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LIFE Project: evolution of survey techniques along the border of the Roman Empire.

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***Abstract* – This article presents the latest results as well as an overview of the continuous evolution of the survey methods applied to the extreme desert environment of the Kharga Oasis, in Egypt's Western Desert. The detailed survey of the architectural and agricultural remains of the Late Roman site of Umm al-Dabadib represent the chance to experiment the application of 3D survey techniques to complex objects. The aim of this research is twofold: pushing the available techniques to their limits in order to obtain innovative results, and eventually obtaining a precise and measurable 3D model of a complex and challenging built-up area.**

I. INTRODUCTION

Umm al-Dabadib is an imposing and remote Late Roman site located at the outskirts of the Kharga Oasis, in Egypt's Western Desert (fig. 1). Virtually unknown until recently, it is now the focus of a large-scale interdisciplinary project of the Politecnico di Milano and the Università Federico II di Napoli named Living in a Fringe Environment (LIFE), funded by the ERC CoGrant 681673. The aim is to investigate this imposing and well-preserved site from an archaeological and environmental point of view, in order to document and reconstruct not only what was built there, but also why and how. The site is endowed with a large agricultural system that consisted of seven underground aqueducts and two cultivations that served a Fortified Settlement as well as a scatter of other installations. Clearly, this site was carefully planned to exploit in the best and most efficient way the rough desert environment in which it was located, both from an agricultural and an architectural point of view.

Fig. 1. Umm al-Dabadib seen from south-east (photograph by Paolo Viviani, 2013).

II. BACKGROUND OF THE PROJECT AND WORKING CONDITIONS

Despite its size, wealth of remains and excellent state of preservation, Umm al-Dabadib remained largely unexplored until relatively recent times. A first description, mainly of the local irrigation system, is due to the British geologists and explorers J. Ball [1] and H. L. Beadnell [2], who worked there as part of the Geological Survey of Egypt in the early 20th century. About fifty year later G. Caton-Thompson and E. W. Gardner worked on the prehistoric remains in the surroundings [3]. In the late '90s C. Rossi (then Cambridge University) became interested in the area [4] and founded with S. Ikram (American University in Cairo) the North Kharga Oasis Survey (NKOS), that carried out the first scientific and systematic exploration of the northern portion of the Kharga Oasis.

The area presents significant environmental challenges that greatly influence the choice of the survey methods: the archaeological sites are located far from the areas served by water and electricity and represent a real challenge for the extent of the area, the richness of the finds, and the complexity of the structures as well as their varying degrees of preservation. Every year between 2001 and 2007 NKOS performed short and extremely compact seasons during which the team performed the first theodolite survey of the core areas of each archaeological site, as well as the GPS survey of the most distant features [5] [6] [7] [8].

The survey performed by NKOS represented a breakthrough as it offered a first glimpse of the extent, variety and complexity of the archaeological remains located in the area. For many sites, those surveys will probably remain the only available documentation for a long time. Only some of them will be the focus of further and more intensive archaeological investigation in the near future; among them, Umm al-Dabadib will be the focus of the newly created Project LIFE.

In order to improve our knowledge of this site and focus our investigation on specific issues, a more detailed survey of the archaeological and agricultural remains represented the first challenge to be faced. This was addressed between 2012 and 2015 by the the Project OASIS (Old Agricultural Sites and Irrigation Systems), of MUSA (Musei delle Scienze Agrarie, Università Federico II di Napoli) and 3D Survey Group (Politecnico di Milano), that represented the basis for the new project LIFE [9].

III. EVOLUTION FROM 2D TO 3D SURVEY

A 3D survey represents a useful tool to be employed in remote and logistically challenging sites, where time and environmental constrains represent an important obstacle. Moreover, thanks to its precision and to the possibility to extract precise measurements, a 3D survey facilitates the comprehension of complex architectural objects and their spatial analysis. If connected to a 3D survey of the surrounding landscape, this method can also represent an important chance to georeference all data, and to allow spatial queries and spatiotemporal interpretations.

One of the objectives of LIFE is to create a new system to catalogue, store and integrate the information that will be gathered during the rest of the survey and the excavation of specific areas, including not only buildings, but also portions of the vast and complex agricultural system. The survey of these features (subterranean winding tunnels and vast undulating surfaces) represents especially challenging tasks.

In theory, a wide range of methods and instruments could be at our disposal, but the practice is different. First of all, the extreme environment (rapid shifts from cold to hot weather, presence of strong sand-laden winds, remoteness of the area and subsequent absence of stable sources of electric power), and the geopolitical situation (the site lies in a military area and some specific tools, such as drones, cannot be used) already pose some fundamental conditions (fig. 2). For this reason, during the activities of the OASIS Project, we envisaged a practical way to obtain a precise and measurable 3D survey of the entire Fortified Settlement, as well as combined method to obtain reliable results in the survey of the cultivated areas.

Fig. 2. Working conditions at the remote site of Umm al-Dabadib (photograph by C. Rossi, 2014).

IV. RESULTS AND CRITICAL COMPARISON

In the last three years, two survey missions were organized in order to test and obtain a good survey workflow and an efficient data modeling strategy, as well as to design the future information system. A critical overview of these tests is presented, together with a comparison with the previous measurements. Two different types of archaeological remains were surveyed: a large built-up area, and one of the ancient cultivations. As the issues relating to the survey of the cultivations have been addressed elsewhere [10], here we will focus on the architectural survey.

The Fortified Settlement is a solid and articulated mass of mud-brick ruins that covers an area of about 100x120 m (fig. 1). In 2003 performing an accurate theodolite survey was ruled out, as this enterprise would have required weeks of work – an impossible task in terms of costs in such a remote place. Therefore, at that time we opted for the production of a sketch map based on measurements taken by laser distomat; the strictly gridded pattern of the settlement certainly helped. It was obviously impossible to obtain a high level of precision in terms of angles and alignments, but the result was a generally reliable and relatively detailed map that illustrated the layout of the settlement [11].

By 2014, the evolution of the available technology opened the way to a 3D survey of the settlement. A 3D survey is an extremely precise tool that can be useful to various purposes, ranging from improving our understanding of the structure to performing a remote virtual analysis of the remains, from representing a faithful and detailed record of the conditions of the remains at a set date, to offering a basis for an archaeological information system supporting future excavation activities.

Our main challenge was to pick the best available technology and tailor it to our specific needs. Our main idea was to use "image-based techniques", well known in the research field of photogrammetry [12], cartography and 3D modelling but still not widely used in the common practice and on the field. In particular, they are still not widely tested to survey very large and complex sites [13]. Moreover, it is necessary today to find well-defined standards for the metric survey of all kinds of archaeological/architectural remains, from complete landscapes, to individual sites and small objects. This is the goal that this project would have from a "measurement point of view".

As already widely said, photogrammetry and, in general, image based techniques are optimal choice and they prove to be particularly suitable in the field of archaeology [14]. There are two reasons for this success, one practical and one theoretical. From the practical point of view, the equipment is relative simple, not expensive, and easy to transport and to be used on the field; in our case, this was a primary concern. From a theoretical point of view, image based techniques are able to provide complete measurements, high-resolution survey where both geometry and colour have a metric quality that can be both designed and tested. One of the main aspects is that exactly the same technique can be used to survey in 3D anything ranging from vast environments to very small objects; this, too, is a key aspect of our project. Umm al-Dabadib requires the production of surveys ranging from a small, cartographic representation scale, to an architectonic scale, down to the real scale used to represent very small objects.

Two survey missions are already performed at the site. During the first year, the activities were concentrated around the Fort and the Fortified Settlement, and the goal was to complete the survey of the exterior of the structures using close range photogrammetry from the ground. This was the occasion to stress this survey methodology in order to test it in very large environment and at a big representation scale. Fortunately, the conformation of the spaces, the arrangement of the structures, the presence of raised areas and the same shape of the structures have facilitated an otherwise daunting task. [9]

During the second season of survey, the attention was paid to the smaller Eastern Settlement, located to the northeast of the Fortified Settlement., covering an elongated area of about 140x30 m. There we used the same survey strategy: multi-resolution survey, from the general to the particular [9]. The general survey is used to georeference all the parts belonging to a building together and used to help the registration all the neighbouring buildings. A larger scale, instead, is used to obtain architectonic representations to a scale of 1:20/1:50 and to enter into narrow spaces.

During the first measurement campaign we could use a total station with which (despite endless operational difficulties) we managed to geo-reference all the different photogrammetric blocks and to scale the elaborated 3D models. During the second campaign, this was impossible; in order to georeference together all the photogrammetric acquisitions we used special markers printed on aluminium, created ad hoc for the case of study. They were placed so that they could be seen from building to building in order to simplify the alignment of different photogrammetric blocks. They had to be acquired from a maximum distance of 50 m; additional targets (printed on paper) were used as constrains during the photogrammetric process. The scaling of the models was obtained by taking more than one measurement between pairs of targets in different areas of the object-building. The use of targets is mandatory in order to obtain reliable metric results.

The second goal of the second mission was to survey some internal rooms of the Fort, small dark spaces, half-filled with sand, that one can access through narrow holes dug by robbers. Surveying these spaces represented a significant challenge: the two main difficulties were represented by the scant but extremely focussed natural light that manages to reach the interior, and by the necessity to geo-reference the interior of the building with the exterior through irregular and extremely small openings.

The issue of the small dimensions of these rooms was solved thanks to the adoption of fisheye lenses, instead of normal or wide-angle lenses, that would have required the collection and processing of a large number of photographs. Fisheye lenses, instead, are able to embrace an angle up to 180° (and in some rare cases even wider), which far exceeds the technological and physical limit of the traditional rectilinear wide angle lenses. Photogrammetry based on fisheye lenses represents the current limit of the available technology: a reliable result can be only achieved by placing a high number of targets to be included in the survey (fig. 3), that will later act as constrains for the bundle adjustment, to be performed by specific photogrammetric software able to model the fisheye internal calibration.

Fig. 3. Targets distributed on the surface of the spaces to be surveyed by fisheye lenses (photograph by F. Fassi, 2015).

The uneven light represented a serious challenge for the correct acquisition of the geometry of the rooms (rather than to achieve nice photographs); in order to solve this problem we used two different solutions: flashlights (for extremely narrow spaces) and Light Painting Photography (for totally dark spaces). In the latter case, the camera is placed on a tripod with its shutter open for a timed exposure sufficient to manually illuminate the object or the space with a hand-held light. Another solution could be the use of multiple synchronized flashes, a solution not always adoptable for practical reasons, in particular when the lack of space does not allow the presence of multiple operators.

The third task is to geo-reference the internal spaces with the external environment. The task was solved by overlapping the internal and the external survey in order to perform a point matching alignment; this can be achieved thanks to well-distributed markers.

Our results demonstrate that it is possible to push these survey techniques to their limits and experiment new solutions to solve specific problems (fig. 4). Our next goal is to identify the best technique to perform the survey of the ultimate narrow space: a subterranean aqueduct, half-filled with sand, and illuminated by vertical shafts placed at irregular intervals and separated by long and dark portions of winding tunnel.

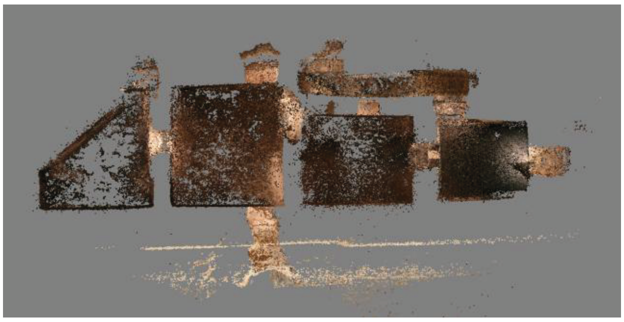

Fig. 4. 3D survey of the western row of rooms under the Fort, aligned with exterior through a robbers' tunnel (elaboration by F. Fassi, 2016).

V. THE SURVEY AS PART OF A LARGE-SCALE PROGRAM

Our survey activities do not represent stand-alone challenges, but are important components of a large-scale interdisciplinary program of understanding of the site as a whole. The 3D survey of the built-up area will document the architectural remains with extreme precision but in a non-invasive way. The survey of the agricultural system will open the way to the creation of a dynamic model, able to illustrate the way in which it functioned, from the water catchment to the irrigation of the fields, also in order to understand the possible amount of annual production.

We are actively working in collaboration with the Egyptian authorities in order to found a Natural Protected Area around this site, which contains a high level of biodiversity as well as significant archaeological remains [15]. Thanks to our joint work, the Kharga Oasis has been just enrolled in the UNESCO Tentative List and more work is necessary to obtain the full status of World Heritage Site. In this respect, our 3D survey of the archaeological remains will represent an important portion of this work, to be extended to the management of the area as a whole.

In conclusion, our 3D survey of the archaeological remains of Umm al-Dabadib represents not only an important achievement in itself, but also an important tool to be used on various fronts. The accuracy of the result, for instance, helps to reduce the need of excavation, in itself a destructive action, and to preserve the delicate balance of the desert environment. Our 3D survey therefore represents an important element of a larger mosaic, made of all the various need of this complex archaeological and naturalistic site.

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