3D RECORDING AND MODELLING OF MIDDLE-AGE FORTRESS IN DENSE VEGETATION ENVIRONMENT

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ABSTRACT:

The Schwartzenbourg castle is a Middle-Ages fortress which was built in 1261. It is situated above the valley of Munster in Alsace, France. It was mainly used as a fortified place and a jail. In the early 15th century, the structure has deteriorated. Even after some repairs, it fell into ruins during the Thirty Years' war (1618-1648) and stayed uninhabited. During World War I, the German army used the place as a vantage point and also built a blockhouse inside the ruins. Nowadays, the ruins are gradually collapsing and the remains of the old walls are completely covered by thick plants.
The goal of this project was to create a 3D-model of the site before closing its access, which became too dangerous for people. This modelling is divided into two elements: on one hand, a digital terrain model (DTM) of the site in order to replace the castle and to analyze the background of its original environment; on the other hand, a 3D modelling of the ruins of the castle invaded by the vegetation. Indeed, the main difficulty of the measurement is obviously the dense vegetation which hides the castle. Held back for years outside the castle, it has now become an integral part of the ruins. This vegetation is finally today usually the first threat of heritage buildings. After a preliminary inspection of the site as well as difficulties of the project, the first step consisted of the survey of the whole environment of the site. We will therefore describe the different phases of the survey with the initial implementation of a georeferenced network on site. We will present the terrestrial laser scanning (TLS) surveys, then complementary surveys carried out by aerial photogrammetry. To be implemented, we had to wait for an advanced autumn in order to have as few leaves on trees as possible. The major step of processing of point clouds described in this paper is then the extraction of a DTM by using techniques to pass through the vegetation, or better to segment the points into different classes, one of these that would be the soil i.e. DTM, another consists into wall parts of the ruins.

1. INTRODUCTION

The architectural heritage is undoubtedly an integral part of the cultural richness of any civilization. This is the mark, the signature of an era that should be preserved for future generations. France, by its history, is attached to a heritage as rich as varied. This richness is also the result of the work undertaken for centuries to preserve as long as possible the traces of those who wrote its history. In spite of that, elements gradually degrade those architectural signatures and, most of the time, only the fortified buildings remain at the end. Alsace, by its geopolitical situation in East of France, was for centuries a coveted territory and today it leaves us a multitude of military buildings that have crossed epochs.

This project focuses on the Schwartzenbourg castle (Châteaux forts de France, 2016), which is located in the middle of the forest on the heights of the valley of Munster (Haut-Rhin) (Figure 1).
Dated from the thirteenth century it has suffered from time and various conflicts so that today only a part of the main walls remains.
Due to its size, the project is scheduled over two years. The first goal was to set up a survey methodology of the site and then to create the digital terrain model (DTM) of the nearby of the castle. After a first part devoted to the latest developments, the rest of this report will follow the chronological steps of the methodology. Firstly, the data survey by presenting the devices as well as the techniques used. Then, the processing of these multiple data will be explained. Finally, the conclusion will include openings for future work, with tracks of study in order to achieve the objective of the whole project.

Figure 1: UAV view of the ruins of Schwartzenbourg

2. HERITAGE CONSERVATION

The heritage conservation is something deeply rooted in French culture. It is part of a desire to remember past generations.
The arrival of digital technology has caused major changes of the way of thinking in heritage conservation. Indeed, while the preservation of the building often returns to delay the inexorable natural deterioration, digital technologies now able to preserve a replica, a "photography" of a building at a given instant. 3D

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modelling then becomes a powerful tool, and our work is to control this power by defining skills, methods and limits. In this section, we will see how digitization is used in heritage conservation, before looking more technically into multiple data surveying and processing methods. Finally, we will discuss the avenues of study to solve the critical point of the project, namely the dense vegetation that surrounds the Schwartzenbourg site (Figure 2).

Figure 2: Dense vegetation environment

3. HERITAGE DIGITIZING

In France and around the world, many programs are now focused on valuing heritage and developing study processes. Digital technology is particularly relevant in medieval castle modelling, for example in the European program "AVER – Des montagnes de châteaux" (D'Agostino *et al.*, 2013). The development of terrestrial laser scanners (TLS) and photogrammetric surveys has revolutionized the work of historians in comparison with traditional surveys. These 3D renderings allow a complete inventory of each digitized site and allow today a complete and quality work. Because it has saved considerable time in the data-collection phase, the arrival of digital technology has also given the possibility of extending the perimeter of study around each site in order to put a model in its environment. Those digitization finally became the main ingredient of many works: historical research, conservation, renovation etc.

3.1 Terrestrial laser scanning and photogrammetry

Thanks to the development of photogrammetric and laser scanning techniques, those technologies have imposed themselves in cultural heritage documentation fields. The possibility of three-dimensional photo-realistic rendering is also the result of those two domains combination, the result of the association of data raised in different ways (Grussenmeyer P. et al., 2012). Having both advantages and disadvantages, photogrammetry and laser scanning are perfectly complementary, as we shall see later on. The methods obviously adapt according to the configuration of the site, but some constants can be retained.

Laser scanning techniques: Laser scanning is widely used for complex or large object survey. Depending on the configuration of the site, time-of-flight or phase difference laser scanners may be used.

Photogrammetric techniques: Photogrammetric solutions are less expensive in equipment (quality camera versus laser scanner) and allow variable shooting angles, and even more with the democratization of UAV, which become a real vector of freedom and diversification. Photogrammetry is finally very complementary in the data survey phase. It's also a valuable data in the perspective of photo-realistic textured models.

3.2 Plants and point clouds

It is the last barrier in this project: vegetation. Held back for years outside the castle, it has now become an integral part of the ruins. This vegetation is finally today usually the first threat of heritage buildings. While methods exist for vegetation removing from point clouds, those techniques most often come from aerial remote sensing. Indeed, more and more data are now collected using airborne or satellite way. Collected, once cleaned from atmospheric interferences, covers all objects present on the ground, whether natural (soil, vegetation) or artificial (human constructions). In order to extract the bare soil for digital terrain model creation, manual, automatic and semi-automatic methods have been developed. Software suites like *LAStools* (RapidLasso, 2016), *Trimble RealWorks* (Realworks, 2016) or 3DReshaper (2015) offers different soil extraction algorithms. But they seem to work better on flat or at least continuous (minimally broken) terrains.

In our case, the configuration of the site presents all type of environment, and therefore discontinuous shapes (slope, breaks of slopes). We will see later that it is this vegetation cleaning which will present the most difficulty during the achievements. It will also be the case in future works, which will be more attached to the modelling of each element of the ruins, whose are largely covered by dense vegetation.

4. DATA COLLECTION

After a preliminary inspection of the site as well as difficulties of the project, the first step consisted of the survey of the whole environment of the site. We will therefore describe the different phases of the survey with the initial implementation of a georeferenced network on site. Then, we will present the terrestrial laser scanning (TLS) surveys, then the complementary surveys carried out by aerial photogrammetry.

Topography: The site of Schwartzenbourg is located on the heights of the valley of Munster, in the middle of the Vosges forest. It was then important to successfully define a georeferenced network before beginning any digitization. Indeed, the final objective is to obtain a georeferenced model in Lambert-CC48 system. We so set up a network around and inside the castle walls. This network was built around four GNSS points. Two points have indeed been taken inside the castle, on its highest part. It must be known that during the World War I, the German army used this point of view over the whole valley by building a blockhouse. This concrete construction was adhered to the vestige of the castle and it is on this building where two points could be lifted. The two other known 3D points were located very eccentrically at the site, on the access path that connects the castle to the village that it overlooks. This configuration was not the best, but the dense forest left little space for satellite signals. Simultaneously with the installation of this network, a first scanning campaign by terrestrial laser scanner was carried out. This simultaneity allowed the positioning by total station of the center of spheres used for the scans association. This permitted immediate georeferencing of the first scanning campaign (Figure 3).

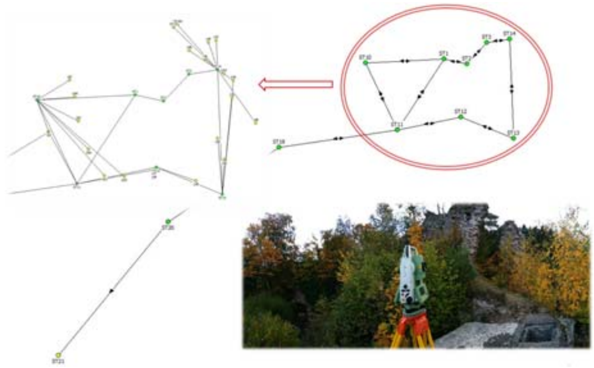

Figure 3: Total station network

Laser scanning: In order to realize the 3D point cloud, the use of terrestrial laser scanner was paramount. Indeed, even if the trees leaves on the Schwartzenbourg site were in order to fall, the main difficulty of this project was obviously the dense vegetation of the site, both on the ruins for the modelling of the castle, and on the floor for the DTM calculation. It was therefore wise to multiply the laser scanner stations hoping to obtain a maximum of points "behind" the vegetation. Several lasergrammetric measurement campaigns were carried out, using the FARO Focus 3D laser scanner: The first, previously mentioned, was carried out simultaneously with the topographic network set up. This made it possible to perform tachometric measurements on the Faro spheres and thus georeferenced the block of scans. This first block consisted of 12 scans (Figure 4) distributed around the castle wall, in order to get data for the digital terrain model around the site. This first campaign also allowed the measurement of first points on the outer ruins.

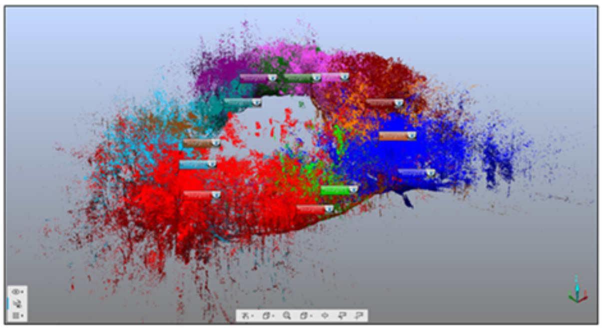

Figure 4: First scanning campaign around the castle's ruins

A second campaign (Figure 5) of laser scanning measurements was carried out in later autumn. Six complementary scans were carried out in direct proximity to the castle walls (inside and outside), with the aim of modelling the already visible ruins. This series of scans were also directly georeferenced on spheres placed on known points.
A final campaign of complementary scans was finally conducted. The approaching winter had indeed allowed the release of some parts outside the ruins which were invisible during first campaigns. Those scans will be processed during a complementary study. As they did not provide additional information for the DTM, they requested further processing in order to extract the points exclusively taken from the ruins which could not be put in place. Treatment tracks have nevertheless been developed and will be presented at the end of this paper.

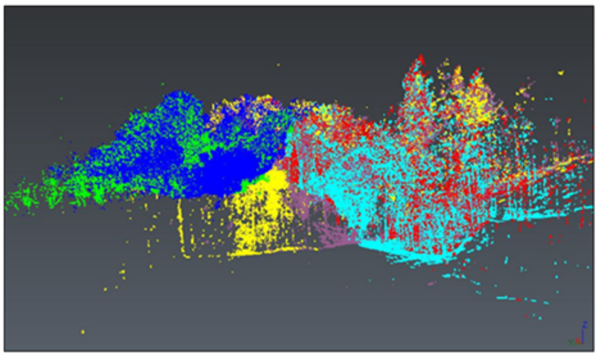

Figure 5: Second scanning campaign inside the ruins.

Photogrammetry: In order to complete the data acquired from the ground by laser scanning, an aerial photogrammetry operation was put in place. Thanks to the DJI Phantom 3 UAV, nearly 500 pictures were taken above the site (flyleaf picture). This photogrammetric survey was georeferenced from targets placed on the ground and positioned by a GNSS receiver. The multiplication of data acquisition angles (laser scanning inside and outside the ruins, photogrammetry over them) has finally allowed, despite the vegetation, to collect data on almost the whole site. The latter could subsequently be processed by several commercial and open-source software.

5. DATA PROCESSING

The second major step in this project was to process these multiple data. Scanner data were processed on *FARO Scene* software, while photogrammetric data were handled on *Agisoft Photoscan* software. It is, at the end more than a billion points which were three-dimensionally known and have been treated on *Technodigit 3DReshaper*.

FARO Scene:
We have previously mentioned the fact that, according to the configuration of the site, most of the data had been recorded by terrestrial laser scanning. The *FARO Focus 3D* scanner is associated with software developed by the same company, *FARO Scene*. It allows scans processing from the output raw data to the exported georeferenced point cloud.

*** Raw scans import:** In their initial state, each scan consists of a non-colored three-dimensional point cloud, and a set of photos taken by the scanner after the measurements. The point cloud can be visualized in 3D but also in a planar way, like a panoramic image. It is on this planar view where it is possible to identify the targets used during the project. The spheres used in the Schwartzenbourg are not the only existing targets. Flat checkered but also planar circular targets are also usable, but rather in an indoor environment (adjacent to the walls). Outdoor projects often see the use of 3D spherical targets that are measurable at 360 degrees. It is possible to automatically detect targets in the *FARO Scene* software but in reality, only the bulk of the work is done. A sorting is necessary between the real targets and the falsely detected ones (trunks of trees, leaves, etc.). Sometimes even real targets are not detected. Then it is possible to do so manually.

*** Scans association and georeferencing:** The association between scans can be done from the measured points but it is not very accurate, especially on outside site. The best way is to use

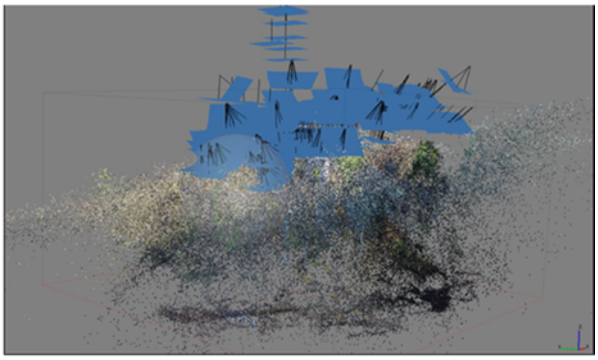

Figure 6: Alignment of pictures taken by UAV (*PhotoScan* software)

targets such as the spheres used during this project. The association of one or more letters to each target makes it possible to name the targets in Scene. Assigning the same name to a sphere in two scans allows them to be associated. A minimum of three common targets between two scans are required for 3D association. Once all the scans of a project are associated, it is possible to calculate their relative positions. The redundancy of common targets between scans allows obtaining RMS errors on the association of the scans. Also, the configuration can allow help more accurate association. Indeed, the 12 point clouds carried out during the first measurement campaign formed a closed loop, which multiply the redundancy and thus the accuracy of the association. The second scanning campaign could not allow this, but more spheres were used and shorter distances between consecutive scans ensured sufficient accuracy. While the association of point clouds by named targets allows a relative registration between the point clouds, it was necessary to provide for each project an absolute registration in order to obtain georeferenced point clouds. The georeferencing from the targets is then very simple: it requires knowing the 3D coordinates of the targets. It was already the case for the first session during witch spheres were measured with the tacheometer and then calculated at the same time as the topographic network. This was also the case for the second session where spheres were positioned on known points. The software allows the import of CSV file containing target's names and coordinates. The association is then the same as presented before. Named in the same way as in each scan, the association is done by name. The absolute position of the cloud is therefore calculated. New RMS errors about the entered coordinates are finally calculated.

* Once positioned, the point clouds are then colored. Each point cloud is finally exported independently to the FLS file to be subsequently processed on 3DReshaper software.

***Agisoft Photoscan*:**
As we have seen, the majority of the data was collected by terrestrial laser scanning, but this technic is limited when the studied object becomes higher, as parts of Schwartzenbourg ruins which amount to more than ten meters. Aerial photogrammetric data were then used to ideally complement the modelling.
*** From 2D pictures to 3D model:** *Photoscan* is a well-known photo correlation software developed by *Agisoft*. It allows reconstructing a 3D environment from 2D pictures. This software is as powerful as intuitive. Indeed, once pictures are loaded, it just needs to follow the workflow tab step by step to reconstruct the 3D. Aligning pictures is the crucial step in autocorrelation. The automatic research of "tie points" between the pictures allows their relative orientation and also their internal orientation. It is then immediately possible to verify that the flight enables sufficient covering pictures and offers surfaces where "matching" is possible (Figure 6).

*** Cloud densification:** Once the alignment of photos is checked qualitatively and quantitatively (a *Photoscan* calculation report is generated), the densification step will build a dense cloud of 3D points of the covered area. It is this 3D point cloud that will be exploited to complete laser scanning surveys.

*** Georeferencing and errors report:** *Photoscan* also enables georeferencing the 3D model. It is possible, thanks to georeferenced targets (Ground Control Points) (Figure 5) placed on the scene during shots. Those targets were pointed on the pictures in order to be three-dimensionally positioned in the model. It should be added that this step can be automatized using specific coded targets that can be recognized by the software. Once associated with their coordinates in the requested system, a calculation was necessary in order to get the absolute orientation of the pictures.

Figure 7: GCPs for model georeferencing.

PhotoScan
3D Modeling and Mapping

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
point 1	0.52	-0.93	-0.27	1.10	0.552 (206)
point 2	-0.68	-0.15	0.19	0.72	0.702 (174)
point 5	-1.74	0.43	2.81	3.34	0.585 (186)
point 6	0.64	1.40	-1.13	1.91	0.520 (181)
point 7	0.82	-0.96	1.47	1.94	0.743 (76)
point 12	0.42	-0.36	-0.16	0.58	0.573 (90)
Total	**0.91**	**0.82**	**1.38**	**1.85**	**0.604**

Table 5. Control points.

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
point 3					0.449 (73)
point 4					0.471 (145)
point 8	0.61	2.83	-13.05	13.37	0.531 (136)
point 9					0.476 (81)
point 10					0.608 (108)
point 11					0.568 (59)
point 13	-1.15	-2.69	11.04	11.42	0.725 (59)
point 14					0.657 (66)
point 15					0.550 (53)
point 16					0.670 (64)
point 17					0.566 (85)
Total	**0.92**	**2.76**	**12.09**	**12.44**	**0.597**

Table 6. Check points.

Figure 8: Error reporting

Despite the "black box" nature of any complex processing software such as *PhotoScan*, it is still possible to have access to RMS errors of the calculations. First of all on the automatically generated "tie points", guaranteeing the quality of the matching and therefore of the pictures, then, on the targets manually pointed, guaranteeing the quality of the "click" but also the overall orientation of the model. Finally, on the targets' position, giving the difference between the actual coordinates and their position in the numeric model. It should be noted that during processing, three targets with excessive altimetry RMS errors were removed from the calculation but retained as "check points". If necessary, it is even possible to obtain RMS errors on pictures coordinates if they were themselves georeferenced. This was actually the case during this project when the UAV recorded in each image the approximate position using its internal GNSS receiver (metric accuracy). A mean accuracy of about 1.5 cm was obtained in this project.

***Technodigit 3DReshaper*:**
Treatments we have just seen have generated 3D georeferenced point clouds from the ruins of Schwartzenbourg castle but also from its direct environment. Then, in order to generate a proper DTM as well as a 3D modelling of the ruins, those clouds had to be processed in *3DReshaper* software. This software, developed by *Technodigit,* is designed for point cloud processing and 3D meshing.

*** Import of georeferenced clouds:** The first step was obviously the import of the different point clouds. *3DReshaper* allows importing point clouds from many different files such as FLS (*FARO Scene* export format) or PTS (format in which the photogrammetric point cloud was exported from *PhotoScan*).

*** Re-sampling and first cleaning:** Rough clouds have a significant memory weight and a very variable point density (especially for point clouds where the density increases strongly when approaching the stations). The first treatments carried out was a resampling of each cloud in order to retain a maximum density of one point per centimeter, and a manual cleaning in order to remove the aberrant points in each cloud (dome of scattered points in the sky for scans, artefacts below the ground in the photogrammetric cloud). Once saved, those clean point clouds were used as for subsequent treatments.

*** Association of clouds from the same survey:** laser scanner clouds resulting from the same measurement campaign were then associated simply because they had already been calculated together during the treatments in Scene. A new centimeter resampling was then done to eliminate the redundant points in parts covered by more than one scan. At this point, we got three clouds corresponding for the first two to the two laser scanning surveys and for the last one to the photogrammetric point cloud.

The next step was obviously the combination of these three clouds into a single one. However, according to the cloud sizes, a rough cleaning had to be carried out in order to lighten the data mass, too large to be exploited in one piece. As a forester, we managed to roughly cut most of the surrounding vegetation. Indeed, this vegetation was destined to disappear during the creation of the digital terrain model, so that the software could take a breath.

*** Georeferencing:** As we saw before, the three clouds were georeferenced on the same topographic network but, as there were calculated separately and on different spheres, a couple of centimeter still remained between clouds coordinates. As the first data survey was planned a few weeks before the others, it was not possible to have similar data to correct this difference (more leaves on the floor). Moreover, not enough surface area was shared between first scans and other data, so nothing was doable. However, the second scanning campaign and the photogrammetric data area were clearly complementary and shared most of their area collected. As we had measured a slightly difference between them (3D translation error measured on a corner of the blockhouse), we had correct it. Using "Best-fit" tool, we were able to translate the photogrammetric point cloud in order to fit the laser scanning one.

Once a unique and accurately merged point cloud created, a last resampling was carried out and the DTM extraction could start.
A key step in this project was obviously the extraction of the DTM around Schwartzenbourg castle. While extraction techniques are possible in relatively flat environments, the configuration of the site gave a lot of worry as to the method that should be used. It was finally directly under *3DReshaper* that this extraction could be made, thanks to the development of a recent tool allowing to extract directly the natural ground for a point cloud: "Ground extraction". This tool allows from a point cloud to directly mesh the ground as a DTM. Two parameters are to be defined as input: the first concerns the expected resolution of the mesh (we chose 10 cm), and the second depends directly on the terrain to be modelled since it is the maximum slope of the natural terrain, which has to be defined between 10 and 80 degrees. Regarding to our craggy site, we chose the maximum value so that the maximum of ground points could be used. Finally, after a mesh cleaning (vegetation noise had created some aberrant face in the DTM mesh), we were able to present an accurate DTM with a quite nice point cloud of the ruins (Figure 9).

6. CONCLUSION

Regarding to the original objectives and the final production, we should be proud of what has been done during this first project.
As results we have:
- Defined a georeferenced network around and inside the ruins
- Collected data from the ruins and the surroundings
- Georeferenced those laser scanning and photogrammetric data
- Accurately merged point clouds from different origins
- Extracted the digital terrain model in such a craggy place
- Established a quite complete data set for future ruins extraction.

This project has to be fulfilled. The next step will be the hard task to focus more on the vegetation detailed cleaning. A data set of point clouds at different steps extracted from more than 100 GB have been made so that next works will easily be merge with this project.

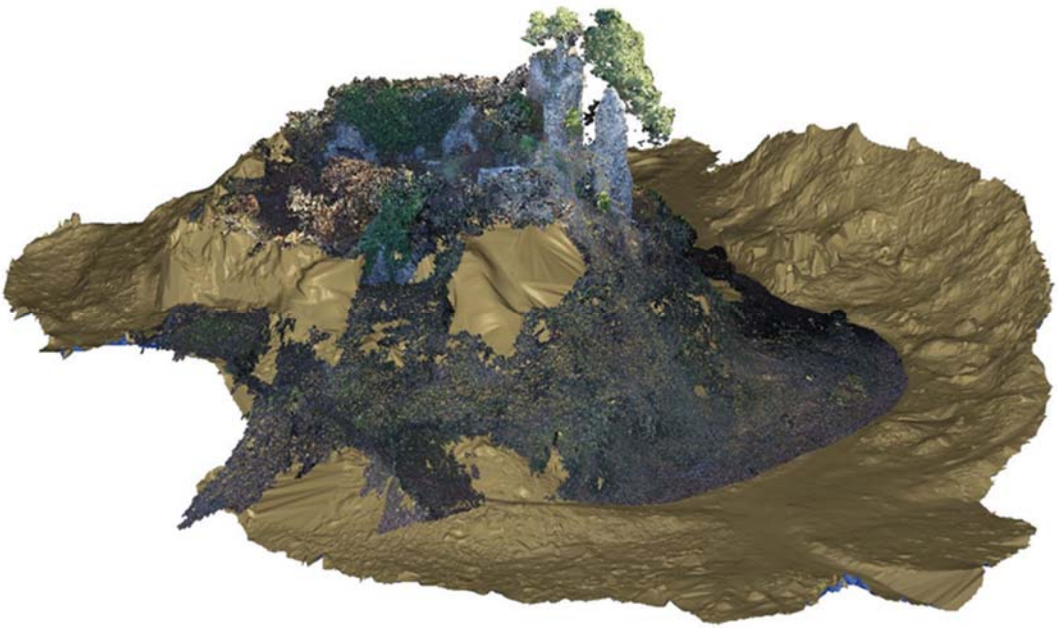

Figure 9: Final DTM with partial ruins model

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