New approaches to understanding the world natural and cultural heritage by using 3D technology: UNESCO's Škocjan Caves, Slovenia

Gregor Novaković[1], Dimitrij Mlekuž[2, 3], Luka Rozman[4], Aleš Lazar[1], Borut Peric[5], Rosana Cerkvenik[5], Karmen Peternelj[5] and Miran Erič[3]

[1]3D ATA Ltd. Mirka Vadnova 1, SI-4000 Kranj, Slovenia
gregor.novakovic@3D-ata.com, ales.lazar@3D-ata.com

[2]Department of Archaeology, Faculty of Arts, University of Ljubljana, Zavetiška 5, SI-1000 Ljubljana, Slovenia
dmlekuz@gmail.com

[3]Institute for the Protection of Cultural Heritage of Slovenia, Metelkova 6, SI-1000 Ljubljana, Slovenia
dmlekuz@gmail.com, miran.eric@guest.arnes.si

[4]Magelan Group Ltd. Glavni trg 1, SI-4000 Kranj, Slovenia
luka.rozman@3D-biro.com

[5]The Škocjan Caves Park Public Service Agency, Škocjan 2, SI-6215 Divača, Slovenia
borut.peric@psj.gov.si, rosana.cerkvenik@psj.gov.si, karmen.peternelj@psj.gov.si

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Abstract:

Karstic landscape is a specific heritage, where surface and underground are part of single landscape. Where underground (caves, shafts...) played an important role in the development of surface. Landscape where natural an anthropogenic processes worked hand in hand. Caves were often treated as being separate from the outside landscape, recorded in isolation form landscape which they are part of. However, this complex heritage requires integrative methodologies, that would integrate cave record with the landscape.

Keywords: Škocjan Cave, Karst, Terrestrial underground scanning, Lidar, UNESCO World heritage, paleo environmental, 3D data management

1. INTRODUCTION

Traditional landscapes, a result of millennia of natural processes and human engagement with environment are under threat. A precondition for integrated landscape protection and understanding is knowledge. Karstic landscape is a specific heritage, where surface and underground are part of single landscape. Surface landforms (sink holes, shafts...) and underground features (caves) are result of same long term processes which worked hand in hand with anthropogenic processes in the long term development of landscape.

Figure 1. Panoramic view of entrance to the Škocjan Caves. (Photo: Borut Lozej; owner: Škocjan Caves archives).

In order to approach this complex heritage we need to develop integrative methodologies that allow us to treat surface and underground heritage as single. Although recording of underground heritage and landscape require different methodologies, our goal is to integrate both datasets into single one. Only in this way we can holistically approach this complex heritage. In the long term, the most sustainable and productive method of protecting landscapes is education and familiarising people with their complexity and time depth. Three-dimensional (3D) technologies with potential for visualizing heritage that is often difficult to observe and understand are ideal tool for presentation of such complex heritage.

1.1 Škocjan Caves, UNESCO's world heritage

Škocjan Caves [1] are situated in the Karst Plateau of South-West Slovenia.

Kras (Carso, Karst) is a low carbonate plateau in the hinterground of the Trieste bay. It connects Mediterranean with the Middle Europe. Karst is known for typical landform such as doline or sinkholes, underground rivers and caves and bora (burja), cold northern wind. People have lived here and shaped their landscapes since Stone Age. The stony landscape, lack of surface water, proximity of industrial centre Trieste and road connections are the main factors that have contributed to the formation of the typical cultural landscape, which is rapidly disappearing.

Škocjan Caves are an exceptional limestone cave system which comprises one of the world's largest known underground river canyons, cut into the limestone bedrock by the Reka River. (Fig. 1) Dramatically roaring, the river disappears into the karst underground, before passing through a vast and picturesque channel of up to 150m in height and more than 120m in width, often in the form of rapids and waterfalls. The canyon's most spectacular physical expression is the enormous Martel Chamber which exceeds two million cubic meters in volume. It is no coincidence that karst research has its origin in this very part of Slovenia, referred to scientifically as "Classical Karst". The caves support many endemic and endangered species, including the olm (*Proteus anguinus*) along with many invertebrates and crustaceans. The very particular environmental conditions of the collapse dolines provide habitat for rare and threatened flora and fauna.

Numerous archaeological sites suggest that vicinity of Škocjan has been densely populated in prehistory. In Late Bronze Age a complex ritual landscape emerges around Škocjan. Prehistoric landscape was structured around caves as entrances to the underground with evidence of ritual deposition of artefact in the caves. The whole landscape was turned into monument, fixed, stabilised and made durable by erection of hillforts on prominent hilltops. However, there are also traces of daily life, cultivation of landscape in the form of clearance cairns and earthen banks. Clearing and cultivation have in many cases left a permanent and clear imprint on the landscape. Most of the fields laid out during this time were reorganised and overlain by medieval and later field patterns. Even so, whilst field systems derived directly from the prehistoric field pattern are rare, traces of prehistoric fields have been identified in several parts of the Karst.

The exploration of the Škocjan Caves dates back to the early 19th century; after that, the caves were explored with greater intensity for another century. The underground Reka River was being explored by various "boating techniques", i. e. wooden rafts and boats, paddles, poles, anchors, hooks, ropes and pulleys. Leading members of the speleology division were searching for caverns and new paths, they were measuring and surveying, while people from neighbouring villages, one could say permanently employed "cave workmen", and cave guides chiselled the trails for them. The first map of the Škocjan Caves was done in 1885. Anton Hanke drew the floor plan and cross section of the caves from the first swallow hole to the 11th waterfall after the end of the Müller Hall. As the first explorers penetrated deeper into the underground world gradually, also maps of the cave system were made gradually. The first complete map of Škocjan Caves

Figure 2. First complete plan of the Škocjan Caves was made at 1913 by Anton Meeraus and published by Sektion Küstenland des Deutschen und Österreichischen Alpenvereins from Trieste (Owner: Civico Museo di Storia Naturale, Trieste).

was made hundred years ago (1913) by Anton Meeraus (Fig. 2). In the early 1990s new measurements of the cave system were conducted by the Institute of Karst Research. Impressively, the new measurements revealed just one major error in early maps: following the end of the Rinaldini Hall, the passage twists sharply from the direction of the Dinarides to NNW, then turns due north in the final section, deviating by about 30° from Hanke's and Meeraus' maps. Today, we have a digital 1:500 scale map of cave system that shows every last detail, including the locations of individual spotlights.

1. Methodology

Laser scanning describes any technology which accurately and repeatedly measures distance using laser pulse, by precise evaluation of time needed for the laser pulse to travel from the object and back. These measurements are transformed into a series of points (or a point cloud) from which information on the morphology of the object being scanned can be derived.

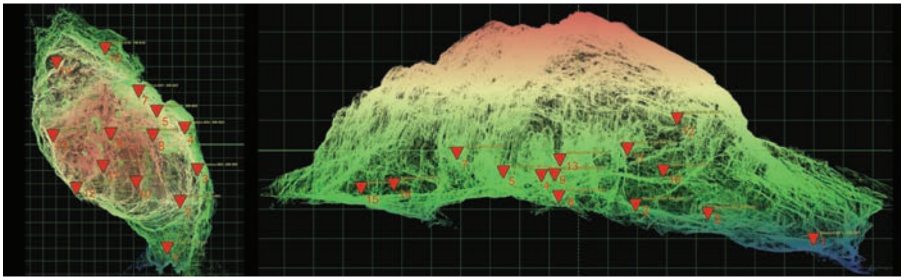
Terrestrial Laser Scanning (TLS) is an effective method for producing comprehensive spatial data which describe the geometry and orientation of visible objects surfaces. The instrument, positioned on the ground can produce millions of measurements in a very short time with a dense cloud of geolocated points as a direct result [2, 3]. Single capture and primary processing of these point cloud data can accurately define high detailed shape of the measured object. Collected data can be used for different purposes and applications

Figure 3. Measuring in the Great Hall in Škocjan Caves (Photo: Luka Rozman).

with further processing. Laser scanners are line-of-sight instruments, therefore multiple scan positions are required to ensure complete coverage of a structure.

Pulse based terrestrial 3D laser scanner Leica Scanstation C10 was used. Pulse based instrument consists of a transmitter/receiver of infrared laser pulses and scanning optics. Distance measurement is

Figure 4. Scan positions in the Great Hall. *Left*: base plan oriented to the north. *Middle*: longitudinal cross-section oriented NW-SE.



based on the time-of-flight of the laser pulse, travelling and reflecting from the surface of interest. Location of each point is acquired in a polar coordinate system. The horizontal and vertical angles are modified by the scanner device using an internal system of rotating mirrors. Compared to conventional surveying methods, a TLS shows a very high data acquisition speed (up to 50k pts/sec.) and very high spatial resolution. Technical characteristics of the Scanstation C10 supplied by the manufacturer show high maximum range (up to 250m for 90% surface reflectivity) and high point accuracy. The main goal of this case study was to measure shape characteristics of the Great Hall of Škocjan Caves and to asses potential of the method for recording of caves (e.g. [4] and many similar articles). Cave was measured (Fig. 3) on the 6th of September 2013, during the night, when the cave is closed for visitors, from 14 scanner positions, which were placed on easily accessible and safe locations (Fig. 4). In general this is relatively low number of scanner positions for such a complex morphological space. Consequently the result of the primary product (3D point-phase model) suffers from shadows (i.e. parts of the cave were not recorded as they were obscured by other features). This can be systematically avoided by placing a sufficient number of optimally located scanner positions. The average point cloud density of 5-10mm was provided (Fig. 5).

Figure 5. Visualisation of Great Hall point cloud data coloured by edge shading.

After conducting field surveying and primary processing (registration of scan-positiones, point cloud data filtration) 3D point — phase model of the Great Hall was obtained. The model is generated by a dense cloud of spatially located points. Otherwise the raster of the points is adjusted to the requirements. Each collected point has an intensity value obtained by reflection of the laser beam. Moreover, each point can be colorized in the real RGB value with use of integrated camera. To ensure quality staining of the points with RGB value the sufficient and uniform illumination is required, though it is difficult to achieve that in the cave environment. [2]

The reflection intensity colour depends on the angle of incidence of the laser beam and the characteristics of the measured surface. The result of the measurements after primary data processing, was edited and exported in standard ASCII format, which allows user to independently manipulate the data in the commercial software tools (AutoCAD, ArcGIS, etc.).

Airborne laser scanning Airborne Light Detection And Ranging (LiDAR or Lidar), Airborne Laser Scanning or Airborne Laser Swath Mapping (ALS or ALSM) is an active remote sensing technique, which records the surface of the earth using laser scanning. [5]

Transmitter, mounted on the airplane or drones, emits series of laser pulses that reflect from the surface back to the receiver. By precise measurement of time needed for the laser pulse to travel, altitude of the aircraft can be calculated and transformed into the elevation of the point on the surface of the earth. In this way a very precise 3D image of the earth's surface can be obtained. Lidar thus allows us to observe ground beneath forest canopy. When laser pulse reaches objects such as trees, part of it is reflected by the canopy, and part of it travels to the ground where it is reflected back. By eliminating canopy reflections, a precise image of forest floor can be produced. This is especially significant in countries such as Slovenia, where as much as sixty percent of the country is covered by forrest.

Lidar allows very precise 3D mapping of the surface of the earth, producing high resolution topographic data, even where surface is obscured by forest and vegetation. The level of detail on digital surface and terrain models produced from high resolution lidar topographic data helps us enormously in identification of past events which reworked and modified the surface of the earth.

ALS survey was conducted in December 2012. Ground conditions were optimal, with no low leaf cover and compressed dry leaves blanket. Average point density is 31,8 pts/m^2, average distance between points is 0,18m. Pulse density is 18,2 pts/m^2 with 0,24m average horizontal distance between points. Ground point density is much lower, 61 pts/m^2 with the 0,4m spacing between ground points (Fig. 6).

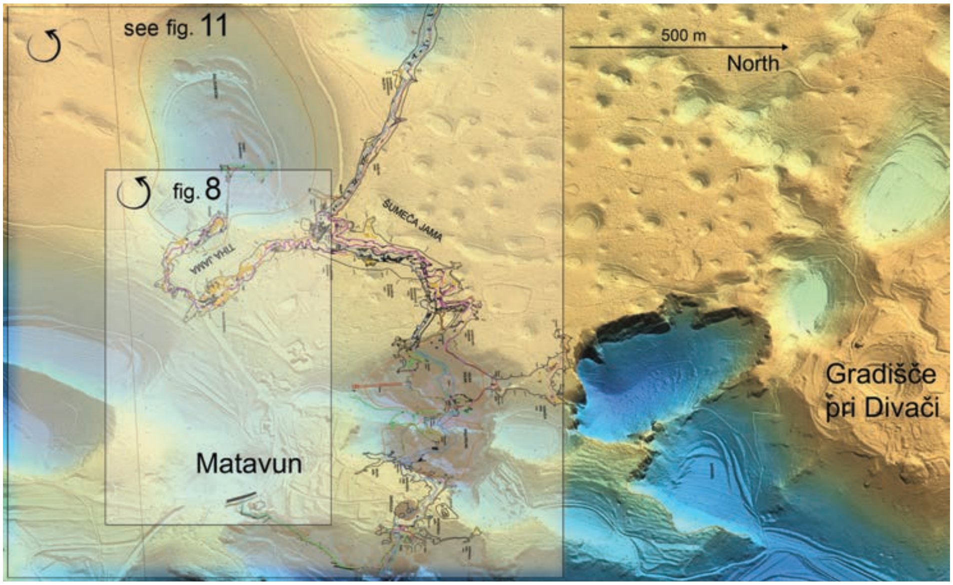


Figure 6. High resolution ALS surface topography of the area around Škocjan Caves

The essential and critical phase in post- processing chain is classification. Points in the point cloud must be classified to returns from the ground and those from vegetation. Classified point cloud allows interpolation of different digital elevation models. Digital terrain model (DTM) is a representation of bare-terrain surface, free of any object, such as trees, buildings, etc. Digital surface models (DSM) includes tops of the buildings, trees, power-lines and other "landscape clutter". For archaeology a combination between DTM with some landscape clutter is usually preferable.

1. RESULTS

The point cloud generated by TLS represents the topography of ceiling and floor of the cave. Each point represents the relative elevation or height of the hall. In this way a number of topographic maps of cave floor and ceiling can be produced.

These can be used for the comparison with existing maps, generated by conventional methods and can represent their upgrade as well. The essential difference among existing maps and maps, measured by TLS, is reflected in the details, since TLS measurements detect morphological forms and features of the surface with much greater accuracy (Fig. 7).

By substracting elevations of ceiling and floor of the cave (in Z-axis) elevation map of the cave can be visualized. The average elevation of the Great Hall is 16,26m, while maximum height of the hall is 30,82m. This enable also accurate calculation of the Great Hall's volume. ALS represents metrically accurate high resolution topographic data of the

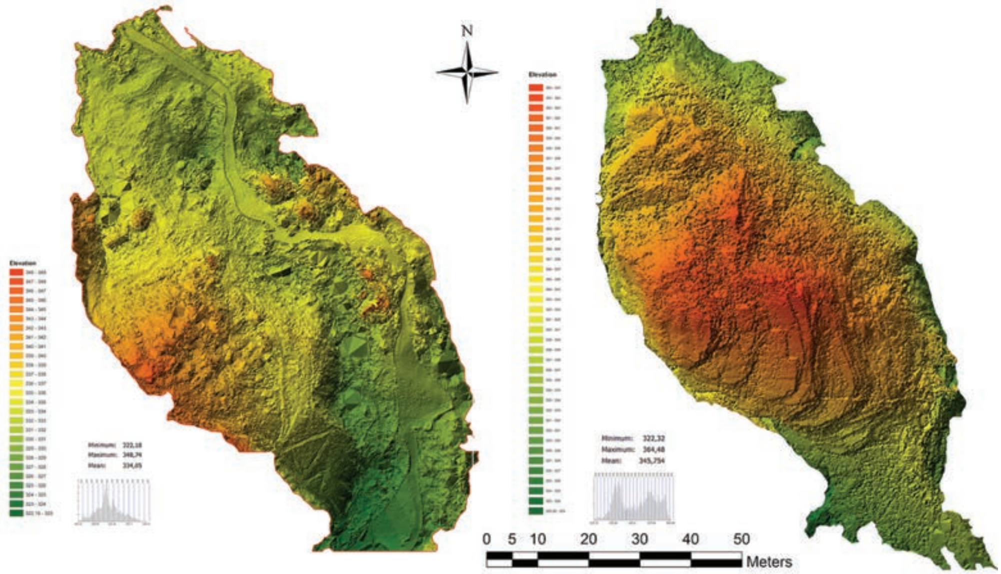


Figure 7. Hypsographic plan of ground and ceiling of Great Hall analytically cleaned of stalactites on ceiling.

landscape around Škocjan caves. Although it has much lower resolution than TLS dataset, it is much more spatialy extensive. Thus it can provide spatial context for the high resolution of TLS data. ALS reveals landscape features such as sink holes, river valleys, collapse dolines, their relation to manmade structures (hillforts, villages) and traces of human engagement with the landscape; from prehistoric field divisions, medieval fields, dry stone walls, lime kilns to traces of 20th century conflicts.

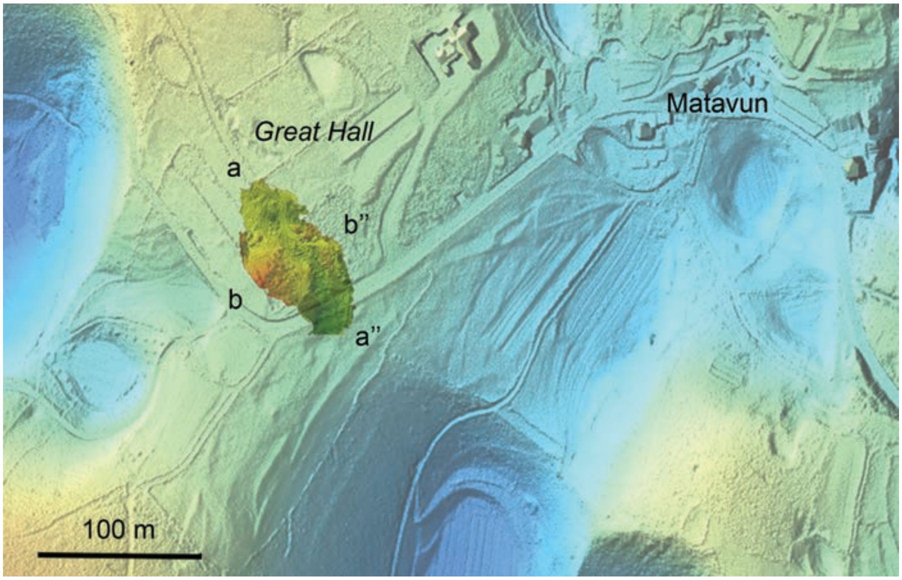


Figure 8. Integration of the ALS surface topography with the TLS 3D model of Great Hall.

Integration with ALS (Fig. 8) dataset of the surface above the cave help us to establish spatial relations between Great Hall and landscape above it. From the initial point cloud we can produce transverse and longitudinal cros-sections and base plan in any direction and location. In this way we can study the shape of cave and its relation to surface (Fig. 9). By calculating height difference between the surface and the cave ceiling in the z-axis direction we can establish the thickness of the cave ceiling. The average thickness of the Great Hall ceiling enclosure is 65m. Farthest point of the ceiling is 87,97m below the surface, the closest point is 49,76m below the surface. The average altitude of the Great Hall ceiling is 345,75m, while the maximum ceiling altitude is 364,48m and the lowest 322,32m.

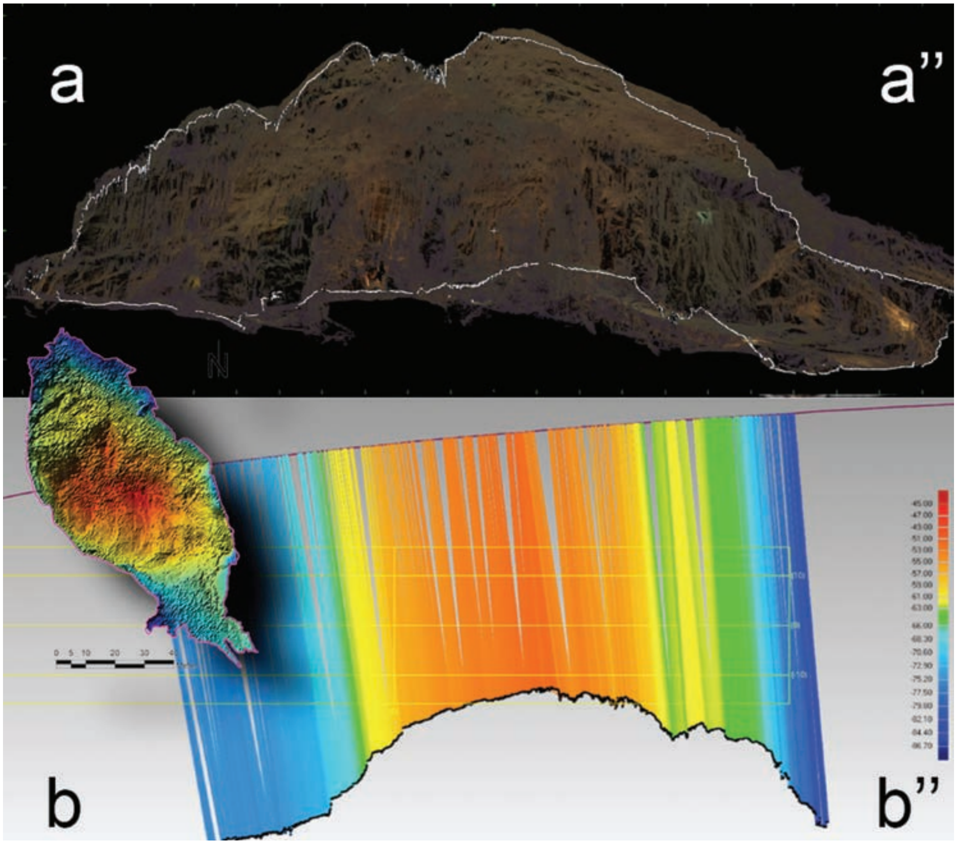


Figure 9. *Left-top*: highly precise cross-section of Great Hall as one of result of TLS 3D model in direction NW-SE, profile a-a”. *Left-bottom*: cross-section and relation of cave to the surface in direction NE-SW, profile b-b”. *Right*: hypsographic map of ceiling thickness analysis.

Škocjan Caves are prone to periodical flooding. Using TLS point cloud data the extent of flooding can be estimate. To determine the level of water, a horizontal plane had to be generated, which could then be interactively raised or lowered on the Z axis (Fig. 10). Finally, a 3D mesh model was produced from point cloud using triangulation

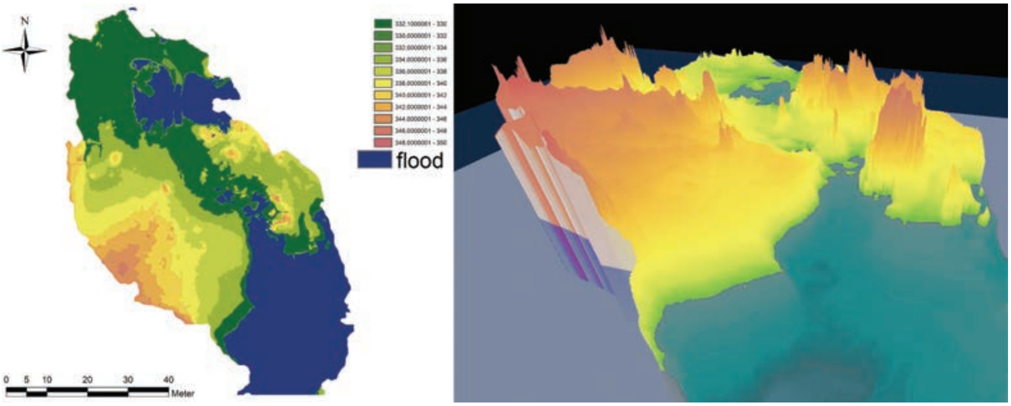


Figure 10. Simulation of the process of cave flooding on diffferent level with study of flood risk of public available parts of cave.

method. In this procedure specific software which has ability to convert large point cloud data in the TIN (triangulated irregular network) model was used. Even though, 3D model to such an extent that allows the processing of data by an average computer and software was necessary to simplified. Obtained 3D model is suitable for making of different cross-sections in any way and direction, calculating volumes, illuminating studies, flood studies, geological dip and dip directions analysis etc…(e.g. [7] and many other articles)

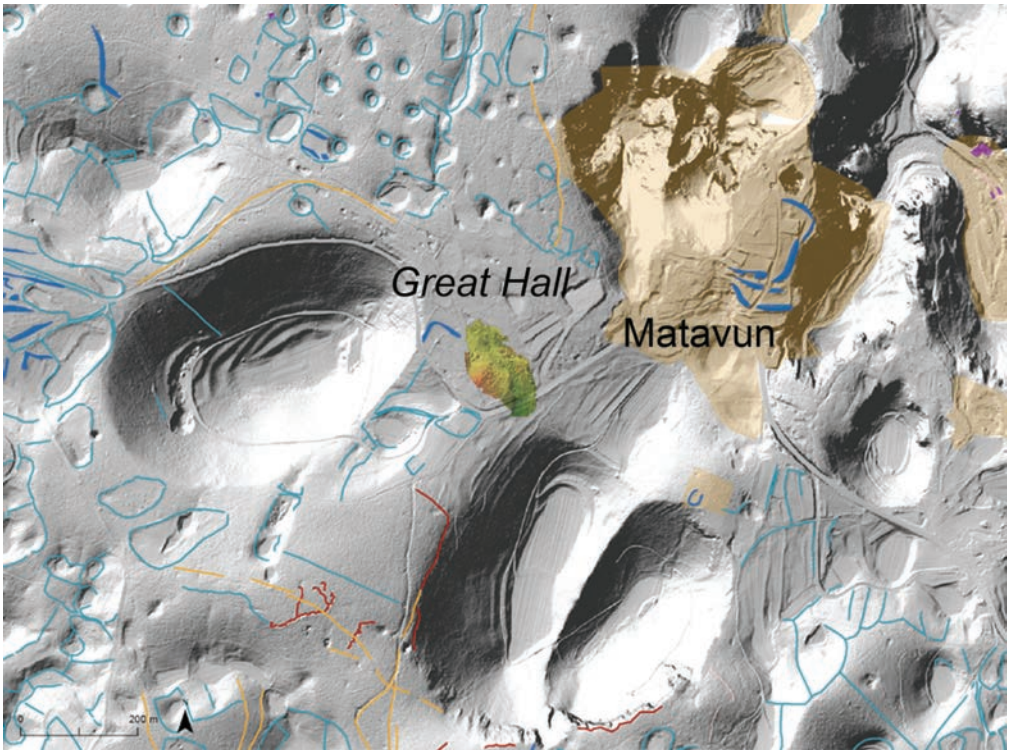


Figure 11. Integration of the ALS surface topography with the model and the TLS 3D model of Great Hall with the protected heritage areas (orange areas) and features recognised on ALS topography (different colours).

1. DISCUSION

This case study demonstrates the potential of both Terrestrial and Airborne Laser scanning as well as their integration for the study of complex heritage such as cavity. By using both methods we were able to capture both underworld as well as landscape, where cave is situated. Combination of two datasets enables us to understand the cave system in its environment and to observe relations between caves and landscape (both natural and anthropogenic) features (Fig. 11). This is a preliminary, proof of concept study demonstrating the possibilities of laser scanning technology and integration of different datasets. In the future, when the whole cave system will be scanned, the integrated datasets will be used for integrated 3D landscape modelling, paleo environmental studies, geological studies, planning, management and presentation of such complex heritage.

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