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Broadening Horizons 5

Civilizations in Contact

Proceedings of the 5th "Broadening Horizons" Conference (Udine 5-8 June 2017)

Volume 3
Interactions and New Directions in Near Eastern Archaeology

Edited by
Costanza Coppini
Francesca Simi

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Verità e Giustizia per Giulio Regeni, ricercatore appassionato

Truth and Justice for Giulio Regeni, passionate researcher

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Rescue archaeology in the sultanate of Oman: methods and solution strategies

Rescue archaeology in the sultanate of Oman: methods and solution strategies

CRISTIANO PUTZOLU, CARLO BAIONE,
ENZO COCCA, SABATINO LAURENZA

Independent Researchers

Abstract

This paper aims at presenting the results of the topographic fieldwork of a team of professional archaeologists invited by the Ministry of Heritage and Culture of the Sultanate of Oman to excavate and survey three graveyards in the area of Sohar (Falaji as Souq, Wadi al Arad and Liwa) in 2014 and 2015.
The construction of the Batinah Express Highway would have led to the destruction of hundreds of burial mounds, therefore the team developed a quick and accurate surveying strategy to document them properly: after a first "test" campaign using monoscopic photogrammetry, the team opted for 3D SfM photogrammetry using a completely open source workflow.
This workflow required two surveyors on the field and in the IT lab to ensure the archaeologists updated orthophotos and to update the 2D and 3D vector plans. To manage the huge mass of data coming from the field the team opted for QGIS and the plugin PyArchInit.
The mix of surveying methodology and managing system developed on site allowed the team to document the numerous Stratigraphic Units produced during the excavation of hundreds of graves, and also proved to be very helpful as hermeneutic tool as shown in the case of the excavation of Grave 21.

Keywords

Digital Archaeology, Open Source Photogrammetry, Rescue Archaeology, Oman Archaeology, Open Source, PyArchInit, QGIS

1. Introduction

From 2014 to 2015 a team led by Sabatino Laurenza was invited by the Ministry of Heritage and Culture of the Sultanate of Oman to excavate a great number of graves located in three different graveyards whose integrity was threatened by the construction of the Batinah Express Highway.[1]

No specific laws in the Sultanate of Oman demand rescue archaeology, but nevertheless a National Heritage Protection Law preserves national heritage by protecting cultural properties and upgrading public awareness on national heritage.[2] This law is applied to all kind of monuments and antiquities on the Oman territory, as well as to "*chattels of cultural properties*", which also include fossils, rare archetypes of fauna and flora, fragments of artistic ruins, ancient coins, engraving and marks, manuscripts and books, documents and print matter of special historic, artistic, scientific and literary value, as well as traditional style furniture items, painted earthenware, musical instruments, jewelry, precious stones and weapons.

The cited Decree requires:

- Nationwide overall inventory which is to be concluded and updated;
- Measures designed to prohibit all kinds of activities or actions that may modify, alter or in a way tamper with the property, be it a monument or a mobile cultural property;
- Measures designed to restrict or prohibit the export of mobile cultural properties, as well as their purchase and sale;
- Measures designed to contribute to the cost of restoring, repairing and renovating registered monuments deemed to be of special historical, artistic and scientific importance.

Considering that Oman witnessed a huge infrastructural development work, especially in the last years, very scarce appear to be the rules about rescue archaeology.

The Batinah Express Highway is a 265 km road which connects the Muscat Expressway up to the border of the United Arab Emirates. The highway will be located inland around 20 km from the sea, and during the construction works it has been divided in 6 Packages, each one managed by different consultants and contractors. Among the other international teams operating in the construction site of the Batinah Expressway Project, our team was charged with the investigations of the Package 5 in the Batinah plain, which included Sohar and Liwa inland areas. Package 5 covers a stretch of 41 km from the kilometer 180 to the kilometer 221 mark of the Expressway; it begins roughly 18 km inland from the coast after Wadi Haibi in the Wylayat of Sohar and ends in the Wylayat of Liwa (fig. 1).

Our team was invited by the Ministry of Heritage and Culture, the costs of the project was financed by the Ministry of Transports and Communications with BOTEC (Bosphorus Technical Consulting Corporation) acting as Consultant and all the needs for our team was arranged on-field by Ferrovial Agroman and Federici Stirling Batco LLC acting as Constructors.

This is an important point to be stressed out, because it was clear from the beginning that our goal was the complete excavation of all the graves that were going to be destroyed by the construction works, and any other result would have been unsuccessful. All the excavated sites were located within the projected roadway, which was a corridor of about 75 meters, but in hilly areas the corridor was wider as the hills should have been blasted away in order to create a correct slope. The expressway was fenced off with a 120 meters wide corridor, and the burials within this zone would not be damaged by the construction of the road. Outside those fenc-

[1] The authors of this paper wish to thank the Ministry of Transport and Communication and the Ministry of Heritage and Culture of Sultanate of Oman, in particular Adj. Director General for Archaeology and Museums, Dr. Sultan Al Bakri, who followed all the fieldwork operations giving us the support needed. Also we want to thank the Contractors staff of the Ferrovial and Federici Stirling & Batco and the Consultant staff of BOTEC Ace for their precious direct support on the field. Special thanks go to our colleague and friend Claudia Tomaselli for the graphics for this paper and to Vittorio Lauro for the excellent work done with the 3D rendering of Grave 21. Finally we would like to thank two anonymous reviewers for their useful feedback.

[2] Enacted by the Royal Decree No: 6/80, dated 10 February 1980.

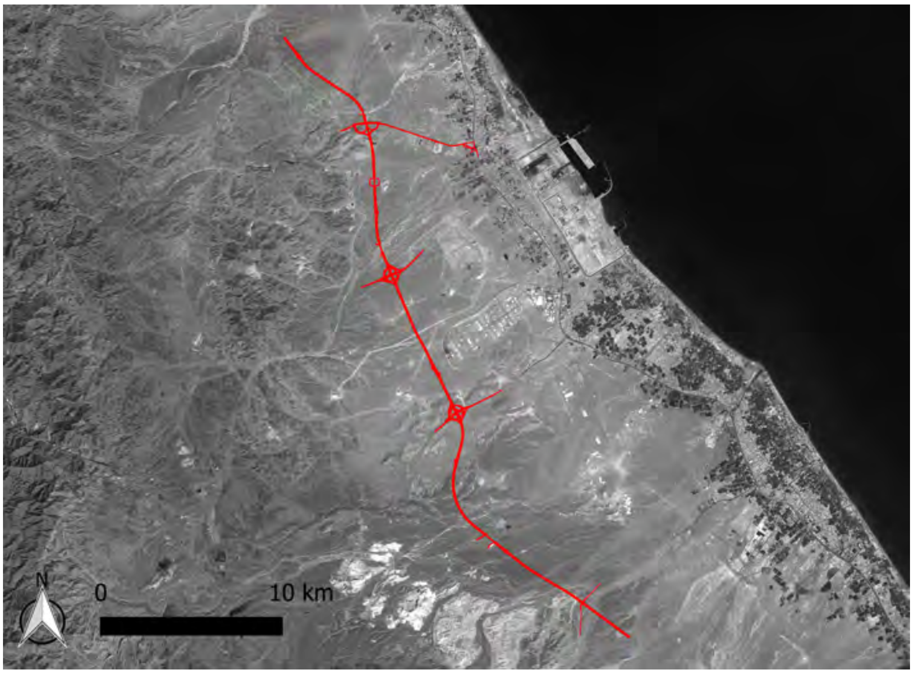


Figure 1
The Batinah Express highway project Package 5

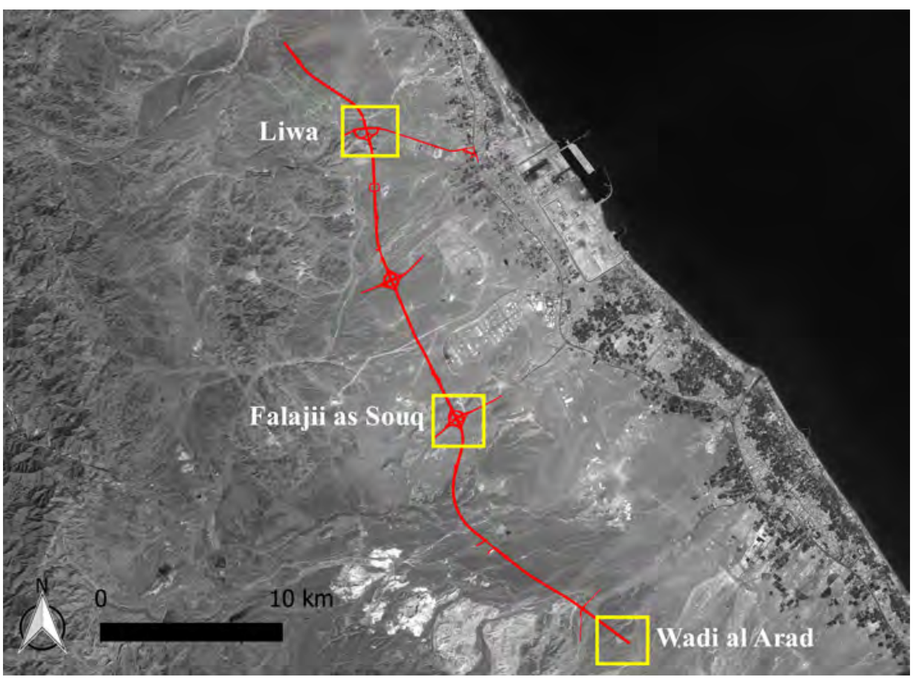


Figure 2
The different areas of operation

es there was the 200 meters wide Right Of Way (ROW), where the burials were not harmed as well. All those burials were fenced with warning tape and with apposite signage to remain untouched.

From June 2014 to June 2015 different teams of Italian professional archaeologists, led by Sabatino Laurenza but never composed by the same people, investigated the Graveyards of Falaji as Souq, Wadi al Arad and Liwa (fig. 2).[3]

(S. L.)

[3] First rescue campaign, which lasted from 30th May to 5th July 2014, was focused on the graveyard of Falaji as Souq, near Falaji Al Qabail interchange of the Batinah Expressway

2. Research questions

Given the extreme environmental conditions and the construction site needs and timings, the survey team that operated alongside the archaeologists in the first campaign opted for the monoscopic photogrammetry as the methodological approach to document the structures. This digitization method provides great accuracy and saves time for field data acquisition, but works best when the surveyed features lie on the same plane. If the features to be surveyed are not on the same level, as it was for the funerary structures investigated in Oman, it is necessary to divide them in different scenes and survey each one separately.

To overcome the challenges of surveying such big structures and to give enough time to the archaeology team to excavate them stratigraphically, the monoscopic photogrammetry seemed the best option at the time. This choice unfortunately ended expanding the time needed for the field data acquisition, for the images processing and for the drawing of the plans.[4]

Another negative aspect of this digitization method is its bidimensionality, which complicated the 3D data acquisition on field, which is crucial to properly read and interpret the original shape and volume of the excavated graves. The acquisition of the heights of every surface recorded with the monoscopic photogrammetry was made with the Electronic Total Station (ETS): this solution added more time on the field for the survey team and less time for the archaeologists to investigate the structures.

At the end of the first campaign, which was successfully concluded as scheduled, the survey team had many issues to be solved in terms of speeding the field data acquisition time and the quality of data produced on and off site.

The issues that needed to be solved in order to improve the survey quality of the second campaign can be summed up as follows:

- Too much time on the field for data acquisition;
- Too much time for the post-processing of digital surveys including maps drawing;
- ETS 3D data acquisition was too long for a satisfactory data-set. In fact, recording less coordinates meant less data, thus less information;
- Bad accuracy in the final maps due to the difficult simplification of three dimensional volumes in different planes.

Before the end of the campaign a preliminary analysis of the satellite imagery of the Wadi al Arad area showed hundreds of graves to be surveyed; the area was soon covered with a fieldwalk survey to estimate the exact number and disposition of the graves inside the construction corridor.[5] The big number of tombs inside the buffer not only required a bigger team but also a complete reorganization of the workflow and a change of the strategy and of the method used on field and in the lab.

(C. P., C. B.)

3. Methodology

A mix between 3D Structure from Motion (SfM) photogrammetry and ETS seemed the best option to fix the issues noted in the first archaeological campaign. 3D digital photogrammetry was already used by the topography team in their professional daily life.[6] The switch to SfM photogrammetry was quickly assimilated by the team and improved the

Package 5. The team was composed of seven archaeologists and three Omani representatives and we excavated in Falajii as Souq graveyard a total of 26 graves plus 6 circular stone structures, surveying (only in the area inside the buffering and fencing zone) around 149 graves. During the second rescue campaign, which lasted from 30th September to 23rd December 2014, the team was composed of fifteen archaeologists and three Omani representatives who excavated 34 graves in Falaji as Souq graveyard and 95 graves in Wadi al Arad graveyard. The team that run third campaign, from 12th April to 18th June 2015, was composed of sixteen archaeologists plus three Omani representatives and investigated 74 graves in Wadi al Arad graveyard and 54 graves in Liwa graveyard.

4 The investigated tombs are generally composed by the collapse of the dome (made of medium/big sized basalt stones) and placed at a different height, the funerary bed/chamber.

5 Which is the area investigated for the second and third campaigns.

6 At the time of the second campaign also composed by Enzo Cocca and Cristiano Putzolu. Bigliardi et al. 2013; Putzolu, Vicenzutto 2013; Cocca 2014.

field data acquisition also enhancing the quality of the work.

3D digital photogrammetry is a low cost method also known as close-range photogrammetry, which belongs to the wider group of the non-invasive, passive digitization techniques. It is an optics digitizing system that consists in the identification of points of reference in digital images shot from several angles, and in the determination of the relative position of those identified points in a three dimensional space using triangulation.[7]

The choice of this digitization method proved to be helpful to accurately record the tombs, furthermore fitting the environmental and archaeological context the team of professionals was operating in. The only equipment needed on site besides the ETS – that was integrated to photogrammetry in this survey – consisted of a compact digital camera with a remote control, a telescopic pole with a camera mount, a smartphone as camera remote control and a bag of paper Ground Control Points (GCP).[8]

This approach to the graphic documentation of the features on site ensured:

- Fast data acquisition on site;
- Fast post-processing of the 3D surveys and prompt plans drawing;
- Accurate and satisfactory 3D data acquisition provided by the 3D point clouds;
- Great accuracy in the georeferenced photomodel and in the orthorectified image.

3D digital photogrammetry and ETS provided the survey team with a quick and effective solution to document all the structures that were going to be destroyed by the construction of the Batinah Expressway.[9]

The acquisition of the image sets for the 3D model creation followed different patterns, each one used to survey a different context situation.[10] The choice of following a regular pattern depended on the needs of the software selected to process the images and to create the 3D point cloud: for the Oman rescue archaeology campaign the team opted for Python Photogrammetry Toolbox (PPT) GUI, an open source software for rendering a 3D point cloud from photos of an object at different angles.[11]

In order to supply the software with the correct sequence of pictures for the point cloud calculation, the tombs were photographed either circling around them clockwise or counter-clockwise, changing shooting angle and pole height every loop; only certain contexts required to photograph the tomb zigzagging on top of it, or even mixing two different patterns in order to supply the software with more information to properly compute the 3D model.

Given the dimensions of the tombs, which were often clustered in two, three or more, the camera was mounted on a telescopic pole to widen the shooting angle and therefore framing most of the structure in each picture. To speed up the image acquisition step each surveyor connected the camera to a smartphone via WiFi to control the shooting angle, hence setting a proper distance from the tomb to be surveyed and also allowing a better quality control during the acquisition.

Each standard sized tomb required a minimum of 60-80 pictures with at least a 75% overlap between each one; a higher number of photos was required for bigger tombs or for important details, for the funerary chamber or also for tombs clusters. The maximum time required to shoot a standard sized tomb with this setup was 10 minutes circa including the camera setup, and a few minutes with the ETS to record each of the 4 GCP placed around the tomb.

To improve the quality of the work and the processing speed both on field and in the lab, for the last campaigns the topography team was upgraded to a team of two surveyors.[12] A bigger team allowed to work on different things at the same time, speeding up the survey on the field, the 3D model creation and the post processing of the survey data (fig. 3).

[7] Howland et Al. 2014.

[8] Wróżyński et Al. 2017.

[9] Alby et Al. 2013; Alby 2015.

[10] The surveyed tombs were very often in groups of three or more or else located on the edge of a cliff, thus complicating the image acquisition.

[11] Moulon, Bezzi 2012; Belmonte et Al. 2017; see *infra*.

[12] Cristiano Putzolu and Giacomo Fontana in 2014 and Cristiano Putzolu and Carlo Baione in 2015.

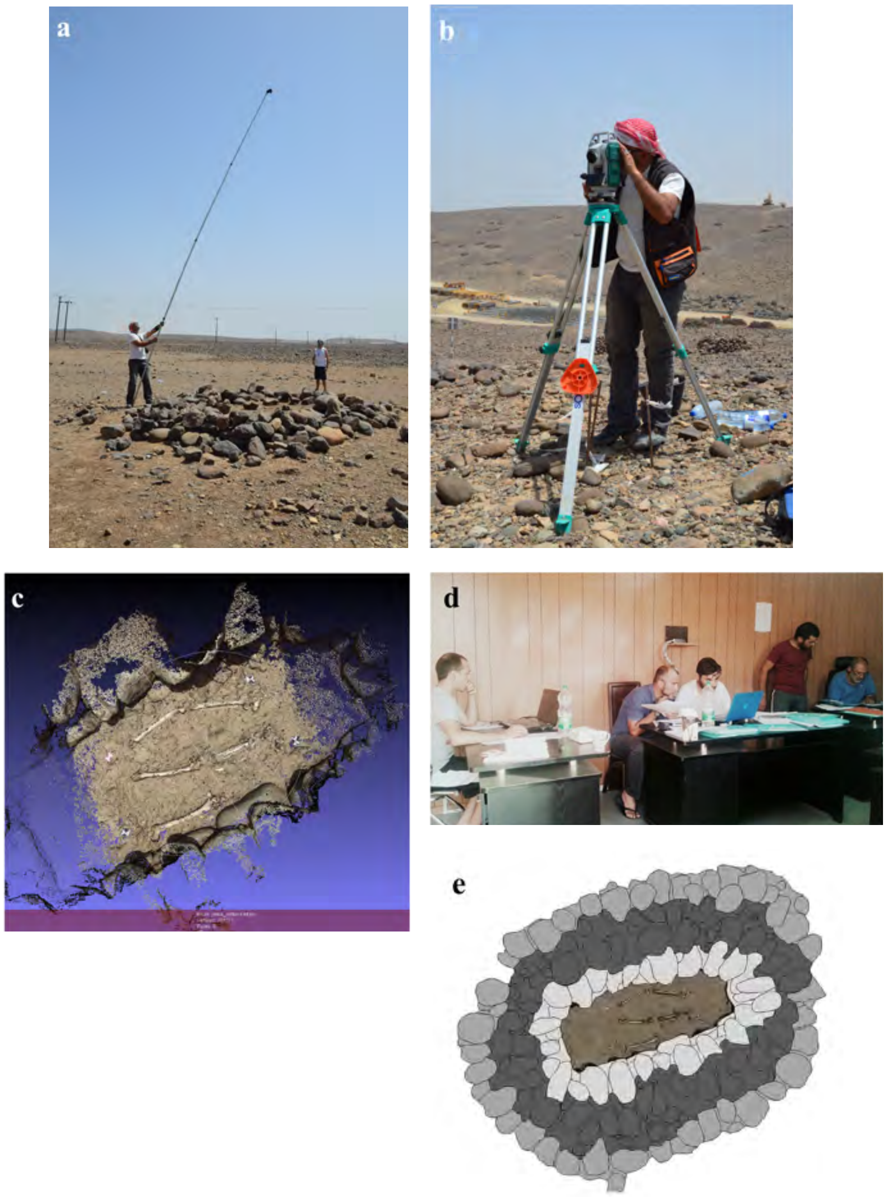


Figure 3
Some moments of the survey methodology workflow:
a) images acquisition,
b) ETS survey of GCP, c) point cloud creation, d) checking drawings on plotted orthophotoplans,
e) vectorized plan

The advantage of using 3D digital photogrammetry was clear during the field data acquisition and became more obvious during the image processing phase: the survey team noticed an instant speeding of the preliminary surveys that improved the quality of 3D and 2D data, but most importantly provided the team of archaeologists with more time to investigate the tomb without losing any relevant information.[13]

Before the beginning of the second archaeological campaign the survey team opted for a complete open source workflow: from the images processing to the production of plans and sections. Most Free/Libre and Open Source Softwares (FLOSS) are released under the General Public License, and the source code is openly distributed and shared. The team chose to use FLOSS to benefit from decreased software costs, increased security and stability, and furthermore to have more control over the hardware.

PPT GUI is a free/libre, open-source and cross-platform photogrammetry software orig-

[13] The first step of the survey, before the excavation of the tomb, was the topographical survey of the structure and its collapses.

inally developed by the Arc-Team in September 2010. The software is composed of Python scripts that automate the 3D reconstruction process from a set of pictures. The processes performed in PPT GUI can be summed up into two parts: camera pose estimation/calibration and dense point cloud computation. Open-source software are employed to perform these intensive computational steps: Bundler for the calibration (using SIFT algorithm) and CMVS/PMVS for the dense cloud reconstruction.

All in all PPT GUI is a user friendly application that produces 3D digital copies of virtually any scene or object, and it provides a low-cost, portable and effective solution to record archaeological structures with just a camera and a total station, which are usual tools on any archeological excavation. This digitization method, especially if executed in a controlled environment, provides similar results to those produced with a laser scanner, which can be difficult to handle and is not as cheap as a compact camera.[14]

The PPT GUI rendering process could last from a minimum of 3 hours of image processing for a 30-45 images set to 12 hours for a grave cluster with around or more than 120 pictures, depending on the hardware used and also on the alignment settings chosen.[15] The first step of the process tends to employ more CPU than the CMVS/PMVS process, which instead relies more on the RAM: during the images processing the user is free to work on other tasks and to run PPT GUI in the background with no need of waiting for the dense cloud creation.

The team opted for Meshlab (v 1.3.3), a FLOSS that provides systems for processing and editing three dimensional triangular meshes, to create the geometry of the photomodel, to georeference it and to produce an orthorectified image of the scene.[16] The 3D point cloud generated by PPT GUI was in fact processed in Meshlab to create both geometries and texture, then it was georeferenced with the GCP coordinates.[17] The georeferenced model and the point cloud imported in a GIS environment were then used to extract cross sections, orthorectified photos and 3D information to the highest level of accuracy.[18]

To create the digital georeferenced copy of a single tomb, to vectorialize it and then add it in the db it took from 2 to 4 hours total; more time requested a cluster of tombs, both on the field and in the lab, taking from 4 to 12 hours depending on the amount of pictures.

During the excavation campaigns both teams of topographers and archaeologists worked together to document the graveyards while the construction site proceeded, and the workflow adopted demonstrated to fit the needs. The topographic work on site was organized in three macro chunks, which left the team the chance to change and adjust strategy in case of need:

- Pre-excavation survey, to record the state of art condition of the tomb;
- During the excavation survey, to record the funerary structure and the uppermost layer of abandonment inside the burial chamber;
- End of the excavation survey, to document how the tomb is left after the stratigraphic excavation.

14 Vicenzutto et Al. 2019; for an updated review of the potential of SfM photogrammetry in archaeology and an accurate bibliography, see Willis et Al. 2016; for a comparison between Laser Scanning and sfm photogrammetry and an accurate bibliography, see Skarlatos, Kiparissi 2012 and Wilkinson et Al. 2016.

15 The first step of PPT GUI pipeline is *Run Bundler:* the parameters needed are *Feature Extractor* and *desidered Photo Width* and our choices respectively *siftvlfeat* and *2400* (resolutions higher than 2400 pixels ended with PPT GUI crashing); the second step is running either *CMVS/PMVS* or *PMVS without CMVS* and our choice is the latter.

16 Falkingham 2012, 2013.

17 Once imported both the sparse cloud and the dense cloud in the software, the dense cloud can be processed with the *Surface Reconstruction: Poisson* algorithm. The parameters needed are *Octree Depth* (suggested range is between 5 and 10, the higher is the parameter the better is the precision in the reconstruction but also the higher is the processing time) and *Solver Divide* (default value is 8, it reduces the memory usage) and our choices were respectively *14* and *12*. The mesh thus obtained is cleaned and then textured using *Parametrization + texturing from registered rasters* algorithm using a *Texture size* of *8192*. Finally the model is georeferenced using *Reference scene* and assigning to the different GCP visible in the textured mesh the corresponding coordinates.

18 As further shown in this paper, this project opted for QGIS and the PyArchInit plugin to manage the alphanumeric data.

As previously stated the images processing results in a 3D georeferenced point cloud that can be imported into the GIS as z-point feature or it can either be used in any other vector based software for 3D reconstruction. The 3D information thus produced allows archaeologists to hypothesize a reconstruction of the volumes of the funerary structures.

The accuracy and fidelity of the final vectorial plan is ensured by the orthorectified image, which, compared to the several photomodels of different portion of the structure proved to be a very important improvement in terms of work quality.[19]

(C. B.)

4. Field strategy

The field survey workflow has been revised and improved several times throughout the archaeological campaigns with the final goal of gathering as much data as possible in the best way, and at the same time giving the team of archaeologists more time to investigate the contexts. The process development led the topography team to adopt an open-source solution that worked well on the Omani geographical and historical context.

To better understand the operating mode it will be useful to describe, as an example, the documentation process of an average tomb.

After a preliminary cleaning of the structure, necessary to understand and highlight the physical limits and the structural elements to be reproduced in 3D, the topographer shoots the set of pictures and then records the GCP placed on the edges of the scene (fig. 4).

After the field survey the images are processed with PPT GUI at the standard resolution and then the mesh is created, textured and georeferenced with Meshlab (fig. 5) as previously described in this paper. Both the ETS data and the orthorectified images are uploaded in the GIS project managed by PyArchInit.[20]

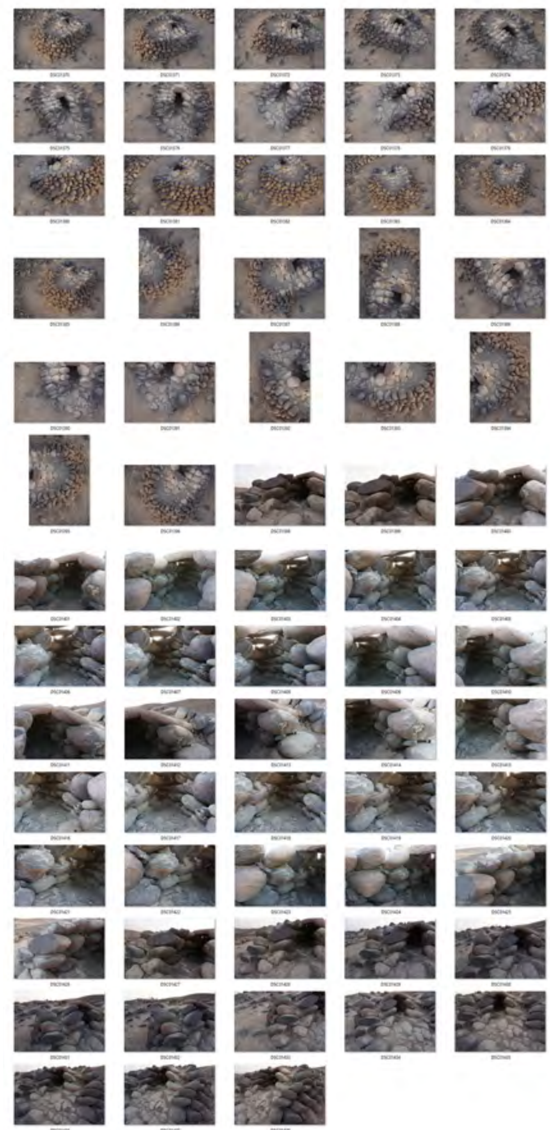


Figure 4 – Data acquisition

As soon as the zenithal image has been produced it is printed and delivered to the archaeologists working on site to be used as a graphic base on which to draw the limits of the different stratigraphic units (SU). Each SU is then vectorized and loaded into PyArchInit together with its recording sheet (fig. 6).[21]

[19] The workflow used during the first campaign, which gave us many distortion problems.

[20] See *infra*.

[21] As well as the pottery, osteological and other recording sheets.

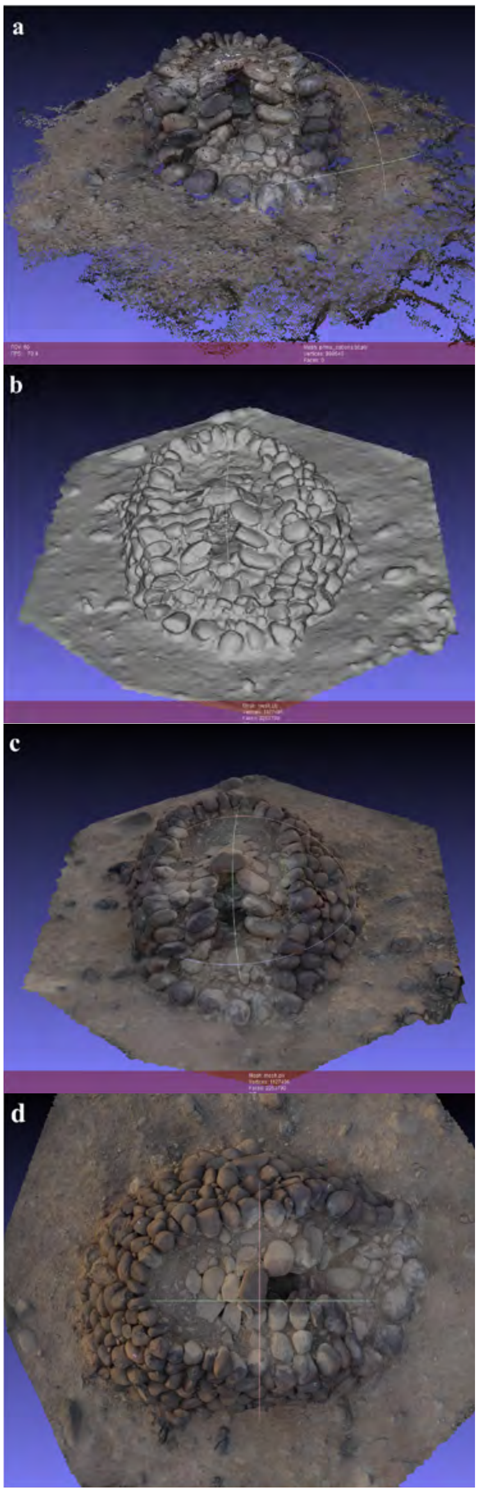


Figure 5
Post processing: from the point cloud to the orthorectified 3D model:
a) point cloud,
b) 3d mesh,
c) textured 3d mesh, oblique POV,
d) textured 3d mesh, zenithal POV

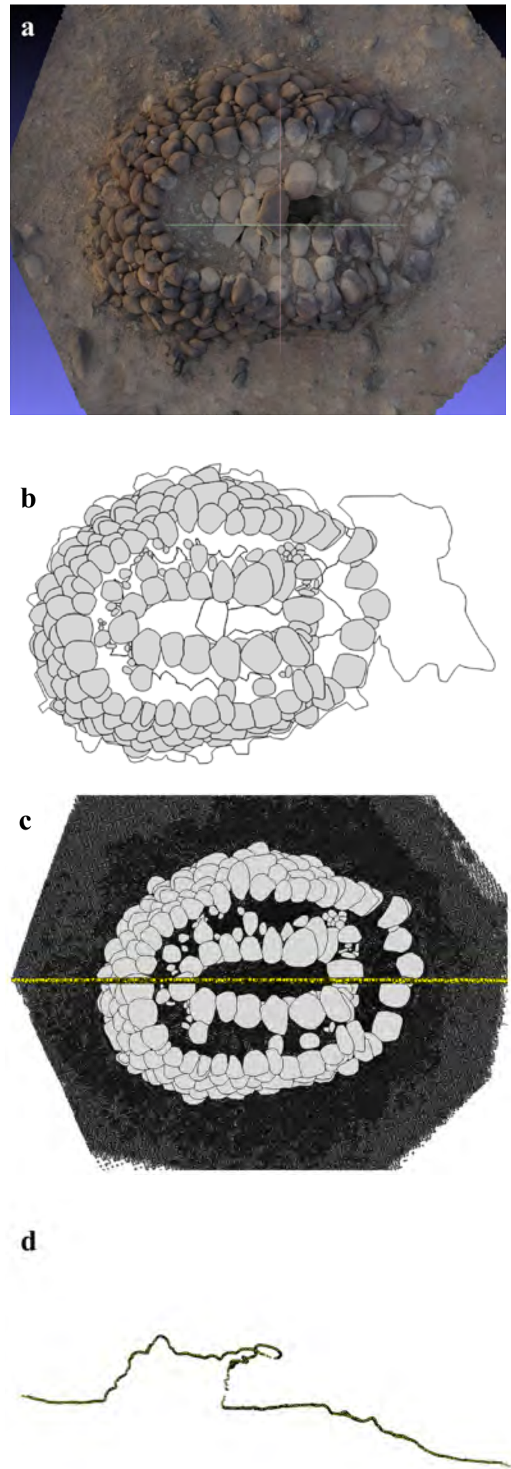


Figure 6
Plans and sections drawing:
a) orthorectified photomodel,
b) vector plan,
c) georeferenced 3d point cloud,
d) selected 3d points along the cross section

The accuracy of the 3D renders produced with Meshlab allowed the topography team to use the textured and geo-referenced models of the burial chambers with the bone remains as a virtual environment: the precision of the 3D scenes was used by the anthropology team to collect the metric information they needed after the work on site in order to speed it up and let the archaeologists team and the construction site to go on faster. The 3D models proved to be helpful for the anthropologists to hypothesize the taphonomy and to get other information from the bones.

(C. P.)

5. PyArchInit

PyArchInit is an open source project written in Python and directly integrated in QGIS designed to manage archaeological fieldwork data. It was originally created by Luca Mandolesi in 2005, it was then implemented and further developed by Enzo Cocca for his Ph.D. thesis in 2010.[22] In 2015 the project expanded to become a web community called *UnaQuantum*.

The geodatabase containing the Batinah Expressway emergency excavation data has been centralized on a single server which can be remotely accessed by all the project members. This allowed the teams to upgrade the geodatabase with their data and to view and access in real time all the excavation data.

PyArchInit proved to have a high capability of adaptation to the specific needs of the project in which is utilized, allowing the customization of the existing applications and the development of new integrated modules. PyArchInit currently contains 20 forms that help the archaeologist to digitize and manage all archaeological data in QGIS.

How it works:

The alphanumeric data can be entered into the PyArchInit database via graphical interfaces: tabs provide the user with a tool to erase, search and input data, while some fields with a combobox can be updated using the thesaurus, through which the user can customize and standardize the specific vocabulary that best fits a given archaeological context. The SU form is linked to the geometric table by means of three external keys that make the data univocal.

The vector file (PyUnitaStratigraphic) is imported into QGIS and is used to draw the topological features. As SU form and geometric tables are linked, the user can search not only alphanumeric data but also geometric data and quickly create phase and period maps.

The implemented functions are:

- Export of the forms into pdf;
- Error check on stratigraphic relationships;
- Export of the matrix media management;
- Export of maps for SU and periods (currently a trial tool).

The GIS time controller board allows the user to build phase and period plans for either absolute and relative chronology, thus allowing a faster export process than by constructing phase plans through queries.

As mentioned above, the core of PyArchInit resides in its geodatabase, which can either be used with a db SQLite or PostgreSQL db. To manage the data from the archaeological excavation in Oman the survey team opted for a PostgreSQL db which would have given the possibility to centralize it remotely, so that all teams could enter the data on a single db. All the excavation data could then be managed connecting the single db to the centralized PostgreSQL db through a Transmission Control Protocol (TCP) connection. This furthermore allowed the institutions involved in the Cultural Heritage management to have a direct and real-time supervision of the archaeological fieldwork in progress.

In the frame of the Batinah Expressway project the team proposed a management information system to facilitate the preservation and the valorization of the Cultural Heritage of the Sultanate of Oman.

The information management system here presented is divided into two modules:

- WebGIS;
- GIS.

[22] Mandolesi, Cocca 2013.

The WebGIS module is the management tool that allows 4 levels of secure access via login:

- The mapping and thematic view of the Oman territory;
- The positioning of archaeological sites (extra site level);
- The positioning of each site excavated (intra site level) with relative performance of work art status;
- Search and query features;
- Print pdf in various scales with custom templates;
- Download data in shapefile format.

The PyArchInit GIS module is the tool that the archaeological operator can use to enter alphanumeric and geometric data of the archaeological sites. This tool offers an information standard with two purposes: on one hand, it will give the Ministry of Cultural Heritage a chance to monitor in real-time the archaeological work in progress and, on the other hand, to standardize the data recorded on site. The QGIS excavation projects will be made available daily and upgraded directly into the server.

(E. C.)

6. Conclusions

The Omani extreme environmental conditions required accuracy and rapidity on the field on behalf of the teams of professional archaeologists. The photogrammetric workflow presented in this paper seemed to fit the needs of the project and the hardware available on field, allowing to investigate and document all of the tombs destroyed by the construction of the Batinah Express Highway.

Although during the fieldwork was not possible to apply this method to survey special finds, recent papers have shown the ductility of SfM photogrammetry for either micro-contexts and for individual objects documentation. In fact, more than just the many improvements made by the team from the first to the last emergency excavation campaign in Oman, there are many aspects that could be further implemented and developed, such as the 3D digital reproduction of special finds for documentation and analysis purposes.[23]

PPT GUI is just one of the many open source solutions for 3D digital photogrammetry, and compared to the more powerful – yet very expensive and not entirely customizable – proprietary software such as RealityCapture or Photoscan is undoubtedly slower but not less precise. In fact, even if the first part of the 3D modeling process in PPT GUI is computationally slow, the 3D dense cloud produced by the software is accurate and can be managed by any program for processing and editing 3D models such as Meshlab.

After all, the methodology chosen to record the excavation processes proved to be effective and to run well along with the stratigraphic method used by the archaeology team also helping the anthropology team in their work.

None of the tombs investigated in the campaigns was found intact at the beginning of the investigations, thus complicating the understanding the original shape of the structures and the distinction between natural collapses and looting holes. Grave 21 in the graveyard of Falaji as Souq is a dome shaped tumulus tomb with a heap of collapsed stones covering the funerary recess and thus making it scarcely perceptible. This tomb can be used as exemplification of the hermeneutical value of this methodology, since it has been digitally recorded in its three dimensionality in many different instants of the excavation and let the archaeologists hypothesizing the construction technique and phases.

In order to record all the stones from the outermost collapse to the internal first course of stones the team opted for a dedicated survey strategy which involved a 3D survey for each level removed. The archaeologists recognized seven different construction steps, all of them recorded in 3D (fig. 7).

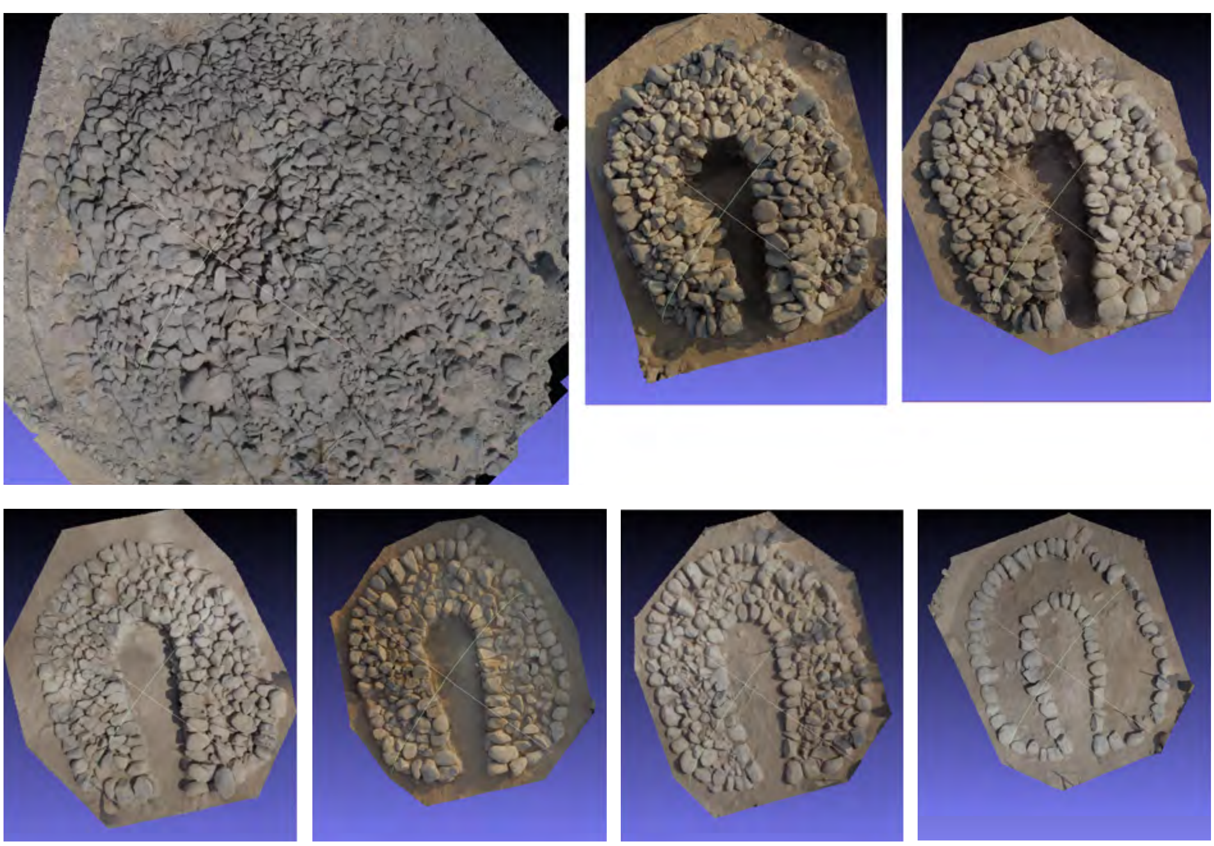
Thanks to the accuracy of the 3D digital photogrammetric acquisition the team was able to hypothesize all the construction phases of the tomb (fig. 8), and also its original aspect (fig. 9).

[23] See for example Molloy, Milić 2018 or also Megale, Baione 2017 for the 3D digitization of artefacts.

Digital photogrammetry and ETS together proved to be useful to read Stratigraphic Units and to interpret the archaeological remains. Freezing different frames of the same scene in a digital environment as done for the Grave 21 in Falaji as Souq helped the team to analyze the masonry and the construction phases, and to transform the workflow from an accurate time-saving technique to a precise interpreting tool.

(C. P., C. B., E. C., S. L.)

Figure. 7
Grave 21 "reverse building"



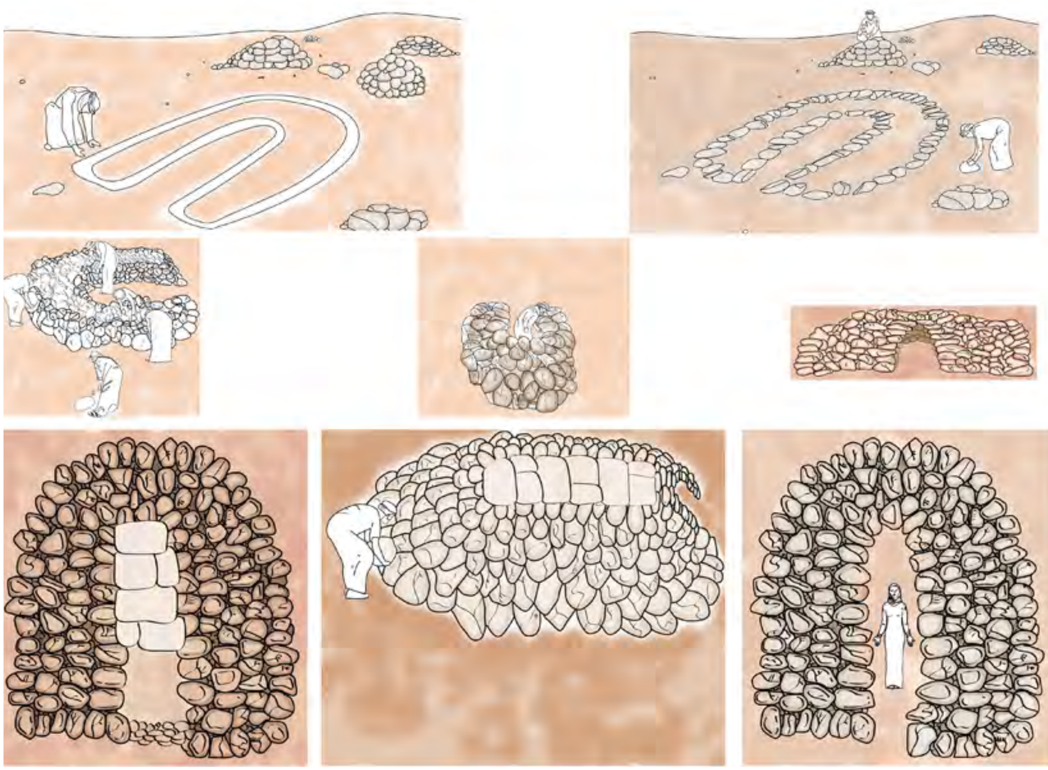
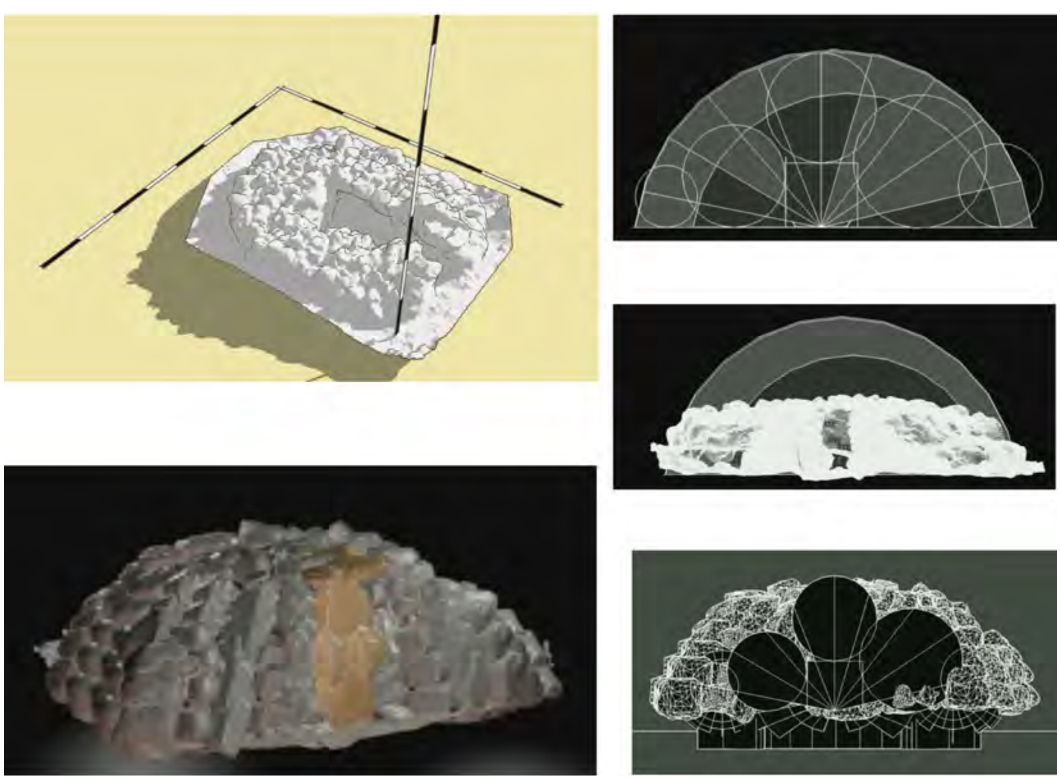


Figure 8
Hypothetical building and use of the grave
(drawings by Claudia Tomaselli)

Figure 9
Hypothetical aspect of the Grave 21
(3D model by Vittorio Lauro)



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