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Metric analysis and interpretation of the unit of measurement in the Late Roman Fort of Umm al-Dabadib (Egypt)

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Abstract **– This paper presents a metric analysis and interpretation of the 3D survey of the Late Roman Fort of Umm al-Dabadib (Kharga Oasis, Egypt). The aim is to verify if a modular measure was used in the construction of the Fort and whether this was congruent with Roman or Egyptian units of measurement. This research is part of the project LIFE (Living in a Fringe Environment), funded by the ERC CoGrant 681673.**

I. HISTORY OF THE SURVEY OF THE SITE

Umm al-Dabadib, located at the outskirts of the Kharga Oasis (fig. 1), contains the impressive archaeological remains of a vast and well-preserved Roman installation, active in the III and IV centuries AD and abandoned at the beginning of the V century. The site was probably inhabited already during the Ptolemaic Period, as attested by ceramics and grave goods. The vast majority of the visible architectural remains date to the Roman Period, in particular to the IV century AD, when this site was selected to become an important element of a chain of aggressive-looking settlements, probably meant to keep under control the caravan routes that crossed the Kharga Oasis [1]. The site covers a total area of 10 square km and consists of three settlements (the Fortified Settlement, the Northern Settlement and the Eastern Settlement) served by an extensive agricultural system [2]. The Northern Settlement, the oldest core of the site, consists of a group of large houses, all different from one another; the Fortified Settlement dates instead to the IV century, and consists of an extremely compact group of houses, surrounded by a continuous wall, in the middle of which rises the Fort (fig. 2).

A first survey by theodolite in 2003 [3] of the entire archaeological site was followed by a complete photogrammetric terrestrial survey of the Fortified Settlement in 2014 [4] and 2015, with the aim to obtain a complete and accurate 3D model of this portion of the archaeological remains [5-6]. The elaboration of the accurate results offered the chance to perform a study on the unit of measurement employed in the construction of the Fort (presented here), which will be extended in the near future to the rest of the Fortified Settlement.

II. THE 3D SURVEY OF THE FORT

The surveys were planned to ensure the minimum requirement of a 1:50 scale. It means that according to a plotting error of 0.2mm, the minimum Ground Sample Distance (GSD) and measurement accuracy should not exceed 10mm.

Fig. 1. The Kharga Oasis, indicated by the arrow, lies 650 km south of Cairo and 250 km west of Luxor.

Fig. 2. The Fortified Settlement with the Fort in the centre.

The Fort, located in the middle of the Fortified Settlement (fig. 2), consists of a (nearly) square building endowed with two rectangular towers on either side of its south side, and consists of 5 floor levels (including the ground floor, labeled 0).

During the 2014 season, more than 500 photos were acquired using a Canon EOS 5D Mark III with a fix 35mm lens, in order to survey the exterior of the Fort [5]. The geometry of the capture network corresponded to a closed circular acquisition of images taken around the external wall of the Fort. The average capture distance from the object was of about 15-20m and the baseline between adjacent images was about 1,5m (baseline/distance ratio of about 0,1). Related to the camera sensor resolution, this distance ensured a GSD of 1mm for the Fort's façade and a maximum of 5mm for the portion in background. The GSD is a very important parameter to establish the details that we can later measure on the output restitutions (final point cloud, orthoimages, etc.).

In order to georeference the models in the same coordinate system, to scale them and to check the accuracy of the reconstruction, a net of GCPs (Ground Control Point) was established and measured [7]. The global accuracy of the topographic network was about 4 mm.

The 2014 exterior survey of the Fort was integrated by the 2015 interior surveys. Some inner spaces of level 0 and 1 are preserved and accessible. It was possible to perform a complete photogrammetric survey of: (1) four rooms on the east side and (2) four rooms in the north-east corner of level 0; (3) two rooms on the east side of level 1; (4) the entire staircase in the south-east tower. Due to the distribution of the accessible inner rooms and the conformation of the space, the photogrammetric acquisitions were divided into the four blocks described above.

The minimum internal dimension of the rooms was about 4x5m with a max height of about 2.4m and a min height of about 1.1m (impost line of the vault). The staircase, the corridors and the passages to move from one room to another are even narrower, even up to 40cm only. In these critical conditions, achieving an accurate and complete dense 3D model which could match the exterior is very a complex task. The lack of operating space makes the use of rectilinear lenses extremely complicated. The fisheye lens, instead, ensures a wider field of view in comparison with a rectilinear lens. This allows to simplify the survey phase and to reduce the amount of photos needed for a complete 3D restitution.

For these reasons, two fisheye lenses were used: i) a Canon EOS 350D coupled with a fix 8mm focal length for the level 0 and the staircase; ii) a Nikon D810 coupled with a fix 12mm focal length for the level 1. During the acquisition with the fisheye optics, the team paid special attention to the base/distance ratio and to the degradation of the GSD in the boundary part of the frame [8]. Generally, was used a capture distance from the object of less than 1m.

The indoor survey was designed in order to have a sufficient overlap with the external wall surface. The model of the exterior of the Fort, covered by the topographic network, was used as reference block to align the four inner block-models in the same coordinate system.

The 2014 and 2015 photogrammetric surveys were planned paying special attention to the camera network geometry [9] and to some important photogrammetric rules. The photos were acquired with an average overlap between two consecutive normal views of about 80%, in order to ensure the automated detection of homologous points. Convergent images were also acquired.

The acquisitions were performed using encoded markers. The markers are very important as external constrains during the image orientation and to optimize the calculation of lens distortion parameters during the self-calibration process (for details see the next section). The markers must be uniformly distributed in the area (especially where the geometry is complex) and visible in a sufficient amount of photos.

III. THE PHOTOGRAMMETRIC PROCESS

For the photogrammetric elaborations we used Agisoft Photoscan, a powerful software to manage a large amount of phots organized in block of images. The first step of the photogrammetric pipeline is the automatic orientation of images, performed using the full resolution of the frame. The second step is the automatic detection of markers on the photos and the consequent optimization of the camera calibration parameters. Before the optimization, a human intervention is necessary to verify and eventually adjust the correct position of the markers on the image and/or manually add undetected markers.

Table 1. Photogrammetric images blocks

Images block	Camera	Focal (mm)	Photos	Average GSD (mm)	Points cloud
Fort exterior	Canon 5D MarkIII	35	509	1.7	32,685,339
Level 0 east side	Canon 350D	8	210	0.7	16,417,253
Level 0 N-E corner	Canon 350D	8	208	0.8	11,862,279
Level 1 east side	Nikon D810	12	508	0.3	77,273,568
Staircase	Canon 350D	8	243	0.6	12,623,173

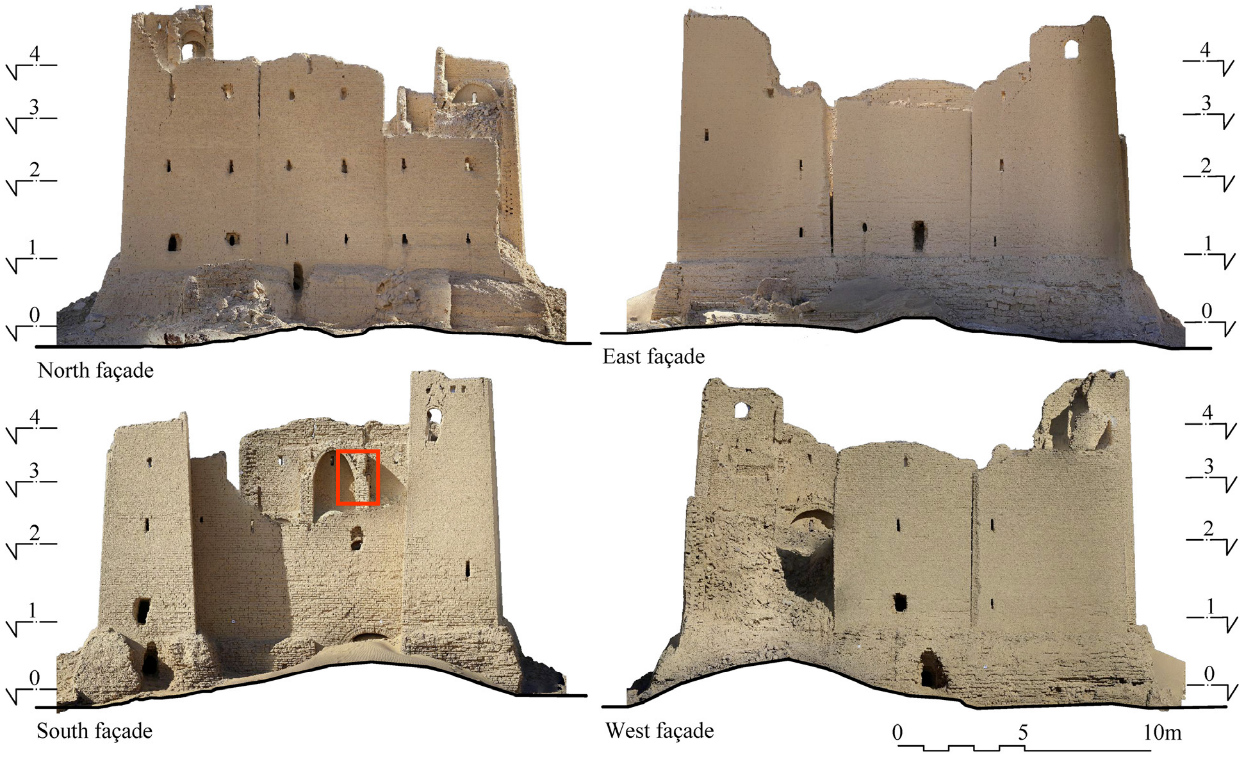

Fig. 3. The orthoimages of the Fort façades showing the altitude of the horizontally-cut sections.

Fig. 3.1. Detail of the orthoimage on fig. 3: it is possible to see the measures of the bricks and the two headers brickwork type.

In the third phase, in order to scale and georeference the external model of the Fort, the coordinates acquired by total station are associated to the markers.

The adoption of this work sequence avoids accidental topographical errors affecting the orientation. Instead, in order to scale the four indoor models, many reference distances among markers had to be measured, since it was not possible to perform a topographic survey.

Up to this third step, each "block" of images was processed separately. In the fourth step, instead, the indoor blocks were aligned to the Fort's referenced model, using a "marker-based" method. Several couples of homologous architectural points taken on the external surface of the Fort were picked manually on the photosWe used a minimum of six markers shared by both the external and the internal survey. These markers were used as reference points to roto-translate the four indoor blocks into the reference system of the Fort.

Although the accuracy of the Fort's survey was about 3mm, the final alignment had to be performed by checking the deviation among shared GCPs for the roto-traslation: as a consequence, the final georeferencing average error on the common GCPs was about 1 cm.

Finally, for each oriented block of images the dense matching process was elaborated to produce a dense point cloud model and a mesh model. From the textured polygon model, it was possible to extract the orthoimages of the main façade of the Fort with a maximum detail of about 2mm that ensured a graphic representation to a scale 1:20 (fig. 3). This precision is due to the fact that the orthoimages were extracted from the 2014 survey only, which had an average GSD of 1,7 mm (see table 1).

IV. THE METRIC ANALYSIS OF THE FORT

The full photogrammetric process of the captured data allowed to obtain a series of dense point clouds and textured mesh models of the interior and exterior of the Fort that were referenced in the same coordinate system.

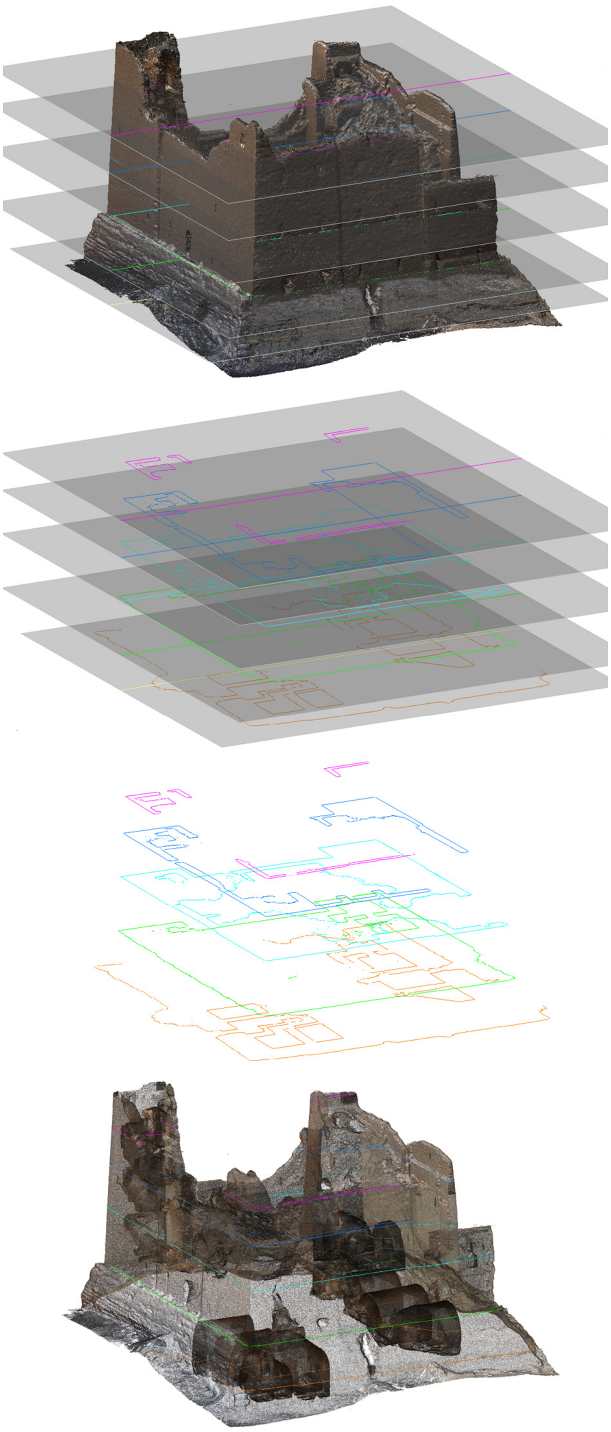

Fig. 4. Horizontal sections for each floor levels, extracted from the final point cloud.

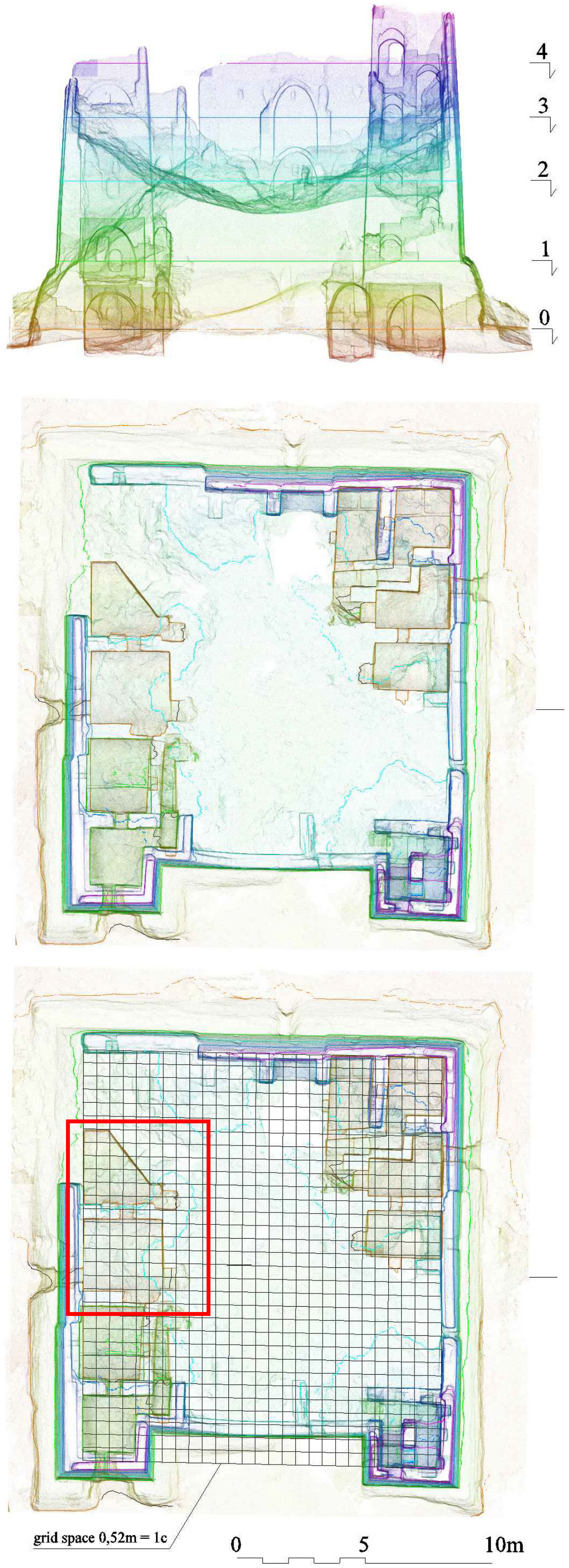

Fig. 5. From above: transparent south façade with the cut section levels, top view of the different levels and the Royal Cubit grid overlapped on the top view.

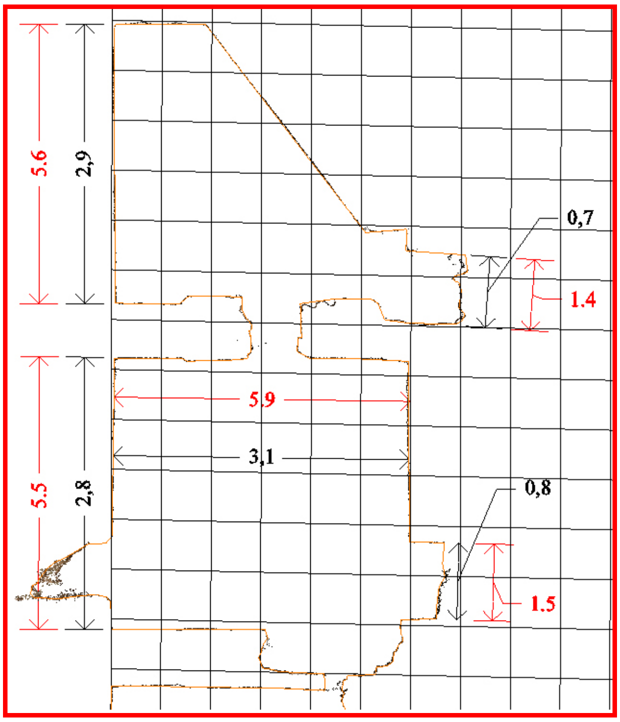

Fig. 5.1. A detail of fig.5 relating to level 0: in red the dimension of the rooms in Royal Cubit unit and in black the corresponding in meters.

The unified 3D model of the building consists of more than 150 millions of points, with many redundant points and a variable resolution, due to the overlapping areas among the different model-blocks, necessary to align them with one another.

In order to homogenize the resolution of the point model and in order to make it more manageable for the successive elaborations, it was subsampled with a minimum point-to-point step of 5mm.Therefore, it was possible to reduce the final point cloud to 37.041.824 points. This operation was useful for the next step: the extraction of the horizontal sections. In fact, using a more uniform and homogenous points cloud, the algorithm of interpolation of the polyline from the point section works better. The final point cloud, obtained in this way, was imported in Autocad to extract horizontal sections for each floor level. In fig. 4 it is possible to see the five planes on the point cloud model and the extracted polylines. The height of the section plan has always been set below the vault's impost line in order to have a correct representation and measurement of the internal spaces (clearly visible in the upper part of the transparent frontal view in fig.5).

In order to ensure the adequate density of points for the extraction of the polyline, the thickness of the slices of point cloud was set equal to 1cm.

The search for a possible unit of measurement started from the analysis of the mudbrick building technique employed for the entire settlement. The most common brickwork type on site is the two headers – one stretcher wall with a thickness of about 52-53 cm. In fact, the bricks have average dimensions of 34-36 cm x 16-18 x 8-10 cm.

This metric information was tested on different portions of the 3D model of the building. Fig. 3.1, for instance, shows a detail of the orthoimage of the south façade (picked up on the internal face of the northern wall), where it is possible to see the measures of the brick and the two headers – one stretcher brickwork type.

This metric module of 52-53 cm does not seem to match the basic unit of Roman linear measurement which was the *pes* (the foot, about 29 cm): instead, it corresponds exactly to the Egyptian Royal Cubit (here abbreviated as c) [10]. In order to verify whether this module can be also detected in the dimensions of rooms and walls, a reference grid of 52 cm was mapped on the floor sections (fig. 5 below).

The grid allowed to interpret and express the measurement of the spaces in Royal Cubits. For example, the width of the rooms at level 0 corresponds to 5.5 or 6 c; the central court measures 13.5 c; the east tower 3.5x4.5 c, and the west tower 3x4 c (fig. 5.1).

V. THE HISTORICAL ANALYSIS

The results of the metric analysis offered an important insight into the interpretation of the historical data. The use of the Royal Cubit in this Late Roman Period fortified site suggests several directions of future research:

- Umm al-Dabadib is one element of a chain of Late Roman fortified sites that punctuate the Kharga Oasis, and the same conclusions might therefore apply to the other sites as well;
- the use of the Royal Cubit in a Late Roman fortified installation (or chain of installations) in the middle of the Western Desert suggests that this building programme was the result of a strategic project evidently funded by the Roman authorities, but deeply rooted in the local building techniques.

VI. CONCLUSIONS

The Umm al-Dabadib settlement is an interesting case study to analyze the Late Roman strategy to control and manage the southern border of the empire. The interpretation of the archaeological remains based on an Egyptian or Roman unit of measurement aims at understanding the history of this well-preserved site, and offers important clues for the interpretation of other similar but less-preserved sites. In addition, the presence of modular measurements may facilitate the graphic restitution of the current state of the remains, and the representation of constructive hypotheses, as basic and repetitive elements (vaults, arcs, etc.) might have been designed according to the module.

The future aim is to extend the metric analysis presented here to the rest of the Fortified Settlement, in order to study how the same unit of measurement was employed in the construction of the other buildings.

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