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Smart tools for archaeological survey in different frameworks and contexts: approaches, analysis, results

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ABSTRACT
The world of geomatics today provides new tools, smart and low cost, for archaeological survey, from geographical positioning to detailed drawing and graphic documentation of past evidence. These instruments, light and not bulky, interface directly with tablets, iPads or smartphones via intuitive applications and speed up the data collection in the field: archaeological data collection seems not to be a big issue today and 3D survey appears to be accessible even to less experienced archaeologists. We have tested the Trimble Catalyst DA2 smart system for centimetric georeferencing at the *Curiae Veteres* in Rome (Italy), at the Sun Temple of Niuserra, in Abu Ghurab (Egypt) and inside the ancient site of Eridu in Iraq: it was a good opportunity to check the accuracy of this tool, especially when associated to detailed and close-range survey activities, related to landscape archaeology and stratigraphic excavations. As we will see, if the instrument cannot replace more precise measurement tools still today (such as total station or laser scanner), in the field of georeferencing can be alternative to more expensive and complex GNSS systems, and it proved to be quite effective in systematic archaeological survey of large areas, especially in association with digital aerial photogrammetry made by UAV-UAS.

Section: RESEARCH PAPER

Keywords: landscape archaeology; GNSS; smart survey; Rome; Abu Ghurab; Eridu

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1. INTRODUCTION

The world of geomatics and digital technology provides today new, smart, low cost and easy-to-use tools for archaeological research in the field, from geographical positioning to detailed survey of past evidence [1].

These instruments, light and not bulky, interface directly with tablets, iPads or smartphones via intuitive applications and speed up the data collection in the field, making the spatial and typological integration of archeological record increasingly faster and easier. So, archaeological data collection seems not to be a big issue today and 3D surveys seem accessible even to less experienced archaeologists. However, beyond their apparent effectiveness, are these tools precise and reliable? And in which frameworks do they work better or worse?

The difficulties in achieving a high degree of precision in the measurement of archaeological features, ±1 cm, using satellite instruments are well known (some inherent the technological structure itself), and there have been numerous solutions used during decades of experience to obtain increasingly appreciable accuracy: the use of double antennas with the support of trigonometric reference points set up on the ground by national agencies, the availability of a remote service of fixed reference antennas, the possibility of receiving the signal from different constellations of satellites, the availability of online correction services for measurements taken with different devices.

Another problem, leaving aside cases of disturbing elements, concerns the data conversion into different cartographic systems: despite the use of identification codes and automatic calculation provided by various software, heavy discrepancies often remain (sometimes tens of centimeters of error) especially concerning the orthometric heights: only the use of local grids that allow the controlled observation of the detachment constants between one system and another allows a high degree of measurements reliability.

The question of precision, however, must be brought back within the scales of analysis adopted in archaeological research contexts: territorial, architectural, stratigraphic and typological, according to an increasingly detailed study path which requires, in its various degrees, increasingly smaller measurements and more precise. It is within them that we tried to verify the

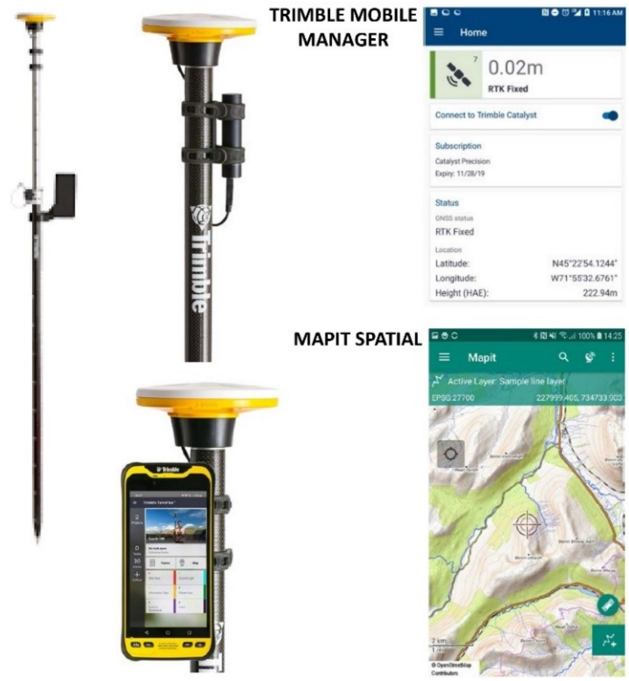

Figure 1. The system configuration and the collecting data applications

effectiveness of these new smart tools associated with others, such as total stations, drones and SFM digital photogrammetry.

In the last 2 years, using the Trimble *Catalyst DA2* system for centimetric georeferencing in various ancient sites of the world, facing different logistic and environmental situations and following distinct purposes and targets, was a good chance to test the efficiency and accuracy of this tool; in all cases it was necessary to set different procedures in order to find a general good methodology, considering also the shape of collected data and the type of disposable information.

The main on-field configuration was made by a *DA2* GNSS receiver mounted on a pole and connected via Bluetooth to a smartphone to get the *Catalyst* centimetric service by the application *Trimble Mobile Manager* and using *Mapit Spatial,* an easy-to-use software for mapping data working with OGC *geopackages* and EPSG codes for coordinate systems and projections (Figure 1).

The places where this configuration has been tested are the *Curiae Veteres* in Rome (Italy), the Sun Temple of Niuserra, in Abu Ghurab (Saqqara, Egypt) and the ancient site of Eridu in Iraq. It worth saying that the use of this new geo-positioning system was always associated with detailed and close-range survey activities, related to landscape-archaeology investigations and stratigraphic excavations: working in these archaeological contexts it has always been possible to check the GNSS measurements with more precise instruments, such as the total station, to verify the results.

In section 2 we will discuss about our experience at the Palatine, in Rome, where survey conditions from a technological point of view were the best, having also the support of well-known starting data and reliable measurements, collected during the past years research; in section 3 we will give a brief description of our work in Egypt, where our activity was strongly linked to ancient landscape reconstruction, and survey was conditioned by difficult access to the cell phone network and to the Trimble service; in the fourth section we will concentrate on the survey activity in Eridu, Iraq, where starting conditions where very bad, having almost no access to web and no previous data to refer to. Despite this unfavourable logistic situation, it was precisely in Iraq that we managed to determine the great effectiveness of the Trimble DA2 system, especially in the preliminary systematic survey of large areas, as we will report at the end of this contribution.

2. WORKING AT THE *CURIAE VETERES*, PALATINE, ROME

The *Curiae Veteres* are located between the northeast slopes of the Palatine hill and the Colosseum valley: here a long archaeological research activity has been carried out, from 1986 to 2017, by the Sapienza University of Rome [2]-[5]. During more than 30 years of excavations and survey activities many ancient buildings have been discovered, bringing to light a topographical and urban continuum of architectural complexes, distributed over time, from Iron Age to the end of the antiquity: these important finds make this sector one of the most important of the ancient Rome [6]-[9]. The excavations are finished and now the area is included in a new restoration and exposition project, carried out by the *Parco Archeologico del Colosseo*. One of the first activity to do was a new general survey of the area to plan the future restoration activities: this new survey, of course, had to be linked to all previous archaeological documentation and at the same time georeferenced in the new topographical network set in 2020 by the *Parco Archeologico del Colosseo* inside the Roman Forum and the Palatine, using GNSS technology and the ETRF2000 geographic system (Figure 2).

This was an excellent opportunity to test the Catalyst DA2 because the 2020 topographic network has integrated some already existing IGM95 benchmarks previously used to geo-

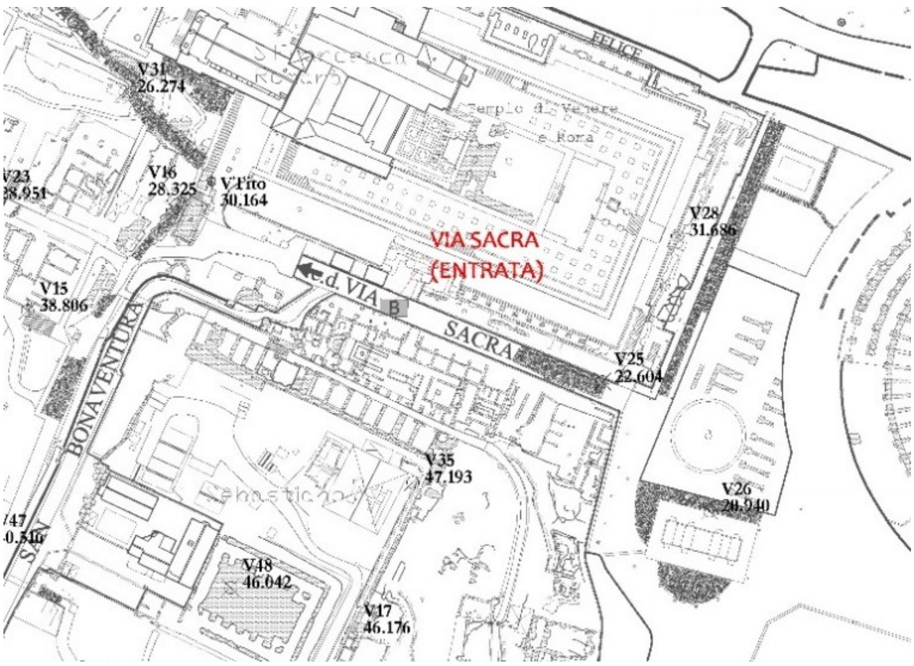

Figure 2. The *Parco Archeologico del Colosseo* updated topographic network.

Figure 3. An IGM95 and ETRF2000 Palatine benchmark, V35 in Figure 2 and C in Figure 4 and Figure 5.

A	CATALYST	X 31.12	Y 41.61	Z 26.24
A	NTW-PARCO	X 31.13	Y 41.61	Z 26.25
B	CATALYST	X 14.18	Y 93.94	Z 31.65
B	NTW-PARCO	X 14.18	Y 93.94	Z 31.67
C	CATALYST	X 26.48	Y 11.89	Z 47.19
C	NTW-PARCO	X 26.49	Y 11.90	Z 47.19
D	CATALYST	X 98.72	Y 68.96	Z 38.81
D	NTW-PARCO	X 98.72	Y 68.97	Z 38.81

Figure 4. Comparison table between the expected values and surveyed measures on the Palatine by Catalyst DA2 (only last 2 integer coordinates numbers are reported while decimal values are rounded to two digits).

reference the *Curiae Veteres* excavation (Figure 3); moreover, it was possible to use our benchmarks, set over the years in our research area, as control points.

It must be added that the *Trimble Mobile Manager* software, which provides satellite data correction, is essentially web-based so it is necessary to connect to the online service to have access to the centimetric precision system; we have also detected that with a continuous connection, the data correction is faster and safer: in Rome the mobile line is excellent, so we worked in optimal conditions. The results were very satisfactory, with deviations contained within 2 centimeters for the topographic benchmarks and with discrepancies of 3-4 cm between the new photogrammetric survey and previous digital close-range drawings, which are physiological in consideration of the different analysis scales adopted (Figure 4 and Figure 5).

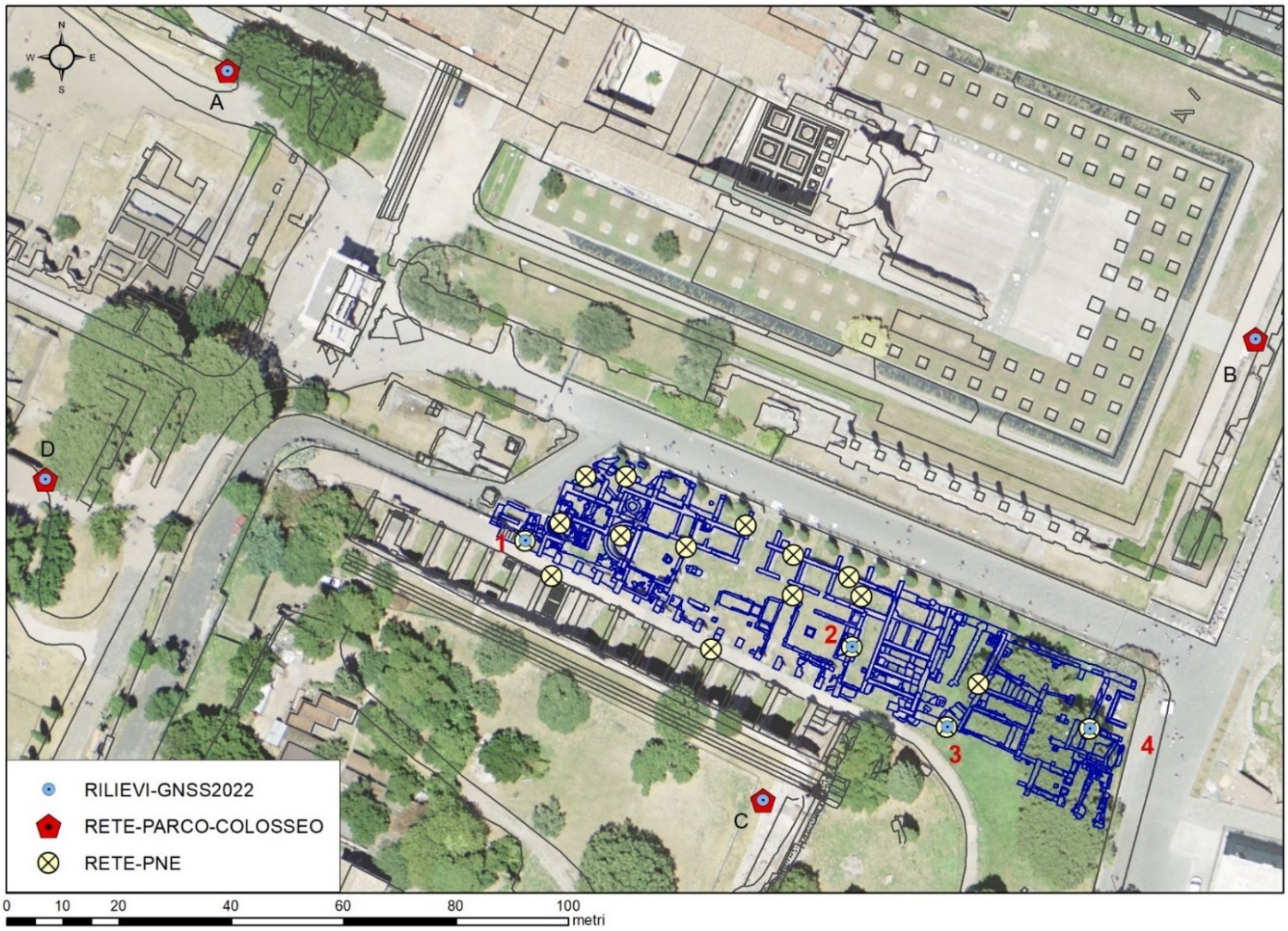

Figure 5. Comparison in the map between the expected values and surveyed measures on the Palatine by Catalyst DA2.

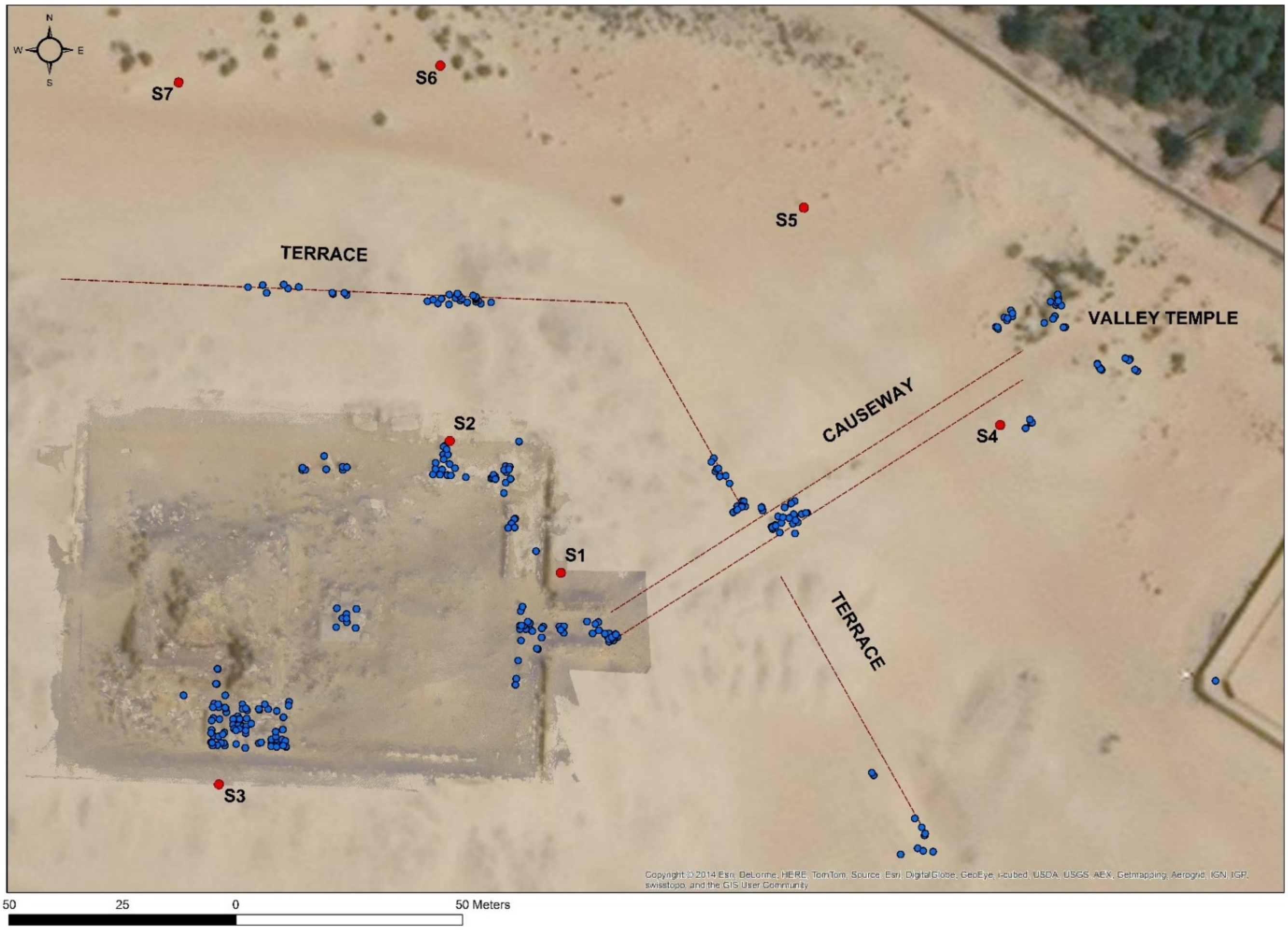

Figure 6. The Niuserra Sun Temple and its surrounding area.

Having verified the reliability of the tool in optimal conditions we decided to continue the experimentation in more difficult conditions.

3. WORKING AT ABU GHURAB, SAQQARA, EGYPT

The archaeological investigation in Abu Ghurab, located inside the Memphite necropolis area, between the pyramids of Abu Sir and those of Giza, has been carried out since 2010 by an international research team, today composed by the Orientale University of Naples, the University of Turin, the Polish Academy of Sciences, and the Uninettuno University plus other very good professionals coming from different countries: the research work is in close collaboration with Egyptian Authorities and Scientific Institutions. The investigations are focused on the Sun Temple of Niuserra, King of the V dynasty, already excavated by Ludwig Borchardt in 1898 – 1901 [10].

Our contribution, together with topographical support, was developed in the field of *Landscape Archeology*, a specialized branch of antiquity study dedicated to space-time contextualization of the archaeological record inside a given territory whose landscape is the result of interaction between human activities and environmental features. Dealing with landscape, the accuracy varies according to the type of analysis level and to the quality of available data. This is why we adopted a multiscale approach, starting from a smaller area and moving toward a wider context.

We started with a focus on the site of Niuserra's sun temple and its surroundings; then, we applied our analysis to a broader area, including the necropolis of Abusir and Saqqara; later, we embraced almost entirely the Memphite necropolis, up to Giza, to the north, and Dahshur, to the south [11].

The first research task was to give a topographical support to the graphic documentation of the excavation and to build a multi-scalar GIS to manage both intra-site and extra-site data, connecting the stratigraphic information to the ancient landscape. For this purpose, it was initially set up a traverse around the temple by total station, expanding it during the years to a local topographic network including a wider external area (Figure 6) [12], [13].

Unfortunately, georeferencing has been for long a concern: national geographic benchmarks are not visible in the surroundings while the use of conventional DGPS and GNSS devices normally is not permitted in Egypt for security reasons. Until 2022 we georeferenced our data using as spatial references notable features of the area, visible on maps and satellite-photos, and carrying out a manual roto-translation with a best-fitting procedure; concerning elevations, it was not possible to assign absolute sea-level values and we had to use our conventional values.

Our GIS is an advanced update of the *Risk Map for North Saqqara Site Project*, started in the 2000 and accomplished in 2010 by the Supreme Council of Antiquities of Egypt and the Italian Ministry of Foreigner Affaires [14]. The GIS covers as much as possible the entire Memphite zone and its base-map is composed of the sheets of the *Survey of Egypt Topographical Series* (France – 1978, scale 1:5000), different aerial photos and several satellite

Figure 7. The Abu Sir and Abu Ghurab areas in our GIS.

images (multispectral, panchromatic, S.A.R.); also, all historical and general archaeological maps of the area have been georeferenced and vectorized in layers. Finally, to reach the most detailed definition, several architectural drawings of the single monuments, published during previous archaeological research, have been georeferenced into the map (Figure 7).

In 2022 we used the Trimble *Catalyst DA2* centimetric GNSS that was essential to geo-reference all our data in a correct way (Figure 8).

Figure 8. Using the Catalyst DA2 at Niussera Sun Temple.

Since its centimeter accuracy in Africa is not fully guaranteed, considering also that the non-constant mobile line on the site decreases the real-time correction of Trimble web-based software, we have repeatedly measured all the benchmarks of our topographic network, taking the same measures every day for many times, and then evaluating the mean squared deviation geographical system: we took measurements using the WGS84-UTM36N (as it is requested by local authorities), taking orthometric heights referenced to the EGM96, in order to be able to connect these elevations values with previous cartography heights.

Apart from gross errors, we were able to obtain multiple measurements varying of two centimeters on X, Y and Z axes.

For a complete data-control it was decided to compare the new benchmarks coordinates measuring

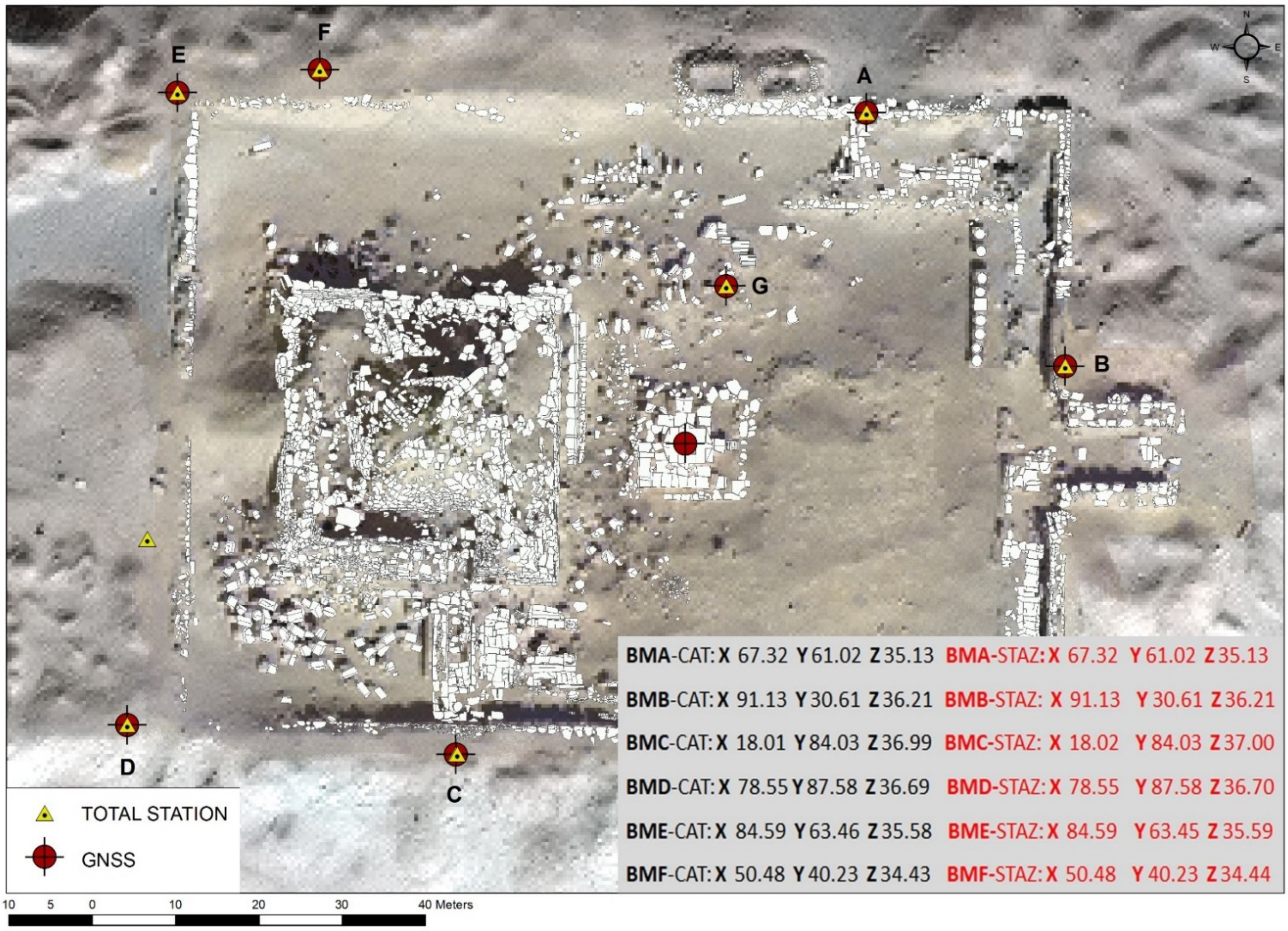

Figure 9. Comparison between surveyed measures by Catalyst DA2 and Total Station (only last 2 integer coordinates numbers are reported while decimal values are rounded to two digits).

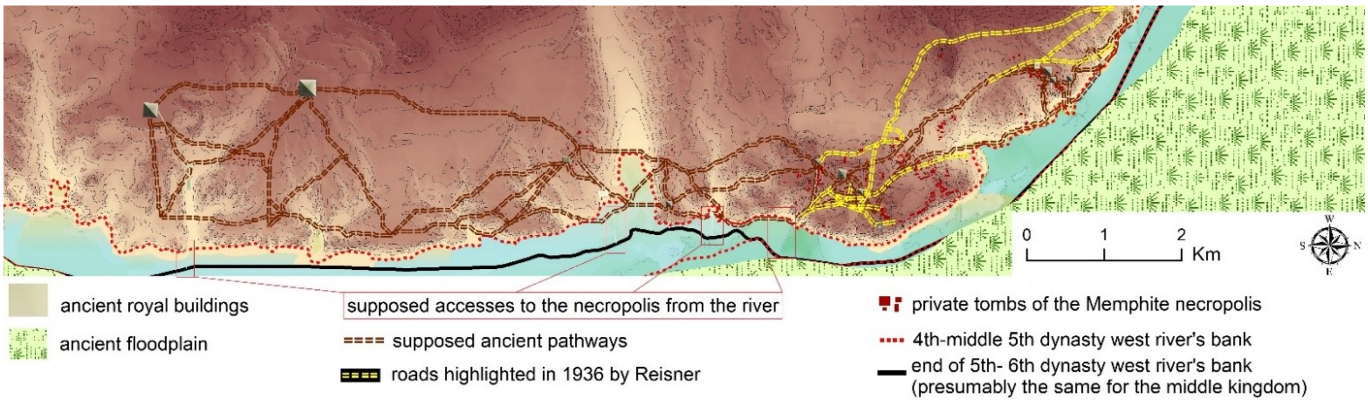

Figure 10. Spatial analysis on the reconstructed ancient landscape of the Memphite necropolis.

them again by total station (Figure 9). Having detected a similar error range and same good accuracy, we were finally sure to place the excavation and our spatial data in a precise geographic context, with sea-level referred elevations exactly linking with those reported in the general map, deriving from the 1978 French survey.

Once we got the chance to use exact coordinates, we started to build DSMs, DTMs and DEMs of all the area, to try reconstructing the ancient landscape and its main features and to perform some spatial analyses, typical of landscape archaeology, like site location analysis, movement and transport modelling, visibility analysis (Figure 10) [15].

4. WORKING AT ERIDU, TELL ABU SHAHRAIN, IRAQ

Eridu (Tell Abu Shahrain) is one of the first urban agglomeration recorded in the *Sumerian King List*, located in lower Mesopotamia, and probably raised around the 5th millennium BCE, about 19 km southwest of Ur (Figure 11).

The life of the urban site, which entered the *World Heritage List* in 2016, begun during the protohistoric *Ubaid* culture (at the beginning of the Chalcolithic in Mesopotamia) and lasted for millennia, in a vast area of hundreds of hectares characterized by the presence of distinct *tells* where structural evidence of different periods was found (Figure 12) [16].

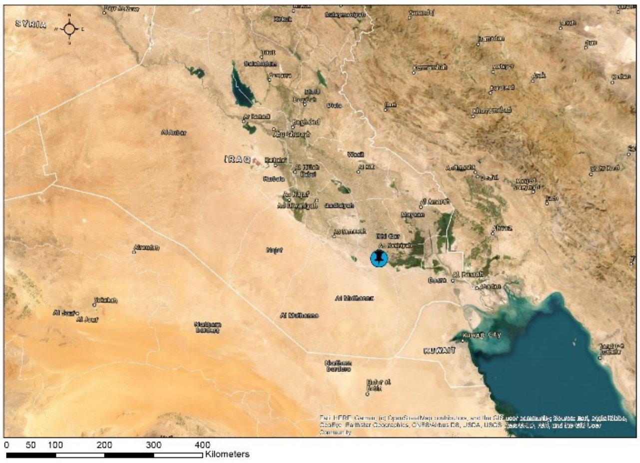

Figure 11. Location of Eridu in Iraq.

The site was partially excavated by an Iraqi mission, led by F. Safar in the mid-1900s [17], but in 2019 new systematic research started again, carried out by a team made up of the *Sapienza University of Rome*, the *Uninettuno University*, the *University of Strasbourg,* and the *Costa Rica University [18]*.

The research, in agreement with Iraqi Authorities and the UNESCO, is focused on stratigraphical excavations and ancient landscape investigation; furthermore, according to the project, a development plan of enhancement of the area has been scheduled.

Figure 12. View of the site from south: the ziggurat in the background.

Uninettuno directs the survey activities, together with data collection and digitization: our target is to acquire 3D-digital documentation of all the archaeological evidence and to manage all data in a single web-GIS for the site.

One of the first operation we have implemented was the creation of a new topographical network, embracing all the ancient settlement: to make this task we have used the Trimble Catalyst DA2 (Figure 13). Here we also adopted a geographic system used by local authorities, the IGRS - UTM38N, collecting orthometric elevations with the EGM96 model.

Since the mobile line in Eridu is practically inactive, the use of Trimble system was more difficult and control operations had to be repeated many times; we have decided then to use a bipod to fix the antenna pole to the ground and to take repeated measures in the best precise way.

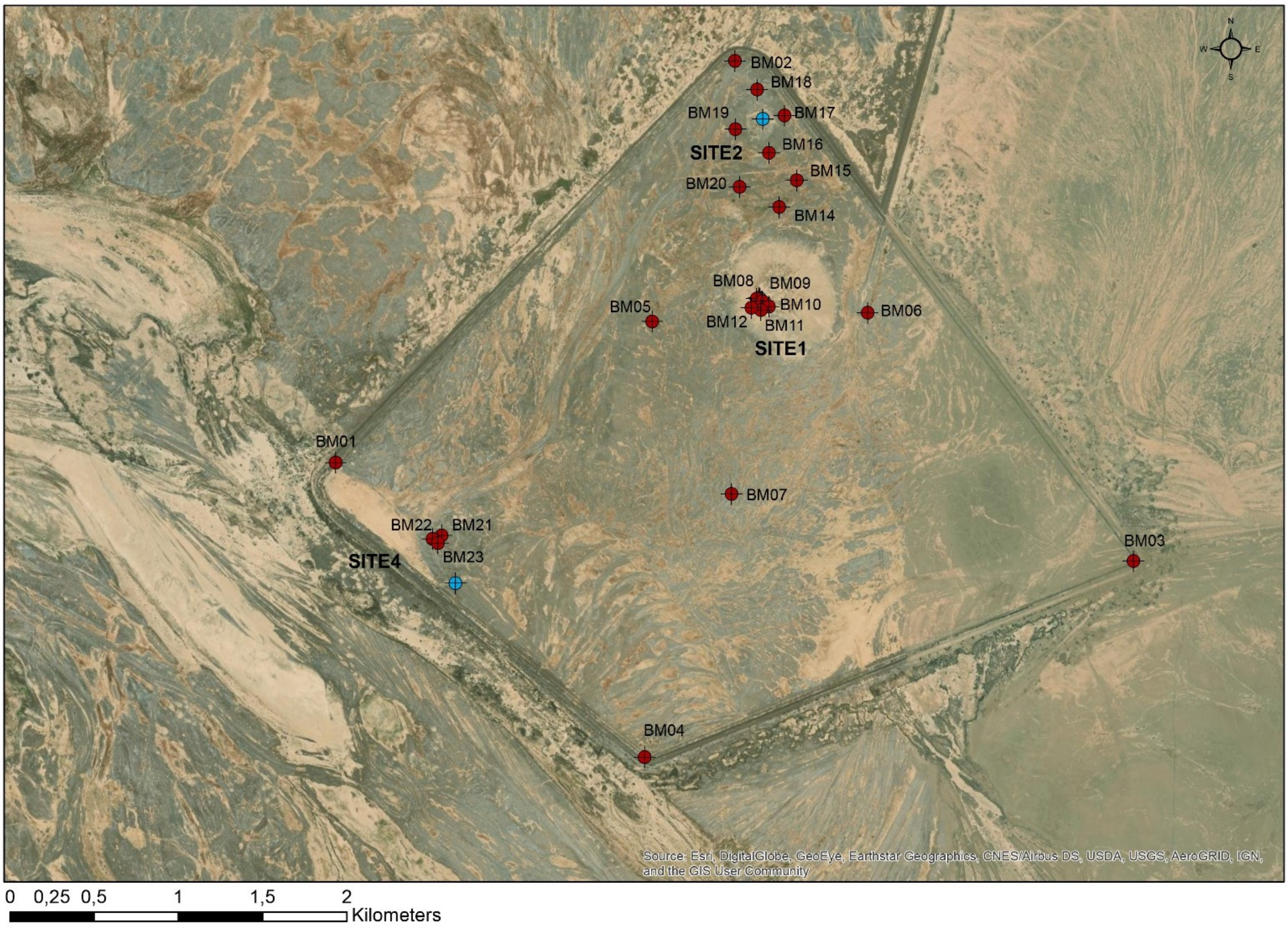

Figure 13. The new topographical network in Eridu set by Catalyst DA2.

Figure 14. The benchmarks around the Ubaid Cemetery excavation area: Site1 in Figure 13.

One of the main activities of the project is a new investigation of the *Ubaid* cemetery (already excavated for a big part by Safar, who discovered hundreds of brickwork graves) in order to better understand burial practices and their social implications during the first urbanization of Eridu: in fact we know that the *Ubaid* society had already reached a high degree of complexity but in the grave assemblages we find an unexpected level of equality, with only a big distinction between depositions inside mud bricks coffins and burials dug directly into the ground.

The graphic documentation of this new excavation was planned to be carried out by digital photogrammetry, aerial and from the ground, focused on recording all archaeological features with the support of a total station. For this purpose we have thickened the presence of reference points around the excavation area: these benchmarks were supposed to be used as topographic base for detailed archaeological documentation and therefore a precise determination of their position in absolute coordinates had to be taken very carefully: also in this case, measurements were taken by Catalyst many times, using a bipod for the antenna, and again, the benchmarks positions were surveyed also by total station to check their accuracy (Figure 14).

The results were satisfactory also here, having deviations of 2-3 cm (Figure 15), and we could proceed to make the detailed graphic documentation of stratigraphic evidence using these benchmarks as reference and alignment points for total station.

Few meters apart from the cemetery, an unknown residential area has been found during the excavations, composed of houses made of mud brick walls and mud slabs pavements, organized in a larger central hall and service rooms at the flanks, equipped with ceramic ovens for cooking and containers to collect water and food.

Next to this residential area, toward SE direction, it has been necessary to carry out a wider exploration to understand the living and productive context of the primaeval occupation, striking from the very strong presence of pottery sherds, concentrated on the surface of this zone and mainly belonging to the *Ubaid* period.

During 2 weeks of work, carried out almost exclusively by a single person, an area of 8900 m^2 has been investigated using the Catalyst in association with a drone *DJI Mavic Air 2*: flying with a constant height above ground level of 5 m, making high-definition photos to produce a new photogrammetric detailed plan of this sector, surveying distinct areas and taking measurements of reference targets used as topographic references for point clouds alignment, scaling and georeferencing

BM8-CAT:	**X** 39.61	**Y** 93.81	**Z** 10.38	(**BM8**-STAZ:	**X** 39.61	**Y** 93.81	**Z** 10.38)
BM9-CAT:	**X** 73.67	**Y** 77.29	**Z** 11.81	**BM9**-STAZ:	**X** 73.68	**Y** 77.29	**Z** 11.77
BM10-CAT:	**X** 11.78	**Y** 44.74	**Z** 12.12	**BM10**-STAZ:	**X** 11.79	**Y** 44.74	**Z** 12.10
BM11-CAT:	**X** 64.15	**Y** 25.44	**Z** 11.25	**BM11**-STAZ:	**X** 64.14	**Y** 25.43	**Z** 11.26
BM13-CAT:	**X** 09.51	**Y** 74.92	**Z** 13.38	**BM13**-STAZ:	**X** 09.52	**Y** 74.92	**Z** 13.36

Figure 15. Comparison between surveyed measures at Eridu by Catalyst DA2 and Total Station (only last 2 integer coordinates numbers are reported while decimal values are rounded to two digits)..

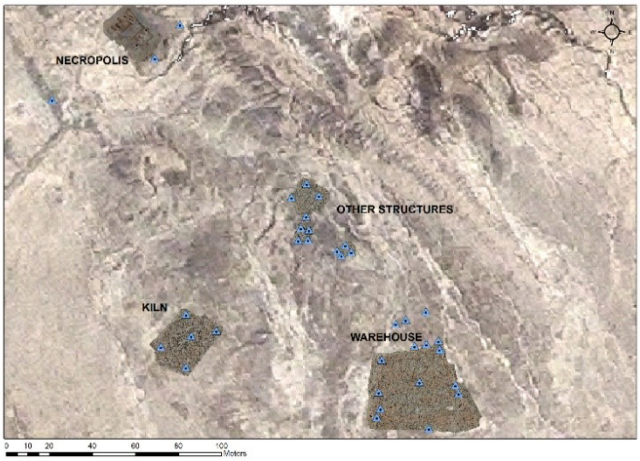

Figure 16. The new investigated area SE of the Ubaid Necropolis.

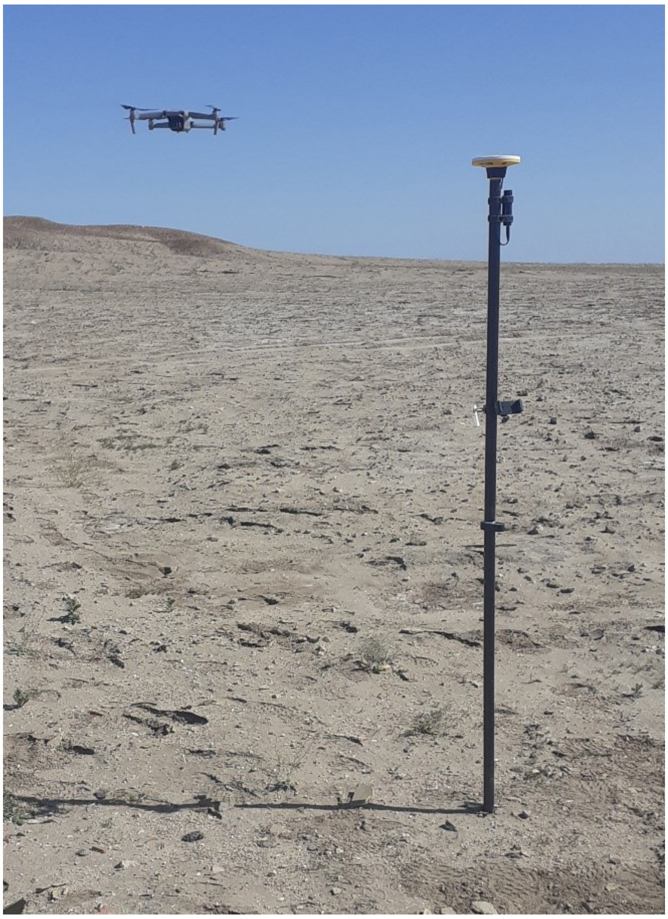

Figure 17. Tools for the preliminary survey of our archaeological area.

in a GIS environment (Figure 16 and Figure 17) [19], [20].

After this analysis the area appeared characterized by production activities: the presence of a homogeneous pile of ceramic slag (Figure 18) in its west sector, covering an area of about 300 m², is probably the clue of a buried kiln, as it was already noticed several decades ago [21].

In the south quadrant of this sector, about 75 m east of the slag concentration, a rectangular-shape buried structure, never noticed before and having an area of about 180 m², was highlighted by very clear soil-marks: it is divided into little and similar square-rooms, each with a surface of about 1 m², and arranged in chess (Figure 19). The shape and the internal layout suggest the presence, under the superficial sand, of a storage building: a similar architecture of the same chronology, in fact, has been found in Iraq, near Larsa [22]-[24].

Figure 18. Large pile of slag, probably an indicator of an ancient kiln.

Figure 19. Underneath ancient building divided in squared rooms having similar dimensions: probably a warehouse.

This ancient architectural evidence, distinguished by its shape, fits very well inside the ancient production character of this zone, and appears much clearer when viewed from above than from the ground: this fact could suggest the existence of an undisturbed archaeological context, precious for its informative potential about Eridu and its first history.

It is therefore our intention to carry out soon, in the forthcoming research campaigns, an intensive and systematic survey of all this area, divided into inspection squares, with *topographic-units* record, erratic material collection and study, together with detailed close-range archaeological survey.

5. CONCLUSIONS

During these various experiences, the use of the Trimble Catalyst DA2 was satisfactory: it is necessary anyway to highlight some not negligible aspects during field work.

First, it is preferable to operate in areas where the mobile line is efficient otherwise it is necessary to connect to the Trimble web service before entering zones without line service: in this second case it is advisable to use a support for the pole of the antenna and take as many repeated measurements as possible for each point.

Secondly, we should pay attention to gross errors and repeat the same measurements for few days. In other words, the system, to date, does not allow millimetric precision and cannot replace a total station for measuring detail-points. However, there are more positive aspects: the system agility, simplicity and lightness (which also can avoid permits and customs passages problems in particular countries), the very low cost, the ease of use and the accuracy, which can be centimetric even in unfavourable contexts.

Our experience has highlighted that this tool, used together with low-altitude aerial photogrammetry, via drone, in the systematic and non-systematic superficial survey of areas of archaeological interest, where a millimetric precision is not necessary considering the analysis level, is extremely effective and allows even quite large zones to be investigated, quickly and in a preliminary manner, by a single archaeologist who knows how to use the instrumentation carefully, referring it to a well-defined archaeological and geographical framework.

For the future we plan to carry out some systematic and intensive surveys of each areas found during our exploration in Eridu, with the study of surface archaeological materials distribution divided by clusters, spatial and typological, positioning them with the Catalyst and making a close-range photogrammetry supported by total station before their collection: in this way, by comparing the results, we could determine the reliability of the detailed measurements taken by GNSS also in this more in-depth research context that can be considered a transition between surface analysis and stratigraphic excavation which instead requires more reliable measurement tools.

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