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## Interpretation of archaeological data based on direct and remote retrieval of information

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# Interpretation of archaeological data based on direct and remote retrieval of information

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**Abstract.** This paper focuses on the archaeological and architectural analysis of the Late Roman settlement of Umm al-Dabadib (Kharga Oasis, Egypt). The available information on the archaeological remains of this site includes on-site hand-made sketches, photographs, 3D surveys. The final aim of this specific research is the interpretation and reconstruction of the historical context of this site by combining sources of different nature. This paper presents the methodology employed to elaborate the 3D data in order to achieve a digital restitution of the archaeological map of the entire settlement, which covers an area of about one hectare. The starting point was the elaboration of the close-range photogrammetric survey of the Fortified Settlement that allowed the creation of a 3D point cloud of the whole area, based on the elaboration of over 5,000 photographs, from which a complete and detailed metric model was derived. This 3D model played a key role to extract metric information and to reconstruct the geometrical structure of the settlement, but this result could only be achieved thanks to the successful combination of the digital data with the hand-made sketches and the pictures taken *in situ* in the recent past. This paper represents an outcome of the project LIFE (Living In a Fringe Environment), funded by the ERC CoGrant 681673.

## 1. Introduction

The evolution of survey techniques underwent a significant turn with the introduction of computer-based 3D surveying and modelling [1] [2], that are now rapidly spreading in the archaeological practice [3] [4]. Long-running archaeological projects that are now using digital imaging face a double challenge: combining the fresh information acquired thanks to the new techniques with that previously collected by traditional means, and identifying the areas in which digital imaging cannot substitute the traditional methods. In a relatively short time, another challenge will become more evident and pressing: the necessity to constantly update the format of the digital data, that quickly become obsolete and illegible.

This paper will deal with the first and second issues, that is, on the necessity to combine sources of different nature in order to gain a comprehensive set of information on the archaeological remains. The case-study is the set of survey data collected in the last twenty years at the site of Umm al-Dabadib, a Late Roman settlement lying at the outskirts of the Kharga Oasis, in Egypt's Western Desert (figure 1), that include hand-made sketches based on direct measures, photographs, topographic measurements, and ground-based photogrammetric acquisitions.

Umm al-Dabadib, located in a remote and harsh environment, was briefly investigated for the first time in the early XX century by J. Ball [5] and H. Beadnell [6], who was mainly interested in the complex system of underground aqueducts.



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**Figure 1.** The Fortified Settlement of Umm al-Dabadib, Kharga Oasis (Egypt's Western Desert) seen from the air. Photograph by Richard Knisely-Marpole, 2002.

The systematic survey of the archaeological remains of the historical period only started in the late '90s [7] and continued until 2015 [8] [9] [10], when the geopolitical situation worsened and the Western Desert was closed to foreign archaeological missions, halting ongoing plans to perform the first archaeological excavation.

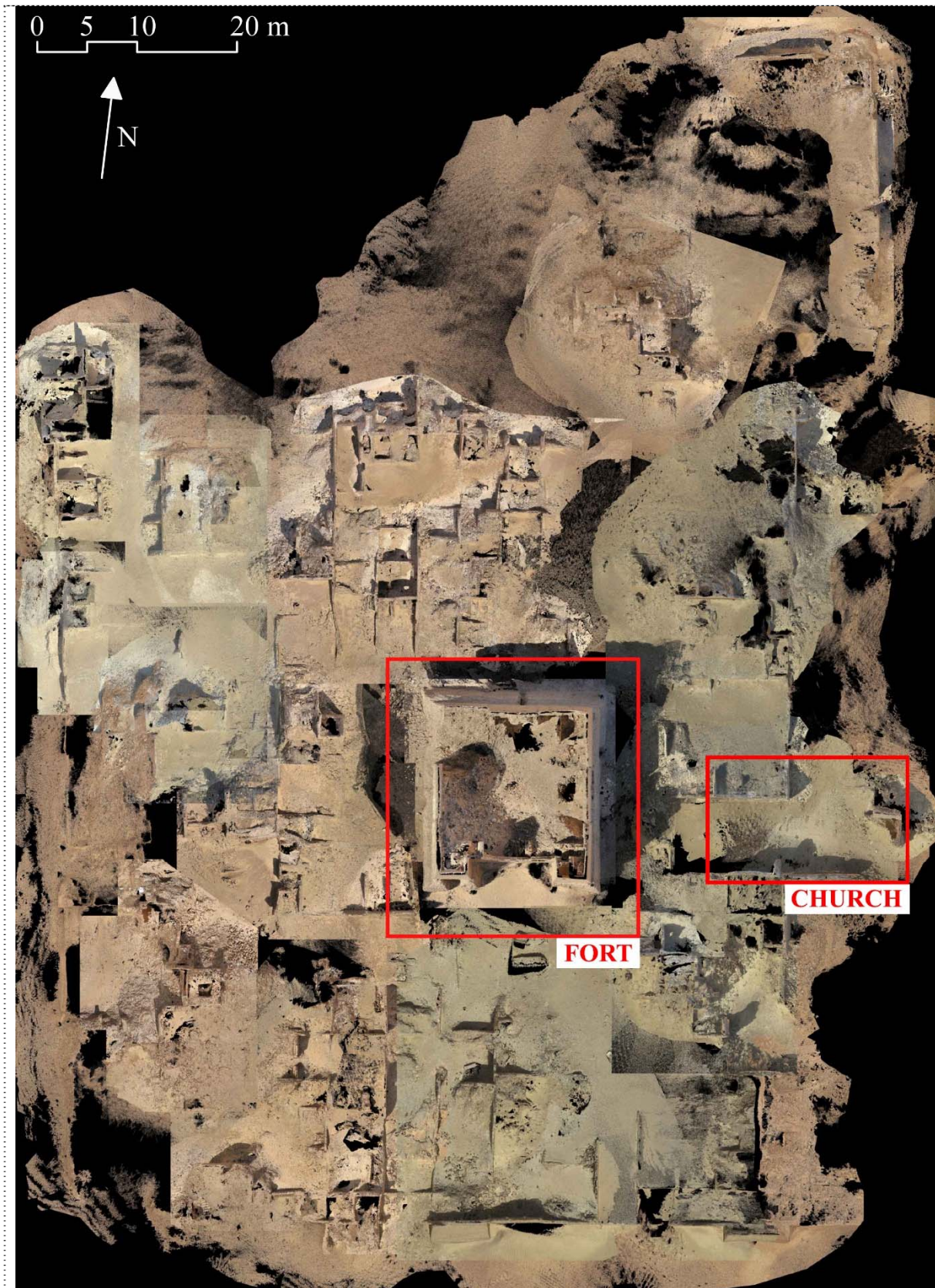
Whilst waiting for the desert to re-open, the Italian Archaeological Mission to Umm al-Dabadib has been experimenting both the survey techniques and the elaboration of their potential on the excavation of the joint mission to Saqqara of Museo Egizio, Torino and Rijksmuseum van Oudheden, Leiden [11]. The results of these tests were used to investigate the raw 3D data that had been collected at Umm al-Dabadib during the last two seasons before the desert was closed, as well as their interaction with the mass of previous survey data. This operation prompted the doubts and questions on the combination of traditional and digital data that are here discussed.

## 2. The survey and the raw output

The survey of the architectural and archaeological remains of the Fortified Settlement of Umm al-Dabadib started in 1998 and evolved together with the available techniques, that are heavily influenced by the extreme environmental and logistic conditions that characterize the site. The first sketches by eye [7] represented the basis for an initial geometric survey performed by laser distomat, set within a grid of points measured by theodolite [10] [12]. A 3D photogrammetric survey performed in 2014 and 2015 [13]; the survey data were stored to await further actions.

In 2016, the ERC-funded project LIFE started the elaboration of the data, in order to improve our knowledge of such a complex, vast and varied architectural object. The data processing showed that the survey achieved an overall accuracy of 1 cm, with a peak of 3 mm in the Fort. The research team focused first of all on the Fort itself, which was the object of a detailed metrological study [14] [15], the results of which are now being extended to the entire Fortified Settlement. The 3D point cloud of the whole area, based on over 5,000 photographs, covering about one hectare, was obtained from the standard and consolidate photogrammetric pipeline: orientation (self-calibration and external orientation); topographic registration; dense cloud generation; orthoimages extraction. Figure 2 shows the orthoimage generated from the dense point cloud of the whole site.

The construction of a complete and detailed metric model was achieved in steps. The first was to align all the photographs globally in order to obtain a unique sparse point cloud. Then, due to the significant dimensions of the photogrammetric project, the elaboration of the dense point cloud of the entire archaeological site was divided into nine parts. Single blocks are more manageable to perform operations such as cleaning the dense cloud, removing the noise (e.g. blue sky points, presence of operators or/and instruments, outlier points, etc.). Moreover, the segmentation allows an easier management of the point cloud in CAD drawing software.



**Figure 2.** The orthoimage of the Fortified Settlement.

In fact, by importing the single 3D models in a CAD environment it is then possible to easily draw the site map directly on the dense cloud, and to report the metrical reference of the vertical plan on the horizontal representation. In addition, CAD software allows the operator to create horizontal or vertical planar sections of the 3D model that can help to better understand the building structure, as well as detect the presence of various architectural elements (passages, vaults, accesses, windows, niches, arches, etc.).

The 3D model played a key role to extract metric information and to reconstruct the geometrical structure of the settlement, but this result could only be achieved thanks to the successful combination of the digital data with the hand-made sketches and the pictures taken on site in the past. In fact, during the elaboration of the digital map, the original hand-made map represented an invaluable source of information and a guide to interpret the 3D data in a more efficient way.

### 3. The research aims

The main targets of the research illustrated in this paper are four: integrating and improving the overall map of the Fortified Settlement; updating the map with the addition of elements that were invisible in 2003 and elements that have disappeared since then; highlighting evidence useful to reconstruct the original layout and shape of the architectural elements that compose the settlement; and finally providing a reliable basis for an overall metrological survey.

Concerning the first point, the latest published version of this map [8] is the stratified result of on-site hand-made sketches, direct measurements and some topographic fixed points; as clearly stated in the paragraph describing the methodology adopted to perform the survey in 2003, this should be considered a sketch plan, as it inevitably presents some typical geometrical errors and dimensional inaccuracies due to the adoption of 'simple' measuring tools on such a large and varied architectural complex. The 3D measurable model of the entire settlement allowed to accurately adjust and fix the geometry and the position on the map of the visible remains. However, the original 'raw', hand-made plan still represents an invaluable source of information, as it includes a wealth of information that cannot be easily found in or matched with the 3D model. For instance, the presence of the collapsed remains of walls or vaults, clearly discernable *in situ*, is very difficult to identify on the digital point model. As in the last 20 years some buildings have been partly or completely destroyed [12], the original map contains the only extant metrical information about them. Therefore, the second target is to highlight and represent the demolished parts too, combining the old measurements with the photographs taken at that time. The updated map of the Fortified Settlement will therefore include both visible and invisible information, which will be treated differently in order to be clearly distinguishable.

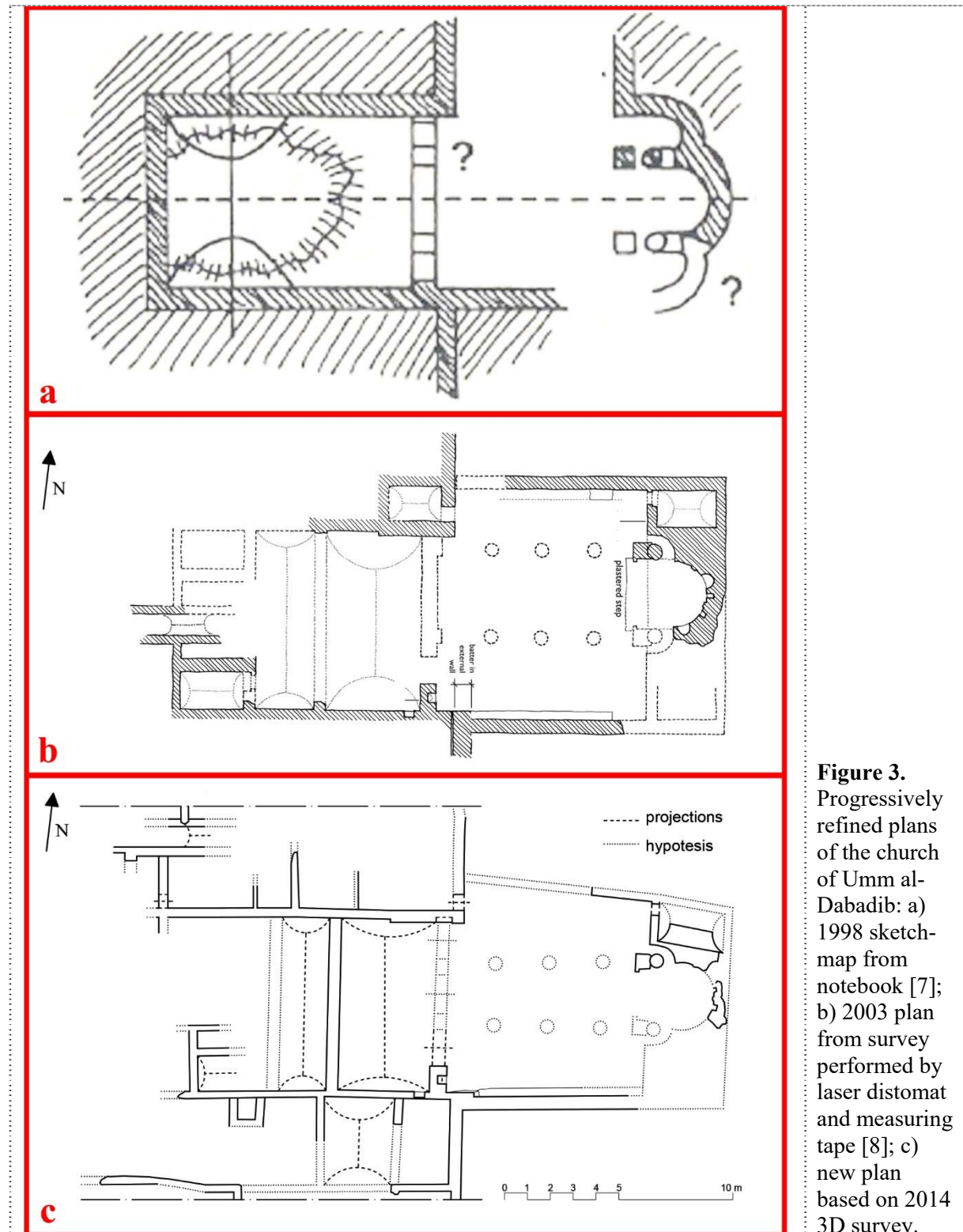
The third target of the research is to interpret the architectural context of the site by combining the observation of the 3D model, photos and hand-made sketches, and to suggest possible architectural reconstructions; the latter will be then reported on the general map as hypotheses and used to develop further studies on layout and typologies. The sole process of reverse engineering cannot achieve this result, as only some elements can be measured, whilst others must be derived by integrating of different types of sources. Finally, the last target is to create a structured database useful for a metrological study of the entire settlement, focusing on dimensional patterns and gridded layout, similar to the metrological study that has been recently carried out on the Fort [15].

### 4. The pilot case-study: the church

In order to define a clear work pipeline to achieve these research aims, the church of Umm al-Dabadib was selected as pilot case-study (see Warner in [8] pp. 236-40 and 479-93). In fact, this building presents the main typical challenges of this kind of analysis: discrepancies between hand-made plan and 3D survey; architectural interpretation to be performed by combining digital model; measurements taken by hand and photos; destroyed parts documented only by old photos and sketches; unclear layout and typology to be investigated; and geometric reconstruction to be refined.

The starting point was the exploitation of the 3D point cloud in CAD software in order to extract a horizontal floor section of the church. A comparison with the 2003 hand-made survey performed by N. Warner revealed two significant discrepancies in geometrical terms, and one relating to the ensuing

interpretation of the original layout of the building (figure 3). First of all, in Warner's plan the east-west axis of the church is shifted slightly to the north, thus producing lateral naves of different depths. The 2014 3D survey confirms instead the alignment suggested by the very first published sketch of the church [7].

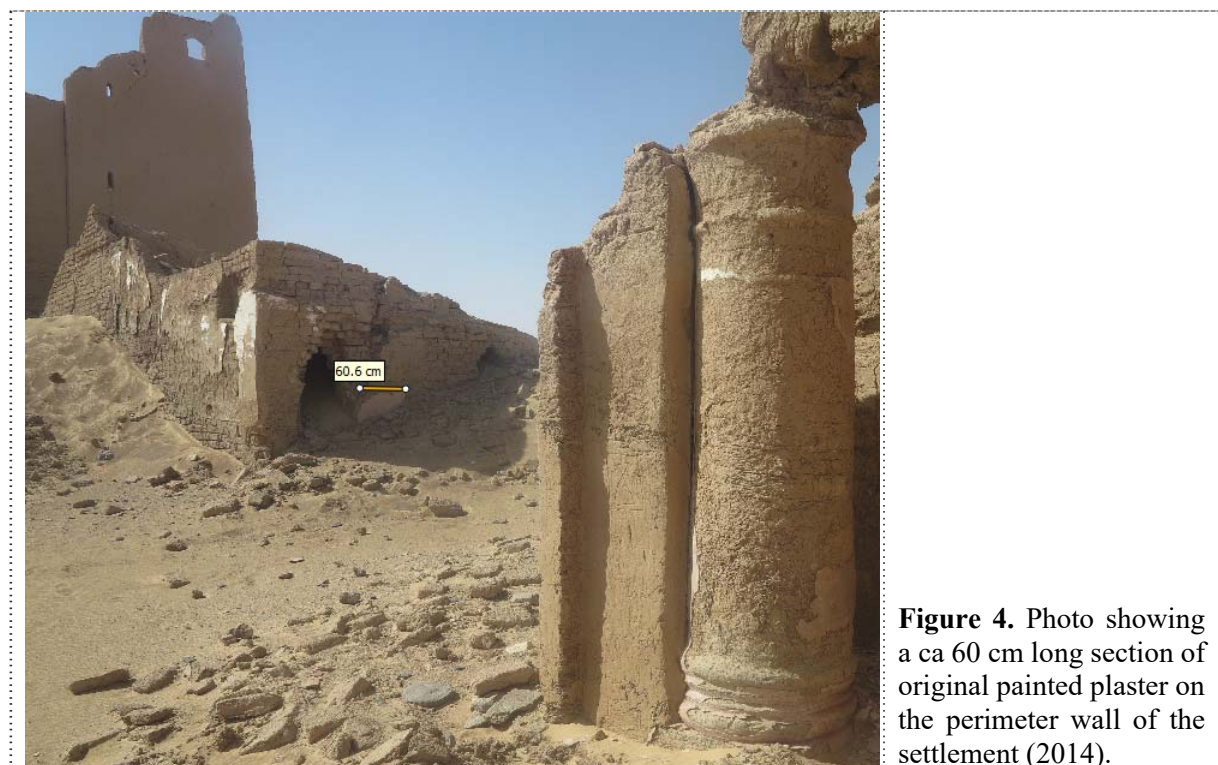


**Figure 3.** Progressively refined plans of the church of Umm al-Dabadib: a) 1998 sketch-map from notebook [7]; b) 2003 plan from survey performed by laser distomat and measuring tape [8]; c) new plan based on 2014 3D survey.

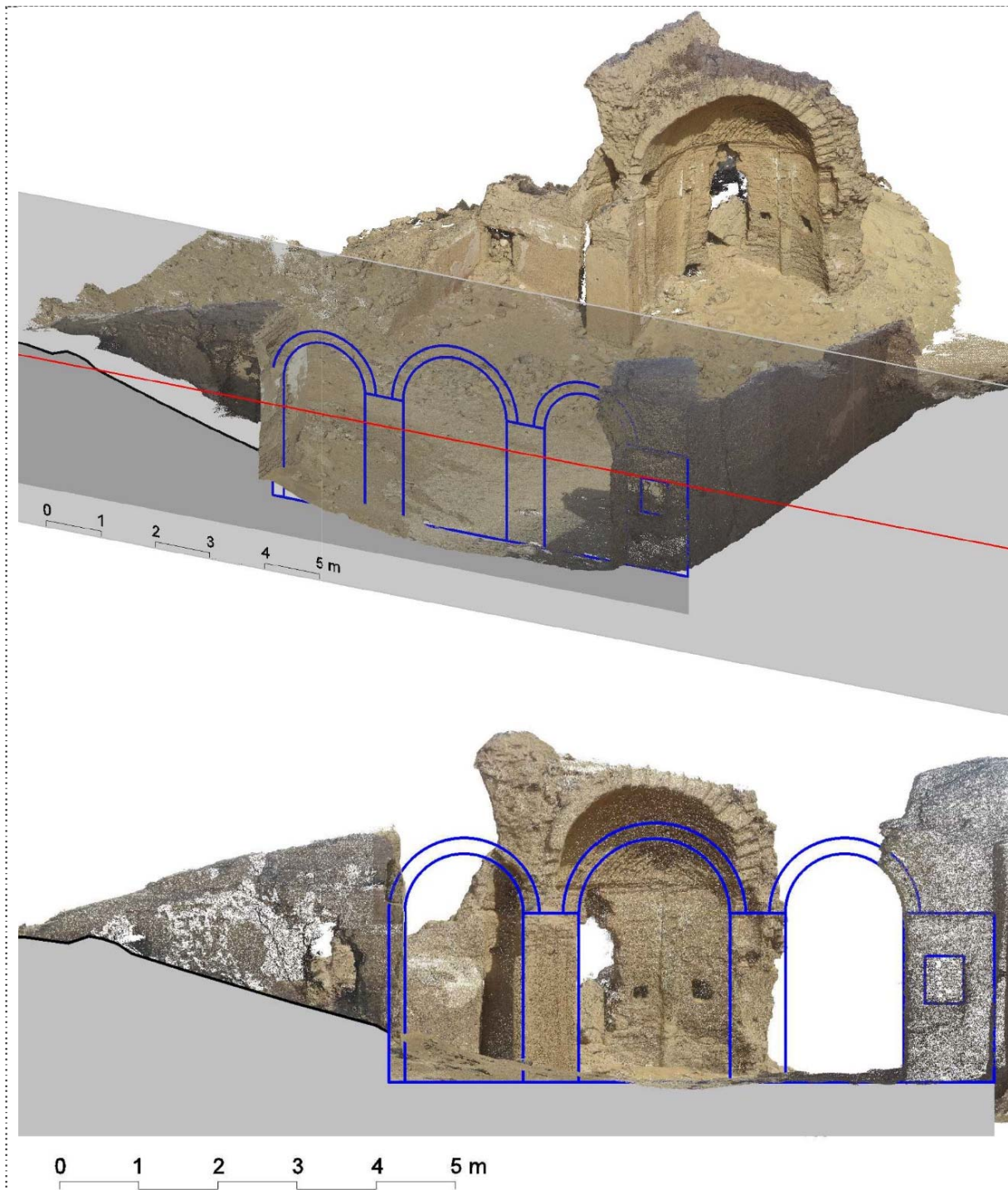
A second element that caught the attention was that the north wall of the church was not orthogonal to the perimeter wall of the settlement, a rather striking detail that had not emerged during the previous survey campaigns. Once both a misalignment and an inaccurate 3D reconstruction had been ruled out by double-checking the data and their elaborations, all pictures of the church taken over the years were analysed in detail. That specific portion of the building was half-filled by sand in 1998, had been partly exposed in 2003, and was heavily damaged in 2004 by the incursion of a heavy vehicle. In the following years, the upper part of the exposed walls suffered from erosion, whereas the lower part was covered by sand; further, small scale scavenging was recorded in this period. When the 2014 photogrammetric survey was performed, the situation was therefore slightly different in comparison with 2003. One specific picture taken in 2014 provided an important clue: it shows a part of about 60 cm of the plaster on the perimeter wall of the settlement after the access to the vaulted room located to the north of the church (figure 4). The plaster shows exactly the same decorative pattern that was found and recorded on the now destroyed northern wall of the church, thus suggesting that this surface still belonged to the same space. This, in turn, appears to confirm that the wall that outlined the church along the northern side was not orthogonal to the perimeter wall.

The second architectural element to be analysed in detail was the transversal wall that appears to separate the church proper (naves and apse) from the room located immediately to the west. The latter was covered by a large (ca 4 × 7 m) and tall barrel vault, which must have rested on two parallel north-south walls, of which very little survives. The stump of an arch springs orthogonally from the southern wall of the church; Warner suggested the presence of a continuous wall supporting the tall vault, with just an (arched) passage across its southern portion. However, the presence of a break in the northern wall might represent a clue pointing in a slightly different direction. This neat, rectangular cavity in the wall, in fact, might correspond to the point from which a symmetrical arch sprung. Starting from this hypothesis, a geometric reconstruction of three access arches corresponding to the three naves of the church was attempted, using a vertical plane and section from the 3D point cloud (figure 5).

The plan of the church presented here, that substitutes the ones published in the past, is therefore based on a successful combination of sources of different types and origins: each source contained a piece of the mosaic, and only their combination produced a final, reliable result.



**Figure 4.** Photo showing a ca 60 cm long section of original painted plaster on the perimeter wall of the settlement (2014).



**Figure 5.** A prospective view (top) and the vertical section (bottom) on the transversal wall of the church's point cloud including the geometric reconstruction of three arches corresponding to the three naves.

### 5. Future applications

This work pipeline, based on merging the information coming from the 3D survey with all the other available sources, will be used to edit, step by step, an updated general map of the whole Fortified Settlement. The final result will allow archaeologists to reconstruct the layout of the settlement and the



shape and distribution of its domestic units; will provide information to architectural historians to carry out a metrological study of both the settlement as a whole and of the individual buildings. A better understanding of how this large settlement was conceived, planned and built will represent an important basis for the research of historians and Egyptologists investigating the events that took place along the desert frontier of the Empire in the Late Roman Period.

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