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USING LASER SCANNER TECHNOLOGY TO ANALYSE MUD-BRICK ARCHITECTURE IN THE ANCIENT NEAR EAST. THE PALATIAL COMPLEX OF ARSLANTEPE (MALATYA, TURKEY)

1. Introduction

In 2014, the Sapienza University of Rome financed and supported The Shape of Monuments Project in cooperation with Leica Geosystems, involving eleven young researchers from different disciplines and Departments in the execution of laser scanning surveys on archaeological areas and monuments. The researchers faced problems concerning how to depict three-dimensionally archaeological artefacts and started a common path, which led them to communicate with each other in order to overcome methodological and theoretical differences among disciplines and to pull together using mutual research tools. Advanced technology is gaining momentum in the fields of archaeology and art history, encouraging to cooperate with scientific disciplines and to deal with sophisticated data collection instruments and procedures without disciplinary barriers. Cultural heritage studies represent an ideal field to test and improve this cooperation.

The Shape of Monuments Project used a Leica Geosystems ScanStation P20, a Hexagon Romer Absolute Arm and their related software, following three main research paths: standardization of graphic renderings; use of 3D scans in the analysis of artefacts and structures; technological education and training at university level (Alvaro *et al.* 2016). Prehistoric lithic and pottery, Etruscan metal objects, and Roman statues, architectural elements and epigraphs have been scanned as well as entire buildings like the Early Christian Basilica of San Lorenzo fuori le Mura in Rome and the Palatial Complex of Arslantepe (Turkey). The very different typology of the scanned objects, which differ for morphology, texture of the material, size and function, provided the researchers with a wide range of possibilities on how to plan and manage both the data acquisition process and the post processing of the point clouds. One of the most significant case studies of The Shape of Monuments Project concerned a complex of building within the archaeological site of Arlsantepe, in Turkey, that we scanned during the 2015 and 2016 excavation campaigns. Advanced measurement technologies depict the shape of an object as it really is, overcoming interpretative ambiguities, which are implicit in the discretional view of the researcher. If this is true for the aforementioned archaeological artifacts, the potential of laser scanning technology is even greater when dealing with earthen buildings like those in Arslantepe, almost completely made with mud bricks and mud plaster.

2. The archaeological site of Arslantepe

Arslantepe is located in the Malatya plain, Eastern Anatolia (Turkey), an oasis surrounded by the Anti-Taurus Mountains, 15 km SW of the Euphrates River (Fig. 1). It rests on lake soils formed by calcareous clays, arena layers and calcareous cement. The whole area is made up of fertile alluvial soils and easily accessible aquifers, which ensure high agricultural potential (Palmieri, Marcolongo 1983). The site is an artificial settlement mound, which rises up to 940 m above the sea level, approximately 30 m height and 4 ha wide. It was occupied without major interruptions from at least the 5th millennium BCE to the Byzantine period. In 1961, the Italian Expedition in Eastern Anatolia guided by Salvatore Puglisi and Alba Palmieri resumed excavations after the archaeological campaigns led by the French Louis Delaporte and Claude Schaeffer (Alvaro 2012). Since then, extensive excavations are running by the Sapienza University of Rome, today under the direction of Prof. Marcella Frangipane.

The investigation of the 4th millennium BCE levels, when the earliest Mesopotamian urban societies were emerging along the Euphrates and Tigris banks (Frangipane 2010) provided the first thorough evidence of a flourishing economic, political, religious, and administrative center. Together with monumental public buildings, the archaeologists unearthed pottery, metal weapons, and thousands of seal impressions, providing documentary evidence of the first known example of a "palace" complex and the birth of an early state system.

The Palatial Complex so far best represents the history of the construction activities at Arslantepe. The excavated portion covers a surface of about 2,000 m^2 along the south-western side of the mound and shows sectors that differ from a functional as well as an architectural point of view, with a bipartite arrangement predominating both in cult buildings and in residences. The complex was planned as a single whole including two small temples, storage rooms, courtyards, corridors, representative buildings, administrative areas, and elite residences where the leaders of the community lived and performed religious, economic, political and administrative activities (Alvaro 2010a). It was built in successive building phases, as a sort of progressive enlargement. The earliest core was in the northern and higher part of the complex, characterized by the presence of a very large courtyard, a decorated entrance corridor, a relatively small temple, and an imposing building communicating with both the courtyard and the residential area. Successive additions greatly widened the public space and deeply transformed it according to the increasing need of separation of the various activities and functions performed by the central institutions (Alvaro 2010b). Besides the ritual places for ceremonial practices, the public area also consisted of buildings where a large number of people carried out explicitly secular activities such as the food redistribution

Fig. 1 – A) Map of Turkey with the localization of Arslantepe; B) Plan view of Arslantepe with the evidence of the Palatial Complex.

to remunerate the exploitation of labor, or the sealing procedures to account for administrative transactions in a period preceding the invention of writing. Nonetheless, there is no evidence of a real urbanization process at Arslantepe or in the entire Middle-Upper Euphrates Valley. The lack of urbanism was both the characteristic feature and the weakness of the Arslantepe Early State organization. The system collapse was inevitable: a violent fire destroyed the palace, and the history of power at Arslantepe was to take a new turn, full of fluctuations, abrupt transformations, and regressions (Frangipane 2012b).

3. Peculiarities of mud brick architecture

The Palatial Complex was brought to light in an extraordinary state of preservation, with mud brick walls over 2 m high and between 85 and 130 cm thick, original white mud plaster and red and black wall paintings. This is due to the abandonment of the buildings after the fire, whose submergence preserved their contents creating what archaeologists describe as a "time capsule" of exceptional decorated small finds and rooms, and providing a complete picture of prehistoric life. By following a branch of study on earthen architecture embarked long time ago, scholars of Arslantepe collected fragments of wall paintings (Fazio 1992), mud plasters and mud bricks (Liberotti, Quaresima 2010) from the buildings of the Palatial Complex and studied them in the laboratories. According to one of the most recent investigations (Liberotti *et al.* 2016), mud bricks from residential and public buildings within the Palatial Complex show coherent response to compression and give no dispersion, hence having a greater load bearing capacity if compared with building materials from other periods within the site. The analysis of the walls texture, which demonstrates a more homogeneous size of the Palatial Complex mud bricks with respect to the other periods (Liberotti, Quaresima 2012), confirmed the increasing of standardization in the mud brick manufacture and the improvement of the construction techniques at the end of the 4th millennium BCE. Given the inhomogeneity and plasticity of earthen building materials and the irregularity of mud brick walls, which are also extremely subject to earthquakes and to the pressure of soils accumulated for millennia on top of them, the lines and points are not obvious and the use of a laser beam for the indirect data capture is particularly suited.

4. The 3D laser scanning survey of the Palatial Complex

Laser scanning enables to collect a large quantity of three-dimensional measurements quickly and with meaningful accuracy values. In order to record and analyze the surfaces and shape of the structures in the Palatial Complex, we scanned the area from 89 different positions during two survey campaigns using the Leica Geosystems ScanStation P20, a time-of-flight laser scanner enhanced with Waveform Digitizing Technology (WFD). It comes with a camera that measures 1,000,000 points per second and captures point clouds with pinpoint accuracy throughout the entire measurement range (up to 120 m). This technology allows acquiring data even in the presence of massive dust, as occurs in earthen buildings like those at Arslantepe.

In 2015, we used the ScanStation P20 from nine different stations and detected twenty-seven targets located across the main corridor of the central area and surveyed by a total station. They served both for the registration procedure and as tie points between the scans and the images. Over 1 billion points have been recorded during this first stage of data acquisition with a scan density of 3.1 mm at 10 m (medium quality level). A built-in high-resolution digital camera captured a snapshot of the whole area. The resulting product of each scan was a point cloud where each point yields the spectral color information for the represented material. In 2016, we used the same ScanStation P20 calibrated with the same parameters from eighty different stations, focusing on the temples area, the courtyard and the external zone of the Palatial Complex. The fieldwork totally took no more than three weeks.

After we completed the fieldwork, we imported data via Cyclone 9.0.3 software without any loss of information selecting 100% in the sampling list. We merged all the 89 point-clouds registering them with both visual alignment and wizard constrain methods, creating the base for a complete surface reconstruction. Manual editing eliminates the erroneous points or "noise" recorded when measuring near the silhouette of the objects with respect to the scanner positions. In this regard, we achieved one result by virtually release the roof, which is an immovable element, from the buildings to be analyzed (Fig. 3). In fact, in 2011 the Malatya Governors in cooperation with the Italian Expedition in Eastern Anatolia constructed an open-air archaeological museum to protect

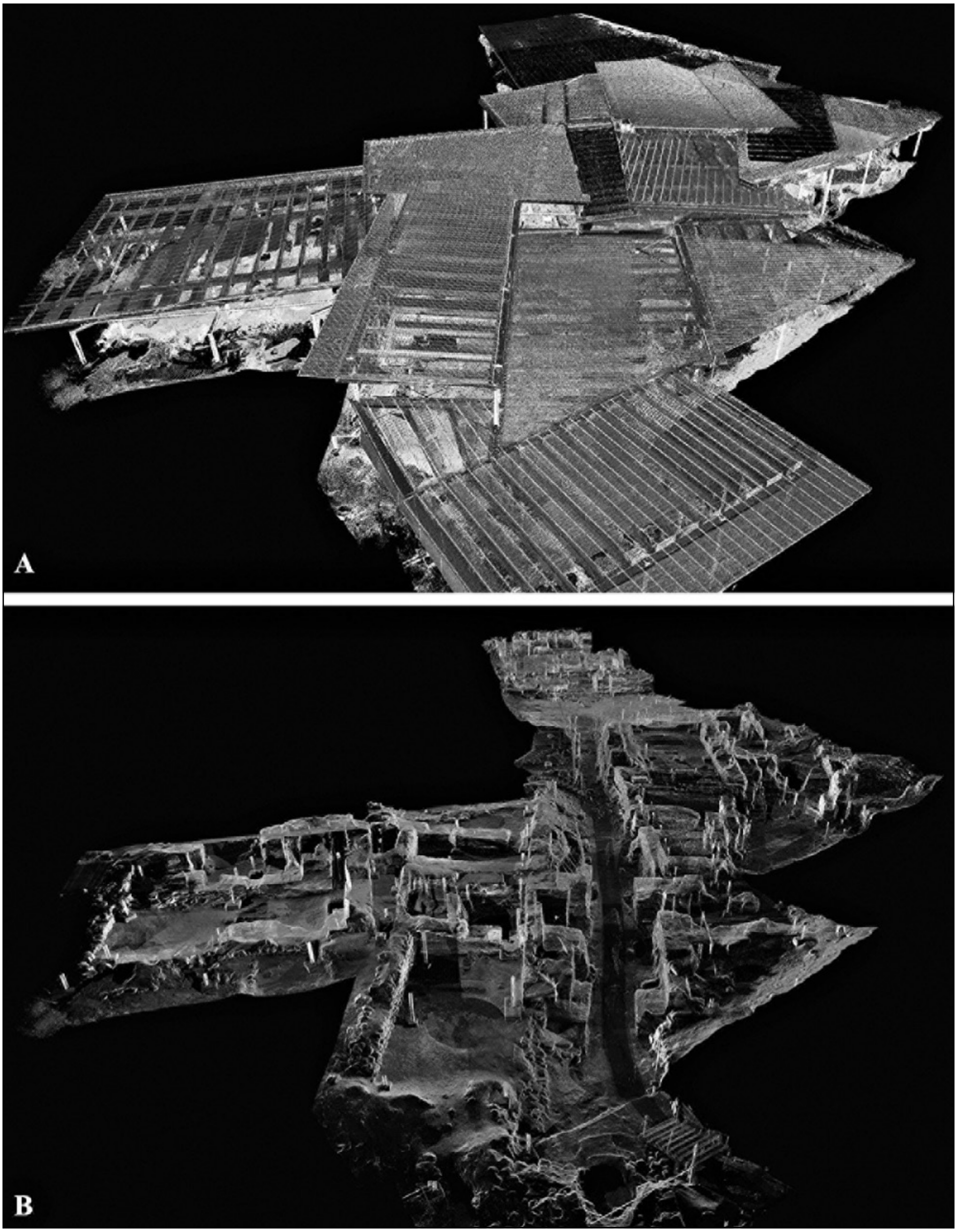

Fig. 2 – Point clouds of the Palatial Complex with (A) and without (B) the roofing system.

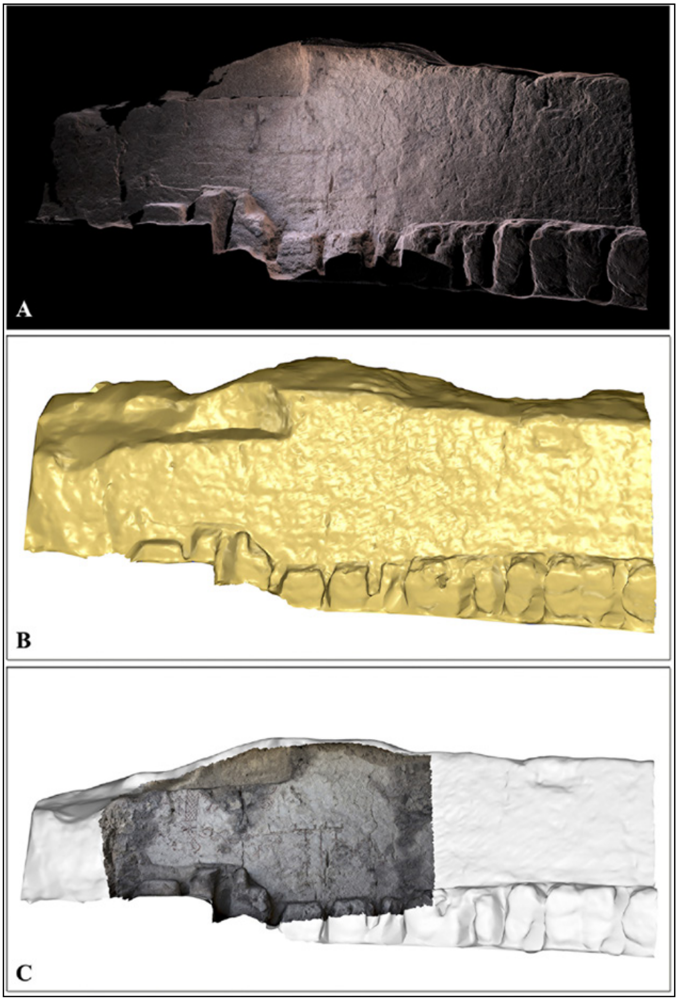

Fig. 3 – Northern sector of the corridor wall showing original paintings: A) A color point cloud from scanner; B) Mesh; C) Textured mesh.

the Palatial Complex and at the same time to enable visitors to explore the monuments by way of specifically built paths (Mangano 2012). The structure has no foundations; it does not affect the underlying archaeological levels in any way. It consists of vertical uprights placed alongside the ancient walls and supported by metal substructures fixed to the ground through small cement bases that wrap around the ancient walls. The vertical posts support a wooden roof that respects what is thought to be the original layout of the Palatial Complex:

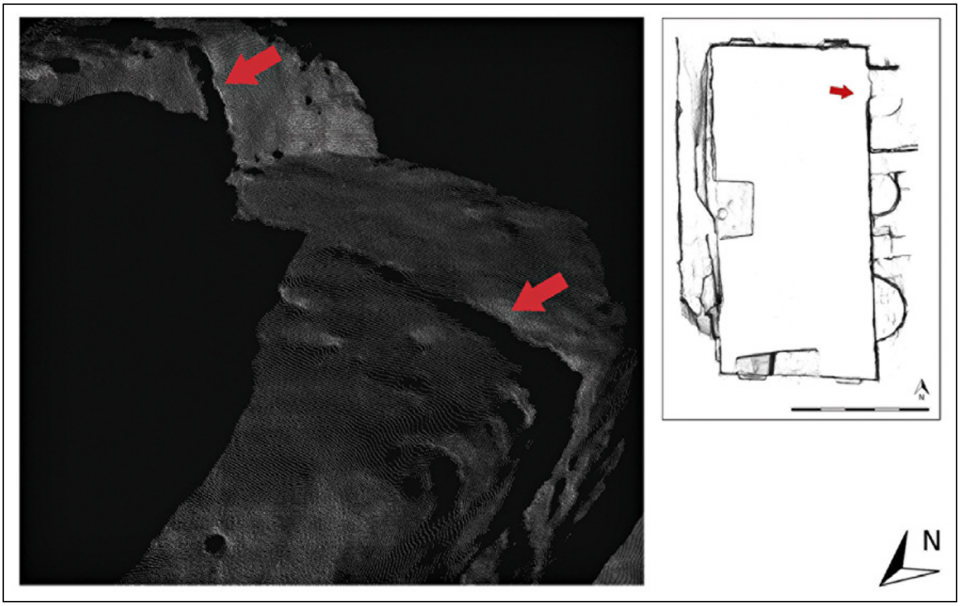

Fig. 4 – Portion of Temple B point cloud showing the damage occurred in 2016.

open areas like corridors and courtyards are covered with glass panels. This roofing system permits a faithful overview of the structures encumbrance and of the internal brightness of the buildings. Nevertheless, since 2011 it is no longer possible to have a full optical view of the Palatial Complex, as the roof hides it.

Although the post-processing is still in progress, we already achieved excellent results especially with regard to the understanding of the buildings shape. We extrapolated from the point clouds a 60 m long NS profile cutting the corridor, the courtyard and the building 37 that would be very difficult to obtain on the field without laser scanning technology. We found out that the corridor, which covers an underground drainage system, has a 10% slope. It links a series of articulated rooms and spaces and opens onto the paved courtyard in front of building 37. The generation of 2D drawings from the 3D point clouds by using Cyclone software provided extremely useful plans, elevation contour lines and profiles that can be used in GIS or CAD packages by Cloudworx plug-in.

Another important result is the representation of the smallest detail of the mud plaster coating, very often consisting of several superimposed layers. As stated before, the sub-millimeter precision of laser technology allows to document in the best way an extremely plastic element like the mud plaster, namely a clay-based mortar with natural binder lying on supports (walls) full of hollows, fractures and false floors. The overlapping layers of mud plaster tell about the monument life as it stresses the maintenance of the building, which has to be made on a regular basis just like people living in earthen houses do even today. In this regard, we worked on the northeastern portion of the corridor wall flanking Temple B by using the Hexagon software for fast processing of point clouds: 3DReshaper. This wall section is particularly important because it has original painted decorations of considerable historical interest. We applied the texture containing a high-resolution picture of the paintings on the mesh elaborated in 3DReshaper (Fig. 3).

5. Impact and conclusions

This paper should be considered as a work in progress. We started with a group of buildings (the Palatial Complex) but as we went along, we realized that we could have scanned, and thus globally addressed, the entire site in order to create a digital archive of the whole mound in a few days. Scholars might use such digital archive in order to analyse buildings, perform micro measurements and investigate on construction techniques and materials. In this way, scanning becomes a tool for analyzing the state of conservation and monitoring the surfaces and the materials exposed to decay over the time, like for example wall plaster. In conclusion, the ideal situation would be to scan the archaeological evidence as soon as it comes out from the excavations to avoid losing data as time goes on. A good example of this actual use of laser scanner technology is in Temple B, to the E of the corridor, where we scanned the same wall in 2015 and the year after. In 2016, we noticed a damage at the top of the wall that was not present in any scan of the previous year: dripping water vertically falling from a very small hole in the roof has eroded the surface of the wall (Fig. 4).

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References

Alvaro C. 2010a, *Public and private architecture at Arslantepe in period VI A*, in Frangipane 2010, 45-71.

Alvaro C. 2010b, *Architectural analysis of the VIA monumental complex at Arslantepe*, in P. Matthiae, F. Pinnock, L. Nigro, N. Marchetti (eds.), *Proceedings of the 6th International Congress of the Archaeology of the Ancient Near East (Rome 2008)*, Wiesbaden, Harrassowitz Verlag, vol. 1, 149-158.

Alvaro C. 2012, *The topography and architecture at Arslantepe during the Second and First millennia BC: Reconsidering more than 100 years of researches*, in Frangipane 2012a, 345-360.

Alvaro C., Albano V., Amici S., Bajeot J., Danesi V., Gerogiannis G.M., La Marca C., Liberotti G., Michalcakova J., Moscone D., Pansini A., Pizzoli E., Tota F., Zinni M. 2016, *"The Shape of Monuments" Project. Current activities and technological training in University-Industry partnership*, «Scienze dell'Antichità», 22, 1, 213-234.

Fazio G. 1992, *Prime annotazioni sulla tecnica dei dipinti murali rinvenuti nell'edificio palaziale della fine del IV Millennio ad Arslantepe-Malatya*, «Studi Micenei ed Egeo-Anatolici», 30, 155-157.

Frangipane M. 2010, *Economic Centralisation in Formative States. The Archaeological Reconstruction of the Economic System in 4th Millennium Arslantepe*, Studi di Preistoria Orientale 3, Roma, Dipartimento di Scienze dell'Antichità.

Frangipane M. (ed.) 2012a, *Fifty Years of Excavations and Researches at Arslantepe-Malatya (Turkey). A Contribution to the Study of the Earliest Centralised Societies. Proceedings of the International Conference (Rome 2011)*, «Origini», 34.

Frangipane M. 2012b, *The collapse of the 4th millennium centralised system at Arslantepe and the far-reaching changes in 3rd millennium societies*, in Frangipane 2012a, 237-260.

Liberotti G., Quaresima R. 2010, *Building materials in the 4th and early 3rd millennium monumental architecture at Arslantepe: Mud bricks and plaster*, in Frangipane 2010, 73-80.

Liberotti G., Quaresima R. 2012, *Building materials and construction techniques at Arslantepe: Results of an interdisciplinary study*, in Frangipane 2012a, 447-463.

Liberotti G., Rovero L., Stipo G., Tonietti U. 2016, *Mechanical investigation on adobe samples belonging to the archaeological site of Arslantepe (Malatya, Turkey)*, in *CIAT2015. Congrès International sur l'Architecture de Terre en Afrique du Nord (Marrakech 2015)*, «Journal of Materials and Environmental Science», 7, 10, 3656-3666.

Mangano D. 2012, *Comunicating Arslantepe. For a semiotic approach to the musealization of an archaeological site*, in Frangipane 2012a, 485-495.

Palmieri A.M., Marcolongo B. 1983, *Environment, water supply and cultural development at Arslantepe (Malatya, Turkey)*, «Origini», 12, 2, 619-628.

ABSTRACT

This paper presents the preliminary results of a laser scanning survey carried out at the archaeological mound site of Arslantepe, located in eastern Turkey. The Italian Archaeological Expedition in Eastern Anatolia has largely brought to light its long history spanning from the 6th millennium BCE to the Byzantine period. The most outstanding evidence unearthed so far is a group of remarkably well preserved monumental buildings erected during the final centuries of the 4th millennium BCE, when the economic and political centralization reached its climax. Recently, the whole area became an open-air museum protecting the archaeological structures from climatic stress and enabling visitors to have a glimpse of the monumental complex as it was. The laser scanning survey was aimed at aiding the interpretation of the archaeological features through extremely accurate measurements as well as to provide the researchers with structural and condition monitoring of the surfaces overtime. Given the ever-changing plastic shape that mud-brick buildings take on over the time, this survey turned out to be an interesting challenge for testing laser scanner technology, since it is not easy to connect to any regular design.