3D documentation of a megalithic building in Sardinia

Laura LAI[1] | Matteo SORDINI[2]

[1] University of Ferrara and University of Sassari (Italy) | [2] ArcheoTech&Survey s.r.l., spinoff University of Siena (Italy)

Abstract: The research presented in these pages is about reality-based 3D modeling for documentation, analysis and sharing knowledge of a prehistoric site called Nuraghe Oes. A “nuraghe” is a megalithic monument built only in Sardinia during the Bronze Age; Nuraghe Oes is a complex type of nuraghe, well preserved, composed of a three-tower basement, similar to a bastion, connected with a main tower. The first season of stratigraphic investigation revealed the need for a high-quality documentation to preserve and to better understand the archaeological site: we planned a complete 3D survey to create a high resolution 3D model using terrestrial laser scanning and close-range photogrammetry. The use of multiple techniques was an essential requirement to produce a complete 3D model of the monument. Data processing was a time-consuming operation performed using different kinds of software. From the points of view of documentation and archaeological analysis, we produced CAD technical drawings to illustrate elevations, sections and plans, and to generate a measurable 3D PDF with the geometry of the monument. These products have been used for conservation purposes by the Superintendence for Archaeological Heritage of Sassari and Nuoro, the local agency of the Italian Ministry of Culture, and to carry out archaeological analysis and interpretation. Furthermore, exploiting the objectivity of the 3D recording, we proposed a standard scheme for the analysis of different features of this type of monument in order to improve the typological comparison of nuraghi. Lastly, we rendered and edited a video to share the results of the archaeological research about the Nuraghe Oes: the short movie leads people into the monument through a virtual tour, showing aspects and peculiarities of the megalithic building.

Keywords: laser scanning, close-range photogrammetry, 3D recording, 3D modeling, High Dynamic Range (HDR) images

Introduction

The case study presented in this work is related to the Nuraghe Oes, a Bronze Age megalithic building located in Sardinia, in the municipality of Giave (fig. 1). This type of monument symbolizes Sardinia and its distinctive culture, the Nuragic Civilization, developed between XVII – VI BC.

Nuraghe Oes is visually connected with the famous Nuraghe Santu Antine (municipality of Torralba), located about 1 km South-East.

Each nuraghe had different functions depending on the context, the geographic position and the natural resources. In the case of Nuraghe Oes, the monument had the function to control the valley of Campo Giavesu.

Fig. 1 – Frontal view and plan of the archaeological site Nuraghe Oes.

Nuraghe Oes is a complex type of nuraghe composed of a group of three towers connected with a preserved main tower at the North-West side. The group of towers, defined as the *frontal addition*, constitutes the remains of three towers: the structures are damaged and the central tower is completely collapsed. During the archaeological excavation led by the Superintendence for Archaeological Heritage of Sassari and Nuoro, in July 2012, a courtyard enclosed between the main tower and the central basement was discovered; the archaeologists also excavated the southern tower discovering a water well.

The *frontal addition* is partly inaccessible because the ruins of the north tower still have to be excavated, as well as the main tower of the nuraghe. In fact, the main tower is partially accessible only through a window, from half of its height to the top.

Peculiarities of this nuraghe are in the internal walls of the main tower and in the southern tower, where offset is visible. It had the function to support wooden floors. This is quite unique in Sardinia, since the towers of the nuraghi have internal rooms, one above the other, built with a *corbel* vault, similar to the Greek *tholos*.

The first campaign of stratigraphic investigation revealed the need for a high-quality documentation of the site, in order to preserve and to better understand the monument. We planned a complete 3D survey of the building to create a high resolution digital 3D model of Nuraghe Oes.

3D recording

Geomatic techniques provide opportunities to document, digitally preserve, and investigate distinctive and peculiar archaeological monuments.

The geometry of Nuraghe Oes is extremely complex because of its circular structures formed by stone dry-walls with a considerable space between the stones. The basement is quite difficult to record. It has many occlusions, a well for water, tunnels, and niches with very complicated shapes. This site, therefore, required the use of multiple techniques. We used the combination of image-based techniques and range-based techniques. The use of multiple techniques was an essential requirement to produce a complete 3D model, balancing the quality of geometric resolution, costs and time (GONIZZI, REMONDINO, VISINTINI 2012).

We chose a Time of Flight laser scanner for a massive data collection of the structures, both in the exterior and interior of the monument (fig. 2). There were two reasons why we selected the laser scanner. One was that the image-based technique was not suited for the drywall because of several dark holes. Another reason was the lack of equipment, such as a UAV, to acquire pictures from the air. The TLS survey was performed with at variable resolutions between 5 and 10 mm, depending on the type of detected element. In 24 scans, about 44.5 million points were recorded.

The TLS survey was not enough to record all structures of the monument. Some areas, like the well and niches, were impossible to record by the laser scanner because the characteristics of the instrument used in this project (Leica Scanstation) did not allow recording them. Additionally, the internal structures of the main tower could only be reached by a ladder 5 meters high. This created an obstacle in carrying equipment to the top due to the ladder's instability and the weight of the instruments.

To record the missing parts, image-based modeling was chosen. We used a calibrated Canon 50D camera with 15.1 Megapixel and CMOS sensor, equipped with 17mm lenses kept at the widest setting, in order to capture the upper room of the main tower, and the niches and the well in the southern tower. The distance between the camera and the object was variable, depending on available space and the shape of each element. Each element was recorded by convergent and nadir images with significant overlap.

The spiral stairs, which connects the first floor with the top of the main tower, was impossible to record since it was too narrow to capture nadir/convergent images.

In order to record the radiometric value of the surfaces and to produce high resolution textures, High Dynamic Range (HDR) images of the entire monument were recorded by the same digital camera used for image-based modeling.

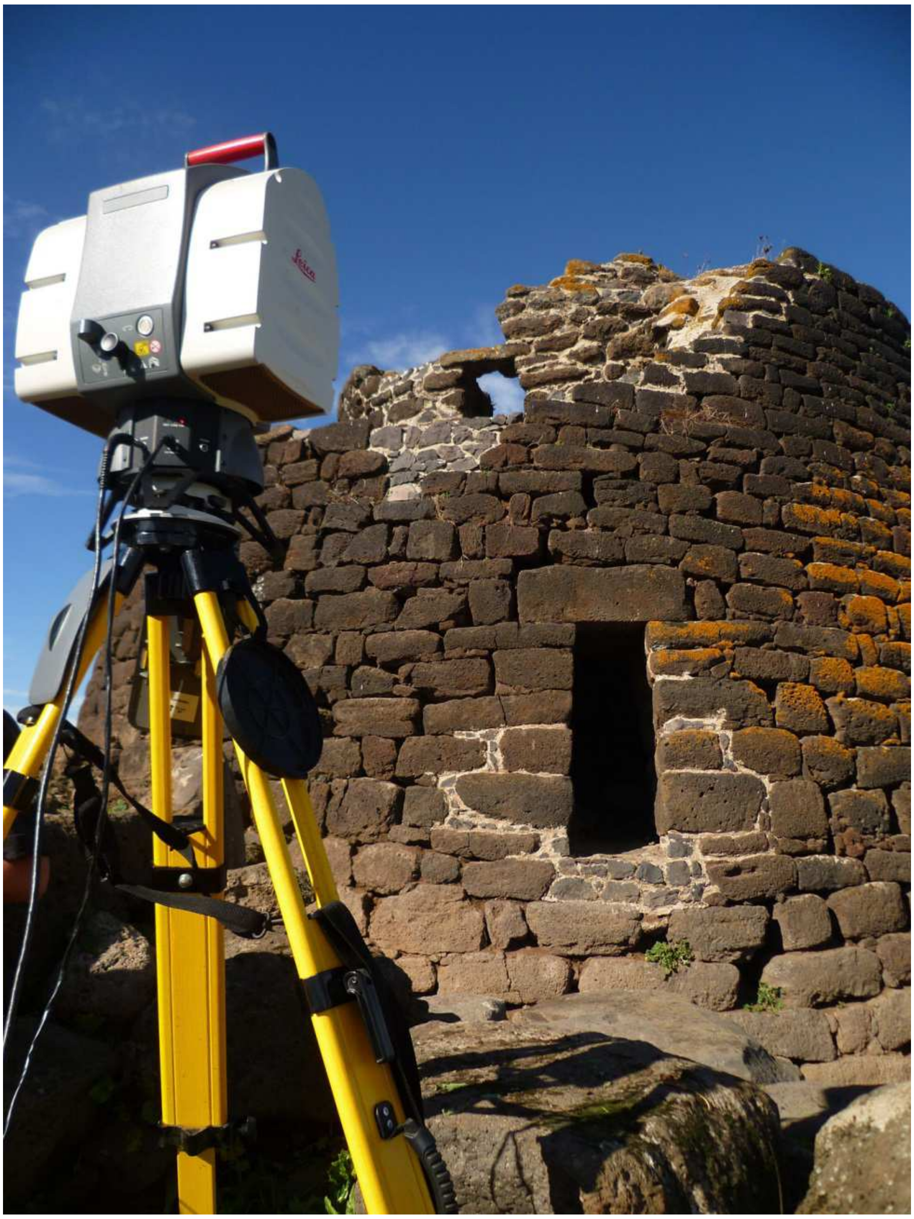

Fig. 2 – The laser scanner during data acquisition.

3D modeling

Range-based datasets and captured images, including HDR images, were processed by several software programs (see fig. 3 for the pipeline). To set the reference distance, image-based datasets were processed with photogrammetry software and TLS point clouds. Noise and unwanted features were swiped from range-based datasets.

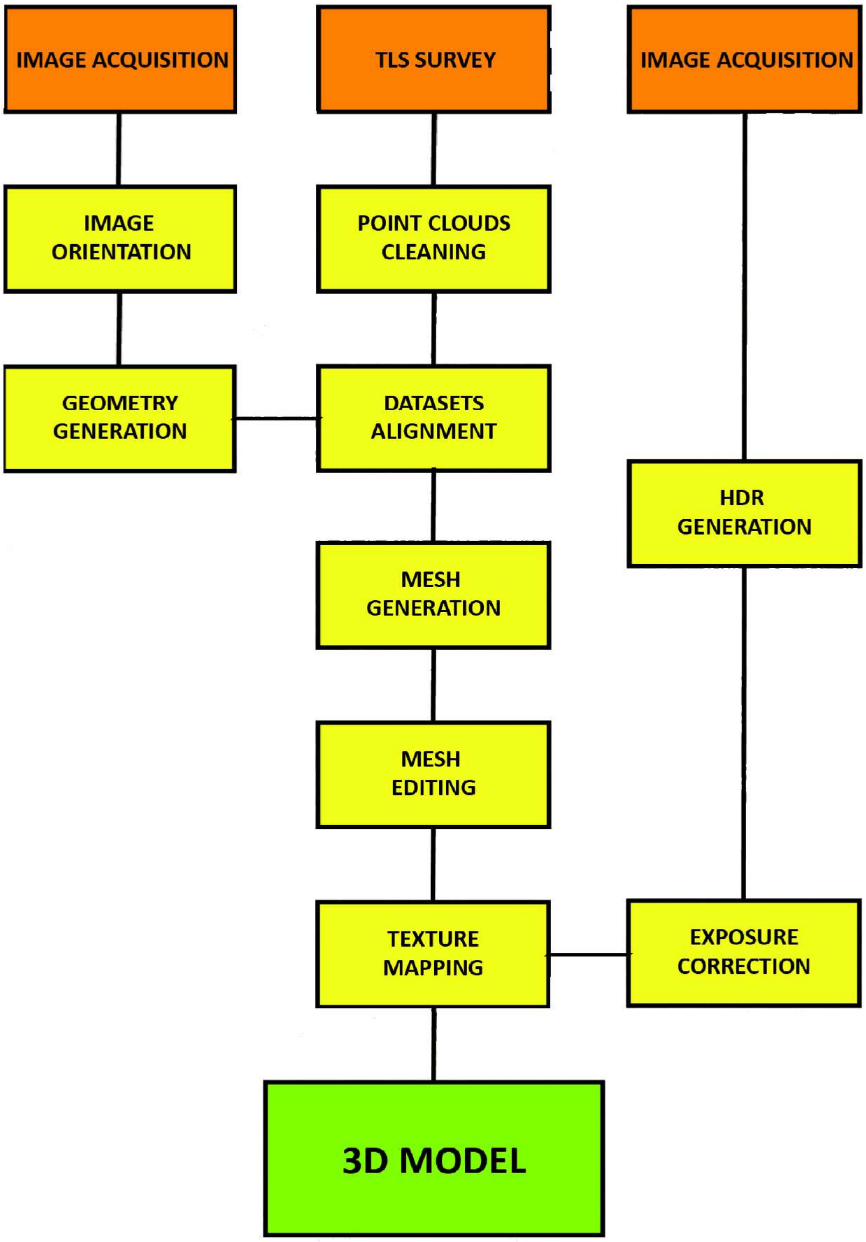

Fig. 3 – Pipeline of the 3D recording and modeling.

All scans, as well as models obtained with image-based techniques, were aligned by dedicated software. The aligned datasets were merged to produce a global mesh of the archaeological site. The resulting mesh was edited to correct defects and close holes.

The technique of editing in images of grass in the area of the collapsed stones was used to cover, to close holes and to fix defects. Another time-consuming problem was the space between the stones in the drywalls, which in some case was large and more than half meter deep. In fact, the scanner was not able to record the complete shape of these spaces and a long manual reconstruction was needed. We also needed a manual reconstruction of some parts of the internal upper room and the top of the main tower, partially occluded by vegetation. The resulting mesh had 16 million triangles. Before proceeding to texture map the monument, the number of triangles was reduced by 60%, preserving the details and making the model more manageable. Furthermore, the images acquired for texture mapping purpose were merged in HDR images and their exposure was balanced to create a uniform illumination. All images were projected on to 3D models using a manual orientation method with homologous points in the mesh. Some corrections in texture maps were also made before the rendering the model. We produced approximately, 95 HDR textures to represent a photo-realistic high resolution 3D model of Nuraghe Oes (fig. 4).

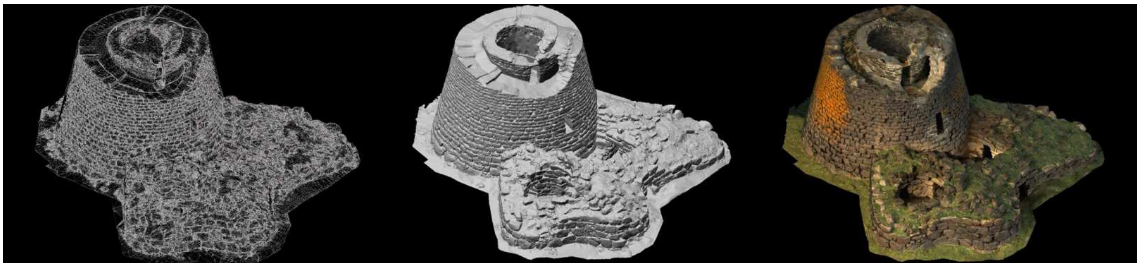

Fig. 4 – 3D model of Nuraghe Oes.

3D documentation and analysis

3D models provide some advantages in archaeological analysis while respecting the principles of traditional archaeological documentation, they provide users with:

- a very high level of precision and accurate documentation
- the possibility to edit sections, plans, and any other measurements at any moment and in any position
- an objective and standardized documentation, useful for improving the typological comparison between the same kind of structures
- an open space very close to reality where the archaeologist is permanently linked to the monument in order to develop interpretations
- a very precise documentation that allows the Superintendence to better preserve the monument

Through the use of a high-resolution 3D model we were able to perform a very detailed architectural analysis of the monument inside a virtual environment. We produced CAD technical drawings to illustrate elevations, sections and plans (fig. 5).

The diameter of the main tower is 16 meters, and its hight is 11 meters although it is partially collapsed. The masonry technique is particularly accurate, with well worked stone blocks. In the first three rows, blocks are considerable, huge in size and irregular in shape. Ascending to the top, the squaring of block sides becomes more accurate and row size decreases to an average height of 30 cm from the mid to the top of the tower wall. The inclination of the wall at the base of the main tower is about 11-12 degrees: the first 3-4 rows are more flared while the rest of the wall shows a constant slope.

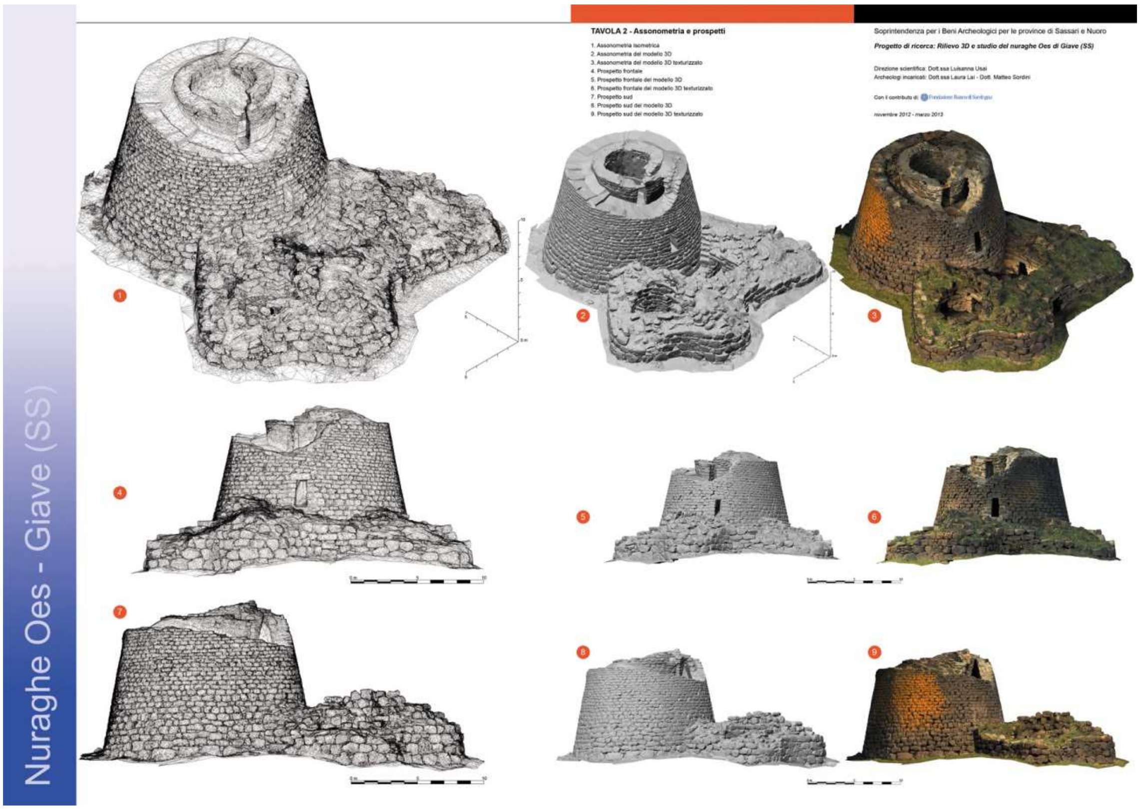

Fig. 5 – Technical drawing in A1 format with axonometric, frontal, and side views in wireframe, non-textured, and textured mode.

The 3D model of Nuraghe Oes allowed us to take detailed measurements for the various elements of the monument, and all these features have been used to perform a very precise and detailed typological comparison with other nuraghi in order to understand original aspects of the monument.

Lastly, after a visual survey of the structures, the high resolution mesh and the 3D photorealistic model were used for mapping the structural problems of the monument, such as cracks and structural instability areas. The external wall of the main tower has three zones showing structural problems. One of these is around the window of the first floor (fig. 6).

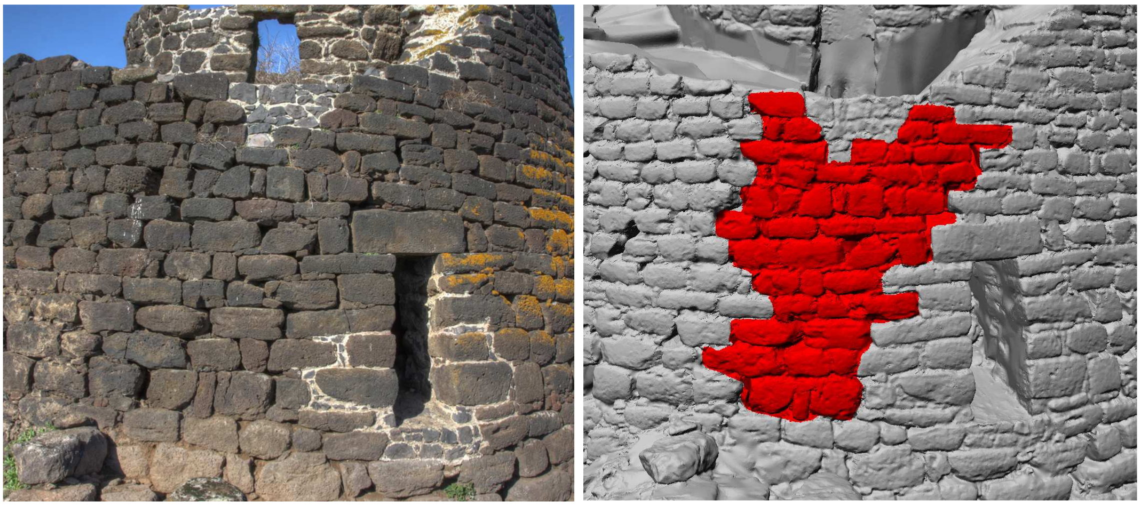

Fig. 6 – Mapping the structural problems.

Many cracks have been highlighted in the monument during the analysis: in the architraves of the principal entrance, in the corridor of access to the north tower, in the room on the left of the entrance to the basement, and in one niche in the southern tower. Mapping structural factors can be useful to plan intervention and to monitor the health of the monument over time.

3D dissemination

In addition to the precise and detailed documentation, this project stressed the importance of 3D recording and modeling as a fundamental link between research object, scientific knowledge and wide public communication.

The high resolution 3D model of Nuraghe Oes has been collaborated for elaborate two types of products to report broadly about the results from archaeological research.

A measurable 3D PDF was created with the monument geometry (Fig. 7, https://skfb.ly/Auny). Additionally, a short animation was rendered and edited to introduce people to aspects and peculiarities of the megalithic building of Nuraghe Oes (YouTube: http://www.youtube.com/watch?v=HvA975e1FtM).

This 3D documentation is highly valuable in terms of communication, and allows people to easily access cultural heritage data and scientific information.

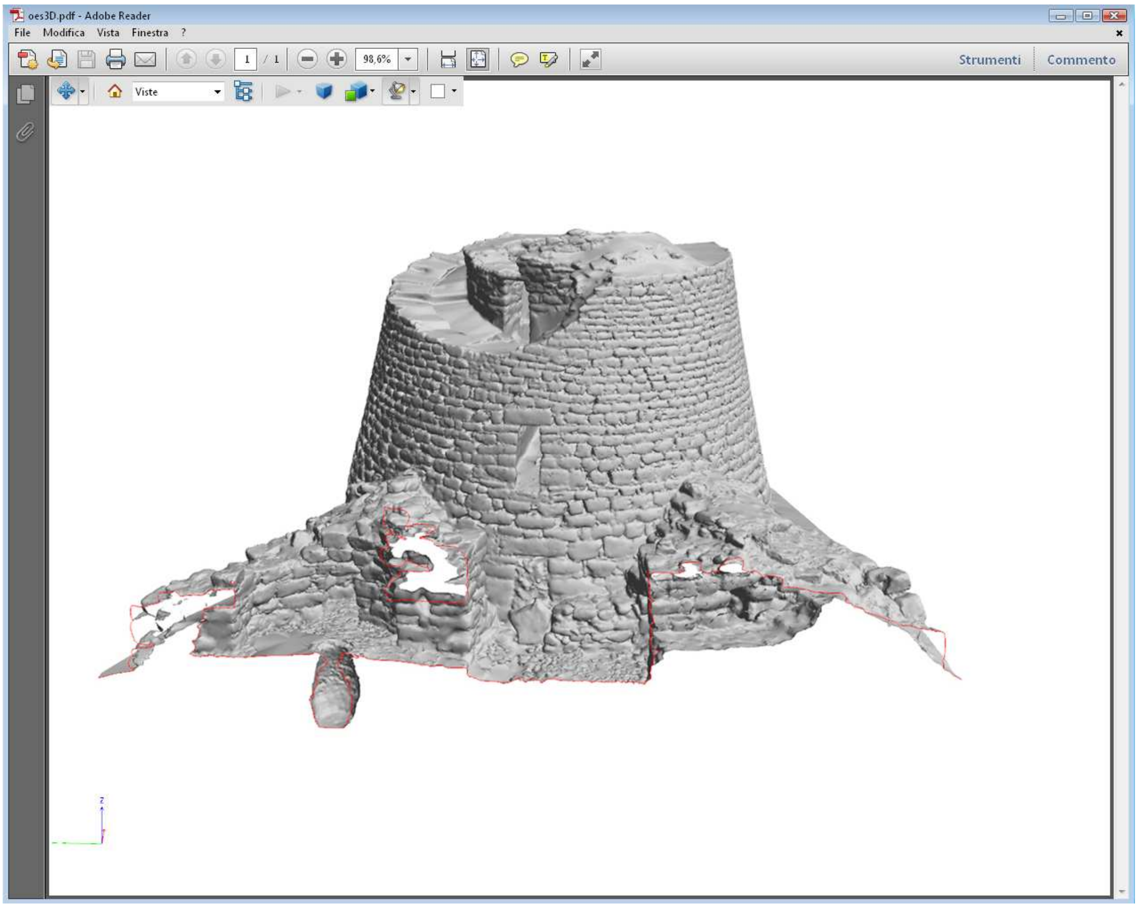

Fig. 7 – A screenshot of the 3D PDF file.

Conclusions and Next Developments

The project illustrated in these pages is a new approach for archaeological research, protection and evaluation of Sardinia's nuraghi.

The integration of various geomatic techniques allowed us to record a very complex building under measuring condition. The project indicated that UAV might help to improve efficiency during data collection and increase quality of image-based modeling.

The three-dimensional thinking supported the interpretation processes inside a virtual environment, which constantly linked with the object of research. The objective nature of 3D recording and modeling also showed that it is necessary to standardize archaeological documentations which is essential to improve and to make less subjective the typological comparison between nuraghi. A detailed and standardized documentation is also a "key" component for cultural heritage institutions in order to recognize the best method for monitoring and protecting historical architecture.

The 3D thinking offers an improved efficiency of archaeological workflow.

The next research steps will be focused on:

- improving 3D recording with UAV
- managing 3D data with Geographic Information System in order to integrate different kinds of information and monitoring the status of the monument
- sharing archaeological knowledge through internet and mobile devices

Acknowledgement

A particular thank goes to Dr. Luisanna Usai of Superintendence for Archaeological Heritage of Sassari and Nuoro for her open-minded attention in this new research approach regarding nuraghi studies.

Sincere thanks are due to the Banco di Sardegna Foundation for their financial support.

Special thanks to Professor Stefano Campana, of University of Siena, for his suggestions and helpful criticism from his wide experience in archaeological research.

Sincere thanks to Dr. Pino Fenu from Studio Associato Metra company that gave us some aerial zenithal photos useful to texture the top of the Nuraghe Oes main tower.

Finally, thanks to Dr. Ken Saito of University of Siena and Dr. Katherine Martinko for their help in English translation.

References

CAMPANA, S., RIZZI, A., SORDINI, M. (2009). *3D modeling of a romanesque church in Tuscany: archaeological aims and geomatics techniques*. Proceedings of the 3rd ISPRS International Workshop

"3D-ARCH 2009: 3D Virtual Reconstruction and Visualization of Complex Architectures", Vol. XXXVIII-5/W1.

CAMPANA, S., BIANCHI, G., FICHERA, G. A., LAI, L., SORDINI, M. (2012). *3D Recording and Total Archaeology: From Landscapes to Historical Buildings*, in International Journal of Heritage in the Digital Era, Vol. 1 n. 3, pp. 443-460.

CIGNONI, P., SCOPIGNO, R. (2008). *Sampled 3D models for CH applications: a viable and enabling new medium or just a technological exercise?*, in ACM Journal on Computing and Cultural Heritage.

FORTE, M. (2008). *La villa di Livia, un percorso di ricerca di archeologia virtuale,* in L'Erma di Bretschneider pp. 54-68.

GONIZZI BARSANTI, S., REMONDINO, F., VISINTINI, D. (2012). *Photogrammetry and Laser Scanning for archaeological site 3D modeling – Some critical issues*, V. Roberto, L. Fozzati (Eds.) Proceeding of the 2nd Workshop on 'The New Technologies for Aquileia', 25 Giugno 2012.

LILLIU, G. (1982). *La civiltà nuragica*, ed. Delfino, Sassari (Italia).

REMONDINO, F., EL HAKIM, S. (2006). *Image-based 3D modeling: a review,* in Photogrammetric record, Vol. 21(115), pp. 269-291.

REMONDINO, F., EL-HAKIM, S., GRUEN, A., ZHANG, L. (2008). *Development and performance analysis of image matching for detailed surface reconstruction of heritage objects,* in IEEE Signal Processing Magazine, Vol. 25(4), pp. 55-65.

ZHANG, W., ZHOU, B. (2004). *An HDR Brightness Correction Algorithm for Panorama Images,* in Proceedings of the 4th IASTED International Conference on Visualization Imaging, and Image Processing, Marbella, (Spain).

Imprint:

Proceedings of the 18th International Conference on Cultural Heritage and New Technologies 2013 (CHNT 18, 2013)

Vienna 2014

http://www.chnt.at/proceedings-chnt-18/

ISBN 978-3-200-03676-5

Editor/Publisher**:** Museen der Stadt Wien – Stadtarchäologie

Editorial Team: Wolfgang Börner, Susanne Uhlirz