUBE it is possible to obtain at a rapid rate: whatever dimensional information, graphic-numeric representations and, thanks to the last functionalities implemented by the software, sections (vertical and horizontal), axonometric projections and perspective cutaways.

Conclusion

The Cueva de los Cristales 3D reconstruction is the result of a pilot investigation, which can be extended to the other Naica caves and, in general, to other hypogean cavities. It can be extended to whatever

context in which it is necessary to manage a remarkable morphologic complexity, a great amount of survey data and, also, particular ambient conditions, which can be important in the acquisition phase.

Starting from the need to document as fully as possible complex surfaces, Virtualgeo has found an applicable solution in the laser scanning technology and reverse modelling methodological approach.

Laser scanning allowed us to overcome the problems of the specific applicative context, surveying in a short time wide surfaces featuring compounded shapes which were impossible to survey with any completeness by using traditional instruments. CloudCUBE software offers a set of tools for processing the millions of points acquired, for their optimized arrangement and for modelling, directly on the point clouds, the 3D model. Such a model constitutes the basis to elaborate rapidly a large range of graphic representations, e.g. sections, axonometric projections and sectioned perspective projections.

The analysis of the three-dimensional data acquired is carried out by Department of Earth and Geo-Environmental Sciences of Bologna University which is also working to plan the future laser scanning survey campaigns.

Acknowledgements

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Websites

www.virtualgeo.it
www.cloud-cube.com
www.laventa.it

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