

UNIVERSITÀ DI NAPOLI L'ORIENTALE
Dipartimento Asia, Africa e Mediterraneo



Studi Africanistici
Serie Egittologica 6

Ancient Egypt New Technology

Edited by
Stefania Mainieri & Rosanna Pirelli



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On the cover: digital reproduction of the south wall
of the King's Chamber in the temple of Ramesses III at Medinet Habu, Luxor.
Image from the article in this volume, *The King's Chamber: A Digital Publication Prototype*,
by A. Singer, O. Murray, and A. Pantos.
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UNIVERSITÀ DI NAPOLI L'ORIENTALE
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6

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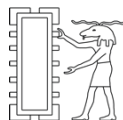


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Preface

In recent years, the world of Egyptology has opened its doors to new technologies, giving rise to fruitful collaborations between specialists in the humanities and digital technologies and propelling the Ancient World into the future. Laser scanning, photogrammetry and 3D modelling allow archaeologists to document the entire excavation process and reconstruct contexts even after they have been physically removed, reproduce small objects with sub-millimetre precision and reassemble ancient papyri or fragments of statues scattered across different museums. At the same time, non-invasive imaging diagnostics, X-rays and CT scans enable us to peek inside a sealed vase, analyse the chemical composition of ancient pigments and virtually unwrap mummies. These are just a few of the advantages that new technologies offer in helping humanists to reconstruct history, preserve the past and disseminate it beyond the confines of museums, universities and research centres. Looking towards these new research horizons, the Conference *Ancient Egypt - New Technology* aims to enable the growing community of Humanists and Digital Technologists to meet, discuss and update each other on projects related to Egyptology.

Conceived in the United States from an idea by Rita Lucarelli (University of California, Berkeley), Joshua Roberson (University of Memphis) and Stephen Vinson (Indiana University, Bloomington), the conference was inaugurated in Bloomington in 2019 (29-31 March 2019), with the hope of being the first in a continuing series of international conferences on this globally 'hot topic'. That same year, the University of Naples 'L'Orientale' carried forward the initiative of its American colleagues by hosting the second edition in Italy, encouraged by Stefania Mainieri's participation in the inaugural conference in the United States. Her involvement, driven by a project on ancient Egyptian coffins and photogrammetry (which culminated in the award of a Marie Skłodowska-Curie Global Fellowship - Faces Revealed Project: 895130), served as a link between the institutions.

Interest in the intersection between humanities and digital technologies has deep roots at the University of Naples. The Department of Asia, Africa and the Mediterranean (DAAM), which houses Oriental Studies and Egyptology, is also home to the CISA (Interdepartmental Centre for Archaeological Services) research centre. Since 1992, CISA has provided support to archaeological activities and developed specific expertise in the field of IT methodologies and 3D surveying, growing in line with broader global developments in digital innovation. Furthermore, the importance of CISA and the continuing interest in the subject have recently led to the creation of an inter-university and interdepartmental initiative: the Digital Humanities and Technologies programme (LMDH). The programme, developed in collaboration with the Department of Science and Technology at the University of Naples Parthenope, integrates rigorous humanities training with cutting-edge computational methods, with the aim of cultivating a diverse set of interdisciplinary skills in line with ongoing social transformations. In these transformations, digital processes are increasingly shaping not only the economic and entrepreneurial landscape, but also the cultural and academic spheres. In this regard, therefore, DAAM UniOr is the ideal venue for this type of international event.

The event in Naples (5-7 July 2023) was attended by 35 speakers from various parts of the world, including scholars, researchers and specialists in Egyptology, as well as in

many other fields of research and disciplines related to Egyptology. The event proved to be a fruitful opportunity to present ongoing projects and establish contacts between physical and cultural anthropologists, conservators, archaeologists, cultural and digital heritage scientists, and museum curators, with a view to future collaborations. The event also provided an important educational opportunity, as demonstrated by the extensive involvement of students in the conference.

This volume, edited by Stefania Mainieri and Rosanna Pirelli, brings together a selection of the contributions presented during the three-day conference and offers a concise overview of the digital initiatives and innovative methodologies employed nowadays in the field of Egyptology. Alongside these the scientific committee also decided to include imaging techniques for restoration and anthropology, as well as forensic and radiological sciences. Whilst tools such as non-invasive diagnostic imaging, X-rays and CT scans are now well established and not 'new', they offer exemplars of the concept of fundamental and instrumental technologies in specific areas of research.

Stefania Mainieri & Rosanna Pirelli

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We would also like to thank Prof. Giancarlo Lacerenza and Dr. Mariano Cinque, Scientific and Technical Directors of UniOr Press, the official academic press of the University of Naples 'L'Orientale' for their support in bringing this publication to fruition. One of the editors' primary objectives was to publish within our University and to ensure that the volume be freely available, so, we are deeply grateful for their support to include the volume in the *Serie Egittologica*, a high-quality, peer-reviewed Egyptological series of DAAM-UniOr available in both traditional print and digital formats via the Open Journal System (OJS) and accessible on the SHARE Riviste portal.

Special thanks to the conference Scientific Committee and keynote speakers, whose contributions greatly enriched the conference: Prof. Andrea D'Andrea (DAAM, UniOr), Dr. Enrico Ferraris (Museo Egizio, Turin), Prof. Bernard Frischer (Indiana University, Bloomington), Prof. Gabriele Guidi (Indiana University, Bloomington), Dr. Stefania Mainieri (Museo Egizio, Turin/ University of California, Los Angeles), Prof. Patrizia Piacentini (University of Milan), Prof. Corinna Rossi (Politecnico di Milano) and Prof. Stephen Vinson (Indiana University, Bloomington). Moreover, we would like to express our deepest appreciation to the anonymous peer reviewers and the Scientific Committee of the *Serie Egittologica*, for their valuable insights and constructive feedback on a wide range of topics, all of which are united by the common theme of integrating new and emerging technologies into Egyptological research. We would also like to thank all the authors and contributors for their exceptional patience, collegiality and scholarly dedication throughout the editorial process.

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Stefania Mainieri & Rosanna Pirelli

List of Abbreviations

ACalc	<i>ArchCalc. Archeologia e Calcolatori</i>
Acta IMEKO	<i>Journal of International Measurement Confederation</i>
ADS	Archaeology Data Service
Aegyptiaca	<i>Aegyptiaca. Journal of the History of Reception of Ancient Egypt</i>
AeUll	<i>Ägypten und Levante. Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete</i>
AIOO	<i>Annali Sezione Orientale</i>
Am. J. Phys. Anthropol.	<i>American Journal of Physical Anthropology</i>
ANEM	Ancient Near East Monographs
ANVUR	Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca
ARKs	Archival Resource Keys
ASCBo	Archivio Strico Comune di Bologna
ASOR	<i>American Society of Overseas Research</i>
AWMC	Ancient World Mapping Center
BÄBA	Beitrage zur Ägyptischen Bauforschung und Altertumskunde
BCH	<i>Bulletin de Correspondance Hellénique</i>
BHA	<i>Bulletin of the History of Archaeology</i>
BHR	<i>Belgrade Historical Review</i>
BJR Case Reports	<i>The British Journal of Radiology Case Reports</i>
BMSAES	<i>British Museum Studies in Ancient Egypt and Sudan</i>
BSAA	<i>Bulletin Société Archéologique d'Alexandrie - Revue Archéologique</i>
CADMO	<i>Revista de História Antiga- Journal for Ancient History</i>
CCE	<i>Cahiers de la Céramique Égyptienne</i>
CdÉ	<i>Chronique d'Égypte</i>
CHI	Cultural Heritage Imaging
CIDOC	Conceptual Reference Model
CIPEG	ICOM International Committee for Egyptology
CHANE	Culture and History of the Ancient Near East
EDAL	<i>Egyptological Documents, Archives, Libraries</i>
ENiM	<i>Égypte Nilotique et Méditerranéenne</i>
Getty AAT	Art & Architecture Thesaurus
GHPE	Golden House Publications Egyptology
GM	<i>Göttinger Miszellen</i>
HÄB	Hildesheimer Ägyptologische Beiträge
HES	Harvard Egyptological Studies
Hieroglyphs	<i>Hieroglyphs. Studies in Ancient hieroglyphic writing</i>

HSO	Hieratic Studies Online
IBAES	Internet-Beiträge zur Ägyptologie und Sudanarchäologie
ICOM	International Council of Museums
IIF	International Image Interoperability Framework
<i>ImagAeg</i>	<i>Imago Aegypti. Intern. Magazin für ägyptol. und koptol. Kunstforschung, Bildtheorie und Kulturwissenschaft</i>
IMEKO	International Measurement Confederation
<i>IJNA</i>	<i>International Journal of Nautical Archaeology</i>
<i>J. Archaeol. Sci.</i>	<i>Journal of Archaeological Science</i>
<i>J. Med. Microbiol.</i>	<i>Journal of Medical Microbiology</i>
<i>J. Raman Spectrosc.</i>	<i>Journal of Raman Spectroscopy</i>
JAES	<i>Journal of African Earth Sciences</i>
JAS	<i>Journal of Archaeological Sciences</i>
JCH	<i>Journal of Cultural Heritage</i>
JCS	<i>Journal of Cuneiform Studies</i>
JEA	<i>Journal of Egyptian Archaeology</i>
JFA	<i>Journal of Field Archaeology</i>
JFS	<i>Journal of Forensic Sciences</i>
JGS	<i>Journal of the Geological Society</i>
JLM	<i>Journal of Language Modelling</i>
JMB	<i>Journal of Molecular Biology</i>
JMLR	<i>Journal of Machine Learning Research</i>
LÄ	<i>Lexikon der Ägyptologie,</i> <i>Rivista della Scuola di Specializzazione in Archeologia -Università degli Studi di Milano.</i>
LANX	
<i>LingAeg</i>	<i>Lingua Aegyptia</i>
LingAeg – StudMon	Lingua Aegyptia–Studia Monographica
LNCS	Lecture Notes in Computer Science
MÄS	Münchner Ägyptologische Studien
<i>Maarav</i>	<i>Maarav. A Journal for the Study of the Northwest Semitic Languages and Literatures</i>
MDAIK	<i>Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo</i>
MOA	Monografías de Oriente Antiguo
MTA	<i>Multimedia Tools and Applications</i>
NeHeT	<i>Revue Numérique d'Égyptologie</i>
OIP	Oriental Institute Publications
OLA	Orientalia Lovaniensia Analecta
ORACC	The Open Richly Annotated Cuneiform Corpus

ORE	<i>Open Research Europe</i>
PeAPA	<i>Publicación Electrónica de la Asociación Paleontológica Argentina</i>
PdÄ	<i>Probleme der Ägyptologie</i>
PES	<i>Prague Egyptological Studies,</i>
Ponda	<i>Predynastic online database</i>
RdÉ	<i>Revue d'Égyptologie</i>
RevEthnSoc	<i>Revue d'ethnographie et de sociologie</i>
RiME	<i>Rivista del Museo Egizio</i>
RISE	<i>Ricerche Italiane e Scavi in Egitto</i>
SAK	<i>Studien zur Altägyptischen Kultur</i>
SAKB	<i>Studien zur Altägyptischen Kultur Beihefte</i>
ScAnt	<i>Scienze dell'Antichità</i>
Sci Rep	<i>Scientific Reports</i>
SEAP	<i>Studi di Egittologia e Antichità Puniche</i>
SEP	<i>Studi di Egittologia e di Papirologia</i>
tDAR	<i>The Digital Archaeological Record</i>
TLA	<i>Thesaurus Linguae Aegyptiae</i>
VIAF	<i>Virtual International Authority File</i>
W3C	<i>World Wide Web Consortium</i>

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Underwater archaeology in Alexandria, Egypt: new methods for documentation through the use of three-dimensional technology

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Abstract

Photogrammetry, Reflectance Transformation Imaging (RTI), and Virtual Reality (VR) are new tools used for documentation in underwater archaeology in Alexandria, Egypt. In addition to being important aids for the conservation of our underwater heritage, they also play an important role in tourism and sustainable development. Underwater photogrammetry was applied for the first time in 2009 by CEAlex (Centre d'Études Alexandrines) on some submerged fragments of statues on the site of the Lighthouse of Alexandria near Qaitbay Fort. In 2013, thanks to the support of the Honor Frost Foundation, a project of 3D-data collection started with the objective of creating a Digital Surface Model (DSM) of the site by using photogrammetry. By 2023, nearly 70% of the 15,000 m² submerged site had been documented. Additionally, Reflectance Transformation Imaging (RTI) was used to apply virtual lighting to a 3D model of two statue bases still underwater, making legible some details on the heretofore invisible inscriptions. Finally, in 2016 a short video was created offering a virtual visit to the site to enhance education through immersive experiences in underwater archaeology. This gave us the idea of creating a simulation of a VR underwater environment to be explored by the public by using a headset worn directly over the eyes. In this paper, we explain the methods utilized and the difficulties encountered in creating the underwater archaeological surface model, combining photogrammetry and RTI to study the two statue bases, and creating a VR experience of the submerged site of the Lighthouse of Alexandria.

Keywords: *CEAlex; Lighthouse; Photogrammetry; VRTI; Virtual Reality.*

1. Introduction

The initial findings and the start of underwater scientific excavation were in the Mediterranean region close to Alexandria. Named after Alexander the Great and located on the coast once occupied by the city of Canopus, Alexandria was founded in 331 BC. on a site chosen because of its defensive and commercial potential. Serving as the capital of the Ptolemaic Dynasty ruling Egypt after Alexander's death, Alexandria became one of the largest cities in the eastern Mediterranean.¹ Its history continues to fascinate archaeologists the world over, undoubtedly because of mystery and myths attached to its name. We know from the ancient sources that the city was designed by the architect Dinocrates of Rhodes and its construction began in the early third century BC under Ptolemy I Soter (305-283 BC). It was completed by his son, Ptolemy II Philadelphus (283-246 BC), about fifteen years later.²

Since 1992, Alexandrian studies in archaeology have partly turned towards the Mediterranean. Coastal areas have become the preferred site for archaeological excavations because they offered virgin sites that had never been studied. Among the unique sites that came to light is the Lighthouse (Greek: Pharos) site near Qaitbay fort. For several centuries, the underwater remains had been noticed beneath the surface

¹ Elsayed 2012, 74-95.

² Hairy 2020.

when the sea was perfectly calm, as is attested in the writings of Benoît de Maillet (AD 1656-1738) as early as 1692-1708, when he served as consul general of France in Egypt. The submerged site extends from the foot of the Qaitbay fort, which Sultan Al Ashraf Seif el Dine Qaitbay had constructed in AD 1477 at the eastern extremity of the ancient island of Pharos. In time, the island became a peninsula when sandy soil accumulated on either side of the Heptastadion and the tombolo which extended between the island and the continent.³ Subsidence is the cause of the disappearance of the islet of Pharos which rose at least 2m above sea level 23 centuries ago when the lighthouse was built there.⁴ Today it is submerged 5m below sea level, as are the coastal constructions of the ancient city. However, the submerged ruins that we study today were only revealed to the scientific community in 1960, through the prospecting work of the Alexandrian amateur archaeologist, Kamel Abul Saadat. In 1962, the Egyptian Navy proceeded to lift several pieces of statuary, including a granite female colossal statue representing a queen in the guise of Isis. Later on, in 1968, Honor Frost⁵ undertook a UNESCO mission on the site which led to the publication of a preliminary report⁶ revealing the importance of the site.⁷

In this paper we present the advances in underwater photogrammetric documentation applied from 2014 until 2023 based on practical experience in using low-cost equipment. Our initial goal was to obtain a three-dimensional georeferenced Digital Surface Model (DSM) for the vast submerged site of the lighthouse of Alexandria, which exceeds 15,000 m². Secondly, using RTI (Reflection Transformation Imaging) we studied two statue bases, which were discovered underwater and still are located there. Our goal was to make legible some inscriptions which cannot be seen underwater. Finally, we created virtual visits to the site both in the medium of a movie and also as a VR experience.

2. CEAlex (Center d'Etudes Alexandrines): 25 years of underwater excavations and surveying techniques on the submerged site of the Lighthouse of Alexandria near Qaitby fort

The submerged site of the Lighthouse was rediscovered in 1994 and studied for the first time by CEAlex (*Centre d'Études Alexandrines*, USR3134) under the direction of Jean-Yves Empereur.⁸ Since then he has conducted one to two campaigns per year⁹ and has produced evidence confirming the ancient historical written and graphic sources describing the Lighthouse as one of the Seven Wonders of the Ancient World.¹⁰ The project

³ Hairy 2003, 20.

⁴ Hairy 2009, 113-122.

⁵ Honor Frost was a pioneer British underwater archaeologist known for her underwater excavations in Lebanon. In 1968, the Egyptian government, via UNESCO, invited her to examine the site believed correspond to the Pharos lighthouse. Frost and Abu El-Saadat examined it and gave a list of 17 different items located there. See Khalil and Mustafa 2002, 520.

⁶ Frost 1975, 126-130.

⁷ Empereur 2000, 54.

⁸ The *Centre d'Études Alexandrines* (CEAlex) was founded in 1989 in Alexandria, Egypt by Jean-Yves Empereur, Director of Research at the CNRS. In collaboration with the Supreme Council of Egyptian Antiquities (CSAE), the CEAlex's main mission is the conservation and study of the heritage of Alexandria, the Ptolemaic capital (EMPEREUR 1998). In January 1999, the Center became a Mixed Service Unit (UMS 1812) of the CNRS. In June 2007, it became a Service and Research Unit (USR 3134). This new status allows the center to accommodate researchers within the laboratory for more or less long periods (Elsayed 2012, 82).

⁹ <https://www.cealex.org/research/current-operations/the-pharos/>

¹⁰ Hairy, I, 2020.

led to a reconstruction of certain parts of the Lighthouse and to an understanding of its design process. The extent and unique nature of this sunken site encouraged innovation in data collection, both as regards the ancient material of more than 3,525 stone blocks as well as the overall site itself, whose size and uneven contours make any analysis difficult.¹¹ To document the submerged archaeological site and objects, CEAlex first used 2D methods standard when the project started in 1994.¹² Then, in 2009, the team switched to using photogrammetry. By 2014 the team had developed a 3D model both of the surface of the submerged site and also of many archaeological objects, whether on land or underwater.¹³

2.1. Underwater surveying techniques from 1995 to 2013

The traditional method of documentation that was used in the project's first phase depended on the condition of the sea. Classic triangulation at the bottom was used during rough seas. In calm weather, a GPS onboard a Zodiac was also used for the topography of the site.¹⁴ Direct survey or direct topography using an electronic theodolite on shore was used to take the measurements. On the surface of the water, a buoy was placed fitted with a reflective prism¹⁵ and attached to an underwater adjustable cord bearing a 35-kilo weight with a pointer. This last method is particularly effective at the Qaitbay site because of its shallow depth, between 2.5m and 9m, and because of its proximity to the shore.¹⁶ However, there is a major disadvantage: it can be used only in very good weather, without any swell moving the buoy on the surface, and without currents that displace the buoy from a position directly above its anchoring point on the seabed. Although the method has been abandoned to plot the position of the ancient blocks, it has nevertheless been retained to orient the site by reference points within the general coordinate system of mainland Alexandria. CEAlex integrated the map of the underwater site with the general topography of the city resulting in the center's Alexandria GIS.

In 1998, another method optimized the time needed for underwater survey: an orthogonal grid system mounted on adjustable feet and set up on the site using a metal frame of 6m x 6m, divided into 1m squares and, covering a large area with a very high concentration of archaeological material. However, the approach could not be used on underwater surfaces exceeding 1 m in height.

In 2001, a more modern method was used to optimize the topographical work: the Aquameter D1007, an underwater acoustic survey device that works on the principle of sound transmissions that can record the precise location, in three dimensions, of submerged objects. Through the measurement of angles and distances or topography, measurements can be taken within a radius of 100m of the base. The method does have one major disadvantage: it is necessary that there be no noise interference (e.g., from the surf, divers in the proximity of the base, boat engines, etc.) between the pointer and the base, otherwise abnormal

¹¹ Hairy 2009, 113-132.

¹² Hairy 2003, 19-23.

¹³ Abdelaziz, Elsayed 2023, 33-57.

¹⁴ Empereur 1997, 831.

¹⁵ Used for long distance measuring, less than 500 meters.

¹⁶ The same method was used to plot the GCP (Ground Control Point) on DSM (Digital Surface Model) starting in 2014, but the system of the buoy was changed: instead of four small elongated buoys attached together, we used a round buoy to be more stable on the surface of water when plotting the GCP. See Abdelaziz, Elsayed 2019.

measurements will be recorded, since the method depends on the propagation of sound in the water. The creation of the site map was combined with the inventory of the mapped items. Each stone block was documented, described in minute detail, drawn, and photographed. The data were recorded in two databases: the cartography in the GIS developed in MapInfo, and the inventory of finds, including descriptive forms and multimedia data, developed in FileMaker Pro. The databases serve in various ways for the study of the site and to rank the items to be studied in terms of their importance. Site management using GIS makes it possible to locate objects underwater with great precision.¹⁷

2.2. Underwater photogrammetry and the creation of 3D-Digital Surface Model

The traditional methods utilized in the early years by CEAlex are effective enough to be used in such aquatic environment, but they are not very precise, and, with the exception of photography, they are time-consuming and error-prone. So, photogrammetry was quickly adopted owing to the quality of the results, the ease of its application, and its low cost. This project began as part of the ANR-SeARCH program between 2009 and 2012 which focused on creating digital twins of some statuary. From 2013 to 2016 the work was supported by the Honor Frost Foundation after the end of the ANR SeARCH programme. The main goals were: (1) the creation of 3D Digital Surface Model (DSM) of the submerged site of the lighthouse through automatic digital photogrammetry and image correlation; and (2) the 3D acquisition and processing of the statuary and architectural blocks of the site. Our goal was to be in a position to undertake virtual anastylosis and reconstructions of the monuments.

Many methods were developed and refined during the seasons of work in the site until 2023. Until 2016, photographic data was using a DSLR camera. From 2018 until 2023 DX-Mirrorless cameras were utilized — a simple and low-cost way to obtain a DSM. The underwater site of the Lighthouse of Alexandria lies in the open sea to the east of Qaitbay Fort. It is affected by natural forces of waves and currents as well as by sewage discharge, all of which change the water quality. In addition, the prevailing wind is N-NW, which is variable from December to May.¹⁸ The poor sea conditions and poor visibility, rarely exceeding 3m because of the particles in the water and sewage, obliged us to develop expertise in site documentation by photogrammetry.¹⁹ The procedures to create a 3D model in general consist of two steps: data acquisition and image processing.

The data are acquired via photographic coverage of the site. This is carried out by means of “flight plans”, which simulate the classic pattern of aerial shots with the difference that our vertical shots are not taken on a vertical axis but at an angle of 45°. This allows us to capture the side faces of the blocks of granite, also with longitudinal and lateral overlaps on the order of 70% to 80%, which is superior to conventional aerial photography; this overlap rate reduces mistaken pairing by increasing the number of combined photos when matching images during the processing operation. To do that, the operating diver moves at a distance not exceeding 2.8m from the surface to be photographed and swimming in a straight line as possible while regularly taking photos

¹⁷ Hairy 2020.

¹⁸ El-Gindy 2000, 144.

¹⁹ Abdelaziz, Elsayed 2019, 2.

at a constant speed.²⁰ At the end of the line, the photographer must make a half turn ensuring lateral overlap with the first line also by 70% to 80%. He orients himself visually by checking his trajectory against the features of the seabed with its many ancient blocks and uneven surface, helped by the meter sticks placed on the sea floor, and respecting the boundaries of the area to be covered, which are clearly marked by measuring tapes and buoys. The major difficulty encountered in the landscape of the underwater site lies in the significant variation in the altitudes of the seabed. In some areas, there is a shift from -8 m to -4 m moving northwards and from -9 m to -5 m while swimming to the southeast. The shots were taken in optimum weather conditions: little or no swell, sunny weather, sometimes overcast, but always with sufficient brightness. Too much sunlight can create a glare that negatively influences image matching and the quality of photogrammetric processing. Depending on the sea conditions and the relative visibility, the camera's settings are either f/7.6 or f/8 and shutter speed between 1/60 or 1/80, or f/5.6 with a shutter speed of 1/40. By the end of 2023, almost 135,000 photos covering more than 70% of the submerged site had been taken. Once processed with photogrammetric software, they have led to the hoped-for result of high-quality DEMs- Digital Elevation Model of the surface.

This brings us to the processing of the photographic data, which we divide into two steps.²¹ The first is the pre-processing of the photographs using Adobe Lightroom and Adobe Photoshop. The goal is to restore the color, contrast, and light of the photos in RAW format or, if they were not shot in this format, then in JPG.²² This is necessary because most of photos start out blurry and dark with a blue-green cast because of the underwater lighting conditions. Hence, a correction is required to increase the contrast, reduce the overexposure, and lighten the dark areas on photos which are underexposed. This step is undertaken not so much for the purpose of producing photographs that are pleasing to the eye, but in order to increase the number of matching points between pairs of images, something that is critical to obtaining good photogrammetric results.²³

The second step is the processing of the corrected photos using the photogrammetry software package Metashape PE 1.16.2038.²⁴ The goal is to produce an accurate 3D model from the photographs, which occurs in four steps: (1) the photographs are aligned, (2) a dense point cloud is built, (3) from the point cloud a mesh is created, and (4) the mesh is textured. The result is an orthographic, photorealistic 3D model of the object of interest, in our case, the underwater remains of the Lighthouse. We begin by entering the uncalibrated overlapping images into Metashape, which then detects and tracks matching points from one photograph to the next by using a powerful mathematical algorithm. All the while the photographs'

²⁰ Mohamed Elsayed is the underwater archaeologist responsible for the excavation' diving operations. He manages and executed the flight plan and photogrammetric coverage of the underwater site and took the thousands of photos shot during the project of creation the DSM-Digital Surface Model.

²¹ Since 2013, Mohamed Abdelaziz, archaeologist and associated researcher - CEAlex, has managed all the data processing. Using various computers over the years with different configurations, he created the project's 3D Digital Surface Model.

²² For photogrammetric processing of photographs, it is necessary to convert the RAW images to JPG format. In rare instances, photographs shot for the project were taken in JPG format. For the first step in postprocessing, RAW format is preferred.

²³ Abdelaziz, Elsayed 2023, 44.

²⁴ Metashape software is published by Agisoft LLC.

parameters are automatically calibrated by the software if they have not been previously calibrated in the camera. This includes main distances (f_x , f_y), position of the main points (c_x , c_y), and the oblique, radial, and tangential coefficients of distortion (k_1 , k_2 , k_3 , k_4 , p_1 , p_2).

Between 2014 and 2023 a massive number of photos (ca. 135,000) were taken to generate the final 3D model/orthophoto covering more than 11,000 m² of the submerged site of Qaitbay. The Ground Sample Distance (GSD), varies according to the different levels of the diver while capturing photos, and it differs also between each dive. However, the approximate GSD value across all missions is ± 0.25 cm to ± 1 cm (Fig. 1).

Thousands of images were processed during every mission using a unique processing method in Metashape, with different characteristics of computers or laptops used in the process because there is no device that could handle all the photographs at once. The best solution was to process the photographs day by day to have a chunk of the site model for each day. So, to date we have produced a total of almost 65 chunks of the site representing the different daily captures on the underwater site during the various campaigns dating from 2014 until 2023. Between each chunk there is an overlap of 25%, which helps us to merge the processed areas with one another using Metashape's manually-positioned digital marker features on each of the paired chunks. After the first two chunks have been merged, the third chunk is paired, then the fourth, and so on, until all the chunks have been combined into a perfectly aligned 3D model of the portion of the site which the diver has photographed to date.²⁵

In the following tables we can see a summary of equipment and the numbers of photos used from 2014 until 2023 to create the 3D model of the site:

Table 1: Cameras, 2014-2023

2014-2016: Nikon D 700, lens 24mm DSLR-fx, housing Ikelite SLR- DC
 2018-2020: Panasonic LUMIX DMC-GH4 4K mirrorless Micro Four Third Digital Camera, lens 12-28mm, housing Ikelite
 2023: Sony A7III, lenses 16-35mm, housing Nauticam NA-7III

Table 2: Number of photographs used in the model, 2014 to 2023

2014: 21,976
 2015: 23,746
 2016: 4,430
 2019: 32,713
 2020: 20,413
 2023: 31,904
 Total: 135,182

Table 3: Computers

2014-2015: RAM 16 Gb, GPU Nvidia GT630, 2G, CPU-Intel core I3
 2015-2018: Alienware Area Tower, RAM 32 Gb, GPU Nvidia GTX 1080, CPU Intel i7; and Mac Pro 6, RAM 64 GB, AMD graphics card, 32-core Xeon processor
 2019-2020: Alienware Area 51 R2 Laptop, RAM 64 Gb, GPU Nvidia RTX 2080, CPU Intel i9 10th Generation
 2023: Custom-built workstation, RAM 128 Gb, GPU Nvidia RTX 4090, CPU Intel i9 13th Generation

²⁵ Abdelaziz, Elsayed 2019, 5.

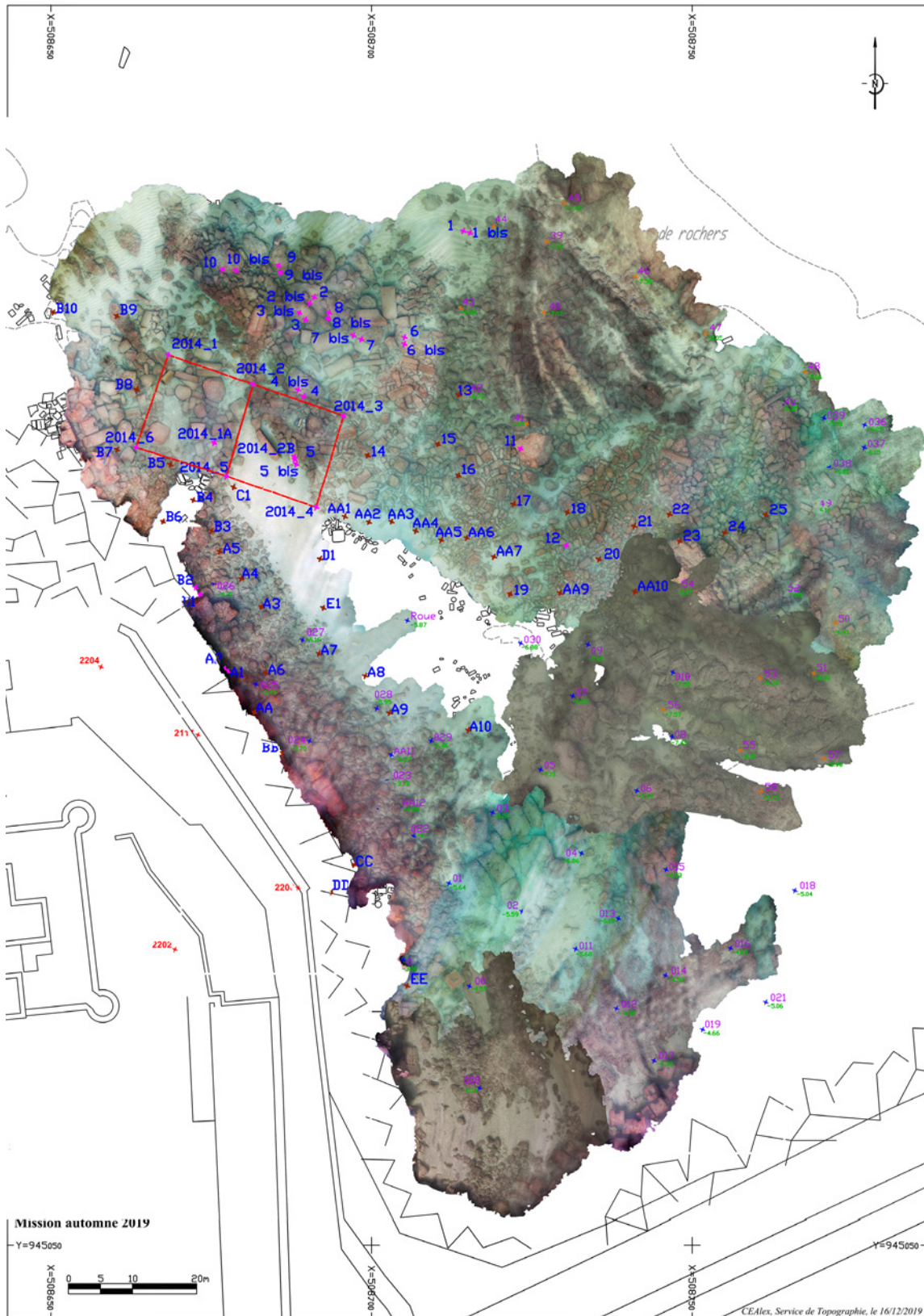


Fig. 1: Orthophoto (135,000 images) of 11,000 m2 from 2014 until 2023 the approximate GSD value is ± 0.25 cm to ± 1 cm. Photography by M. Elsayed, processed by M. Abdelaziz.

3. The Virtual Reflectance Transformation Imaging (VRTI) applied to two 3D models of red granite statue bases still underwater

Reflectance Transformation Imaging (RTI) is a significant technique in the field of archaeological recording. It involves capturing sets of photographs of a scene from the same viewpoint or a stationary camera position with variations in the angle of light incidence creating multiple digital photographs.²⁶ The result is displayed in a 2D interface known as an RTI viewer, which allows users to interact with the scene by manipulating a virtual directional light source and observing real-time changes in lighting. The Virtual Reflectance Transformation Imaging (VRTI) proposed here is an alternative to the normal RTI method. VRTI combines reflectance transformation techniques with photogrammetry and noncontact digitization. It uses animated virtual domes, leading to a sequence of renderings of the 3D model, processed using the same methods as normal RTI. Virtual RTI provides an advanced level of interaction with the 3D model and enhanced visualization of the surface topography, applying the “virtual” lighting to 3D model objects, using multiple images of fixed view-points and varying lighting conditions. These two techniques allow virtual automated reconstruction of highly detailed 3D texture-mapped models showing all visible or invisible details of the object using some specific filter and altering the light in RTI after stripping any color and texture information from it.

The VRTI processing was applied to two 3D models of red granite statue bases still present underwater. One base has an inscription that could already be read once photographed under the water. It was not certain if the other was also inscribed. The goal of using VRTI was to enhance the legibility of the first inscription and to determine whether the second is also inscribed. It may be noted that RTI was impossible to apply underwater to either inscription. So, by making a digital twin of the inscription using photogrammetry, we could apply VRTI in the lab as opposed to RTI underwater. We proceeded by making a very high-resolution 3D model of each to which VRTI could be applied by using multiple images of fixed viewpoints with varying lighting conditions. These two case studies were selected to assess the suitability of the VRTI method.

3.1. Block no. 2422 (Fig. 2)

Dimensions: H= 132,67 cm; L=68,9 cm top/71 cm bottom; inscribed surface: L=61 cm top/66 cm bottom - 1,3 tons.

This base made of red granite was discovered underwater at a depth of 4.8 m by the archaeologist Mourad el-Amouri, who could distinguish that there was an inscription on one of its sides, but the letters incised on the granite were very difficult to read underwater. The Egyptian authorities granted permission to CEAlex to make a cast or a copy of the inscription by using a latex.²⁷ One or two lines are missing at the beginning. Seven inscribed lines are preserved. The height of the letters is 1.5/1.7 cm with line spacing of 1.0-1.4 cm. Reading is made difficult by the erosion of the surface of the stone.²⁸

²⁶ Malzbender *et al.* 2001.

²⁷ Empereur 2021.

²⁸ Empereur 2021.



Fig. 2: Block 2422. Left: photograph in situ; center: photogrammetric 3D model; right: 3D model enhanced by VRTI, 101 spot lights surround the object.

3.2. Block no. 2385 (Fig. 3)

Dimensions: H = 125 cm; L = 69 cm; 72 cm bottom; inscribed area: l = 68.7 cm.



Fig. 3: Block 2385. Left: photograph in situ; center: photogrammetric 3D model; right: 3D model enhanced by VRTI, 101 spot lights surround the object.

The second inscribed red granite base presented here was discovered in 2019. After underwater cleaning, no inscription was detected by the divers. However, the 3D photogrammetric model did reveal the presence of an inscription to the photographer Philippe Soubias and architect Isabelle Hairy. Then, VRTI processing was needed to enhance the appearance of the inscription and the letters, but the text remained difficult to interpret.²⁹

²⁹ Empereur 2021.

The base was found at a depth of 7 m on the underwater site of Qaitbay. One or two lines are missing at the beginning. Six inscribed lines are preserved. The height of the letters is 1.5-1.7 cm and the line spacing is 1.0-1.4 cm. Reading was difficult because of the erosion of the stone, especially at the left and right ends.

The inscription dates to the time of Constantine and Licinius near the beginning of the 4th century CE.

3.3. Workflow

After the creation of a detailed and accurate 3D model by using photogrammetry underwater for the two bases (Fig. 2, center), both had to be imported into a common 3D modeling program like Autodesk 3DS Max or Blender.³⁰ The goal was to simulate a virtual camera mode to capture snapshots from the 3D model as if they were taken in authentic settings and in a real situation. These simulations also enabled the placement of virtual light sources, allowing accurate interactions with the geometry and physical properties assigned to virtual objects in creating a real-world scenario. This combination of features enabled the simulation of the RTI techniques in a virtual mode, so this process is called VRTI-Virtual Reflectance Transformation Imaging, offers several advantages: first, there are no limitations on the size of the object or scene since there is no need to construct a physical arrangement of cameras and lights in virtual worlds. Secondly, light in a virtual environment is fully controlled, so we can eliminate external light sources that could impact the estimation of light source positions. In addition, virtual snapshots are free from noise and artifacts, and they always maintain perfect sharpness.

3.4. Processing pipeline

After creating a high-resolution photogrammetric model for the two bases, each one is imported into 3ds Max 2024 software. They are set into the 0x, 0y, 0z position, and then through two scripts a fully virtual dome light is automatically integrated with a camera. To capture highlights, a black sphere is added to the scene in the same way that is used in non-virtual cases. This approach can lead to conclusions about the optimal distribution of light and how best to rescale the 3D model to be inside the dome light, then 101 spot lights surround the object taken the shape of hemi sphere (dome), each spot light has the X, Y and Z positions like the following example:

1. the first script is used to integrate the dome lights and the camera (Fig. 4) as follow:

```
function GDLight unaposition = (l1=omnilight() l1.position=unaposition)
    caml=freecamera()
    caml.position = [0,0,12]
    GDLight[4.330127,7.5000000,5.000000]
    GDLight [7.500000,4.3301270,5.000000]
    GDLight [8.660254,0.000000,5.000000]
```

³⁰ Earl *et al.* 2010.

2. the second script includes information about when each spotlight is turning ON or OFF, and it saves the file in the chosen destination, as shown in the following example:

```
$omni001.enabled=on
r=render camera:$camera001 outputwidth:3200 outputheight:2400
r.filename="C:\Users\...\Desktop\RTI_Render\img001.jpg"
save r
$omni001.enabled=off
$omni002.enabled=on
r=render camera:$camera001 outputwidth:3200 outputheight:2400
r.filename="C:\Users\...\Desktop\RTI_Render\img002.jpg"
saver
```

The second script is designed to render each image and to adjust the resolution and format of the final image. After running the scripts for several minutes, the rendered images are created. To be processed, they must be imported inside RTIBuilder. The final results can be displayed by using RTIViewer.

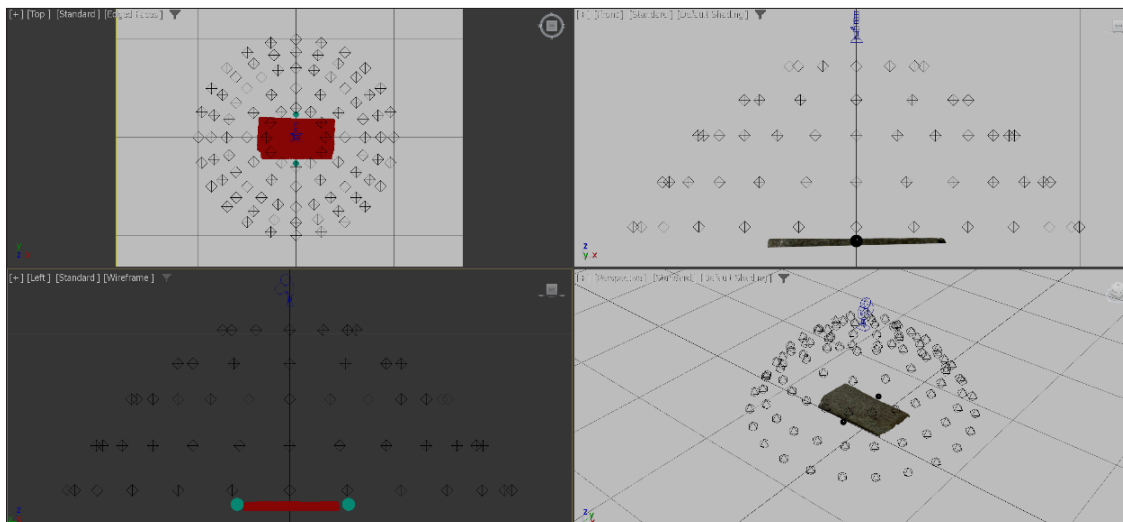


Fig. 4: Graph showing the distribution of the virtual dome lights and cameras.

4. Virtual Reality and the creation of an underwater visit to the submerged archaeological site of the Lighthouse near Qaitbay fort.

Virtual Reality (VR) is a valuable tool in archaeology, offering immersive and interactive experiences in order to support research, education, preservation and the virtual reconstruction of ancient sites and objects of cultural heritage.³¹

In 2015 we considered ways that we might use to exhibit the underwater site to the public. We determined that there were three possible approaches. The first was to create a virtual animation video simulating the underwater site based on the photogrammetric data. The visibility of the remains could be improved by digitally manipulating the lighting so that they could be seen with greater clarity than is possible for divers in situ. The second

³¹ Ch'ng *et al.* 2005.

approach was the creation of a Virtual Reality experience using the 3D site model. The third option was the creation of an Augmented Reality model making it possible for visitors to the fort to visualize it on a smartphone or on tablets using a QR code.

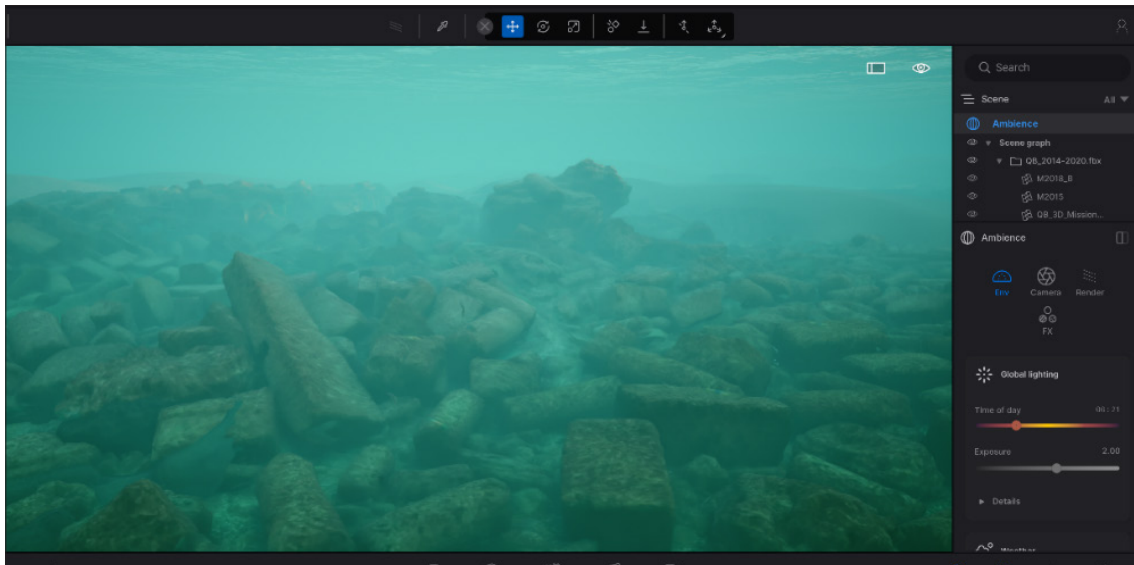


Fig. 5: Screenshot of Twinmotion workspace as it creates a VR experience of the site based on the project's 3D photogrammetric model.

Given various practical considerations, in 2015 we decided to adopt the first option. The result is a 4:38 minute video presenting the site, which took one month of nonstop rendering to produce. It is available on Youtube and also is embedded on the CEALex project website.³² More recently, we experimented with making a video animation using Unreal Engine 5. To generate an equivalent length of video from the model took only a few minutes using this tool, which is clearly very promising. In the same year, the second option of creating an immersive VR experience of the site became practicable thanks to the software package Twinmotion (Fig. 5). This is a powerful visualization tool published by Epic that helps designers to create stunning immersive 3D experiences quickly and at little expense.

So, as we write, the only unimplemented option remaining is the third: creation of an AR app for visitors to the actual site in Alexandria. We plan to fill this gap in the future.

5. Conclusion

Underwater photogrammetry in the documentation of the submerged sites in Alexandria was an interesting tool to study and manage the changes of the site features, as we documented a big part of the submerged site of the Lighthouse of Alexandria for the first time in Egypt we could cover more than 11000 m² about 70% of the surface of the site which exceed more than 15000 m², using a photogrammetric techniques application for submerged archaeological site with low cost materials for data acquisition and data

³² To see the video animation on the web site of CEALex: <https://www.cealex.org/recherches/operations-en-cours/phare>

processing for such documentation of a huge site, allowed to create a 3D Georeferenced DSM-Digital Surface Model which revealed a preliminary good and high efficiency result. Once the model is completed, it will offer the possibility of performing lengthwise and transverse profiles, of creating with complementary data a DTM digital terrain model of the site, and it already allows the production of orthophoto plans with a pixel size, which must unfortunately be adapted to the power of our computers, but which, in absolute terms, can reach a pixel resolution equaling between ± 0.25 cm to ± 1 cm on the ground.

As the site of Qaitbey is not always accessible for the non-divers public, and the conditions of the sea and visibility underwater is not stable, so we get the idea to create a virtual diving tour animated from the model of finished area of 7200m² in 2016, but it must be developed in the future, so after finishing the entire model of site we will create a complete video animation from the 3D model and develop a virtual tour. In this virtual space, we can achieve greater depth and quality than what is possible in reality offers a new tool to manipulate the underwater environment according to our preferences or to better suit the audience's needs.

Finally, underwater V-RTI, which merges photogrammetry with RTI, introduces a new approach for enhancing invisible inscriptions or those that are difficult to read due to various underwater conditions. While traditional RTI can be challenging and time-consuming to apply underwater, it is limited by the camera frame. In contrary, V-RTI offers unlimited control over object scale, as it is derived from a photogrammetric model. However, it is essential to ensure that the quality of the photogrammetric model meets the necessary criteria.

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Online Resources

CEAlex	https://www.cealex.org/research/current-operations/the-pharos/ https://www.cealex.org/recherches/operations-en-cours/phare https://www.youtube.com/watch?v=AemGVUYiDBI&t=277s
Agisoft Metashape	https://www.agisoft.com/downloads/installer/
Meshlab	http://www.meshlab.net/
RTI	https://culturalheritageimaging.org/Technologies/RTI/ https://www.digital-epigraphy.com/tutorials/physically-based-rendering-pbr-of-egyptian-collection-at-brooklyn-museum-new-methods-for-photorealistic-rendering-of-virtual-objects
Virtual reality	https://www.unrealengine.com/fr/unreal-engine-5 https://www.twinmotion.com/en-US/news/twinmotion-2023-1-is-here https://www.sentiovr.com/post/how-to-transform-twinmotion-designs-into-vr-experiences-using-sentio-vr

A digital archive for religious texts from the Nile Valley and beyond

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Abstract

Within the project ITSEERR, granted by Recovery Plan, the WP 10 ReTINA aims to create an environment that defines and optimizes guidelines for the digitization of a diverse range of sources, considering the challenges posed by very different languages and types of scriptural media. The dataset includes religious texts from sites in the ancient world of the Nile Valley and beyond. The contents of these texts are very diverse and varied: descriptions of religious ceremonies, funerary texts, prayers, incantations, lists of offerings and temple personnel. So far, several attempts have been made to achieve automatic textual analysis from digitized religious texts. However, three main problems still hinder this task: firstly, the lack of sufficient material, which results in small data sets, mostly related to a single site; secondly, the variety of languages and writing forms; and finally, the lack of dedicated methods, intentionally developed to analyze and process such ancient religious texts.

This paper intends to bridge the gap between the state of the art of linguistic text analysis on the one hand and image processing applied to historical texts on the other, starting from a review of AI and metadata projects in the field of Egyptian language text analysis. The paper aims to: a) study the datasets, methods and tools that enable the restoration of missing text fragments from scanned images of religious texts from the Nile Valley, including funerary inscriptions on tombs and other types of related materials such as papyri, parchments, wood, etc.; b) apply image processing and linguistic analysis to obtain transcription and possibly analysis and restoration of other religious manuscripts, covering a wide range of languages. The survey intends to provide a comprehensive review of the state of the art of this research topic, including three main aspects, which will be the focus of attention during the implementation of the project: i) datasets, including digitized images and manuscripts, ii) open data repositories, with associated metadata standards, taxonomies and thesauri, iii) the state of the art projects that has already been realized, either for Egyptological or other archaeological data annotation and 3D visualization and iv) artificial intelligence methods and tools, mainly for image processing and linguistic analysis, commonly used for this type of problems. Finally, a novel idea for applying artificial intelligence methods to the related data types is proposed in the framework of the project ITSEERR.

Keywords: *Artificial Intelligence; Egyptian religious texts; Metadata; Image processing; Deep and Machine learning.*

1. Introduction

This paper is a preliminary review of Artificial Intelligence (AI) and metadata projects starting from the main goals of ITSEERR (Italian Strengthening of the ESFRI RI RESILIENCE) project.¹ The main questions we asked are related to what data are used for the AI applications and how they are managed in the open data repositories, what are the projects currently exist and how image recognition can be used with 3D. On the base of this preliminary survey and the objectives of the ITSEERR project we have to define our strategies of research.

¹ Funded by the European Union- Next Generation EU, Mission 4 Component 2 CUP B53C22001770006.

The proposal is part of Work Package 10 of the ITSERR project, an Italian interdisciplinary infrastructure for religious studies. ITSERR, funded under the Italian Recovery Plan, aims to define, and optimize guidelines for digitizing a wide range of data, including religious texts from ancient world sites in the Nile Valley and beyond. The contents of these texts are very diverse and varied: descriptions of religious ceremonies, funerary texts, prayers, incantations, and lists of offerings. The project fits into the RESILIENCE (Religious Studies Infrastructure: Tools, Innovation, Experts, Connections and Centers) European network infrastructure.²

In 2021, the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap identified RESILIENCE as a new project belonging to the area of social and cultural innovation. Led by the Foundation for Religious Studies (FSCIRE, Bologna-Palermo, Italy), RESILIENCE is an interdisciplinary research infrastructure for religious studies that builds a high-performance platform, providing tools and services to scholars studying religions in their different forms and in their diachronic and synchronic variety. The digital archives are dedicated to complex, rare and/or endangered religious texts written in various media (stone, papyrus, etc.). The user needs analysis conducted by RESILIENCE enables ITSERR to effectively address the scholarly community at the European and national levels. Among many goals, RESILIENCE aims to develop semantic models and multilingual data and metadata standards for religious studies research. Furthermore, different digitization approaches, and 3D technologies will be tested to identify ways to digitally acquire these materials. Our team is currently involved in the analysis of the existing AI projects and open data repositories in archaeology for understanding how it is possible to extract information from shared knowledge, as well as drawing up Best Practice for digitization approaches and 3D technologies.

2. Preliminary survey

In recent years, there has been significant growth in AI, with machine learning algorithms being increasingly published and made accessible for use. Simultaneously, vast amounts of data continue to be generated, inundating the web. Data serves as the fuel for training powerful machine learning programs. Given the pivotal role of data and code in powering AI, prioritizing the quality of digital data, particularly in terms of consistent labelling, is paramount.

For decades, numerous domain specialists have focused on the collection, annotation, and archiving of data to ensure the long-term preservation of valuable digital assets. The overarching goal has been to facilitate their discovery and reuse for further investigations and applications, with AI being the latest beneficiary of these efforts.

Various projects have invested in data management infrastructures, particularly in fields like archaeology where several digital repositories have been established. Resources are stored in different structures such as aggregators, digital libraries, or simple databases. The main part of the repositories aims to promote data quality to facilitate open-ended reuse, often adhering to FAIR principles of Findability, Accessibility, Interoperability, and Reusability.

² <https://www.resilience-ri.eu/>

In Italy, the *CulturaItalia* project endeavours to aggregate data related to the country's cultural heritage. The project's portal collects and organizes information from participating providers, with data described according to metadata standards by the entities managing the resources. Since 2008, *CulturaItalia* has served as an accredited aggregator for *Europeana*,³ a European initiative promoting digital cultural heritage. Noteworthy cloud-based projects such as the UK Archaeology Data Service (ADS) provide infrastructure to ensure the FAIRness of archaeological research data in the long term under payment. ADS offers data on sites and monuments, grey literature, fieldwork reports, and research archives. Additionally, ADS collaborates with *ARIADNE*⁴ to integrate existing archaeological research data infrastructures. Another notable project is *Open Context*⁵ by the Alexandria Archive Institute.

While these projects contribute to digitizing museum collections and other resources, data descriptions often fall short in accuracy or detail, impacting data quality. Sometimes, data can only be explored through brief textual descriptions and locations, lacking access to images or thumbnails, posing a significant challenge for AI applications, especially image recognition. In the realm of textual data, two projects stand out for their implementation of good practices to enhance data quality: the ERC project *PATHs*⁶ and the *Beta Maṣāḥəft* project.⁷ *PATHs* aim to provide a comprehensive understanding and representation of the geography of Coptic literary production, particularly focusing on religious texts produced in Egypt between the 3rd and 13th centuries. The main scientific outcome of *PATHs* is the *Archaeological Atlas of Coptic Literature*.

Similarly, the *Beta Maṣāḥəft* project seeks to compile manuscripts, literary and documentary texts, along with reference authority files for historical figures and places. These resources adhere to FAIR principles, with each having a persistent identifier and described with rich metadata standards, ensuring accessibility, interoperability, and reusability for further applications.

3. AI for Archaeology

The most common applications of AI algorithms in archaeology aim to simplify and speed up the processes of analysis and documentation (examples include projects for the automatic recognition of ceramic fragments, or those supporting the re-composition of decorative elements, e.g. *ArchAide* and *RePair*⁸); to support the scholar in research and typological classification (this is the case of on-line catalogues that exploit AI as a real super search engine, e.g. *Cleo*⁹); to identifying new archaeological sites (there are many projects that use neural networks in the field of remote sensing,¹⁰ obtaining incredible results, especially in terms of time savings on searches, e.g. the *Kalam* project¹¹) and deciphering unknown languages or interpreting incomplete.

³ <https://www.europeana.eu/>

⁴ <https://ariadne-infrastructure.eu/>

⁵ <https://opencontext.org/>

⁶ <http://paths.uniroma1.it/>

⁷ <https://www.betamasahaft.uni-hamburg.de/>

⁸ <http://www.archaide.eu/>; <https://www.repairproject.eu>

⁹ <https://cleo.ainciant.org/pages/en/>

¹⁰ Argyrou, Agapiou, 2022.

¹¹ <https://site.unibo.it/kalam/en>

Almost all projects are based on automatic image recognition methods. Automatic imagery detection is a data-based method that is highly dependent on data, and the trend towards automation results from the availability of more complex and high-quality data. Data collection involves the extraction and storage of data from various data catalogues.

Despite the great evolution of these systems, which generally exploit deep learning Convolutional Neural Networks methods, the accuracy of the results is highly dependent on the classes defined in the training phase. Indeed, there is no missing case of completely meaningless results.

Different approaches of Artificial Intelligence methodologies have been used for ancient texts: application of OCR systems for scripts that have already been deciphered and classified (this is the case, for example, of the OCR - PT - CT Project on Egyptian hieroglyphics¹²); applications on signs that are difficult to interpret, also due to the writing media, such as clay tablets that make sign recognition operations more complex texts. Such cases require precise annotations and extensive image segmentation work (e.g. DeepScribe Project,¹³ which refers to a database of 5,000 images of annotated tablets and 100,000 bounding boxes of cuneiform signs from the Persepolis Fortification Archive); and finally, applications that provide virtual interpretation and restoration of inscriptions, like the Ithaca project¹⁴ on ancient Greek inscriptions.

It is well known that epigraphy cannot avoid a combined analysis of medium and text. The intrinsic connection of the written text with its support is often lost, or at least more blurred, at the digitalisation stage. 3D acquisition methodologies with high photographic resolution, which have recently had great development and application in the field of Cultural Heritage, could in the near future, combined with deep learning algorithms, overcome this gap in the proper digital documentation of these kinds of artefacts.

4. AI and 3D

Three-dimensional data processing has achieved very high levels of development. It is now possible to create a digital twin of the archaeological asset, thanks to the integrated use of tools, software and sensors. This has made it possible to create a data sharing environment, even in real time.¹⁵

Unfortunately, the absence of a standard workflow, which can be defined as an 'open method', does not allow the extraction of objective information from the shared models. Interesting examples of these immersive environments are developed, following an internally standardized workflow, even by Italian researchers but still at a visualization level.¹⁶ Nevertheless, the three-dimensional model is no longer to be considered as a "simple" visualization tool, it must be intended as an innovative field of research.

Following these examples, limited to the workflow for acquisition, it is certainly possible to create unified standards in data collection which must not be influenced by interpretative schemes. This kind of approach would open up new and promising

¹² <https://www.mortexvar.com/ocr-pt-ct>. See also in the present volume the article by Gracia Zamacona *et al.* 2026.

¹³ <https://datascience.uchicago.edu/research/deciphering-cuneiform-with-artificial-intelligence/>

¹⁴ <https://ithaca.deepmind.com>

¹⁵ Demetrescu *et al.* 2020.

¹⁶ Fanini *et al.* 2021.

horizons in the field of AI applications to archaeological 3D models helping researchers to converge on a generally recognized method.

5. Project goals and prospected methods

These premises are some of the key points of our survey. This work is useful to define strategies that help us to develop the ITSERR objectives for providing services to RESILIENCE platform. The project is then subdivided into three main tracks, each taking care of a different side of the project, as described in the following. Besides, the data materials and computational tools that need to be collected and used will be thoroughly detailed.

5.1 Projected works

5.1.1 Track 1: Image-based hieroglyphic character recognition

The first goal of this project is to create an Image Based Hieroglyphic Character Recognition that allows anyone curious about the meaning of hieroglyphs to utilize an algorithm to match the hieroglyphs to a well-known language, such as English. In the field of image processing, such a software should be primarily developed with Optical Character Recognition (OCR) and machine learning tools.

The projected software should be able to provide, from scanned images of hieroglyphics, a translation in a modern language such as English, using either image recognition, or automatic hieroglyphic symbol translation.

As required materials, a large collection/corpus of hieroglyphic texts and images is required. The projected deliverable is an open-source software for online/offline hieroglyphic character recognition and prospectively providing and English translation.

To implement such a software, the following tasks need to be fulfilled:

- Collection/acquisition of a large corpus of hieroglyphics
- Image scanning and quality control
- Applying image pre-processing: denoising, segmentation and edge detection
- Development of a model of pattern recognition for hieroglyphics, based on machine learning tools such as Deep Neural Networks (DNN), Hidden Markov Models (HMM) and/or Support Vector Machines (SVM).
- Development of a machine translation tool, that allows converting the recognized hieroglyphic symbols to text in the language selected, e.g., English.
- Software test and validation

5.1.2 Track 2: Restoring ancient text using deep learning

One of the most significant issues with epigraphic inscriptions is that they are frequently destroyed over time, necessitating the restoration of unintelligible portions of the text by specialists known as epigraphists. As a result, ancient text restoration uses machine learning methods to recover lost characters from a damaged text input. Long-term context information should be handled by the algorithm, as well as missing or corrupted letter and word representations.

Therefore, a software able to provide from old scripts the missing parts of the text is projected. The input can be either a script or a scanned image. In the latter case, a character recognition step is required.

As required material, a corpus of ancient texts, preferably mixed (with and without spontaneously missing parts) is necessary. The deliverables consist in an open-source software that can be implemented following these steps:

- Collection/acquisition of a large corpus of epigraphy in a selected language, e.g., ancient Greek, Latin, Hebrew, Arab, etc...
- OCR scanning and quality control
- Development of a model able to guess the missing words/letters in the text taken from the epigraphy. Such a model should be based either on statistical N-gram models, or on machine learning models, such as word2vec and skip-gram that may provide a word embedding model. The latter is used to suggest the missing word/character.
- Software test and validation

5.1.3 Track 3: Lexical and semantic analysis of ancient sacred texts using machine learning and Natural Language Processing (NLP)

The practice of examining and analysing vast amounts of text data to extract high-quality information based on patterns and trends in the data is known as text mining. The study of similarity measures, as well as opinion mining or emotive analysis represented in the texts, are examples of patterns and trends. Text data mining uncovers hidden relationships in one or several text data sets. Applied to ancient religious texts, text mining may provide more insight and information about the cultural and religious context, and the hypothetic interconnection between neighbouring or contemporaneous religions.

The outcome is a software able to analyse ancient religious texts, to show the degree of similarity, influence and interconnection. Therefore, a corpus of ancient religious texts, preferably categorized by historic era and geographic location is required to provide input data. As a deliverable, an open-source software is projected. It should be implemented as follows:

- Text pre-processing: including tokenization, tagging, chunking, stemming, and lemmatization.
- Text normalization: including sentence extraction, HTML escape sequences, expanding contractions, lemmatizing text, removing special characters, stop words, unnecessary tokens, stems, and lemmas
- Text summarization and information extraction
- Clustering of texts, using similarity measures (metrics such as distance measures)
- Semantic and sentiment analysis model
- Software test and validation
- Finally, once the projected software parts are tested and validating, it will be possible to deploy them, either as online tools, or also as portable applications, either separately or jointly in an integrated system.

5.2 Prospected computational methods

The tasks required to implement the aforementioned applications can be classified into standard and specific ones. Standard tasks include text and image scanning and quality control, image enhancement and denoising, segmentation and edge detection,

text normalization, lemmatization and tokenization, and finally software test and validation. However, other tasks are more specific and require using or developing special computational methods or training novel models based on the input data. Such tasks are for example pattern recognition and automatic symbol-to-word translation (for track 1), text analysis and word prediction, cf. Track 2, and text summarization, information extraction and clustering, and sentiment analysis through semantic models, as required for track 3. To fulfil such special tasks, data-driven models, based either on machine learning or deep learning are highly recommended.

5.2.1 Deep learning methods

Deep Neural Networks (DNN) have shown notable success in several classification, recognition, and prediction problems, related to several areas such as image, text, speech, and natural language processing, in comparison to other “shallow” neural networks like the Perceptron architecture. The “deep” portion of “deep learning” refers to a neural network with a high number of layers together with extra weights and biases to boost the neural network’s capacity to approximate more difficult tasks. There are many distinct types of neural networks for various goals in the complex field of deep learning. Novel DNN versions can be either recurrent or convolutional. Recurrent Neural Networks (RNN) are generally used to handle dynamic/time-varying signals, while Convolutional Neural Network (CNN) are usually used to train static/spatial data, such as pictures.

5.2.2 Machine learning methods

Despite the novelty of deep learning methods, pattern recognition and particularly hand-written character recognition have a long history of probabilistic modeling, using especially the Hidden Markov Models (HMM). This powerful tool has proved its ability to predict hand-written characters with a high precision, thanks to its sound mathematical formulation, based on a state-based model and the estimation of transition and emission probabilities. Thus, the features extracted from the text, or the image represent the observations, whereas the targets to be predicted are the characters or the patterns. Therefore, HMM can be used as a complementary tool, when DNN for example fails to achieve accurately the pattern recognition task; or to extract useful information that can be used to boost the performance of DNN. For instance, HMM-based transition and emission probabilities can be used as input features for the DNN. Conversely, a DNN can be used to cluster HMM models at the final prediction stage, instead of the standard classification trees. Particularly, this choice has been proved to improve speech recognition task and has been adopted in several speech and language processing tasks.¹⁷

Another powerful machine learning method is the Support Vector Machines (SVM) that were mainly applied for Optical Character Recognition (OCR).¹⁸ However, their classification and regression abilities have been assessed in several problems, such as Historical Document Processing and Handwritten Character Recognition.¹⁹ SVM are

¹⁷ Zangar *et al.* 2021.

¹⁸ Scholkopf *et al.* 1999.

¹⁹ Nasien *et al.* 2010.

also based on a sound mathematical formulation and have the advantage of being highly explainable and interpretable. They are based on approximating a discrimination function that divides the feature space. Thus, it can be applied either to binary, multi-class or multi-label classification.

5.2.3 Unsupervised methods

The methods mentioned above are based on supervised learning, i.e. where all datasets are labeled, and the task consists in learning a model that fits the input features and the target labels. However, large datasets are either not totally labels, or require a huge amount of time and human resources to accurately label all samples, e.g. categorizing all images and analyzing texts, with the underlying costs and risk of errors. Therefore, another approach can be used when using large unlabeled datasets, includes unsupervised modeling. These models are based on clustering methods, such as K-means, that aim at grouping data into clusters, based on similarity or distance measures. Thus, the aim of training is to minimize the distance measure through the computation of a cost function. Once the cost function is optimized, the clustering model can be applied to all samples. However, it should be noted that such a method does not provide the desired labels as output, and therefore, a further step is required to match clusters with labels.²⁰

6. Projected applications

The aforementioned methods can be used to establish analytic models or learn data-driven ones, based either on a probabilistic approach, e.g. for HMM, a statistical one for DNN, or on explicit formulation for SVM. However, their use depends on the final task. Therefore, through some examples, we explain how these methods can be used to fulfil the projected tasks.

6.1 Image segmentation

Several techniques for interpreting images need segmentation. It entails segmenting pictures into several items, regions or patterns. There are several uses for image segmentation, such as medical image analysis, video surveillance, and augmented reality. In the specialized field of archaeology, this method has been used for item identification and geographic image analysis.

The task of segmenting an image may be approached in two ways: either by classifying pixels with semantic labels (semantic segmentation) or by splitting distinct objects (instance segmentation). While image classification predicts a single label for the whole picture, semantic segmentation does pixel-level labeling for each image pixel using a collection of item categories (e.g., human, car, tree, sky) for each pixel. As such, it is often a more difficult task. By identifying and separating each pertinent component in the image, instance segmentation broadens the scope of semantic segmentation, e.g., splitting separate items.²¹

²⁰ Ahmed 2015.

²¹ Minae *et al.* 2021.

6.2 Image classification

Finding similar attributes amongst images is the first step in categorizing them. These qualities, which are frequently referred to as descriptors or features, may be overt or covert. Classification may be accomplished by a variety of machine learning techniques, which fall into two main categories: supervised techniques (like DNN) and unsupervised techniques (like K-means). The latter are dependent on whether the original labels are available during the learning process. Since labels are unknown a priori in the latter scenario, the word clustering fits the data better than classification.

Typically, each visible feature is carefully extracted or selected to ensure that it matches a physical description of the image. However, additional statistical methods such as Principal Component Analysis (PCA) or even more sophisticated machine learning methods like Deep/Variational Autoencoders (DAE/VAE) are used to retrieve latent features. Latent features are believed to be more discriminating but less explicable than visible characteristics. Despite their lack of interpretability, deep features make the classification model more accurate.²²

6.3 Character recognition

Even if printed works and ancient manuscripts differ, optical character recognition and handwriting recognition may be used to handle text extraction challenges in a similar fashion. Text recognition either extracts keywords from a line of text or creates a verbatim transcription of it after pre-processing and segmentation.

Whether the material was written or printed, the primary objective is to accurately translate the words in the document picture into digital text. The expected regularity of the space between letters and words serves as the foundation for optical character recognition's classification. The character is the fundamental unit of recognition. Because words and their constituent characters may be separated frequently and accurately, optical character recognition classifiers are able to recognize and produce a transcription using individual character glyphs. Consistent letter and word spacing, however, is insufficient for handwriting identification due to the quirks of human handwriting.²³

6.4 Language modelling

Systems will often utilize a statistical language model to improve optical character recognition and handwritten text recognition accuracy if the document language is known ahead of time. A language model makes sure that the words that the computer recognizes are consistent with the grammar and even the known vocabulary of the language. For optical character identification and handwriting recognition, deep learning techniques based on neural networks as well as traditional machine learning techniques can be applied.²⁴

²² Coates, Ng 2011.

²³ Fischer 2011.

²⁴ Frinken 2013.

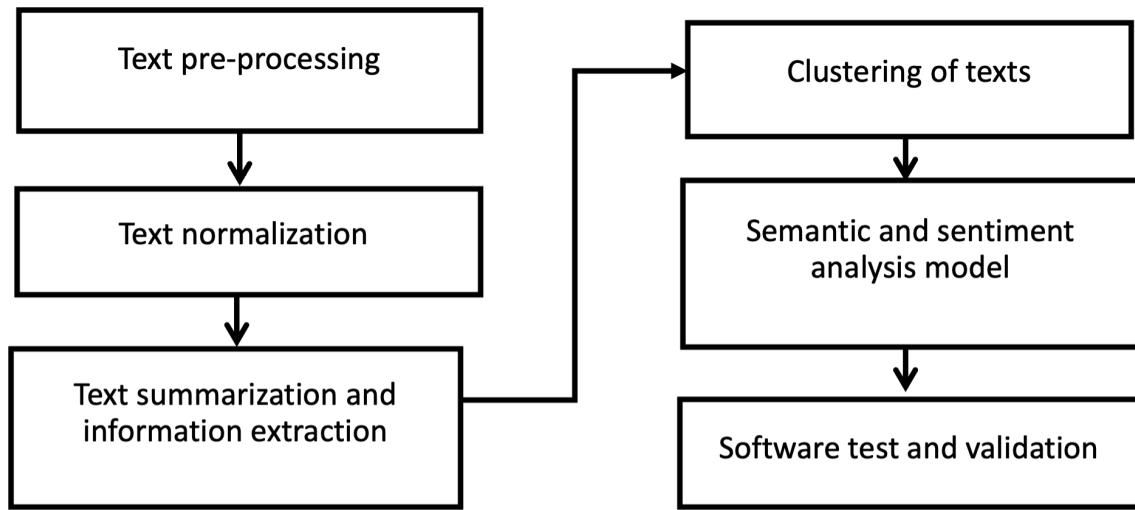


Fig. 1: Generic flowchart of automatic text processing techniques.

7. Conclusion and future directions

The ITSERR project, under the RESILIENCE European network infrastructure, endeavours to create a comprehensive digital archive for religious texts from the Nile Valley and beyond. This initiative faces several challenges, including the diversity of languages and writing forms, scarcity of material, and the absence of dedicated methods for analysing ancient religious texts. This paper serves as a bridge between the state-of-the-art linguistic text analysis and image processing, focusing on AI and metadata projects in the field of Egyptian language text analysis. By reviewing existing projects and methodologies, the paper aims to develop strategies for applying AI to the analysis and restoration of ancient religious texts.

This work outlines three main tracks for the ITSERR project, each addressing different aspects of text analysis and restoration. These tracks include image-based hieroglyphic character recognition, restoring ancient text using deep learning, and lexical and semantic analysis of ancient sacred texts using machine learning and NLP.

To achieve the goals outlined in the project tracks, various computational methods are proposed, including deep learning, machine learning, and unsupervised methods. These methods will be employed for tasks such as image segmentation, character recognition, language modelling, and semantic analysis.

The projected applications of these computational methods offer promising avenues for advancing the digitization and analysis of ancient religious texts. By leveraging AI and metadata standards, researchers aim to enhance the accessibility, interoperability, and reusability of these invaluable cultural artefacts for scholars and the broader community alike.

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Online Resources

ArchAide Project	http://www.archaide.eu
ARIADNE	https://ariadne-infrastructure.eu/
Beta Maṣāḥaft Project	https://www.betamasaheft.uni-hamburg.de/
Cleo	https://cleo.aincient.org/pages/en/
DeepScribe Project	https://datascience.uchicago.edu/research/deciphering-cuneiform-with-artificial-intelligence/
Europeana	https://www.europeana.eu/

Ithaca Project	https://ithaca.deepmind.com
Kalam Project	https://site.unibo.it/kalam/en
Mortexvar	https://www.mortexvar.com/ocr-pt-ct
Open Context	https://opencontext.org/
PATHs Project	http://paths.uniroma1.it/
RePair Project	https://www.repairproject.eu
RESILIENCE	https://www.resilience-ri.eu/

The Abu Ghurab landscape: from Total Station to GIS

Emanuele Brienza & Marco Anzalone¹

Abstract

Our study, following the practices of Landscape Archaeology, is focused on the relationship between humans and environment in ancient time, supposing that was not unilateral or rather passive: human choices were influenced by the landscape but gave to it a specific asset. Even if it is hard to understand how these relationships took place in the past, we try to reach a plausible interpretation of these phenomena, with a study centered on the Sun Temples of Abu Ghurab trying to also include the whole Memphite area, using different scales of analysis and specific and new technology.

We built a GIS environment where we process all collected data, from the first investigations of 2010 up to the most recent finds, trying to recreate a living historical framework of ancient Egypt, mainly relating to the 5th Dynasty.

For survey we adopted the most updated technology, including newest smart tools for centimetric satellite positioning, using a single antenna and a smartphone (Trimble Catalyst DA2), together with other innovative types of investigation, such high-resolution satellite images interpretation.

On the base of the collected data, the georeferenced historical/previous cartography and bibliography, we have performed different spatial analyses, like viewshed, intervisibility and least cost path analysis.

We want to point out that our study must not be intended as a result but as the beginning of a more complex investigation that, we hope, can lead to fruitful results in understanding some aspects of the ancient Egypt during the 5th dynasty, particularly related to the Sun Temples.

Keywords: *Sun Temple; Landscape Archaeology; GNNS; GIS; Spatial Analysis.*

1. Introduction

The archaeological investigation of the site of Abu Ghurab, located inside the Memphite necropolis area, immediately to the north of the pyramids of Abusir, has been carried out since 2010 by an international research team, currently headed by Massimiliano Nuzzolo and Rosanna Pirelli, Universities of Turin and Naples 'L'Orientale', in cooperation with the Uninettuno University of Rome and the Polish Academy of Sciences in Warsaw. The research work is conducted in close collaboration with the Egyptian Authorities and Scientific Institutions.²

The investigations are focused on the Sun Temple of Niuserra, sixth king of the 5th Dynasty, already excavated by Ludwig Borchardt in the years 1898-1901.³

¹ The authors have discussed and agreed on the general content of this paper, where the first part (§ 1-3) was edited by Emanuele Brienza and the latter (§ 4-5) by Marco Anzalone.

² For a preliminary report of the activities see Nuzzolo *et al.* 2020.

³ The Sun Temple of King Niuserra (2400 BCE ca.), is the most significant evidence of architectural complexes dedicated to the solar cult in ancient Egypt: at the beginning of the 5th Dynasty, we find this new type of sanctuary, exclusively dedicated to the cult of the solar god Ra. The temple is structured according to a tripartite layout which is well known in Old Kingdom and can be found in almost all the contemporary

Our contribution, together with topographical support, was developed in the field of *Landscape Archeology*, a branch of antiquity study dedicated to space-time contextualization of the archaeological record inside a given territory whose characters are the result of the interaction between human activities and environmental features, from the beginning until today.⁴ The analysis of the ancient environment is crucial to understand the scenario of past events. The landscape and natural resources directed the choices of human communities of the past. In the other hand, it is difficult to reconstruct ancient environments and landscapes characterized by human activities, because many transformations occurred in the past could be enormous or very little in number, realized in a short time, through big phenomena, or in a long time, by constant agents. We must also add the consequences of modern and contemporary industrialization, such as urban growth and abnormal exploitation of territory.

Normally for big changes in geography, linked to climate mutation and geological events, like shift of coasts or river courses, it is necessary a geoarchaeological approach:⁵ this can be the case of the desert burial areas of the Old Kingdom, partially affected by alluvial processes and movement of waters towards the east.⁶ In our case if the desert character of the area seems to have remained the same since millennia, we must take in account the continuous movements of sand dunes and wadies, which certainly changed the morphology and the ground level; we must also consider contemporary activities carried recently in the desert.

The flood plain, located between the rock desert plateau and the west bank of the Nile river, is a decisive item for the ancient landscape reconstruction. This area had to be characterized by intense cultivation and canalization for agricultural purposes but also for transport and communication: those canals probably run in parallel to the Nile but also transverse to its course. The appearance of this area was a mixture of desert and vegetation, plotted by channels managing the water regime, giving access to the entrances of burial and religious complexes, supporting the activities of small villages sprung around them and allowing the transport of objects and goods linked to calendar feasts: first of all the water itself, necessary for the purifying rites performed in the Sun Temples.⁷

This flood plain between the plateau and the Nile river has today a very different aspect compared to the Dynastic one, if we consider that ground level has risen in last centuries and the course of the Nile shifted hundreds of meters to east;⁸ in addition, apart contemporary interferences, the general asset based on cultivation and canalization

pyramid complexes: 1) Valley Temple; 2) Causeway; 3) Upper Temple; the latter is composed of a surrounding wall, measuring 110 x 70 m, which encloses a varied ensemble of cultic rooms, open-air spaces and functional areas. These monuments played an important role in the religious life of Old Kingdom but were suddenly abandoned by the end of the 5th Dynasty. See Borchardt 1905.

⁴ About *Landscape Archaeology* see, in general, Turner, Shillito, Carrer 2018 as an updated approach; about this kind of studies in Egypt see Tristant, Ghilardi 2018.

⁵ For geoarchaeology applied to ancient Egypt see Tristant, Ghilardi 2012; see also Tristant, Ghilardi 2012b.

⁶ About these processes see Jeffreys, Tavares 1994; Willems, Dahms 2017; Bunbury 2019.

⁷ Nuzzolo 2018, 239-241.

⁸ Jeffreys, Tavares 1994, 157-159; fig. 15.

changed continuously during ancient periods (from Dynastic to Greek-Roman periods, and after, during Late Antiquity and Arabic times), so it can represent for us a vague reflection of Old Kingdom situation.⁹

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 began 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.

The different analysis scales are part of a single study and are performed in the same GIS environment, taking in mind that the choice of a site or a building place could be influenced by parameters detectable using different approaches: decisions could be dictated not only by principles of economy, technology and minimum effort, but also by cultural parameters and by political will and its ideology.¹⁰

2. Survey and topography

Our first task was to give topographical support to excavation graphic documentation and to a multi-scalar GIS, managing both intra-site and extra-site data, connecting stratigraphic information to ancient landscape.

The first step of this work has been checking the general Borchardt map¹¹ (the most complete previous documentation about the temple), to verify its accuracy and to identify discrepancies with visible archaeological evidence.¹² This examination was made by total station, measuring the ancient architectures.¹³ Even if a general validity resulted from Borchardt drawings, some discrepancies came out in several zones, caused probably by different survey techniques but also by ancient walls and blocks displacements made after Borchardt investigations.

In the second step we decided to set up a new topographical network by total station, based on fiduciary points physically represented by pegs fixed on the ground, choosing best reciprocal visibility without damage risks for ancient remains. The network was based on a closed traverse, initially composed by 5 benchmarks set up around the temple where a forthcoming laser-scanner survey was planned.¹⁴

From 2017 this topographical network has been expanded, including the area of the terrace walls retaining the ancient complex, the Causeway and the Valley Temple: we traced an open traverse¹⁵ addressed to the surroundings of the Sun Temple, including

⁹ For these changes during past times see Alleaume 1992, Cooper 2015; Gonçalves 2019.

¹⁰ Nuzzolo 2018, 53-54; 97-104.

¹¹ Borchardt 1905, bl. II.

¹² Nuzzolo, Pirelli 2011, 664-679.

¹³ We took several detailed points using a temporary network, partially fixed on the ground, composed of 5 benchmarks around the temple area with a reciprocal triangulation carried out by resection from three points for each of them. For the use of total station in archaeology see in general Bedford, Pearson, Thomason 2016. See also Andrews 2009 for standard metric specifications.

¹⁴ D'Andrea *et al.* 2014.

¹⁵ For open traverse see Bedford, Pearson, Thomason 2016, 19-20.

also some near *koms*, in the effort to detect their possible spatial relation with Niuserra Sun Temple, like affinities in orientation and elevation.¹⁶

During the following years this topographical network has been constantly used as the base of archaeological and architectural drawings, made by Structure from Motion (SfM) photogrammetry, integrating all graphic elaboration in a unique spatial framework.

Georeferencing has been for long our concern: national geographic benchmarks are not visible in the surroundings while the use of conventional Differential Positioning System (DGPS) 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 performing 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.

In 2022 we used the Trimble Catalyst DA2 centimetric Global Navigation Satellite System (GNSS) that was essential to geo reference all our data in a correct way: these tool, composed of a small single antenna fixed on a pole, interface directly with a smartphone 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.¹⁷ 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 the 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; apart from gross errors, we were able to obtain multiple measurements varying of two centimeters on X, Y and Z axes. For final data control we decided to compare the new benchmarks coordinates measuring them again by total station: having detected a similar error range and same good accuracy, we were finally pretty 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 French survey¹⁸ (Fig. 1).

¹⁶ See Nuzzolo, Zanfagna 2017, 114-120.

¹⁷ For several use-cases of this new tool in archaeology see Brienza 2023; Brienza 2024.

¹⁸ For this survey, published in 1978, see *infra* § 4.

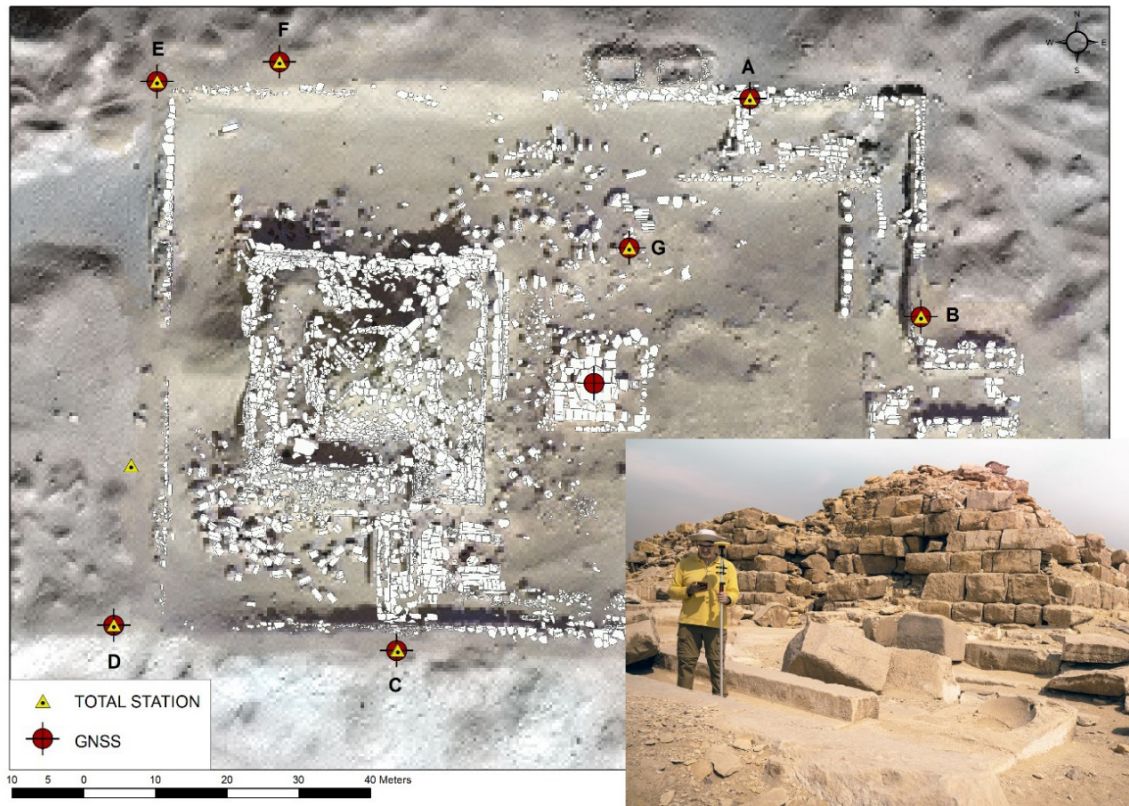


Fig. 1: GNSS Survey. Photo by Patricia Mora Riudavets.

3. GIS

We built a GIS for geo-referencing and managing all surveyed data. This system is an advanced update of the *Risk Map for North Saqqara Site*.¹⁹ Our GIS covers as much as possible the entire Memphite zone and its base-map is composed by the sheets of the *Survey of Egypt Topographical Series* (France – 1978, scale 1:5000, International Ellipsoid Hayford 1909, projection UTM 36N, produced by CONSORTIUM SFS/IGN and based on a 1977 aerial survey), different aerial photos and several satellite 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, even in recent years, have been georeferenced into the map and drawn in vectorial form.²⁰ Finally, we also imported the main web-cartographies

¹⁹ For a general review of this project see Bresciani, Giammarusti 2003; for methods and principles used in planning and building this system see Brienza 2003; for technical aspects see Yehia 2003.

²⁰ The updated geodatabase has been used for a study of tomb distribution in Saqqara during the 5th Dynasty, see Nuzzolo, Zanfagna 2017b; in addition, the same spatial data have been shared with E. Sullivan for the project *Constructing the Sacred. Visibility and Ritual Landscape at the Egyptian Necropolis of Saqqara* <https://constructingthesacred.org/>

of the ancient world available in digital format, in particular the digital maps of the *Barrington Atlas of Greek and Roman World*,²¹ those of the *Digital Atlas of the Roman Empire*²² and other resource available at the *Ancient World Mapping Center*,²³ to relate our area with the most important ancient sites in the wider Egyptian framework (Fig. 2).

Once we could use exact coordinates in WGS84-UTM36N geographical system and elevation values linked to previous detailed cartographies reporting contour lines, we started to build DSM, DEM and DTM of all the area to try reconstructing the ancient landscape and its main features.



Fig. 2: Abusir and Abu Ghurab areas in our GIS.

We have performed some spatial analyses, typical of *Landscape Archaeology* usually carried out by specific GIS tools²⁴ that, from a theoretical point of view, today can be grouped into three main distinct sectors: site location analysis, movement and transport modeling, visibility analysis.²⁵ There has been a long debate on the use of computerized procedures which involved exponents of Processual and Post-Processual Archeology but today this confrontation has faded: in fact, it is precisely in the field of GIS applications

²¹ Talbert 2000.

²² <https://imperium.ahlfeldt.se/>

²³ <https://awmc.unc.edu/>

²⁴ Gillings, Mattingly, van Dalen 1999; Chapman 2008; Hu 2012; Gillings, Hacigüzeller, Lock 2020.

²⁵ Verhagen 2018.

that it is possible to carry out pluralistic approaches and experiments, proving various probabilistic solutions to archaeological questions.

One part of our spatial analysis concerned the reconstruction of the communication network during the Old Kingdom, on land and by water, based on what is already known and implementing a least cost path analysis in order to identify the most accessible routes, from point to point, according to places morphology and accessibility:²⁶ focal points are the most important architectures, such as Pyramid complexes and Sun Temples, but also their Valley Temples and Causeways, which give us very important indications to interconnect, transversely, the desert plateau with the Nile Valley. From our results, it is difficult to suggest an uninterrupted main road in the desert plateau connecting all the sites of the Memphite necropolis: this role should be played instead by the main channel that flowed at the edge of the cliff. On the other hand, it is possible to reconstruct internal paths that connected the various monuments of the area.

A second part of our work concerned the visibility and viewshed analysis,²⁷ usually conducted in association with other spatial analysis types to understand the visual relationship between archaeological sites and their system of communication.²⁸ Some limits of this analysis have been highlighted in the past²⁹ but many have been solved over the years: it is now easy to set the distance and orientation of the visual ray³⁰ or the distance to the horizon³¹ while binary responses are diluted through multiple, cumulative and total viewsheds.³² Furthermore, it is now possible to use complex procedures, such as the *fuzzy viewshed*, which determines the visible surface from a multiple number of observation points, considering the recognition capabilities of the human eye and the size of the objects and the *probable viewshed*, which is based on a general re-evaluation of the heights, based on the evaluation of the mean squared deviation, of the DEM used as base-surface.³³

The results of our analysis (see *infra*) show, that the Giza Pyramids were visible almost from the entire Memphite necropolis while Userkaf's and Niuserra's Sun Temples did not have a direct visual relation with Dahshur.

In a general reconstructed framework (Fig. 3), we must imagine a sequence of temples and funerary complexes, during the 5th Dynasty, that had to take into consideration symbolic needs and best places available for building.³⁴ In this process, the communication routes – internal or in the liminal area below the desert plateau – must have played a role of visual connection among the given monuments, which functioned as not only geographic guidelines, but also as symbolic markers: the roads must have been built

²⁶ Fábrega Álvarez, Parceró Oubiña 2007; White, Surface-Evans 2012; Murrieta-Flores 2014; Herzog 2014; Herzog 2016; Herzog 2020.

²⁷ Viewshed Analysis is the process of identifying locations that are visible from one or more observer points: usually is performed by GIS on the base of a digital elevation model.

²⁸ De Montis, Caschili 2012; Murrieta-Flores 2014; Lock, Kormann, Pouncett 2014.

²⁹ Wheatley, Gillings 2000; Gillings, Wheatley 2020.

³⁰ Wheatley, Gillings 2000, 16-24.

³¹ Lake, Woodman 2003, 697-698.

³² Llobera 2003.

³³ Rášová 2014.

³⁴ Nuzzolo 2015, 296-303; Nuzzolo 2018, 53-54.

following principles of practicability but also of visibility. In this way, a visual network was formed here like a monumental palimpsest that, already in antiquity, must have assigned to the main monuments the role of reference points (spatial but also cultural) for those who were moving in the area coming from both directions, north and south, as still happens today. This cultural significance of the landscape memory which some places have played, as benchmarks of the territory and together with a road network of very long use, is a phenomenon of antiquity observed in many places and probably contains the fascination of landscape history.³⁵

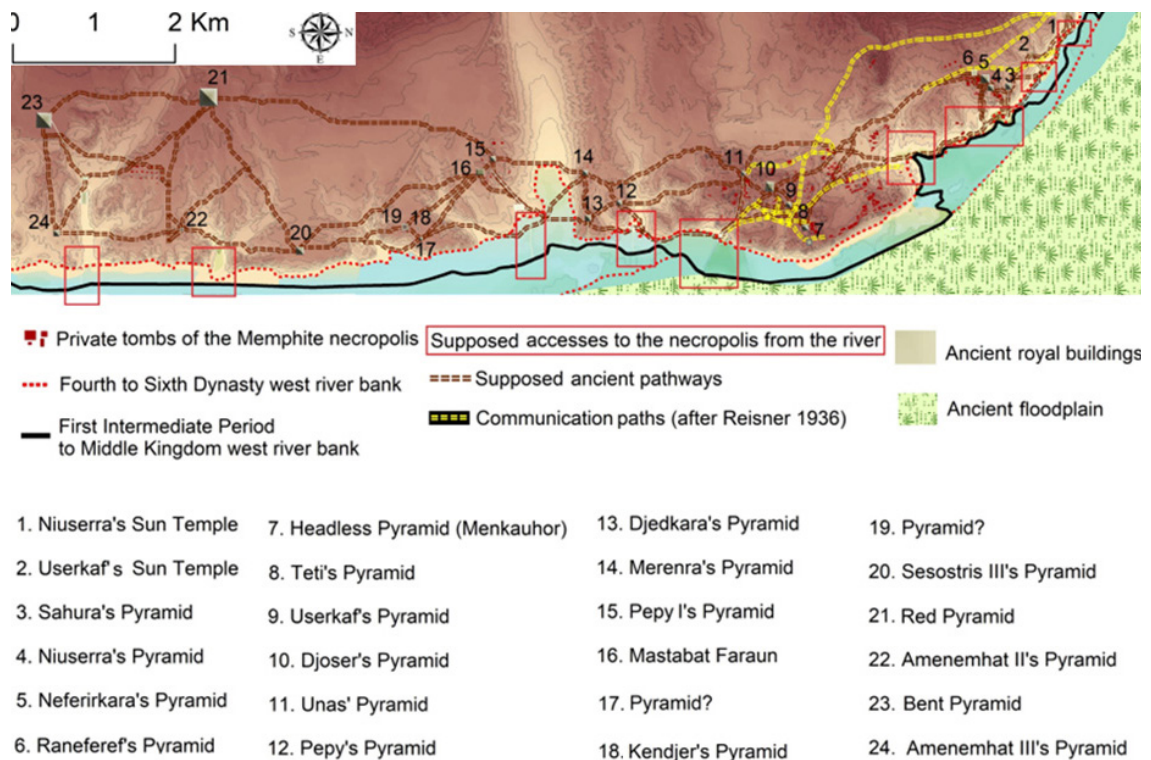


Fig. 3: Ancient landscape and pathways reconstruction proposal.

4. Description of the methodological approach

As usual, the starting point of landscape analysis is the research of a good cartographic base, both historical and contemporary; so we used the plans of Lepsius,³⁶ De Morgan³⁷ and Porter-Moss,³⁸ needful for anyone that wants to study the Memphite necropolis; if the first puts the accent on pyramidal structures (many of which still not excavated at the time of the scholar), the latter focus more on tombs, even if they're not mastaba structures. We also used the geodatabase built by Emanuele Brienza during his work in Saqqara and Abu Ghurab.

³⁵ Garland 2013; Verhagen *et al.* 2016; Brienza, Cultraro, Draia 2020, 204-205.

³⁶ Lepsius 1849, Abth I, bl 32-34.

³⁷ De Morgan 1897, taf 1-11.

³⁸ Porter-Moss 1974.

These maps, of course, present problems in terms of metric accuracy; we used them overlapped to the satellite images provided by ESRI ArcGis,³⁹ trying to identify structures and remains of historical maps on data. Given the impossibility of varying the chromatic scale of these Maxar's satellite images, we also used images supplied by E-geos and Isi, detected with SAR dual use satellites COSMO-SkyMed, second generation COSMO-SkyMed satellites and EROS Next Generation Elettro Optical with a very high resolution. In the latter, each pixel represents an area of 0.30 m per side; they allow to elaborate variations of the 8 chromatic bands, highlighting possible remains (buried not very deep) with different index of reflection.

We also used the 1978 IGMF Cairo maps 1:5000; from the contour lines obtained by the vectorization of these, was therefore possible to extrapolate a Digital Terrain Model (DTM) with a resolution of 1 m per pixel, a useful starting point for the creation of a "calibrated" DTM, a model of the terrain in which were present only the structures certainly visible in the Fifth Dynasty, and thus eliminating modern buildings and Pyramids or structures subsequent to the aforementioned period.

We are aware that the elaboration of a DTM from contour lines extracted from French cartography dated to 1978 (see *supra* § 3) cannot be representative of the landscape situation of the 3rd millennium BC; but in our case it is useful both for the analysis of visibility and for the elaboration of possible connection paths. In the case of visibility, the absence, at least apparent, of works aimed at leveling hills or heights larger than the pyramids themselves (or which in any case could somehow obstruct their view) put this problem in background; we want also to remark that the dimensions of the structures have been inserted according to the most recent reconstructive hypotheses.⁴⁰

In the case of the least cost analysis, however, the situation is different; the leveling work and the extraction of buildings' materials (for example for the two Pyramids of Snefru in Dahshur),⁴¹ contrary to what happens for visibility, may have had a different weight in the choice of the routes used; in this sense we should imagine that such roads have been planned after all construction processes. We should add the process of sands' accumulation, carried by the wind or by the waters that descend from the wadies; considering these features recalibrating a DTM is quite difficult, at least at the current state of our knowledge of the area. It is also true that these accumulation processes seem to be less consistent in the areas of the plateau of the pyramids and necropolis and the wadi, with their extension on the E-W axis, may have served the funerary areas, especially in the construction phases, but may have acted as blocking points in the case of the N-S direction, both inter-site or infra-site;⁴² however it's sure that they have changed the morphology of the east part of the Memphite necropolis, more than the west side (see *infra*).

From the DTM we extracted data relating to the slope (expressed in degrees and not as a percentage) and shading (with azimuth at 315 degrees and 45 degrees of altitude). If the latter helps to better highlight reliefs that are not very visible from satellite images or even from the DTM, the slope is needful to calculate travel costs; after having reclassified

³⁹ These are shots made between May and July 2020.

⁴⁰ Lehner 2000, 16-17; Nuzzolo 2018, chapter III.

⁴¹ Alexanian et al. 2012, 131-133.

⁴² Bebermeier *et al.* 2011, 329.

the gradual values of the slope (from 1 to 9), a weight equal to 70% of the total was assigned; the remaining part was instead attributed to soil geology, remodeling the *Geologische Karte des memphitischen Raums südlich von Kairo*⁴³ 1: 500.000 with the help of military maps at 1: 5000 of 1978, and assigning values from 1 to 9.

From the overlay obtained it was therefore possible to calculate routes to and from points arranged near the most important buildings of the necropolis, i.e. Pyramids, Valley and Upper Temples and Solar Sanctuaries, trying to guess even if the currently known causeways used the most convenient route or not.

For the visibility analysis, two different approaches have been used:

- the macro level analysis was carried out using Google Earth pro and tracing more than 40 visibility's lines; due to the impossibility of converting the other part of the 1978 cartography relating to Memphis (now Mit Rahina) and Heliopolis (in the neighborhood of al-Matariya inside the city of Cairo), and also given the low level of detail of Barrington's DEM (whose pixels of 70 m per side make it useful only for a preliminary analysis of macro-visibility), we choose this solution; the tracking tool for paths of the Google software allows to extrapolate an elevation profile of these lines, and since the distances are always expressed in km while the heights in m, we needed to modify the images through a CAD software, re-projecting the most important altitude features of these profiles and proportioning them to the distance scale;
- for the area that goes from Dahshur to Abu Ghurab, it was instead possible to use the much more detailed DTM, and to realize a fuzzy viewshed analysis, i.e. an analysis that takes into account not only what is visible or not, but also the percentage of visibility; this percentage can be translated into the distance and size of observed objects, and also into the dispersion and absorption indices of light into the air mass placed between the observer and the objects; thus taking up Ogburn's formula, in turn a reworking of Fisher and Higuchi's theses on visibility,⁴⁴ it was possible to attribute values that had a constant degradation between 1 and 0; 1 represents full visibility, and is obviously an expression of the "close-up" of human eye, extendable about 1 km in radius; 0, on the other hand, tends to infinity, since anything with this value is invisible to human eye.

5. Achieved results

Analyzing the viability, we can see that the entire Memphite necropolis has very precise boundaries, and the fact that it extends in length for about 13 km from Dahshur to Abu Ghurab and for other 19 km from the last to Abu Rawash makes it very difficult to hypothesize land routes for the entire extension.

The area of Dahshur, for example, expands from the wadi flowing into the homonymous lake, in the south, up to the Wadi Taflah, in the north. Moving inside an area of about 6.5 km to transport the needful offerings for the cults was very hard, and certainly the orientation of the Causeways and the location of the Valley Temples had

⁴³ Bebermeier *et al.* 2011, 329, fig. 2.

⁴⁴ Ogburn 2006, 405-416.

to play a key role in this transport of goods for the sanctuaries; it would therefore have been easier to move in various points of the necropolis by crossing a canal, of which the Bahr Libeini is possibly an evidence still visible today. Within the median wadi of the Dahshur area there are the Valley Temple and Causeway of the Bent Pyramid, as well as a structure to the east of the same temple surely used as a landing place for boats and as a garden entrance to the Snefru complex.⁴⁵ The structure was located at about 20-21 m a.s.l.,⁴⁶ but today the area has an altitude of about 25-26 m, thus showing an accumulation of about five meters, probably created not only by the wind (someone talks about a climate change between 4th and 5th Dynasty – 2500 BCE ca.);⁴⁷ this would also explain the abandonment of the area during this period, only to resume in the Middle Kingdom, during the 12th Dynasty (20th-19th century BCE).⁴⁸

Further north, and at the same time, Wadi Taflah must have been partly covered by the waters of what is known as the 'Lake of Saqqara' and served as an access point to South Saqqara. In the time of Pepy II (2270 BCE ca.) substantial changes in the layout of the wadi and the lake seem to have started, with a retreat, westwards, of the canal and the lake. The lake's shore seems to have shifted eastwards up to reach the altitude corresponding to the current 21-20 m contour lines.⁴⁹

Going to north, in the southern area of Saqqara the monument of Pepi I (2300 BCE ca.) could reconnect its NE causeway to a possible artificial canal visible with high resolution images (canals of this type, already highlighted by the *Description de l'Égypte*⁵⁰ at the end of the 18th century in other areas, would also have carried out drainage and irrigation tasks of the alluvial plain),⁵¹ reflecting a further situation of the lake, before Pepi II but after the middle 5th Dynasty, with a shore that could have reached the current 21-20 m contour line.

Two hypothesized paths could have connected South Saqqara with the area of Netjerykhet Pyramid in central Saqqara⁵² (Fig. 3), since these are natural rocky depressions of about one kilometer of extension to the right and left of the small hill located south of the aforementioned pyramid, in the NW-SE direction. Moving to central Saqqara, the access to this area would certainly have been obtained from the area where the valley temple of Unas (2300 BCE ca.) was later built. The paths inside the central area of Saqqara, useful for connecting necropolis and monuments, are not known today, but the roads highlighted in 1936 by Reisner⁵³ (and still in use today) may have been used in ancient times.⁵⁴

In the north part, instead, Abusir's area could be reached by the lake of Abusir (was it, in ancient times, part of a river?), whose coastline was probably located at the level corresponding to the current contour lines of 22-21 m.⁵⁵

⁴⁵ Bebermeier *et al.* 2011, 344-347.

⁴⁶ Alexanian, Arnold 2016, 1-16.

⁴⁷ Bunbury 2019, 64-65.

⁴⁸ Bebermeier *et al.* 2011, 328; Bunbury 2019, 120-130.

⁴⁹ Bunbury 2019, 120.

⁵⁰ Neret 2002.

⁵¹ Antoine 2017, 31.

⁵² Mariette 1885, Pl. II; see also Porter, Moss 1974, Pl. XLI-XLII.

⁵³ Reisner 1936, Tav. I.

⁵⁴ Barta, Brūna 2006, 25.

⁵⁵ Bebermeier *et al.* 2011, 327.

Going instead to the analysis of visibility, it is certain that at least the Pyramids of Giza were practically visible from the entire Memphite necropolis, and from the temple of Ra in Heliopolis; in the same way, the Pyramids of Abu Rawash and Zawyet el-Aryan were observable because they were in a higher plateau; from the Pyramid of Khufu it was certainly possible to view at least the upper part of the obelisk of the solar sanctuary on the opposite bank.

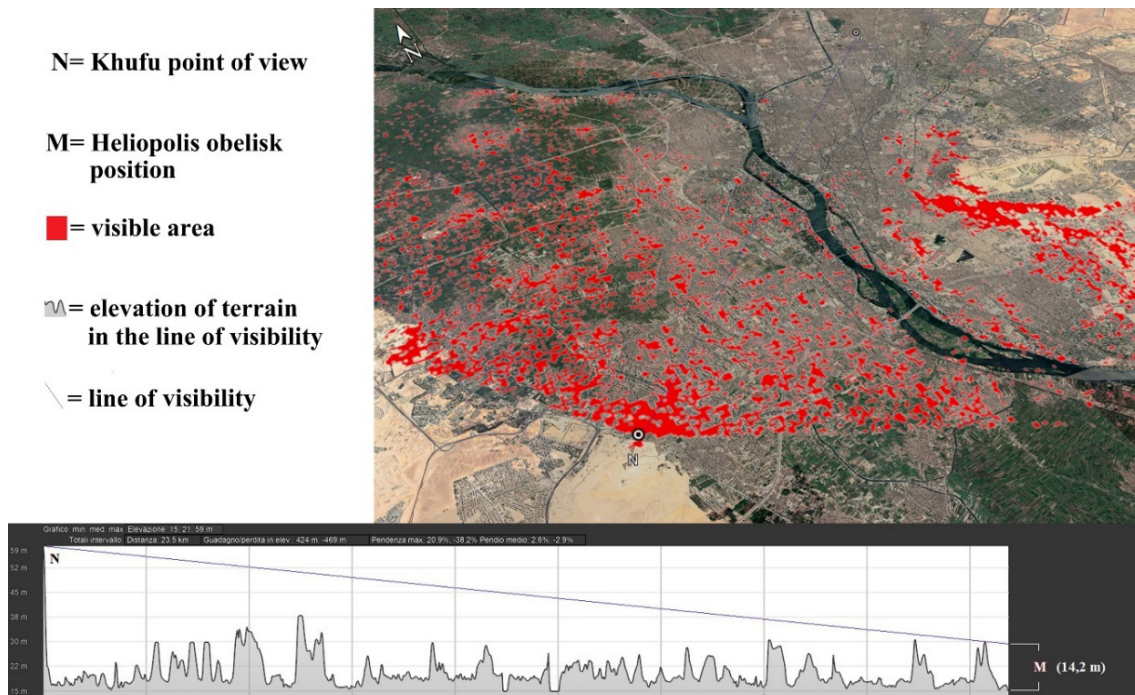


Fig. 4: Visibility line from Khufu's Pyramid to Heliopolis.

But is there also a connection between the 5th Dynasty's monuments at Abusir and north Saqqara and the Solar Temple at Heliopolis? According to Jeffreys,⁵⁶ from the two Solar Temples of Niuserra and Userkaf it was possible to see the upper part of Heliopolis' obelisk; Verner argued that only from the Solar Temple of Niuserra⁵⁷ it was possible to see that obelisk.⁵⁸ Our analysis can now confirm that no one of these monuments had a visual connection with the obelisk.

In the North-East part Al Muqattam and Al Fustat hills cover every hypothetical line of sight between the solar temples and Heliopolis. But we also observed something more. If we track a hypothetical line of sight between the funerary monument of Neferefra and the South-East corner of Kufhu's Pyramid, this line will pass from the Solar Temple of Niuserra. And if we track the same line also for the funerary monuments of Sahura and the not sure Pyramid of Menkaurhor, these lines will pass respectively for the Pyramids

⁵⁶ Jeffreys 1998, 63-64.

⁵⁷ Verner, Bruna, 2011, 291.

⁵⁸ Nuzzolo, however, suggested that none of these two monuments was visible from Heliopolis. Nuzzolo, 2015, 289-292.

16 and 28 drawn by Lepsius. It's just a suggestion, and we need to prove it, but this could draw a distribution pattern between Sun Temples and funerary monuments, a kind of indirect connection between the Sun Temples and the obelisk of Heliopolis through its visual alignment with Khufu's Pyramid.⁵⁹

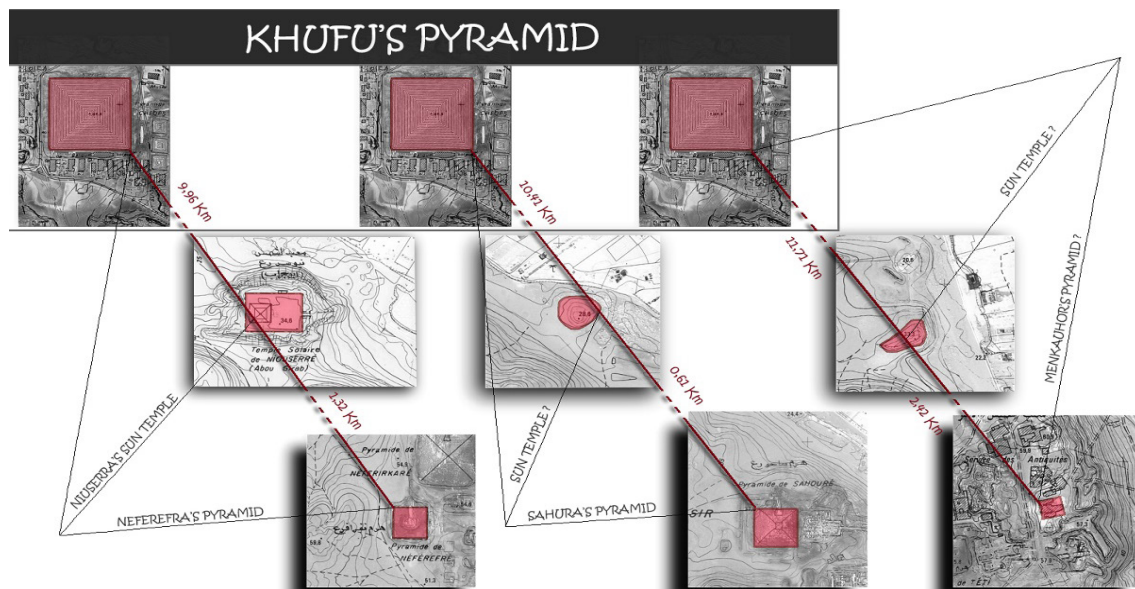


Fig. 5: Corners' alignment with Khufu's Pyramid.

Therefore, we have seen that choosing the foundation places for royal monuments in Old Kingdom were considered ritual and political reasons, of course, but also climatic and territorial changes which, in addition to being fully attested by the scientific research of the last decades, find direct correspondence in various kinds of literary sources, and this can only comfort researchers about a progressive approach to the historical truth of the Old Kingdom.

We strongly underline that our research must be considered as a mere starting point for future investigation aimed at understanding the meaning of Memphite necropolis' monument's distribution.

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⁵⁹ Verner 2002, 302-303.

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Online Resources

AWMC	https://awmc.unc.edu/
Constructing the Sacred	https://constructingthesacred.org/
Digital Atlas of the Roman Empire	https://imperium.ahlfeldt.se/

Archaeological data and digital society

Andrea D'Andrea

Abstract

Speaking in 2006 at the annual conference of the Association of National Advertisers, British mathematician Clive Robert Humby coined the famous phrase "*Data is the new oil*". The next 17 years proved that Humby was right about the dominant role that data would play in business as well as in culture and research. However, unlike oil, which is a non-renewable source, data is not limited, it is renewable and reusable, and its quantity will continue to grow in the future. Like oil, data cannot be used in a raw way; it must be refined and transformed to have value. Artificial intelligence and machine learning are certainly very hungry for data that must be in some form structured according to a standard schema with defined types and relationships. Today's challenge lies in the ability to transform Big Data resources into valuable training models for machine-learning based applications. The increasing use of data contributes to a paradigm shift in science increasingly characterized by the navigation of an almost infinite sea of data, capable of generating new knowledge. Starting from this premise, the paper illustrates how in the world of archaeological research, data has progressively become a key aspect not only in the reconstruction of the past, but also in practices dedicated to sharing archives.

Keywords: *Data-sharing; Semantic Technologies; Big-Data; Artificial Intelligence; Repository.*

1. Introduction

Today's society is characterized by the deployment of a technology that influences every economic, scientific, and cultural relation. Therefore, it is necessary to reflect on the correct use of these innovations to avoid losing control of them. Recent discussions on the perspectives of artificial intelligence-based applications and their potential positive or negative effects on humanity confirm the widely shared need to discuss the value of technologies and their effective use. Therefore, rather than focusing on the efficiency of digital applications in archaeology, it is better to investigate the role that data play in historical research today, including highlighting the ambiguity in the use of terms related to the archaeological record (data, information, digital documents, information resources, etc.). The risk, which exists in the misuse of technology, often stems from the choice of overly rigid formal structures that nullify all possible uncertainty and variability to the advantage of consistency on the purely IT side.¹

Many scholars pointed out that we live in a world of data captured by multiple sensors, instruments, devices, automatically or manually, consciously, or unconsciously. But what does the term data means? Data is a collection of discrete values describing quantity, quality, facts, basic units of meanings or simply a sequence of symbols that may be further interpreted. Data are stored into structures and used as variables in a computational process. Data, moreover, may represent abstract or practical concepts and they are commonly used in scientific research and, virtually, in every form of human organizational activity. It has been estimated that more than 2.5 quintillion bytes of data are being produced every day. We often use the term information as a synonym for data; on a linguistic level, the two terms

¹ Huggett 2020a.

are equivalent, but from a computational point of view, confusing data, and information, can generate errors difficult to be discovered when the structure of the digital document is inaccessible. But what data can be used for? In the wisdom hierarchy, data is at the lower level. Data are entities that carry information but are not information on its own, while information derived from data through the process of interpretation and analysis.

Data can be aggregated to increase their information content; there are corpora that include heterogeneous sources, datasets that organise coherent resources, and repositories that integrate digital data with metadata, providing a range of search, aggregation, and preservation operations. Finally, we have the infrastructures that, in addition to the requirements of repositories and aggregators, add services, tools and best practices for researchers.

Given the value that data are taking on in archaeological research, this paper aims to explore how digital data are produced, interpreted and, most importantly, shared. At this stage, characterized by the still experimental use of artificial intelligence, a process of knowledge standardization is making data *machine-understandable* and *machine-readable*.

2. Data from oil to soil and a fourth paradigm

The growing importance of data in the world economy prompted the British mathematician, Clive Robert Humby, to declare in 2006 that “*Data is the new oil*”.² Speaking at the annual conference of the Association of National Advertisers, the scholar pointed out the dominant role that data would play in business as well as in culture and research. Data in the 21st century is like oil in the 18th century: those who understand the fundamental value of data, and learn how to extract and use it, will be able to best develop their business. In the digital economy, data is the key to growth, and without it, progress would stop. The following years proved that Humby was right.

All the statistics about the largest companies by market cap show how much the value of data industry has grown at the expense of the oil industry in the last years. Today the most important players are all Internet service providers, thus suppliers of digital data. Not only the players have ousted the oil producers in the ranking of most lucrative business, but they have also significantly increased their revenues over the oil industry. The digital knowledge industry has developed primarily with the refinement of data, as raw data is not usable on its own. Value enhancement is possible when data is collected, accumulated, and linked with other relevant and meaningful data.

Nevertheless, unlike oil, which is a non-renewable source, data is not limited, it is reusable, and its quantity will continue to grow in the future. Despite being a sustainable source, data must be protected and maintained. Not only does it contains patterns, indicators, and information, but it is also a renewable supply without limitation. You can repeatedly use the same data for different purposes and applications. Data not only needs to be refined but also needs to be cultivated and curated to be fertile. For this reason, other scholars highlighted that data is not oil but rather “a new soil”. According to British journalist David McCandless,³ data is a reusable resource for producing new forms of value that, in turn, feed new data in a virtuous cycle. McCandless sees data as fertile soil that can be cultivated and reused over time (unlike oil). Data is a valuable

² Palmer 2006.

³ McCandless 2010.

resource that makes new products blossom and improves the user experience. Data takes root and multiplies in an evolving ecosystem for the benefit of tomorrow's users. Like soils that are not all equal, data to be transformed into fertile resources require the careful and competent work of scholars/farmers.

The increasing use of data is contributing to a paradigm shift in science, which is more and more characterized by navigating an almost endless sea of data generating new knowledge. Data scientists are using advanced statistical and machine learning methods to produce more detailed information for various users, including decision makers. Data organisation, and especially its standardization through the use of shared data-models, becomes the benchmark for data integration, access and reuse for advanced research. The goal of the new paradigm is to aggregate data to discover meaningful information for decision making. Therefore, predictive analysis is a technique used to estimate the probability of an outcome based on past data. Because data science models today are computer simulations, different possible scenarios can be easily tested, enabling stakeholders to make an informed decision. But data science is not a mere application of solving complex mathematical calculations. Data analysts must possess domain knowledge to evaluate specific conditions in datasets and their aggregation. Value extraction requires solutions that allow searching for data from various sources and types. These sources can include applications, databases, web sites, and cloud environments and can come in all shapes and sizes, structured, semi-structured, and unstructured. Therefore, data must be standardized using coding models acknowledged by the relevant community before being processed and analysed.

The world of science has changed. The new approach involves data being acquired from instruments or generated by simulations before being processed by any software. Only then is the information or knowledge extracted by the data stored in computers. Scientists can only examine their data at a late stage in this process. The techniques and technologies for this data-intensive science are so diverse that it is worth distinguishing data-intensive science from computational science as a new, fourth paradigm for scientific exploration.⁴ This scenario is possible if we use appropriate mathematical methods and if data are encoded in a homogeneous way. People now no longer look through telescopes. They look through complex, large-scale instruments that transmit data to data centres, and only then researchers look at the information on their computers. This new approach has pushed toward open data and more collaborative and transparent science. If data is the fuel for any professional, economic, or research activity, then analytical and aggregation techniques are the tools for extracting new knowledge.⁵

Starting from these premises, 10 years after Humby, scientist Andrew Ng⁶ has uttered a new phrase that complements the previous one: "if data is oil, then artificial intelligence is the new electricity". Just as electricity has changed the world by disrupting transport, manufacturing, agriculture, and healthcare, artificial Intelligence will have a similar impact, even if it is not running as fast as we would expect for two reasons: the absence or scarcity of good data and the lack of specific skills capable of adapting the application of algorithms to contexts. Artificial intelligence is certainly very hungry for data, which

⁴ Hey, Tansle, Tolle 2009.

⁵ Huggett 2020b.

⁶ Ng 2017.

should be structured according to a standard knowledge representation scheme to be properly digested. Today's challenge lies in the ability to transform Big Data resources into valuable training models for machine-learning based applications.⁷

If data is the soil where products grow, Big Data should represent the harvest, while artificial intelligence should be the engine that reinforces soil fertility. Scholars-farmers should know when to sow, how to eliminate weeds, when to water, how to harvest the product and how to transport it, still fresh, to the scientific market.

Data collection and description are central to having good models and good harvest. The first issue that one encounters in this process is that very often data and information are confused with serious effects for the process of machine-learning. If, for example, a scholar includes dating and/or function or interpretation in data description, the machine will take these parameters into account when analyzing other similar data, thus influencing the result. For these reasons, the researchers need to spend about 50% of their research time to curate and prepare data before their use.⁸

Data and information are not interchangeable terms:⁹ data are individual entities, while information represents the structure and interpretation of those data. In other words, data are the building blocks of the house, while information represents the organisation of spaces. Data may come in the form of text, observations, figures, pictures, numbers, graphs, or symbols. Data is a raw form of knowledge and has no meaning or purpose. In other words, you must interpret the data to give it a meaning. Data can be simple and may even seem useless until it is analysed, organized, and interpreted. There are two main types of data: quantitative, provided in numerical form, such as weight, volume, or dimensions; and qualitative. Information, on the other hand, is the result of analysing and interpreting pieces of data. But what is the situation in archaeological research? Data has progressively become a key aspect not only in the reconstruction of the past, but also in practices dedicated to sharing archives.

The growth of user-friendly computer tools, as well as the increased availability of digital data and archives, is driving archaeologists to a greater understanding of digital techniques and methods also for the purpose of promoting the results of their own research. This has prompted scholars to think about promoting a new discipline called Digital Archaeology,¹⁰ the development of which can be traced back to the 1950s and 1970s.

Digital archaeology encompasses numerous fields of activity with related application areas that highlight some specific cross-cutting issues:

- The digital representation of the archaeological record.
- The normalized descriptions.
- The formalization of reasoning.
- The implementation of procedures for the validation of the archaeological discourse.

The extensive digitisation of data and of archaeological techniques themselves, such as surveying, photography and data processing is highlighting several critical areas. Despite the changes that computer science has brought to archaeological methodologies, there are some areas where a closer look at the relationship between archaeology and computer science is

⁷ The expression Big Data primarily identifies a data set that is too large or complex to be handled by traditional data processing software.

⁸ Marsolek *et al.* 2023.

⁹ Zins 2007.

¹⁰ Evans, Daly 2006.

needed. I will list just a few of them: the ambiguity and bias of data that make the integration of archives difficult; the ways of long-term preservation of legacy data and their reuse; and, finally, the development of 3D technologies aimed at creating BIM platforms according to the emergence of the so-called digital twin. Therefore, archaeologists must place, at the heart of the debate, the issue of the correct formalisation and digitisation of data by reflecting on the nature of the archaeological record, which today includes old paper and digital data.¹¹

3. Data-sharing

The first area of criticism and reflection must concern the data-sharing and the databases, the most basic, but also the oldest, form of data digitisation.

The figure 1 shows the record of a possible digital archive concerning the Professors at the University “L’Orientale”. The structure, typical of a database, has columns with attributes and rows containing values. It is a simple record, with some values such as a name (Andrea D’Andrea), an academic affiliation (the University “L’Orientale”), a location (Naples) and two disciplines (Digital Humanities and Archaeology). As the structure is flat and the knowledge is implicit, the lack of cross-references could create potential ambiguity; we do not know the relationship between Andrea and the University of Naples, just as we do not know the relationship with the city or the various disciplines. The author of the database can understand and process data, but a computer is not able to solve the ambiguity of the statements. Therefore, this dataset can be linked only to other data with a similar structure. To avoid implementing a database that meets all possible needs of every archaeologist, we can use the semantic technologies to reconstruct the representation of the record by eliminating ambiguities and inserting links and relations to overcome the uncertainty.

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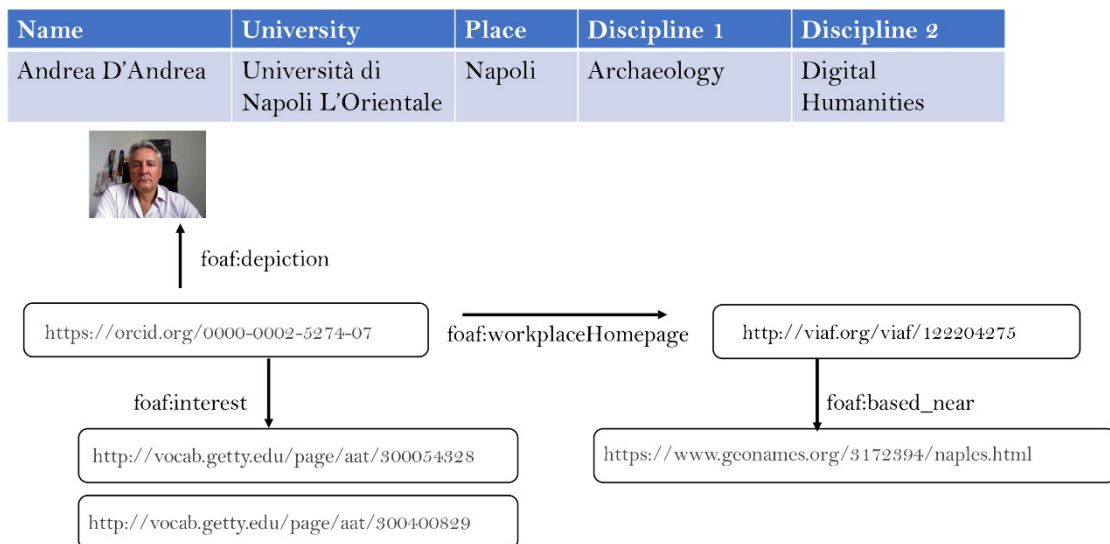


Fig. 1: On the top a simple text; in the middle the formalization of the text into a database; on the bottom the graphical schema of the semantic description of the text.

¹¹ Castelli, Felicetti, Proietti 2021; Huggett 2020a, 2022; Kansa *et al.* 2019.

To make my statement shareable and comprehensible by a machine, I must use a language based on a standard encoding with unambiguous terminology according to LOD (Linked Open-Data) principles.¹² In the example my name is replaced by my ID of ORCID¹³ which deleted issues with other Andrea D'Andrea researchers. Instead of the University of Naples "L'Orientale" I entered the URI (Uniform Resource Identifiers)¹⁴ of the public register VIAF;¹⁵ if the name of the university changes, I do not need to modify the record. For the location I use the list of places published by GeoNames,¹⁶ thus avoiding writing the city in English or in another language. Finally, to define the disciplines taught, I use the Getty AAT thesaurus.¹⁷ By adding some properties as *depiction*, *workplaceHomepage*, *interest*, *based_near* between the statements, I can enrich the description and make more explicit the record. By using a machine-readable ontology, codified in RDF (Resource Description Framework),¹⁸ it is possible to construct any kind of statement in form of triples that a computer can understand. If we use URIs instead of values, multiple connections and relationships can be potentially discovered. A truly open and collaborative science requires the use of metadata and thesauri to make data homogeneous and to enable the integration of archives.

To support the creation of good data for open science, some researchers developed in 2016 the FAIR (Findable, Accessible, Interoperable, Reusable) principles.¹⁹ These recommendations, mandatory for those receiving European funding for data-driven projects, should encourage scholars to open their data to achieve four goals: making data findable, accessible, interoperable, and reusable. FAIR Data simplifies the integration of repositories and ensures the integrity of the digital data and the long-term preservation. The rules of the FAIR principles enable data protection and, more importantly, can support a data-intensive approach by recognising a clear license in case of reuse by third parties.

Metadata schema, Open-Data, Linked Open-Data, Ontologies, and FAIR principles are the conceptual tools of the Semantic Web²⁰ that make discovery open, complete, and easily reproducible. Accelerating the change to a more open and shared space requires the adoption of behaviours compatible with the Open Science scenario.²¹ If the semantic technology facilitates the use of transparent, collaborative, and integrable workflows, the repositories, and the research infrastructures host systems able to map specific metadata or data models or with a mapping process between a local metadata system and a standard one.

¹² Linked Open Data (LOD) is a way of publishing structured data that, through the use of appropriate technologies and open web standards, allows resources to be linked together. LODs are readable by machines that can directly interpret the information on the web.

¹³ <https://orcid.org>

¹⁴ A URI is a unique sequence of characters that identifies an abstract or physical resource.

¹⁵ The Virtual International Authority File, <https://viaf.org>

¹⁶ <https://geonames.org>

¹⁷ Getty AAT (Art & Architecture Thesaurus) <https://www.getty.edu/research/tools/vocabularies/aat>

¹⁸ RDF is the basic tool proposed by the World Wide Web Consortium (W3C) for encoding, exchanging and reusing metadata by enabling semantic interoperability between applications sharing information on the Web.

¹⁹ Wilkinson *et al.* 2016, 2019; Hermon, Niccolucci 2021.

²⁰ The Semantic Web is an extension of the World Wide Web aimed at making data, found on the Web, machine-readable.

²¹ Huggett 2015.

Repositories are the first level of the Open Science perspective. They store a significant amount of information and perform several operations, including protecting, classifying, processing, searching, and duplicating documents. Resource management is centralized and implemented in an environment accessible from multiple hardware machines. Repositories ensure proper management of document flow through metadata and template-data that are compliant with international standards. Moreover, they facilitate classification and search mechanisms for data retrieval and visualization. OpenContext,²² tDAR,²³ and ADS²⁴ offer the best solutions to implement a simple archaeological repository in a secure cloud that deploy metadata compliant with FAIR principles. An aggregation of different archives is Ariadne,²⁵ a European research infrastructure aimed at aggregating archaeological data through a schema able to integrate digital data stored in different repositories. Ariadne manages more than 3.000.000 metadata and offers some services as mapping tool, guidelines, and recommendation for making data open and FAIR, and a platform to upload 3D data or images.

4. Legacy Data

A second critical area of so-called legacy data is that of archive management and maintenance.²⁶ Unlike the issues addressed in the previous section, which seem to have been solved by the evolution of semantic technologies, the area of legacy data involves the development of a largely manual approach. The term legacy data refers to a wide range of digital documents that cannot be (re)utilised without substantial migration to formal structures that have been updated to the latest technological and information processing innovations. A non-exhaustive list of legacy data includes:

- Records acquired in a predigital era or with early devices and stored in embryonic database forms.
- Records, often inaccessible, not usable in more modern computer applications.
- Records produced by Digital Archaeology and soon to become obsolete due to the rapid speed in the evolution of digitisation processes.
- Records belonging to abandoned research approaches.
- Records to be reused with substantial restructuring of data representation forms.

In short, these are digital resources, stored somewhere in our computers, but which need to be revised to be reused. There is a wide variety of legacy data, but the most widespread are the outcomes of the massive digitisation that took place in the 1990s in archaeology without any standards or long-term preservation perspective.

Archaeologists frequently come across digital data or archives created at the dawn of digital archaeology. One of the most complex aspects to deal with concerns the transfer of old archives into new digital formats and structures without changing or forcing their content. If one wants to introduce old excavation data into a database that records new stratigraphic information, it is not correct to adapt the previous data to the new excavation and documentation methodologies, but,

²² <https://opencontext.org>

²³ The Digital Archaeological Record <https://core.tdar.org>

²⁴ Archaeology Data Service <https://archaeologydataservice.ac.uk>

²⁵ <https://www.ariadne-research-infrastructure.eu>

²⁶ Allison 2008.

on the contrary, to safeguard the different approaches used, which must remain distinct. This solution may not allow research or comparisons to be made on all the data acquired, but forcing the nature of the legacy data, to align all records, could lead to an alteration of the original data and a falsification of the results.

In a recent revision of the documentation of the investigation of the medieval city of al-Balid, ancient Zafar, in Oman, it was necessary to migrate the old CAD archive, created in the 1990s, to a GIS application.²⁷ Although CAD has long been the most widely used drawing programme to produce plans and sections, even in archaeology, the need to integrate a multiplicity of georeferenced spatial information sources has driven many scholars towards the adoption of GIS systems to ensure better management of the data associated with geometries. Despite the common basis of geometric primitives to represent any spatial information, the conversion of CAD data into GIS is not exclusively an automatic process.

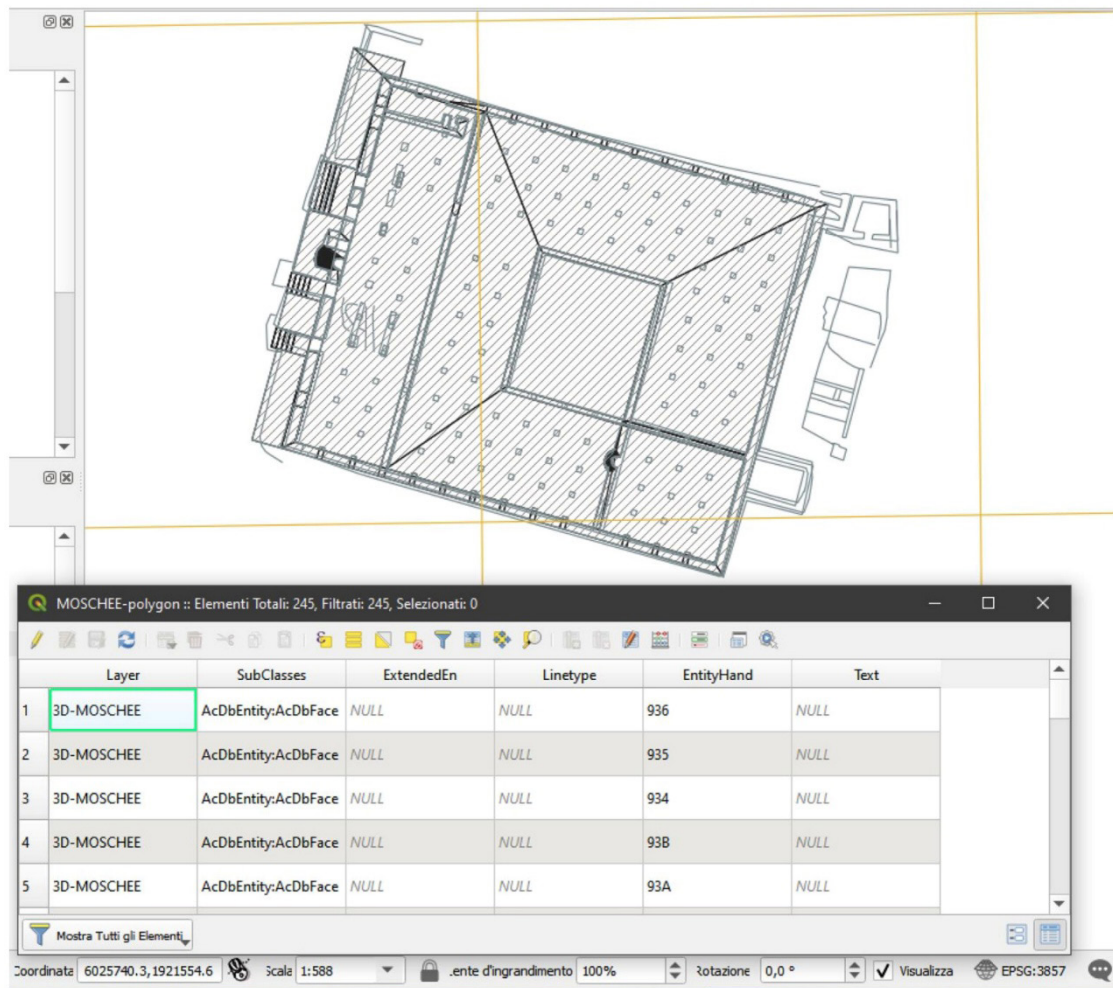


Fig. 2: On the top the plan of the Great Mosque visualized into QGIS. On the bottom the table associated to the 245 geometrical entities imported into QGIS from the original CAD file.

²⁷ D'Andrea 2021.

Figure 2 shows the result of importing a CAD file of the Great Mosque into QGIS. While the drawing appears geometrically correct, the various structural and architectural parts of the building are not defined in layers or semantic objects, but rather in individual entities, thus making the automatic import of vector objects impossible.²⁸ Probably the simplest and most correct way would be to re-draw the spatial information, but this would raise a problem with the re-arrangement of the imported geometric data.

When archaeologists identify a layer, they first define it in space by drawing it in plan. Often, however, due to the inconsistency and reworking of deposits, it is not possible to precisely indicate the boundaries of the layer; in such circumstances, the drawing shows dotted lines that suggest the uncertainty of the boundaries. From the planimetry, it is therefore not always possible to reconstruct the boundaries of the layers without having a text that clarifies their extent and spatial relationships with other stratigraphic units. Since GIS requires the association of a geometric datum with an attribute, without manual intervention it is not possible to import a CAD drawing and automatically create archaeological objects. Furthermore, only through the description of the relationships between the various deposits is it possible to reconstruct the topology. Conversion is therefore not based on the development of automatic procedures, but on patient work that consists of following the transition from graphic and geometric entities to a semantic digital system using the available archaeological documentation, even if it is largely incomplete and often lacking the necessary stratigraphic data. In short, GIS does not replace CAD. After developing an appropriate strategy for the migration of legacy data, good metadata must be associated with the spatial data to enable preservation and reuse of the spatial archive.²⁹

5. 3D Replica

The third and final critical area is that of 3D replicas. The topic does not concern acquisition and restitution tools and methodologies. The 3D technology industry has made great strides in recent years and today we have low-cost tools that allow the acquisition of complex architectural structures in a short time and with great accuracy.³⁰ Many protocols have been developed to produce geometrically correct digital replicas and there are various equipment and methods to obtain good 3D reproductions. On the geometric information processing side, studies on semantic segmentation are opening new frontiers for the automatic management of large amounts of 3D data. Unlike semantic data and legacy data, which remain areas of study, 3D is now an integral part of professional and academic archaeology.

²⁸ Bibby, Ducke 2017.

²⁹ Chapman 2001.

³⁰ Bosco 2022.

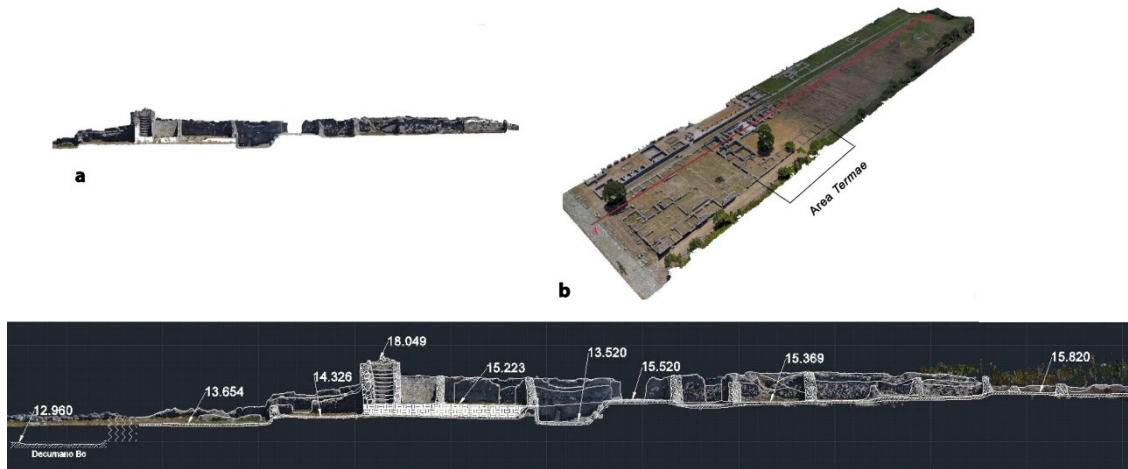


Fig. 3: The 3D replica of the Insula 4-6 of Paestum.

The introduction of BIM (Building Information Modelling) also in archaeology has made it possible, the entire 3D workflow has been reorganised and given a specific structure that goes beyond the production of simple and beautiful images or interactive models. BIM allows traditional graphic documents such as sections, elevations and plans to be easily extracted from 3D. In Figure 3 one can see the result of a recent archaeological investigation in a block of Paestum.³¹ The model was generated by integrating different 3D spatial technologies, such as aerial and terrestrial photogrammetry and laser scanning. Georeferencing was performed using points measured with GPS. BIM greatly facilitated the work of rendering and analysing geometric information, but, in my opinion, this is not what makes the software or the BIM approach truly innovative.

The most important feature of BIM is the creation of libraries that can be easily shared. Analytical descriptions of walls, materials, binders, and construction techniques can be used to identify certain parametric values characteristic of a specific masonry work. This data can, in turn, be reused to reconstruct missing architectural and construction components of other buildings, even those belonging to other archaeological contexts. The library can be encoded in a standard language and format and imported into other projects, constituting a special form of shared knowledge that can be used by different specialists.

BIM is certainly a second-hand technology, as the software was originally developed for civil engineering. However, today it is also widely used in archaeological research for the study and understanding of architectural techniques and historical buildings. Unlike three-dimensional reconstructions, created for scientific or popular reasons, in which the choices made by the scholar are invisible to the user, BIM records every logical-functional step of the monument reconstruction process, from the import of the 3D replica to the modelling and definition of attributes, allowing any formal verification of the process.

³¹ Bosco *et al.* 2020.

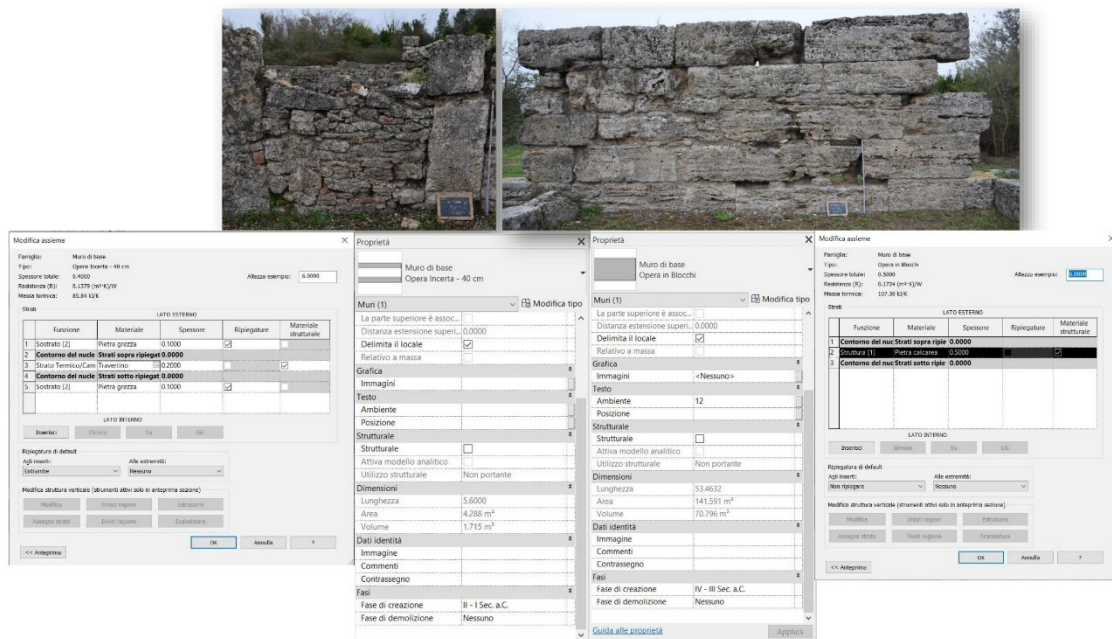


Fig. 4: Different construction techniques described in BIM.

Figure 4 shows the description of two masonry techniques encoded in a structure very similar to a database connected to geometric data. The libraries function like Lego bricks that can be used to reconstruct other contemporary architectures and structures. The possibility of sharing libraries makes BIM a tool of great impact on the study of ancient architecture that shows a minimum of standard structuring to a certain extent that can be parameterised. In another example, developed for the solar temple of Niuserra,³² we demonstrated the strength of an approach that makes the reconstruction process transparent based on assumptions that can always be verified.

The archaeological object, decomposed and organised into different semantic levels, can be easily interrogated. The digital replica becomes the basis for the formulation of alternative reconstructive hypotheses and for simulations aimed at ensuring the preservation of the monument. This interaction, guaranteed by BIM between the physical and virtual world, is one of the distinguishing features of the Digital Twin, which is not only a geometrically correct replica of an object, but also a metaphor for a digital sphere in which the researcher can perform different types of tasks.

The Digital Twin is a computational representation of an abstract or real physical product, system or process that acts as a replica for practical purposes such as simulation, integration, monitoring, and maintenance. The digital replica enables continuous feedback between real and virtual that enriches the knowledge of the monument and improves its preservation. The Digital Twin is not simply a digital and static replica, perhaps with more detail, but a digital document that can be viewed and interrogated dynamically from multiple disciplinary perspectives. The virtual model can become the

³² Bosco *et al.* 2019.

pivot point of a possible metaverse that starts from a digital replica and is enriched through content on the web.

In a recent project aimed at digitising the Catacombs of San Gennaro in Naples,³³ the final product was uploaded onto the Sketchfab³⁴ platform and enriched with annotations and links that refer to further descriptions or details of the monument acquired with different techniques. The currently available network of relations and references was implemented manually; in the future these connections may be generated automatically. In this perspective, it will be necessary to have good models and 3D replicas, but also good metadata associated with digital objects published on the web. The metadata schemes currently available in the repositories mentioned above are not able to correctly describe the 3D digitisation protocol.

A solution to this critical issue was provided by the European project 3D-ICONS,³⁵ which developed a specific metadata schema based on digital provenance and paradata. Provenance describes the technical process of digitising the replica, i.e. the tools used to capture and process the data, while paradata should be used to indicate the reasons why the replica was created. Paradata can also contain information that makes the process of interpreting a monument transparent by clarifying the assumptions followed by the author in the reconstruction. The metadata developed in the 3D-ICONS project can capture the semantics related to the physical object and the methods and tools used to achieve the digital replica. The scheme, designed to provide 3D replicas of archaeological monuments to the Europeana library,³⁶ reuses part of the CIDOC-CRM ontology³⁷ and its extension CRMdig.³⁸ Furthermore, where possible, for some fields the values are expressed as URIs to facilitate possible further connections.

6. Conclusions

The paper examined the importance of data not only for scientific research but also for society more generally. Next, some critical areas in archaeological data management that would require more attention from scholars were highlighted and described. First, the knowledge and databases are not shared, thus making it less easy to create added value for interdisciplinary research. In addition, the excess of data virtually available on the web complicates the work of analysis and information retrieval. Finally, considering the increasingly complex tasks of researchers, the future challenge will be to create datasets that can be queried and aggregated by automated agents. Researchers must, therefore, be aware that not only physical assets must be protected, but also digital archives that risk being underutilized or, at worst, dispersed. While technology enables innovative strategies for long-term preservation, the lack of standardization often makes it difficult to extract data from interconnected archives. The challenge in the coming years will be increasingly related to the need to produce quality digital data associated with metadata that also records the processes of digitisation of sources.

³³ Bosco, Minucci 2020.

³⁴ <https://sketchfab.com/GlobalDigitalHeritage/collections/catacombs-of-san-gennaro-italy>

³⁵ <http://3dicons-project.eu/>

³⁶ <https://www.europeana.eu/it>

³⁷ CIDOC Conceptual Reference Model (CRM) <https://www.cidoc-crm.org>

³⁸ CRM Digital <https://www.cidoc-crm.org/crmdig>

Archaeology as a science has developed in parallel with the transformations of a society that today appears increasingly immersed in the digital domain. If scholars must invest part of their working time to the curation of data, it is necessary at the same time to ensure the transparency and reproducibility of digital processes thus increasing the credibility of archaeological research. The quality and integrity of archives play a central role at the data reuse stage and in the independent evaluation of final research results. The sharing and accessibility of archives should encourage researchers to create quality data, while the adoption of open science principles and practices should promote inclusiveness by removing those financial, institutional, and cultural barriers that prevent researchers from freely exchanging knowledge, methods, and data.

The future appears to be shaped by the development of a 5.0 society, centred on the balance between economic progress and problem solving within a space that is not only physical but also cybernetic. Digital ecosystems will concretely support this transformation by connecting people, things, data, and knowledge through the spread of semantic technologies, artificial intelligence algorithms and Digital Twins. Technological changes in the coming years will progressively free scholars from very demanding manual tasks by innovating the methodologies of archaeological research and outlining new perspectives for the study and reconstruction of the ancient world.

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Online Resources

ADS	https://archaeologydataservice.ac.uk
ARIADNE	https://www.ariadne-research-infrastructure.eu
CIDOC	https://www.cidoc-crm.org
CRM Digital	https://www.cidoc-crm.org/crmdig
EUROPEANA	https://www.europeana.eu/it
GeoNames	https://geonames.org
Getty AAT	https://www.getty.edu/research/tools/vocabularies/aat
OpenContext	https://opencontext.org
ORCID	https://orcid.org
Sketchfab	https://sketchfab.com/GlobalDigitalHeritage/collections/catacombs-of-san-gennaro-italy
tDAR	https://core.tdar.org
VIAF	https://viaf.org
3D-ICONS	http://3dicons-project.eu/

Mobile 3D recording as a means of digital preservation. An experience in documenting stone structures from the west bank of Aswan (Egypt)

Sara Facciani, Alessia Brucato, Alberto Urcia,
Antonio Curci & Maria Carmela Gatto

Abstract

This study presents our experience documenting stone structures during the 2022 Aswan-Kom Ombo Archaeological Project (AKAP) field season. Using a combination of smartphones and GIS software, we established a recording workflow for a week-long pedestrian survey at two prominent sites on the west bank, north of Aswan. These locations contain numerous stone structures that vary in position, typology, and function. WK71 is a cluster of Late Roman tumuli located on the plateau behind the modern village of Nag el-Qarmila, covering approximately six hectares. NH11 is similarly situated atop a plateau extending toward the river, just north of the village and namesake of the renowned rock art site of Nag el-Hamdulab (NH1). This site spans roughly 19.5 hectares and contains several archaeological features, including numerous stone structures of uncertain function and date. Satellite imagery was instrumental in the preliminary documentation and fieldwork planning. During the survey, we recorded the stone structures in 3D using smartphones, placing metric references on the ground to ensure accurate scaling and orientation of the digital models. To assess the accuracy and reliability of this experimental approach, we supplemented the documentation with additional 3D and linear measurements using other devices and recording techniques, such as digital cameras and Structure from Motion.

Thanks to the inbuilt GPS/GNSS receiver, all stone structures processed through the smartphone app were embedded with global WGS coordinates, facilitating precise geo-positioning within the project's coordinate system. Additional software allowed us to generate planar ortho-projections of each structure, which were then imported into the GIS project for vectorization and spatial analysis. This workflow enabled us to document over 140 archaeological features in a short time without compromising resolution or accuracy. Moreover, it allowed for a preliminary archaeological classification of these features before the field season concluded.

Keywords: *3D scanning app; Stone structures; Digital preservation; GIS; Egyptian Archaeology.*

1. Introduction

This paper provides a more technical perspective on the archaeological and topographic documentation of two large stone structure sites discovered within the concession areas of the Aswan-Kom Ombo Archaeological Project (AKAP) (Fig. 1).¹

The two sites, Wadi Kubhaniya 71 (WK71) and Nag el-Hamdulab 11 (NH11), are both situated on the west bank of the Nile, near New Aswan City. WK71, named after its location in Wadi Kubhaniya, is part of a larger Late Roman stone tumuli site associated with the ancient town of Nag el-Tawil, approximately 20 km north of Elephantine, in the heart of old Aswan. NH11, on the other hand, is located atop a shallow plateau on the western edge of Nag el-Hamdulab, a modern village from which it takes its name. The chronology and function of NH11's stone features remain uncertain. The data obtained

¹ www.akapegypt.org

from the limited number of excavated structures are not yet sufficient to determine the site's purpose. However, its broader context and the materials discovered indicate that it predates the modern era.

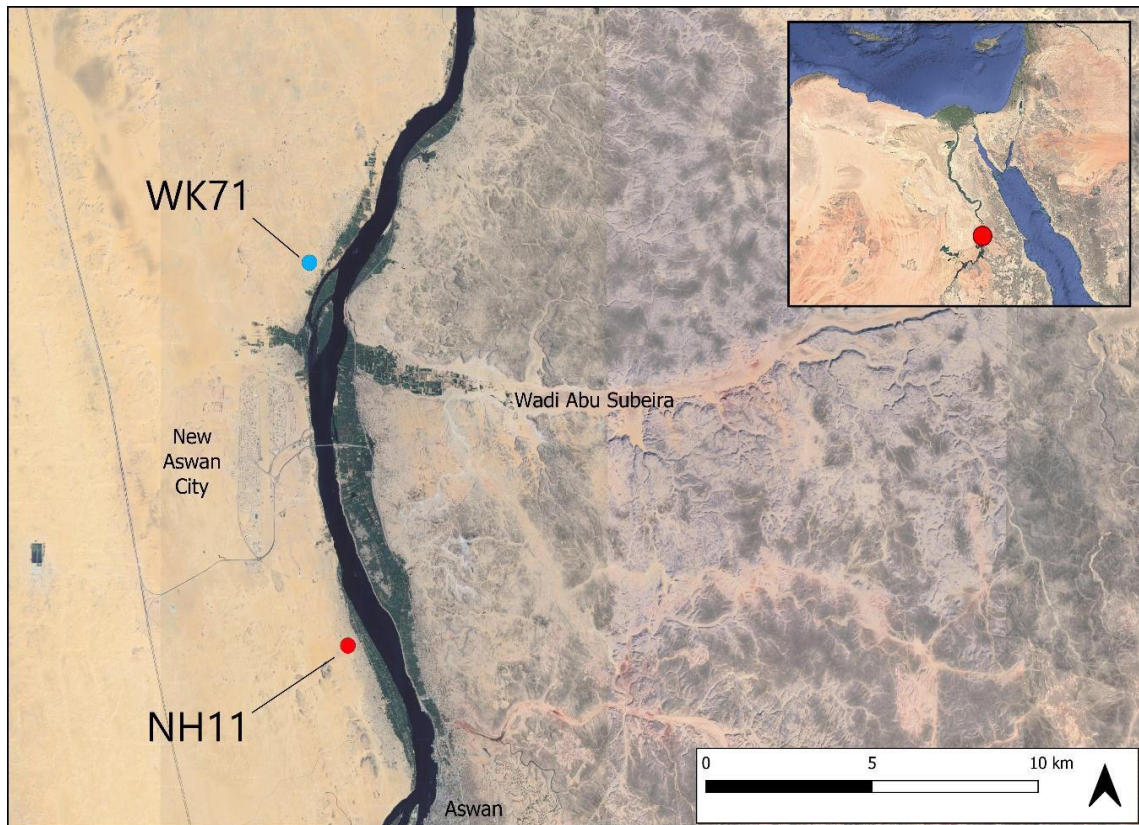


Fig. 1: Locations of WK71 and NH11 in the West Bank of Aswan (Egypt).

A crucial aspect of this case study is the precarious state of preservation of both sites. Their proximity to modern villages significantly threatens their survival. The increasing expansion of human activities along the Nile Valley—particularly urbanization and infrastructure development—continues to endanger Egypt's antiquities,² leading to substantial losses since the late 19th century.

Given these risks, it was essential to develop a fast yet effective recording strategy to document the large number of archaeological structures at these sites. The project was structured into four key phases:

1. Conducting a preliminary geo-morphological and topographic analysis using remote sensing applications.
2. Recording the sites through mobile-based photogrammetry.
3. Processing the collected data.
4. Managing and mapping the information within a Geographic Information System (GIS).

² Bewley *et al.* 2016; Rayne *et al.* 2017; Rayne *et al.* 2020.

This workflow allowed for a more systematic approach, helping to identify and address procedural, material, and technological limitations.

A standard photogrammetric workflow was unfeasible due to the high number of features requiring documentation, the limited timeframe (one week), and the small team (two members) available for the task. Additionally, a significant obstacle was the ongoing ban on Unmanned Aerial Vehicles (UAVs) and other aerial vehicles across Egypt. Imposed by the authorities for security reasons, this restriction applies to all nonmilitary activities. Beyond this limitation, access to professional topographic and 3D scanning equipment—such as laser scanners, total stations, and differential Global Navigation Satellite System (GNSS - dGPS)—was also a challenge. These devices are difficult to source or import into Egypt, and they were either unavailable on-site or beyond the project's budget, preventing their inclusion in the survey equipment.

From this perspective, the methodological framework for documenting NH11 and WK71 was further refined by maximizing the use of archival data and satellite imagery. Critical fieldwork data—including descriptions, sketches, photographs, and measurements—were integrated with 3D recordings of the stone structures, processed, and systematically stored within a GIS project. AKAP, a joint initiative between the University of Bologna and the Polish Academy of Sciences, has been conducting research in the region between Aswan and Kom Ombo since 2005. The project's primary field activity is a geoarchaeological survey focusing on selected areas along the river and the desert hinterland. Among the identified sites are the two large clusters of stone features discussed in this study.

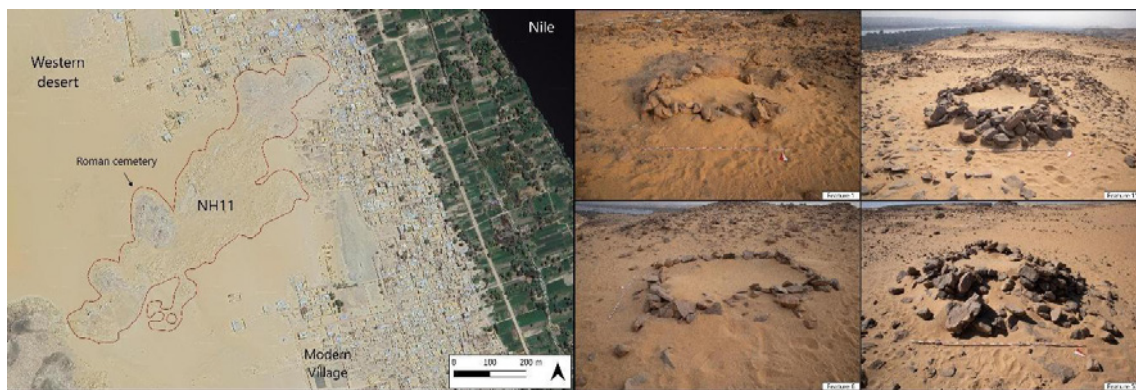


Fig. 2: (On the left) Location and extension of NH11. (On the right) Examples of stone structures at NH11.

2. Archaeological background of the two case studies

NH11 spans approximately 19.5 hectares and is situated atop a small plateau at around 160 meters above sea level (a.s.l.). It overlooks the modern village of Nag el-Hamdulab, located about one kilometer from the Nile (Fig. 2). This plateau marks the northern boundary of the wadi that shares its name, where the renowned rock art panels dating to late Dynasty 0 (3200–3100 BCE ca.) were discovered³ and later documented by

³ Hendrickx *et al.*, 2012.

the AKAP team. More information on these rock art panels can be found in the Digital Interactive Book: AKAP NH1 DIB.⁴ NH11 is positioned on the hill to the north/northeast of viewpoints A, B, and C.

On the steep northwestern slope of NH11, where an intermediate terrace runs along the flank of the main relief, numerous looted Late Roman hypogeal tombs are present. Similarly, at the southwestern end of the plateau, a massive circular mound (tumulus) measuring 21 meters in diameter dominates the small hill atop a low inselberg rising from the southern slope. Beneath this imposing structure, several Late Roman features are carved into the inselberg's flanks, forming a complex network of underground tunnels.

A past topographic survey identified a large number of stone structures (244 recorded so far) of various shapes and sizes in the surrounding area (Fig. 2). These features, scattered across the relief, do not appear to be directly associated with the Roman burials or the large tumulus. Their forms can be categorized into eight classes: subcircular rings, square rings, double rings, small rings, rings with accumulations, elongated structures, and round or amorphous stone accumulations. The average size of these structures is approximately 5.6 m², though there is significant variation in dimensions across the site. No distinct orientation or distribution patterns have been observed. Their function and chronology remain uncertain and will be clarified through future investigations.

Approximately 11 kilometers north of NH11, site WK71 is located on the eastern edge of another large plateau (altitude ca. 154 m a.s.l.), near the villages of Nag el-Qarmila and Wadi Kubbaniya.⁵ This site was first identified during previous AKAP field missions (Fig. 3). While the entire archaeological area of WK71 spans approximately 6.6 hectares, the stone structures examined in this study are concentrated along the plateau's Nile-facing side.

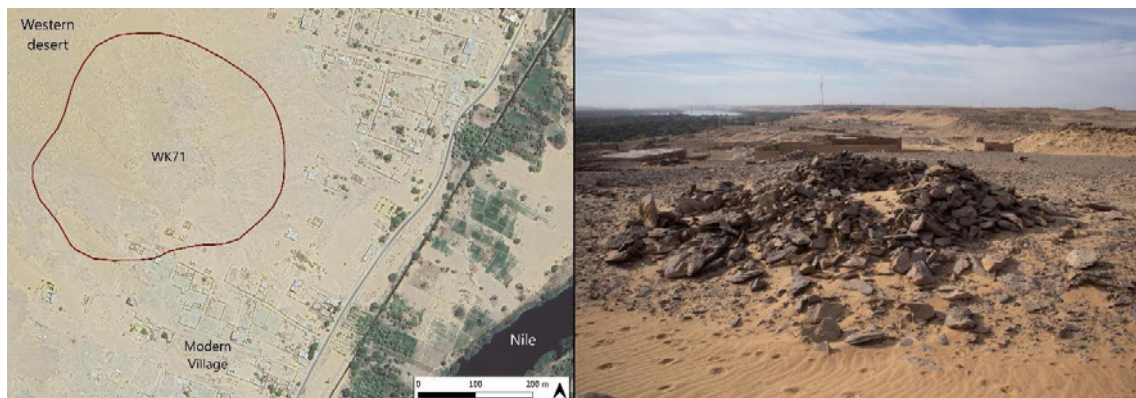


Fig. 3: (On the left) Location and extension of WK71. Example of a tumulus from WK71 showing the overlooking position of the site.

Initial investigations suggested a preliminary Roman-period chronology for these structures, though they had not been extensively documented. During the 2022 field

⁴ https://www.akapegypt.org/media/AKAP_NH1_DIB/index.htm

⁵ Banks *et al.* 2015.

season, 38 stone features were recorded, showing little variation in morphology and orientation. Most of these structures are located on the eastern side of the relief, with only two isolated examples found to the west of the main site. They consist of stone slabs quarried from the local bedrock, arranged in subcircular formations. Their diameters range from 2 to 7.5 meters, with a maximum height of approximately 0.60 meters (Fig. 3).

In both NH11 and WK71, the high visibility of the archaeological features in satellite imagery and on the ground greatly facilitated preliminary documentation and planning for 3D recording. However, these same conditions have also made the sites vulnerable to looting and other destructive activities over the years, often compromising their integrity. This ongoing threat underscores the urgency of promptly documenting both sites before further damage occurs.

3. Acquisition and processing methods

3.1 Remote sensing

Two team members completed the entire project in approximately two weeks, organizing the work into four operational phases:

1. Preliminary observations using remote sensing
2. 3D recording of the structures and field annotations
3. Post-processing of 3D data and measurements
4. GIS mapping and analysis

The satellite-based investigation of the two sites was conducted alongside other project activities during the first week of fieldwork. This step was crucial for generating preliminary documentation to support the ground-level survey. Key attributes such as the number of structures, their average dimensions, orientation, shape, and position were imported into a Quantum GIS (QGIS) project.⁶ A selection of base maps was integrated, ranging from widely used datasets like Bing Maps and Google Earth to more specialized resources such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Map (ASTER GDEM) open-access repository.

Bing and Google imagery, which provide composites of Very High Resolution (VHR, <1m/px) RGB raster files from various sources (Earthstar Geographics SIO, Maxar 2023, Landsat 8 NASA, IKONOS, QUICKBIRD), were sufficient for detecting and analyzing the spatial distribution and general morphology of the structures. However, ASTER GDEM's lower spatial resolution (>15m/px) allowed only for broader landscape evaluation.

To mitigate georectification errors inherent in non-professional mapping sources like Bing and Google⁷, additional manual adjustments were required to ensure proper overlay alignment before analysis. In the NH11 and WK71 areas, the Bing Map tiles provided more accurate location and projection data than Google Earth tiles. However, Google Earth imagery had superior color and pixel resolution. To optimize both accuracy and visual clarity, the remote sensing analysis was conducted using Google Earth tiles reprojected onto a Bing Map base layer.

⁶ <https://qgis.org/>

⁷ Youngu *et al.* 2022.

3.2 Photogrammetry

Building on the preliminary results from remote sensing analysis, the fieldwork was initiated, structured into four distinct operational sub-phases. The first step involved verifying satellite-detected features on the ground. This process was crucial for distinguishing genuine archaeological anomalies from modern disturbances. Notably, most of the features identified in satellite imagery corresponded accurately to the findings observed onsite. Simultaneously, new descriptions and measurements of the structures were recorded and integrated into the archaeological database. Special attention was given to assessing the degree of preservation and documenting the presence of surface materials associated with each structure.

Following traditional archaeological documentation, 3D recording of the main archaeological features was conducted using either a Canon M50 Mark II reflex camera or an iPhone 11 Pro smartphone. The mobile application Scaniverse (www.scaniverse.com), available for iPhone and iPad via the Apple Store (www.apple.com), was tested for this research. Our team selected Scaniverse over other similar apps primarily because it operates entirely offline, utilizing the iPhone 11 Pro's A13 Bionic chip (Apple, 2019) for both Graphics Processing Unit (GPU) and Central Processing Unit (CPU) processing. This offline functionality allows for on-site scanning without reliance on internet connectivity. Despite not using external servers or cloud computing platforms, Scaniverse can generate 3D point clouds and high-resolution textured meshes within 5 to 15 minutes. Another key advantage of Scaniverse was its compatibility with Apple devices, which AKAP has previously relied on for their durability, reliability, and portability in hot and harsh desert environments. These factors made Apple devices the preferred choice for this type of survey.

Scaniverse offers scanning options based on photogrammetry and, when available, laser measurements. While all Apple devices from the iPad Pro 2020 and iPhone 12 Pro onward feature built-in Laser Imaging Detection and Ranging (LiDAR) cameras, our study relied solely on photogrammetry-based functions, as we used an iPhone 11 Pro. The Structure from Motion (SfM) algorithm processes frames from a real-time video captured by the phone's front camera (typically the highest-resolution camera). It then calculates depth masks and generates digital surfaces (meshes) of the scanned object or scene. A key feature of Scaniverse is its ability to embed and preserve GPS, gyroscope, and accelerometer data, allowing for rough positioning and georeferencing of the models.

Scaniverse provides three object size presets for calibration:

- Small (<1m)
- Medium (≈1–4m)
- Large/Area (several meters)

During scanning, the app uses Augmented Reality (AR) to guide user movements and acquisition. A real-time video frame overlay provides progressive visualization, enhancing resolution while employing false-color or blurred overlays to highlight the scanned object's structure. More details on this functionality can be found at Scaniverse Support.⁸

⁸ For information on how to use Scaniverse 3D Scanner for iOS and Android, see <https://scaniverse.com/support>

Once the video-based acquisition is complete, the point cloud can be optimized before processing the 3D mesh. Scaniverse offers three processing modes:

- Speed – Uses a basic Depth Fusion, providing a fast but less accurate result.
- Area – Employs an advanced Depth Fusion, balancing accuracy and processing time (a few minutes).
- Detail – Based on Photogrammetry/SfM, producing the most accurate model but requiring the longest processing time.

The scan's raw data (video-derived images and point cloud) can either be saved or deleted, but only the point cloud can be exported. The final texturized model can be visualized in Virtual Reality (VR) or as an Augmented Reality (AR) scene within the app. Scaniverse also allows users to measure, edit textures, create video clips, and export 3D models in multiple formats (FBX, OBJ, GLB, USDZ, STL, PLY, LAS).

On April 20, 2024, Scaniverse introduced an update featuring Gaussian Splatting, a volume rendering technique that visualizes 3D objects without converting them into surface or line-based representations⁹. This update significantly improved AI-trained photorealistic rendering, particularly for shiny or transparent surfaces. Users can also reprocess older scans using Gaussian Splatting, provided they have retained the raw data—though this replaces the original texturized mesh, as the app currently lacks a duplicate scan feature.

The average time required to scan and fully process each stone structure at NH11 and WK71 was approximately 10 minutes. Despite the advantages of mobile 3D scanning, this technology remains relatively new and requires careful data acquisition (including metric, georeferencing, and orientation redundancy) and rigorous archiving (with enhanced annotations and measurements). To ensure accuracy, each structure was scanned with multiple references (e.g., scale bars, north arrows).

Since the phone's internal gyroscope lacks the precision needed for vertical orientation, manual verification and correction were performed. Additionally, the mobile scans were compared against traditional camera-based photogrammetry and stratigraphic excavation data from one of the NH11 structures (F53). This comparative analysis proved invaluable for assessing resolution, texture quality, and geometric accuracy across different 3D modeling methods (Fig. 4 and see *infra* § 3.3).

3.3 Data Processing

The camera-based 3D recordings were processed using professional image editing software such as Adobe Bridge and Lightroom¹⁰ to equalize and prepare the images for the 3D workflow. The 3D models were then generated using Agisoft Metashape Pro,¹¹ a widely recognized software with a robust processing workflow that extends beyond Structure from Motion (SfM). Metashape enables advanced operations such as point cloud and mesh filtering, classification, geo-processing, 2D/3D drawing, and ortho-rectification.¹² The orthorectification function in Metashape is particularly crucial

⁹ Westover 1991.

¹⁰ www.adobe.com

¹¹ www.agisoft.com

¹² Metashape User Manual (<https://www.agisoft.com/downloads/user-manuals/>; González-Quiñones *et al.* 2022).

for producing ortho-mosaics (composite orthographic views) of archaeological features. However, since Scaniverse automatically processes footage into 3D data within the app—without the ability to create ortho-mosaics—each model was exported as an OBJ file and subsequently imported and processed in CloudCompare (CC).¹³ CloudCompare (CC) is a point cloud editor capable of performing various operations on 3D models, including ortho-projections, making it an essential tool for refining and analyzing the data collected during the survey.

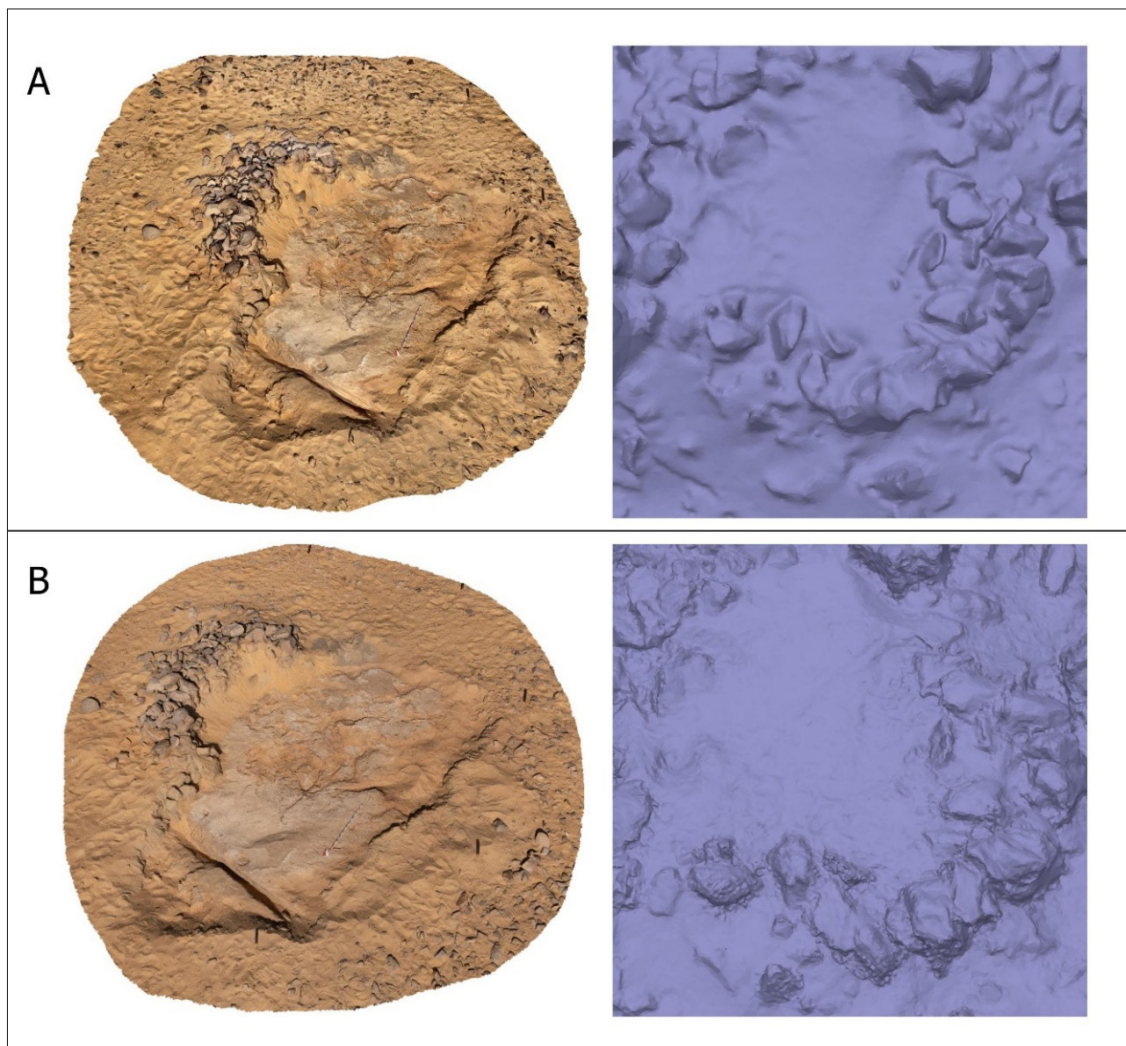


Fig. 4: Structure F53 - Comparison between: A. Model produced using the smartphone + Scaniverse; B. Model produced by camera + Metashape.

3.4 Mapping and drawing into the GIS

The resulting ortho-images were then imported into QGIS for vectorization and subsequent spatial analyses. Due to the relatively simple morphology of the stone

¹³ www.danielgm.net

structures, ortho-rectification of the models was unnecessary, as exporting them as orthographic top-view images did not introduce any significant metrical distortions. This is because our tumuli are not characterized by significant reliefs (data along the Z axis) in relation to their planimetric shape (data distributed on the X, Y axis), a condition that keeps errors between the 3D projection of the object on the bidimensional plan or its view from above, equal or less than 1cm (so largely within our range of accuracy). This approach provided a reliable dataset of raster images, which were then vectorized and exported as shapefiles for further geospatial analysis. However, due to discrepancies between the spatial accuracies and coordinate reference systems (CRS) of the satellite images and the model-derived ortho-images, it was necessary to override the embedded location data of the ortho-images. To correct this, satellite base maps were used as a reference. This georectification process was carried out using the QGIS Processing Toolkit along with the Freehand Raster Georeferencer plugin, enabling the graphical alignment of all documented data.

All ortho-images of the structures were carefully vectorized as polygonal shapefiles, and the associated database was populated with archaeological and metric information. The integration of satellite data with fieldwork observations enabled a comprehensive documentation and description of the majority of structures at both sites. Finally, within QGIS, various spatial analyses were conducted, including distribution and density evaluations of the structures. These analyses facilitated the creation of detailed graphic layouts and maps, enhancing the overall interpretation of the sites.

4. Results and Conclusions

The main goal of our paper is to describe and share the results of our field experience, which focused on documenting stone structures using app-based and non-Structure from Motion (SfM) recording techniques, while combining the data with GIS. During the experimentation, we gathered a series of technical and methodological insights, as well as identified advantages and disadvantages.

Firstly, the combined use of satellite analyses and SfM recording allowed us to promptly complete the documentation of 140 stone structures (102 in NH11, 38 in WK71) and the excavation of Feature 53 at NH11. Secondly, the preliminary use of remote sensing enhanced the effectiveness of our fieldwork by quickly gathering diverse information about the topography, landscape, and structures. In less than two weeks, we processed, validated, and organized all data from satellite readings and analyses, as well as topographic and photogrammetric recordings.

The mobile and camera-based 3D documentation of the structures allowed us to enrich the archaeological dataset and enabled comparisons between the two recording approaches. The acquisition time, influenced by the dimension and complexity of the structures, was almost three times faster using Scaniverse compared to the reflex camera. The larger image format of the DSLR camera (6024x4020 pixels) facilitated the creation of more accurate geometries compared to the iPhone 11 Pro camera (2436x1125 pixels). This higher resolution is also reflected in the difference between the point cloud counts of the two recording and processing approaches: Feature 53 scans showed a camera-based point cloud count of 700,000 versus a Scaniverse-based count of 170,000 points. Consequently, the meshes generated also differed in resolution (about 1,000,000 faces

versus 350,000). Differences were also noticeable in the texture: those produced by Scaniverse can achieve a maximum of 8k resolution, while the camera-based models always attain higher definition (thanks in part to the Metashape texture count tool).

In our case studies, the reduced resolution of mobile recording did not affect the visibility and interpretation of the archaeological structures, but it could represent a significant obstacle for documenting evidence with a high degree of detail and complexity (e.g., rock art panels, very small objects, etc.). Additionally, favorable environmental brightness and the almost complete absence of undercuts were advantageous conditions for performing the 3D recording. It would have been a different issue if the goal was to investigate highly detailed surfaces, such as depicted/carved rock art or inscriptions, and tiny decorated objects. Based on these results, the Scaniverse models generally show a resolution loss of about 70% compared to standard SfM models (Tab. 1).

Stratigraphy	Software (Vertices / Faces)	
	Camera-based / Metashape	Mobile-based / Scaniverse
Surface meshes	ca. 502.360 / 1.000.000	ca. 110.703 / 220.785
Layers 1-2-3 meshes	ca. 965.226 / 1.929.640	ca. 160.895 / 321.196
End of Excavation meshes	ca. 720.080 / 1.439.627	ca. 176.100/351.977

Tab. 1: Comparison between model mesh resolutions in F53 excavated layers.

An interesting option offered by Scaniverse is the ability to generate 3D models immediately after acquisition onsite, enabling a rapid check of the quality of the geometries (Mesh). Furthermore, like other similar apps, Scaniverse allows for the automatic calculation and embedding of metrical information, GNSS positioning, and geographic orientation with sufficient accuracy (at least for our type of structures and landscape). Nonetheless, we included metrical references such as scales and a north arrow in each recording scene to ensure redundancy and provide a backup control for the measurements.

This study also led to the identification of essential improvements and new functions for future applications in archaeology that are currently unavailable in the app:

1. Exporting pictures/video frames in raw formats (not only as points cloud);
2. Processing and exporting models in batch;
3. Enabling background mode processing;
4. Creating an ortho-rectification function within the software.

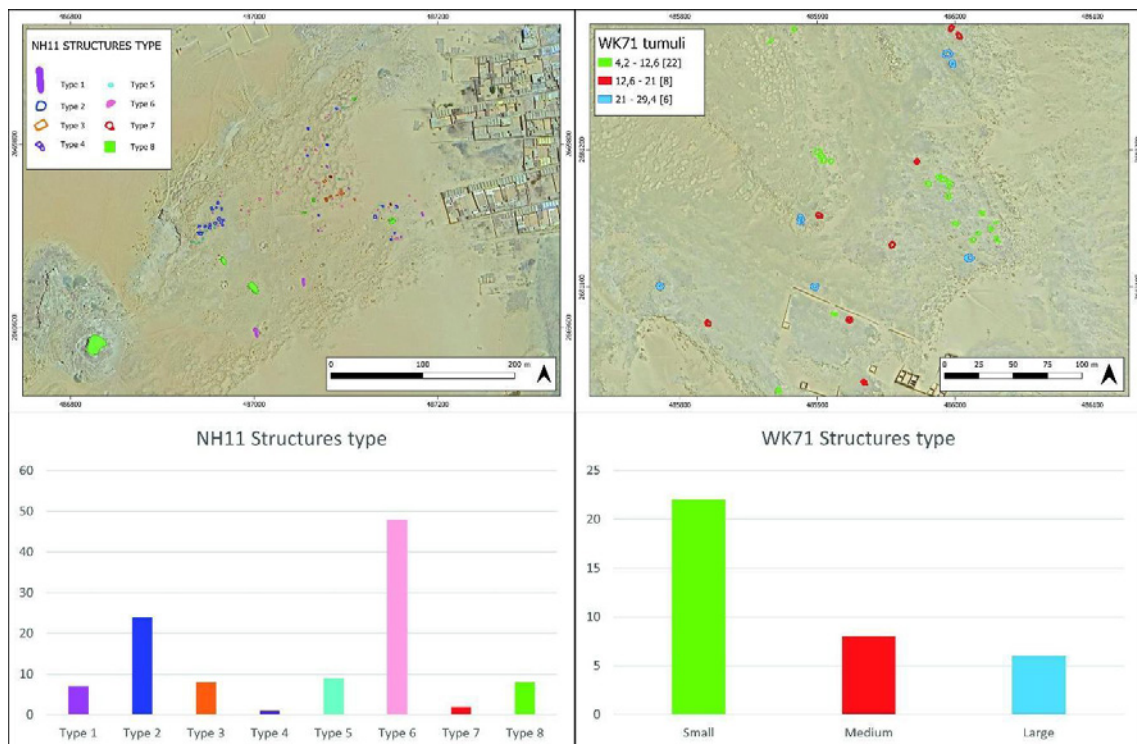


Fig. 5. (On the left) Morphological classification of stone structures at NH11 and their spatial distribution. (On the right), Dimensional classification of stone structures at WK71 and their spatial distribution.

QGIS was a very convenient choice to combine and manage all the data within the same environment, as it allowed us to easily integrate, process, and classify the features by morphologies, dimensions, positions, and densities. At NH11, we identified eight morphological classes (Fig. 5): subcircular ring, square ring, double ring, small ring, ring with accumulation, elongated shape, round accumulation, and amorphous accumulation. From a dimensional perspective, no significant differences were found at NH11 between the documented stone structures within the same morphological category. Conversely, in WK71, the main classification is determined by dimension (Fig. 5): small tumuli (ca. 4-8.9 m²), medium tumuli (ca. 9-13.9 m²), and large tumuli (ca. 14-29.4 m²). They could also be classified based on their position: most mounds are concentrated on the central plateau, with only two stone structures isolated on the western side of the site.

Throughout our work at the NH11 and WK71 sites, we observed that using smartphones to document large archaeological structures is a reliable and functional strategy, especially for endangered sites and challenging work conditions. By the end of the field mission, we were able to properly document two large areas without the need for advanced and professional topographic and 3D scanning equipment (such as Laser Scanners or UAV systems) and leave the field with sufficient data already processed and ready for archiving and publication.

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Online Resources

AKAP	www.akaegypt.org
Rock Art Site of Nag el-Hamdulab	https://www.akaegypt.org/media/AKAP_NH1_DIB/index.htm
QGIS	https://qgis.org/
Scaniverse	https://scaniverse.com/support
Adobe	www.adobe.com
Agisoft Metashape	www.agisoft.com ; https://www.agisoft.com/downloads/user-manuals/
Cloud Compare	www.danielgm.net/cc/

3D visualisation of fourth-century Christian monuments and archaeological sites of Egypt

Victor Ghica & Mohamed Abdelaziz

Abstract

The paper proposes solutions to four technical problems related to the photogrammetric recording of archaeological sites over several excavation seasons and to the visualisation of the resulting 3D models. The issues discussed are: cleaning sky-noise, merging models from different excavation seasons, blending sharp textures captured in different light conditions, and the mixed visualisation of structure-from-motion models and 3D reconstruction. The pipeline presented here was produced within the ERC project DEChriM in response to practical challenges encountered both on the field and during post-excavation processing. It allowed not only to enrich the project's library of structure-from-motion models, but also to document various excavation stages in dynamic 3D models and to supplement these with 3D architectural reconstructions.

Keywords: *3D visualisation; Photogrammetry (SfM); Model merging (Metashape); Texture blending; Fourth-century Christian monuments.*

1. Introduction

This short paper concentrates on the 3D data visualisation component of one of the work-packages of the ERC-CoG project DEChriM (*Deconstructing Early Christian Metanarratives: Fourth-Century Egyptian Christianity in the Light of Material Evidence*, grant agreement no. 819368).¹ Building on numerous field operations geared towards acquisition of archaeological data and supported by a massive repertoire of archaeological sites, DEChriM produced two databases, which have been opened to the public in September 2021. The first one, 4CARE (“Fourth-Century Archaeological Record of Egypt”),² is a GIS-based gazetteer of archaeological sites to which extant Christian material, mobile or immobile, is associated. The various types of metadata used as descriptors for each individual archaeological site incorporated in 4CARE include also photogrammetric models, which we produced for about half the sites of the database. What we are presenting here is the workflow our team developed for the 3D models – both photogrammetric and 3D architectural reconstructions – embedded in 4CARE.

Two quick preliminary notes on the rationale for embedding 3D models in the 4CARE database and the platform chosen for public visualisation. Besides its inescapable utility for off-site studies, our gallery of photogrammetric models represents a very limited and short-term answer to the problem of the preservation and accessibility of archaeological remains. Considered on the backdrop of the wide-spread and fast-paced degradation of exposed mudbrick constructions in Egypt, be it through natural processes, plundering or sheer vandalism, it is our team's desperate attempt to save something of the materiality of the phenomena we are studying. With that goal in mind,

¹ <https://4care-skos.mf.no>

² <https://4care-skos.mf.no/4care-database>

our project has been running a good number of field operations throughout Egypt for photogrammetric, and in two cases Terrestrial Laser Scanner (TLS), data acquisition. With regards to the platform chosen for publishing light versions of our Structure-from-Motion (SfM) and 3D reconstruction models, we have opted for the Sketchfab website.³ The versatility, cross-platform compatibility, and display capabilities of its 3D model viewer, including virtual (VR) and augmented reality (AR) content, go beyond those of customised in-house built viewers. Additionally, it could be easily integrated into the respective web pages on 4CARE, thus making it an ideal choice for us.⁴

The goal of this paper is to discuss four technical challenges that our project had to overcome: 1. cleaning of sky-noise; 2. merging models from different excavation seasons; 3. blending sharp textures captured in different light conditions; and 4. mixed visualisation (SfM model and 3D reconstruction). We have applied extensively this pipeline on DEChriM's excavations at Dayr Muṣṭafā Kāšif (2021, 2022 and 2025 seasons), Šams al-Dīn (2021, 2022 and 2025 seasons) and Dūš (2024 season), as well as during our surveys at ʿAyn al-Ṭurba (2019, 2021, 2022 and 2024 seasons). Similar techniques were also used for producing numerous other SfM models, all of which are embedded in the 4CARE database.

2. Cleaning of sky-noise

Because of the diverse types of difficulties encountered there, we shall be using the main structures of the site of Dayr Muṣṭafā Kāšif as the key example. Two key factors compounded the problems that we had to address: the complexity of the architecture (three floors, preserved height of walls up to 9.6m, numerous enclosed spaces with ceilings in situ, etc.) and the lack of equipment for aerial spatial data acquisition. In order to capture the built surfaces and the terrain, only close-range photogrammetry was accessible to us.

Although we photographed the entire monument only from ground levels (without using photography masts or ladders), we obtained a decent photogrammetric model. However, the upper parts of the building required a significant amount of postprocessing. Indeed, because of the angle of the camera photographing from the ground, the number of pixels on the top of the walls was reduced, with extra geometry appearing in the upper parts of the building blended with the sky. Manual cleaning of this parasitic sky-textured geometry was done in Agisoft Metashape and Maxon ZBrush (Fig. 1).

³ <https://sketchfab.com>

⁴ For an example, see the 4CARE page dedicated to the site of the necropolis of al-Bağawāt: <https://4care-skos.mf.no/4care-sites/15/>

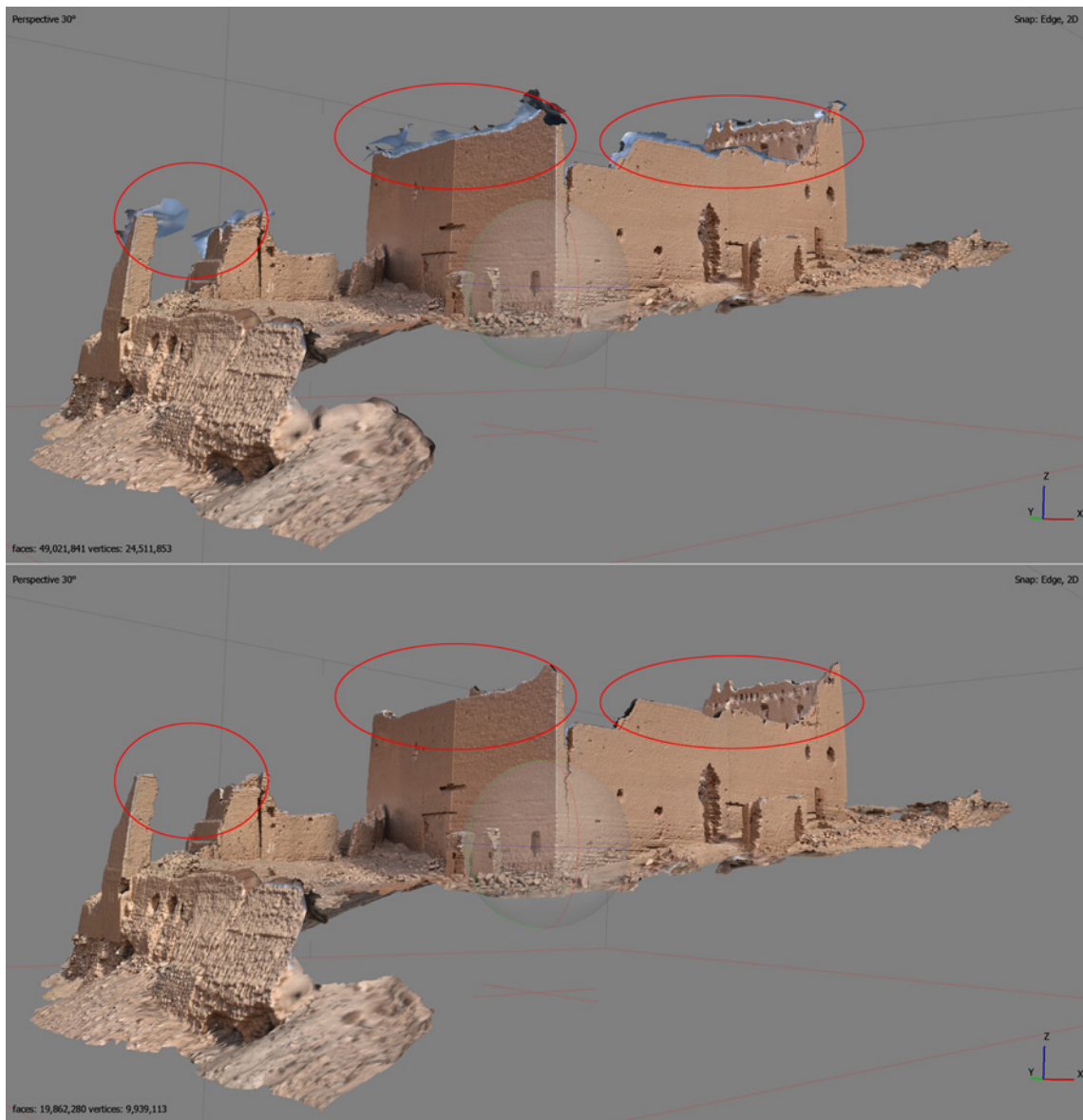


Fig. 1: Parasite geometry blended with sky, before and after cleaning in Metashape and ZBrush.

The removal of the sky-noise results in a loss of points in the cleaned areas on top of the walls. In addition to these gaps, the model featured several holes in the upper floors resulting from them not having been covered by the camera. The solution we adopted was to combine two different pieces of software. Although ZBrush is a valid option, we preferred Geomagic Wrap, which has an excellent tool for closing holes (Fig. 2).

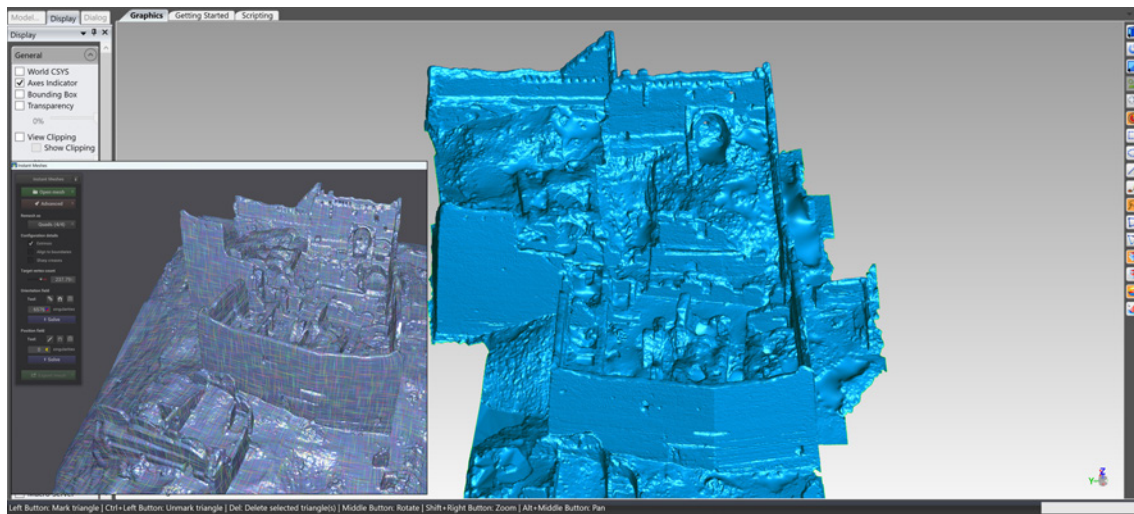


Fig. 2: Closing holes in 3D Systems Geomagic Wrap (main window) and polygon count reduction in Instant Meshes (bottom left).

After closing the holes and fixing the errors, the polygon-count of the Metashape model hovered around 50,000,000 polygons. To reduce it, one had the one-click solution of decimating the mesh inside Metashape. However, the more advance option provided by Instant Meshes, a software that allows for converting any high-count mesh from triangle to quad polygons, gives the possibility of executing a manual wrapping of the final texture, which provides a smoother visual rendering in a web viewer such as Sketchfab than the automatic decimation in Metashape (Fig. 2).

At this stage, the modified 3D model was brought back into the Metashape file for building the texture. Since no cameras captured the top of walls, the textures in these areas were blended with the sky, displaying white and blue colours. To address the issue, we used Adobe Substance Painter, which permits modifying 2D textures on any 3D surface model and where a tool similar to the “Clone Stamp” of Adobe Photoshop allows for erasing the blended textures deriving from the sky-noise and turning them into wall textures.

3. Merging models from different excavation seasons

Another frequently performed operation has been the merging of two or more Metashape models from different excavation seasons into one cumulative 3D model. Again, we are giving here an example from the same site of Dayr Muṣṭafā Kāšif, although we had to deal with more complicated cases. The first photogrammetric model of the building complex was captured in 2020. Then, in 2021 and 2022, three areas were excavated in both the eastern and western halves of the main building (Fig. 3).

The goal was to have Metashape ignore the debris from the model captured in 2021 and accept the area excavated one year later and thus avoid incorrect geometry reconstruction and software confusion. To do so, we used the mask option. In order to ignore the unwanted area, this task was done manually image by image. The same process was repeated for subsequent excavation seasons.

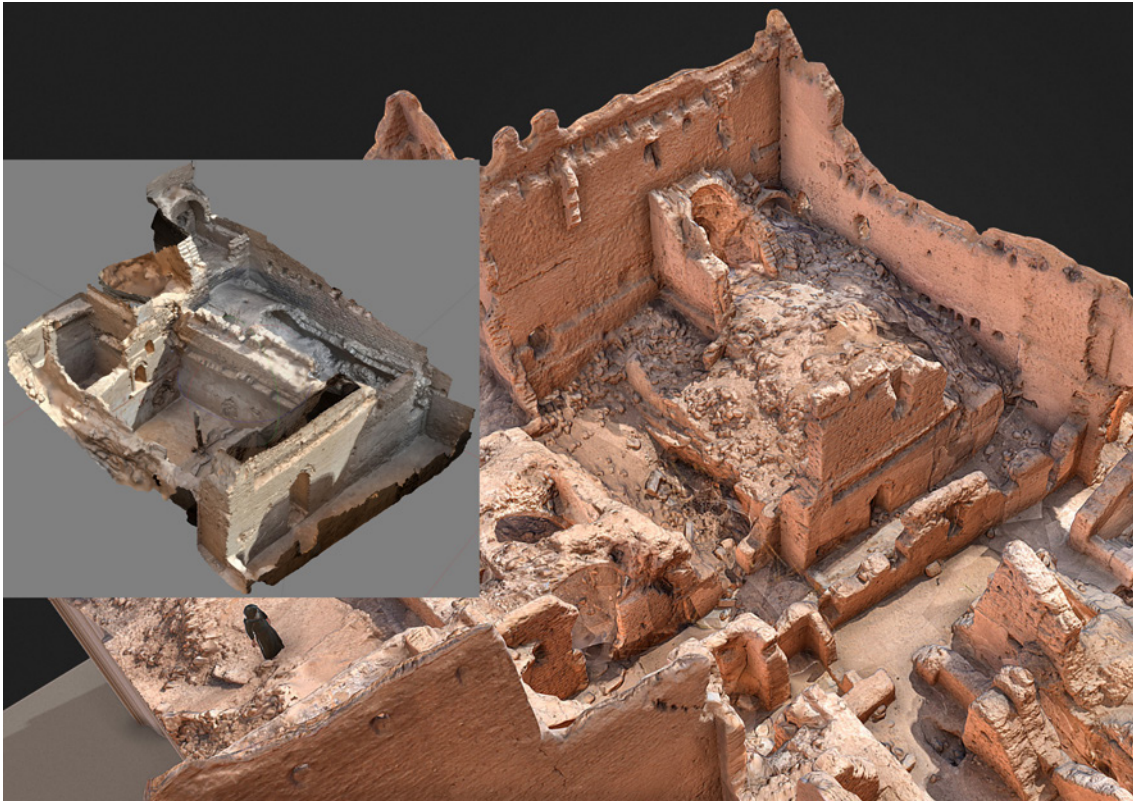


Fig. 3: Metashape models from 2021 and 2022 seasons.

4. Blending sharp textures captured in different light conditions

If we take the same example from Dayr Muṣṭafā Kāšif, the different Metashape models of the site that we had created featured different textures, as they had been photographed in distinct light conditions. We needed then not only to merge the newly excavated areas into the general 3D model, but also to blend the respective textures of all the models. To do so, we first performed a manual removal of the area to be replaced with a new model. Then, we used the Metashape function “Merge by marker”, a tool that allows one to pick up the same feature in the model of each season, by inserting several points.

However, after merging the two models in Metashape, they still had to be merged as one single piece to avoid sharp texture edges after building the texture. This second merging was performed in ZBrush, whose DynaMesh tool allows for retopologising the model as a single, new model, although without details. We then used the “Project” tool in ZBrush to bring back the details from the Metashape detailed model. After that, we exported the new model from ZBrush and imported it back to Metashape into the same project, containing now the two merged models. Then we rebuilt the texture again (Fig. 4).

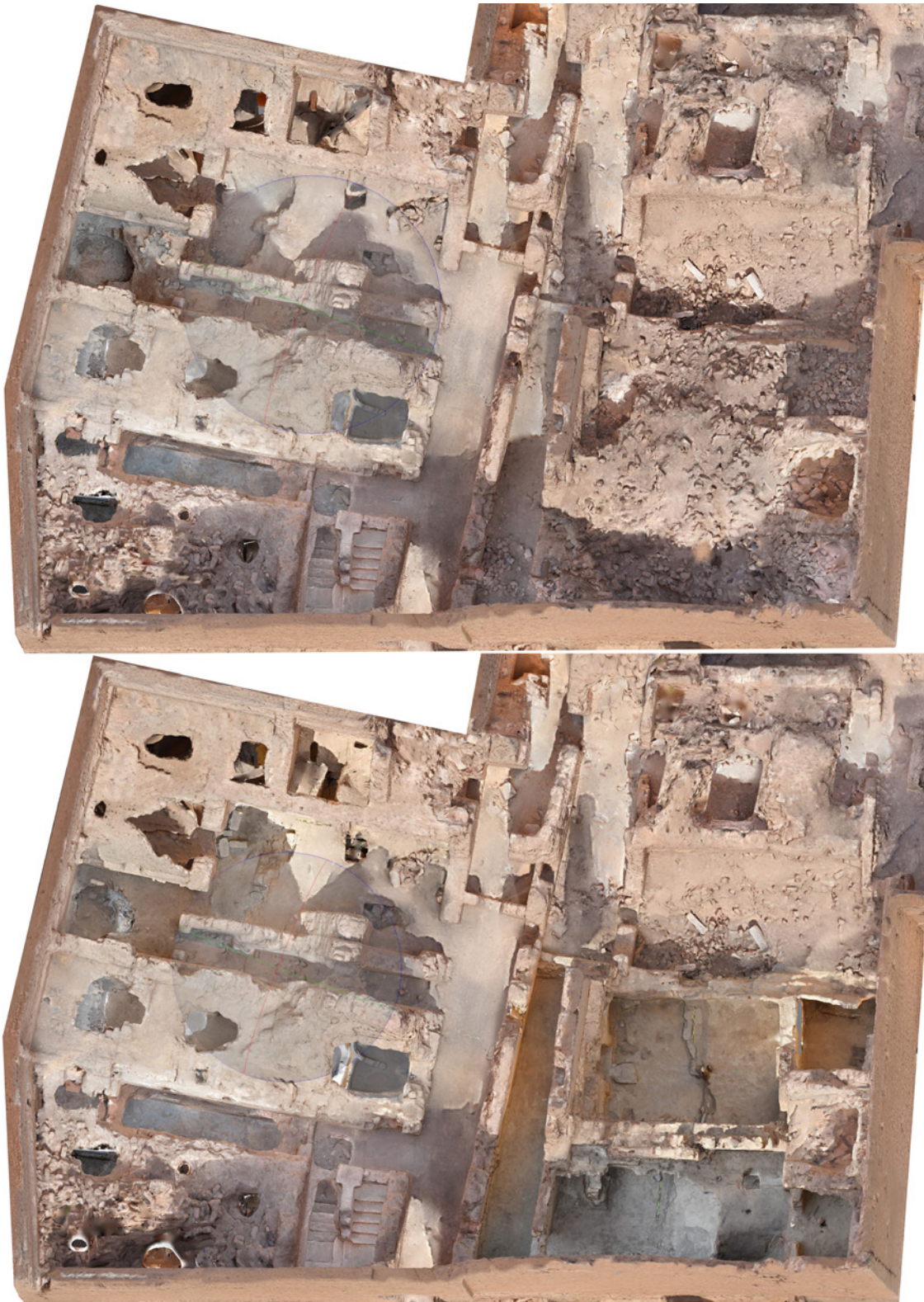


Fig. 4: 2021 Metashape model from 2021 and merged models (2021 and 2022 seasons) imported from ZBrush into Metashape.

5. Mixed visualisation (SfM model and 3D reconstruction)

Accessibility and versatility have turned photogrammetric range imaging into a ubiquitous technique also in Egypt, where Metashape models of archaeological remains of varying quality proliferate. What has been experimented with far more rarely is incorporating virtual three-dimensional reconstruction of monuments into SfM models. While a small handful of workflows have been published,⁵ we will briefly present our own, which was developed based on the needs of the archaeological sites of Kharga Oasis that DEChriM studies.

To illustrate our pipeline, we will use again the same site, whose state of preservation and monumentality present the double advantage of allowing for virtually no unwarranted architectonic speculation and integrating seamlessly the reconstruction into the photogrammetric model.

The reconstruction process was based on planimetric documentation produced by our team, 3D photogrammetric models and spatial analysis. Our end-to-end pipeline consists of: 1. Agisoft Metashape for SfM model building; 2. 3D Studio Max 2023 for 3D reconstruction; 3. Sketchfab as a platform for team feedback and visualisation.

Using 8149 images taken with a Canon EOS 5D Mark IV, a high-resolution photogrammetric model was generated, scaled and geo-referenced. The Metashape model was then imported, as a FBX file, into 3ds Max 2023, a 3D graphics software that has the double advantage of incorporating and using the photogrammetric model as a 'skeleton' and reference for reconstructing the architecture to scale, but also of documenting the reconstructed architecture in colour; this colour coding able to be recorded as a texture in the three-dimensional space. So, the pipeline rather organically integrates the photogrammetric model and the reconstructed architectural elements, with the latter virtually reanimating the ruins (Fig. 5).

In 3ds Max, we divided our 3D reconstruction into different layers containing, for example, walls, ceiling, arches, or stairs, with each architectural category having its own material ID. We then imported the model on Sketchfab⁶ using the FBX file format and colour-coded each layer. In addition, since the reconstruction model is unavoidably somewhat crowded, and to allow for a better visualisation of the architectural ensemble, we rendered the colour-coded reconstructed elements transparent (Fig. 5).

⁵ See, for example, Fritsch *et al.* 2023.

⁶ <https://sketchfab.com/3d-models/d17d8838df274cf3935ad2d93efae3a4>

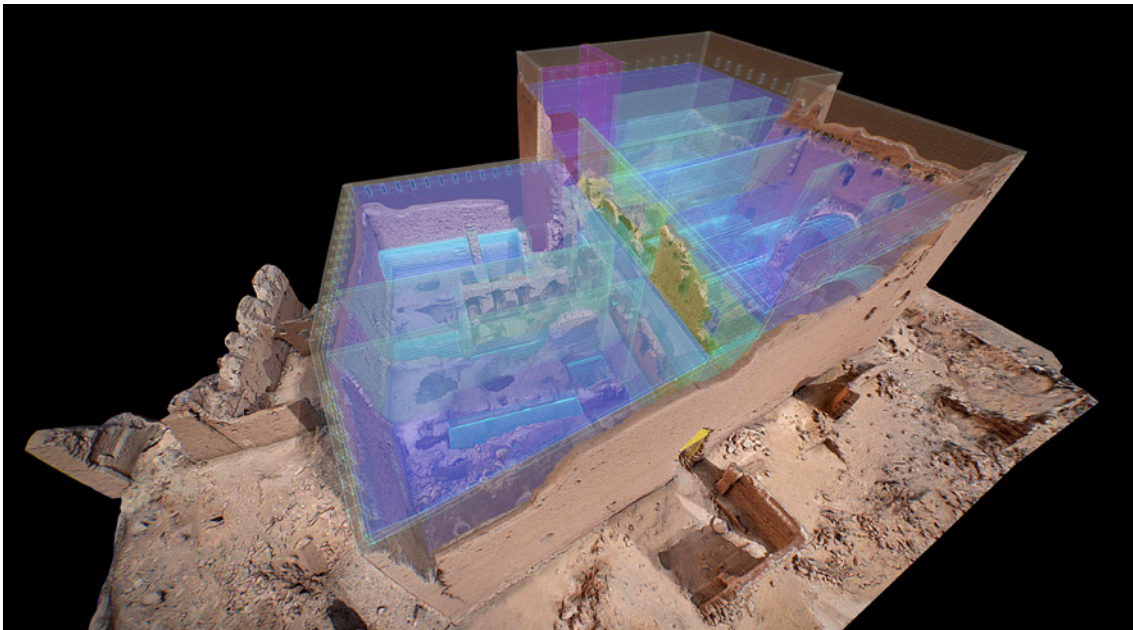


Fig. 5: Semi-transparent colour-coded reconstructed architecture in 3ds Max 2023.

6. Conclusion

The pipeline sketched above presents several immediate advantages. Close-range photogrammetry involving no photography masts results constantly in sky-on-walls-pollution. Given how difficult to access aerial photography is in Egypt, the solution proposed here for the manual cleaning of this sky-textured geometry offers a convenient and affordable alternative to drones, kites and masts.

The merging of models obtained during several field seasons responds to the need of documenting different stages of an excavation. Additionally, geo-referenced composite Metashape projects permit generating digital elevation models and orthomosaics allowing for time-efficient site mapping. As for the blending of sharp textures captured in diverse light conditions, it offers outreach-ready slick visuals.

The benefits of 3D models for the off-site study of excavated areas that cannot be visited after excavation need not to be underlined. These advantages are even more evident in the case of remote regions and often translate into financial and human resources savings.

In the context of quickly degrading sites, photogrammetric modelling takes on also a heritage dimension. Digital site conservation is, indeed, one of the impetuses behind the 3D models included in the 4CARE gazetteer, with the digital preservation of this data another area of interest for the DEChriM project.

Finally, the type of SfM models embedding 3D architectural reconstruction that we propose fulfil a double function while avoiding favouring one over the other. The benefits of such mixed models for architectural study and spatial analysis cannot be overstated.

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Online Resources

DEChriM website	https://4care-skos.mf.no
DEChriM 4CARE database	https://4care-skos.mf.no/4care-database
DEChriM SKOS database	https://4care-skos.mf.no/skos-database
DEChriM Sketchfab library	https://sketchfab.com/vghica/models

Digital projects on Earlier Egyptian mortuary texts at the University of Alcalá

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Abstract

This paper presents five interrelated digital projects on Earlier Egyptian mortuary texts written in the hieroglyphic script and conducted at Universidad de Alcalá since 2019.

The MORTEXVAR project (2019-2024) features the beta version of a database of the Middle Kingdom mortuary texts accessible on the Internet, an international conference plus collective volume on variability, a monograph on the variability of the Coffin Text spells, and a doctoral thesis on some fifty Coffin Text ensembles (coffin sets plus eventually burial chambers). The OCR-PT-CT project (2022) created and developed a digital toolset to perform optical character recognition (OCR) of the dataset available from the standard editions of the Pyramid Texts (PT) and the Coffin Texts (CT) to provide a semi-automatic transcription of the original text into Manuel de Codage (MdC). The resulting transcriptions are organised according to text paragraphs, spells and witnesses into a CSV file ready to be integrated with the MORTEXVAR project dataset. The recognition of hieroglyphs is based on the YOLOv3 network, which has been trained for that purpose with real and synthetic data. The TTAE project (2024) is the second phase of the OCR-PT-CT project; it proposes a semi-automatic transliteration by matching transliteration strings from the MORTEXVAR database with images from the CT publication (vols. I-II), some 4,000 image samples in all. This line of action will be furthered by the TM-CT project (2024-2026), extending the transliteration strings to the whole corpus (CT I-VIII) to make a much larger sample available for OCR. Complementarily, the T3D project (2025) will provide our research with a comprehensive catalogue of Middle Kingdom mortuary documents, mainly wooden coffins. This project will merge the archaeological information with the philological information obtained from the other projects, opening the possibility of creating 3D models of those documents.

The research line implemented through these five projects has two aims: to accelerate the access of the research community to the most extensive corpus of texts ever written in Earlier Egyptian with a powerful tool that will permit the conduct of large-scale and in-depth analyses on graphemics, morphology, syntax and semantics, as well as interdisciplinary studies in history, religion, anthropology and archaeology; and give these texts universal access through the Internet following the basic principle of open science.

Keywords: *OCR; Hieroglyphs; Coffin Texts; Pyramid Texts; Earlier Egyptian mortuary texts.*

1. Introduction

The development and integration of supporting computational tools have facilitated faster and different approaches to the treatment, exploitation and dissemination of

ancient Egyptian texts.¹ The approaches fall into three categories: encoding-annotation-based;² computer-vision-based;³ or a combination of both.⁴

In this lively context, researchers from three fields (Egyptology, computer vision and natural language processing) have joined forces to develop five related projects at Universidad de Alcalá (UAH) since 2019. These projects seek to combine encoding-annotation-based and computer-vision-based approaches to tackle the main problem of the first kind of approach, which is the need for a large amount of annotated texts. This main objective is done through a digital tool of the second kind, which the Egyptologists then refined. The teams include researchers from two Departments at UAH (Electronics, and History and Philosophy) and other universities (Jaén, Jerusalem and Rey Juan Carlos).

These projects are motivated by the OCR (Optical Character Recognition) techniques, which are valuable tools for improving the study of ancient languages like ancient Egyptian. Its development allows linguists and other researchers to analyse large amounts of data whose manual analysis requires prohibitive costs and propose interpretations on sounder grounds.⁵ Indeed, transcription (conversion of hieroglyphs in an image to an alphanumeric code such as Gardiner's list) and transliteration (formation of words and phrases in a modern alphabet from a transcription) involve a high cost in hours by an expert. Current techniques based on deep learning have demonstrated a remarkable capacity for text analysis (translation and transcription) in practically all current human languages, including a wide variety of writing and grammar systems, many similar in complexity to ancient languages. The use of these techniques in ancient Egyptian is conditional on the existence of large labelled data sets, both in transcription and transliteration. Currently, there are no large databases in the public domain for developing these systems with the same quality and complexity level shown in modern languages. Furthermore, in the case of ancient Egyptian, it is worth highlighting the diversity of writing styles for the same period and the diversity of formats of said writing depending on the medium used (inked on papyrus; carved, painted or inked on stone or wood).

A brief chronological presentation of the five projects follows.

1.1 The MORTEXVAR project (2019-2024)

Financed by the Region of Madrid (Atracción de Talento programme), the project *Earlier Egyptian Mortuary Texts Variability*⁶ has as its primary outcome a beta-version database of the Middle Kingdom mortuary texts accessible on the Internet,⁷ an international conference plus collective volume on variability in Earlier Egyptian mortuary texts⁸ and

¹ Gracia Zamacona, Ortiz-García 2022; Lucarelli, Roberson, Vinson 2023; Ilin-Tomich, Konrad 2024.

² Nederhof 2002; Nederhof, Rahman 2017; Winand *et al.* 2006; Winand, Polis, Rosmorduc 2008; Berlin-Brandenburg Academy of Sciences and Leipzig Academy of Sciences 2017; Jauhiainen 2021; Quack *et al.* 2023.

³ Nederhof 2002; Nederhof, Rahman 2017; Winand *et al.* 2006; Winand, Polis, Rosmorduc 2008; Berlin-Brandenburg Academy of Sciences and Leipzig Academy of Sciences 2017; Jauhiainen 2021; Quack *et al.* 2023.

⁴ Lucarelli 2017; Lucarelli 2019; Tabin *et al.* 2023.

⁵ Gracia Zamacona 2020.

⁶ www.mortexvar.com

⁷ Gracia Zamacona 2022.

⁸ Gracia Zamacona 2024a.

a monograph reassessing the Coffin Texts.⁹ In addition to the previous, Sika Pedersen is preparing her doctoral thesis on the editorial arrangement of some fifty Coffin Text ensembles (coffin sets plus, eventually, burial chambers).

The project's text corpus is probably the most extensive corpus of mortuary texts ever produced in ancient Egypt. It includes the Pyramid Texts from the Old Kingdom,¹⁰ Pyramid Text copies on Middle-Kingdom documents¹¹ and the Coffin Texts from the Middle Kingdom.¹² These texts are closely related by the topics covered and the vocabulary, grammar and specific spellings employed. The shared cultural, linguistic, and graphemic backgrounds of these texts, together with their high degree of variability within, are one of the project's most substantial assets from both the Egyptological and technological points of view. In addition to that, both the Pyramid Texts and the Coffin Texts are readily available in PDF format.

By combining material and digital philology approaches, the MORTEXVAR project has been operational to house, foster or initiate the related projects described below. The recruitment of two researchers has been highly operative to this end.

Thanks to the INVESTIGO programme of the Spanish Ministry for Employment and financed by the European Union (NextGenerationEU programme), Noelia Madinabeitia Ruiz was hired from October 2022 up to September 2023 to create an image bank of 4,000 images with Coffin Texts out of volumes I and II De Buck's edition in PDF format. She used a cropping application made by the engineering team at the University of Alcalá. The images are linked to the MORTEXVAR database, allowing combined OCR-based analysis and annotated transliteration to semi-automatise the coded transcription line and further the semi-automatic transliteration.

Luisa M. García González (Universidad de Jaén) has recently joined the Universidad de Alcalá as a Margarita Salas resident junior researcher (2024). Her contract, funded by the Spanish Ministry for Universities, will allow her to apply Social Network Analysis (SNA) techniques to the MORTEXVAR database. In the vein of her previous research¹³, Luisa will study relationships between documents and text units with their owners to ascertain eventual correlations between the documents (primarily wooden coffins), the mortuary texts and their socio-historical context. Trained with Danijela Stefanović at the University of Belgrade, Luisa will use the Gephi software for these analyses.

1.2 The OCR-PT-CT project (2022)

Funded by the University of Alcalá, the *Semi-automatic transcription of ancient Egyptian hieroglyphic documents* project (OCR-PT-CT) created and developed a digital toolset to perform OCR of hieroglyphs of the Earlier Egyptian mortuary texts, using the above-mentioned PDF editions of the Pyramid Texts and the Coffin Texts by producing a semi-automatic transcription of De Buck's handwritten transcription of the original text into a

⁹ Gracia Zamacona 2024b.

¹⁰ Allen 2013.

¹¹ Allen 2006 = CT VIII.

¹² De Buck 1935-1961 = CT I-VII.

¹³ García González 2023; García González forthcoming.

standard code commonly referred to as Manuel de Codage (MdC).¹⁴ The OCR-PT-CT project is a proof-of-concept project, and the first results are pending experimentation and will be published soon.¹⁵ The outcome of the whole process (OCR - transcription) will be regularly revised by Egyptologists. The web tool that was implemented can import images of the said PDFs, identify the existing hieroglyphs, transcribe them into codes based on the sign list of Gardiner¹⁶, organise them according to text paragraphs, spells and witnesses, and store all the resulting information into a CSV file ready to be integrated with the MORTEXVAR project dataset. The latter task will be developed with the project TTAE (*see infra*).

The OCR-PT-CT combines an image-based approach with manual encoding. In a nutshell, it comprises two stages. In the first stage, the system automatically isolates hieroglyphs in pages extracted from the digital edition of the Coffin Texts using classical segmentation methods. A pre-trained artificial neural network (ANN) is used to describe each hieroglyph with a numerical descriptor, which is then used to search for coincidences in the Coffin Texts using a clustering strategy. Egyptologists supervise each cluster to generate a dataset of image patches associated with their MdC code. In the second stage, the dataset of labelled hieroglyphs is used to train a state-of-the-art character detection ANN based on the YOLO (You Only Look Once) v3 strategy. This system requires a dataset of labelled texts, including the bounding box and class (MdC code) for each hieroglyph. This dataset was synthetically generated using image patches from the previous stage, where hieroglyphs cut out of the Coffin and Pyramid Texts are pasted in specific places with random and slight angles changes to provide data augmentation to the system training, searching for a more robust and generalizable approximation, whose coordinates are recorded to define bounding boxes and MdC categories. An example of these synthetic data and the associated ground truth is shown in figure 1.

The last stage is dedicated to the final post-processing and refinement of the results and the web visualisation. It includes detecting the different columns of text, text orientation, and producing the text transcription in ASCII code characters.

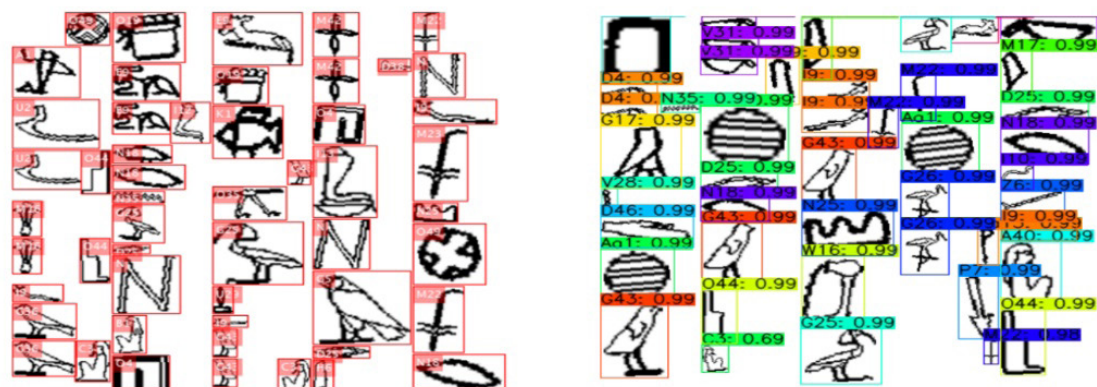


Fig. 1: A sample of the OCR-PT-CT synthetic image dataset. © The authors.

¹⁴ Buurman *et al.* 1988; Grimal *et al.* 2000.

¹⁵ Fuentes-Jiménez *et al.*, 2026.

¹⁶ Gardiner 1928, 1929, 1931, 1953 and 1957.

1.3 The TTAE project (2024)

Financed by the University of Alcalá, the *Semi-automatic Transcription and Transliteration of Ancient Egyptian Texts* (TTAE) project aimed to design a transcription-transliteration OCR system of ancient Egyptian hieroglyphic texts through deep learning techniques. The project investigated semi-automatic transcription and transliteration of the hieroglyphic signs as images from different textual sources, mainly standardised handwritten hieroglyphic transcriptions made by Egyptologists, but also from photographs of the original texts. Stemming off the transcriptions achieved through the OCR-PT-CT project in 2022, the TTAE project tried natural language processing (NLP) approaches for semi-automatic transliteration of the texts. The project was based on the processing and merging of different data sources that form a corpus of labelled data of a volume, allowing training deep learning systems to meet the planned objective. The TTAE project was run by a multidisciplinary team of researchers specialising in computer vision, signal processing, and Egyptology from the Universities of Alcalá, Jaén, Jerusalem, and Rey Juan Carlos (Madrid).

The project was based on the processing and fusion of various data sources, which, together, allow reaching a critical size for the development of tools based on deep learning:

- The MORTEXVAR database contains transliteration, grammatical analysis, and French translations of the Coffin Texts.
- De Buck's edition of the Coffin Texts (CT I-VII) contains a standardised handwritten hieroglyphic transcription of the texts originally inscribed in cursive hieroglyphs and hieratic on coffins from the Middle Kingdom.
- Allen's edition of the Pyramid Texts contains a standardised handwritten hieroglyphic transcription of the texts originally in monochrome monumental hieroglyphs carved on walls and the photograph inscription of only one of the sources, as well as transliterations associated with the texts.
- The BBAW Egyptian digital corpus by the project led by the Berlin-Brandenburg Academy of Sciences contains transcriptions, transliterations and German translations of more than 100,000 lines of text.
- Open-access (CC0) primary sources and access-granted sources will be used. These sources consist of high-quality photographs of texts and do not include labelling, transcription, or transliteration.

Corpus	Images	Coded transcription	Transliteration	Size
MORTEXVAR	Yes (13%)	No	Yes	> 30,000 sentences
Coffin Texts	Standardised handwritten hieroglyphic transcription	No	No	> 20,000 sentences

Pyramid Texts	Photographs (15%), Standardised handwritten hieroglyphic transcription (85%)	No	Yes	> 20,000 sentences
BBAW	No	Yes (40%)	Yes (100%)	> 100,000 sentences
Museums	Photographs	No	No	-

Tab. 1: Image and text sources for TTAE.

The sources above comprise a considerable corpus. Still, they are incomplete in addressing the project's tasks through the training of deep learning systems. In TTAE, all available sources were fused, and the data labelling were completed where necessary.¹⁷

1.4 The TM-CT project (2024-2026)

This line of action is being furthered by the *Text Mining the Coffin Texts* (TM-CT) project, a challenging project funded by the Spanish Ministry for Research, Universities and Innovation starting mid-2024.

The TM-CT project will bring new specialised staff (one database manager, one engineer for computer vision and one Egyptologist for annotation) to the approach initiated with the TTAE project to extend the transliteration strings to the whole corpus (CT I-VIII) to make a much larger sample available for OCR and meet the main objective, which is to link the MORTEXVAR database beta version with the images from the handwritten transcribed edition (CT I-VIII) and provide Open Access to the entire database of the Coffin Texts corpus, all text variants available, in transliteration and translation into English.

More specifically, with the TM-CT project, we expect to improve our chances of:

- Tracing the text variability of the whole corpus by linking the material philological information already in place (transliteration, translation, in-document location, geographical and chronological distribution of the texts) with the original publication of the hieroglyphic texts (images).
- Refining the study of the variations on the different witnesses using the database to identify textual, dialectal, diachronic and grammar indicators of change.
- Generating inventories of spellings/signs using the OCR toolkit designed and implemented by the projects OCR-PT-CT and TTAE.

¹⁷ The TTAE project ended in December 2024, and its results led to the OCR improvement by applying novel classification techniques based on metric learning and a semantic and contextual analysis of Egyptian texts. Its achievements have allowed the continuity of the research line by means of a new project AMPITET (2025).

1.5 The T3D project (2024-2025)

The *Texts in 3D: Middle Kingdom Egypt coffins as documents* (T3D) project, financed by Castilla-La Mancha region, has been launched in November 2024. The purpose of the T3D project is to create a systematic, digital, internet-available collection of all the sources for the Middle Kingdom mortuary texts. This group of sources currently numbers about one thousand objects,¹⁸ primarily wooden coffins, and increases yearly with new publications. The number of sources is only approximate due to the state of conservation of many of them and the difficulty of locating them with certainty. For this reason, generating a more accurate catalogue of the sources will be one of the T3D project's significant contributions. Of those estimated thousand sources, Leonard Lesko only verified the texts of about 400 in his *Index*,¹⁹ namely those used by Adriaan de Buck to make his reference edition of the Coffin Texts.²⁰

Verifying these sources will establish the position and arrangement of the texts (at different levels, from the textual unit to the writing of each word, passing through the phrase) in each source and document them photographically, whenever possible. The T3D project will prioritise verifying textual units ("spells"). Depending on the needs, this task will be run by at least an archaeologist and a photographer. This approach to sources needs a thorough review for two reasons. First, numerous new sources have been found since the publication of Lesko's *Index* in 1979. Second, philological studies have focused on ecdotics, which is based on the synoptic edition of sources (such as De Buck's), thus missing how the texts are structured in each source, i.e. how they were *originally* published.²¹ Therefore, and in line with recent philological approaches increasingly focused on the materiality of texts,²² an in-depth review of the sources like the one proposed by the T3D project is required.

2. Concluding remarks

The five projects briefly discussed above respond to the need for an integral approach, which contrasts disciplinary approaches, mainly archaeological or philological or focused on selected items, which opacify the production of the Middle Kingdom mortuary material as a recognisable ensemble.

In addressing the previous necessity, material and digital approaches are not contradictory at all but complementary. Both approaches combined provide the possibility of recovering the original union of this material between what we call matter and form, a distinction which we may take for granted but that we should not too hastily ascribe to the creators of this material.

These five projects will provide a large amount of contextualised data to improve future analyses of these texts in linguistics, graphemics, textual studies, cultural studies, and history of religions, among many other fields.

¹⁸ Willems 2014, 230–315.

¹⁹ Lesko 1979.

²⁰ De Buck 1935-1961.

²¹ Gracia Zamacona 2024b.

²² Hays 2012; Parkinson 2012; Quirke 2013; Morales 2017; Gracia Zamacona 2024a-b.

Lastly, obtaining access to these materials is urgent to implement future research on Middle Kingdom mortuary materials for two reasons: first, no research is possible without access to the sources or with restricted access to them; second, Egyptological practices must meet open science standards to expand the discipline's impact and fight for its spot in future curricula.

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The OCR projects at the University of Alcalá (2019-2026) that are described in this paper are funded by the University of Alcalá (Own research programme), the Region of Madrid (Atracción de Talento programme), the European Union (NextGenerationEU programme) through the INVESTIGO programme of the Spanish Ministry for Employment, the Spanish Ministry for Research, Universities and Innovation (Research Consolidation programme), the Castilla-La Mancha region (Research and Transfer Projects programme) and the European Union (FEDER programme).

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Online Resources

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Aligning encoded hieroglyphic and transliterated words with Needleman-Wunsch algorithm

Heidi Jauhiainen

Abstract

This paper presents a corpus-specific approach to aligning hieroglyphic texts with their transliterations, leveraging machine learning techniques. While Assyriological practices benefit from machine-readable cuneiform texts, Egyptology lacks a similar tradition, hindering digital analysis of hieroglyphic texts. To address this gap, we employed the Needleman-Wunsch algorithm, originally designed for bioinformatics, to align encoded sentences with their respective transliterations. We created a dictionary of encoded word-transliteration pairs from the Ramses Transliteration Corpus (RTC) and the Thesaurus Linguae Aegyptiae (TLA) corpus, adapting the algorithm to handle editorial additions and discrepancies between encoding and transliteration. Several rules were implemented to handle cases without a direct match in the dictionary, enhancing alignment accuracy. Additionally, heuristics were introduced to refine the alignment method, including penalty adjustments for annotations and manual validation steps. The alignment method demonstrated effectiveness in aligning complex sentences. However, disparities between the RTC and TLA corpora made the latter corpus unhelpful in aligning the sentences in the former underscoring the need for corpus-specific rules. Incorporating additional machine-readable hieroglyphic texts could further streamline the alignment process, making it applicable to other corpora without similar formats.

Keywords: *Hieroglyphic text; Alignment; Encoding; Transliteration.*

1. Introduction

To leverage digital methods for text analysis, the texts must be in a machine-readable format.¹ I have collaborated with Assyriologists and Language technologists to investigate the contextual usage of words within Akkadian texts.² Depending on the specific task at hand, we utilize up to seven thousand texts sourced from the Open Richly Annotated Cuneiform Corpus (Oracc).³ Oracc provides an extensive collection of machine-readable cuneiform texts for download and local use.

In contrast to the Assyriological practices, Egyptology lacks a tradition of publishing machine-readable texts. While hieroglyphic texts are commonly produced using text editors such as WinGlyph⁴ or JSesh,⁵ only visual representations of the text are typically published. Although the encoding, primarily the Manuel de Codage (MdC)⁶ system, used

¹ I would like to thank the editors of the volume and the anonymous reviewers for their valuable input. This research was funded by the Kone Foundation and the Research Council of Finland (Funding decision no. 34179).

² Alstola *et al.* 2019; Alstola *et al.* 2022; Jauhiainen, Alstola 2023; Svärd *et al.* 2021.

³ The Open Richly Annotated Cuneiform Corpus <https://oracc.museum.upenn.edu>

⁴ WinGlyph appears to be obsolete (*WebGlyph, a free Web version of GLYPH* <http://ancientworldonline.blogspot.com/2021/12/webglyph-free-web-version-of-glyph.html>), but see WebGlyph <http://71.174.62.16/Demo/WebGlyph2>

⁵ Rosmorduc 2014.

⁶ Buurman *et al.* 1988.

for accurate hieroglyphic placement, is machine-readable, the project files containing the encoding are seldom made public.⁷

Despite this, specific invaluable online resources such as the Thesaurus Linguae Aegyptiae (TLA)⁸ and Ramses Online⁹ facilitate word searches and studies. Furthermore, the MdC-encoded texts underpinning these platforms have been made available to the public. The Ramses Transliteration Corpus (RTC),¹⁰ derived from the Ramses Online service, comprises a sentence corpus featuring MdC-encoded sentences in one file and the corresponding transliterations in another.

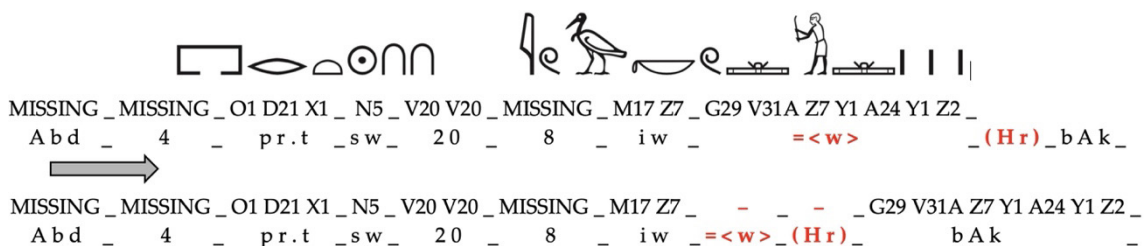


Fig. 1: An example of a sentence pair from the RTC corpus in encoded and Buurman transliterated formats with two editorial insertions in red. The second version exemplifies the desired alignment of the words.

To construct transliteration models encompassing all hieroglyphic words alongside their potential transliterations and frequencies from both corpora, the alignment of words in the RTC's sentence versions was necessary. However, editorial additions present in both versions posed a challenge (Fig. 1). These additions are typically denoted using various markings such as parentheses and angle brackets.¹¹ To address this challenge, we employed the so-called Needleman-Wunsch algorithm¹² to align the encoded sentences with their respective transliterations.¹³ Despite its original application in molecular biology to align lengthy protein sequences, this algorithm has found utility in aligning natural language sequences¹⁴ due to its ability to identify missing items from either sequence while assuming the correct order of the items.

To apply the algorithm to the RTC corpus, it is necessary to align transliterated words with encoded ones, requiring a dictionary for comparison. Consequently, our approach to implementing the alignment method involved constructing a dictionary comprising pairs of encoded words and their corresponding transliterations, which was then employed alongside the Needleman-Wunsch algorithm. This dictionary was generated by extracting data from both the Thesaurus Linguae Aegyptiae (TLA) corpus¹⁵ and the

⁷ Nederhof 2013, 105.

⁸ Thesaurus Linguae Aegyptiae <https://thesaurus-linguae-egyptiae.de>

⁹ Ramses Online: an annotated corpus of Late Egyptian <http://ramses.ulg.ac.be>

¹⁰ Rosmorduc 2021.

¹¹ Rosmorduc 2020, 235.

¹² Needleman, Wunsch 1970.

¹³ Jauhiainen, Jauhiainen 2023.

¹⁴ E.g. Itoh 2016; Lai, Hockenmaier 2014; Song *et al.* 2016.

¹⁵ Richter *et al.* 2018.

sentences within the RTC that feature an equal number of tokens in both the encoded and transliterated versions, thus ensuring the absence of any inserted elements.

The method and its validation have been explained elsewhere.¹⁶ In this paper, I seek to explain the alignment in Egyptological terms and to exemplify the corpus and the Egyptian language-specific rules that had to be implemented. In Section 2, I begin by explaining the concept of text alignment and reviewing previous experiments conducted to align hieroglyphic texts. Section 3 outlines the data utilized for constructing the dictionaries, while Section 4 delves into the implementation of the Needleman-Wunsch algorithm for aligning hieroglyphic texts. Section 5 illustrates the Egyptian language-specific heuristics employed to achieve alignment of sufficient quality for constructing a transliteration model of the RTC corpus.

2. Alignment of parallel texts

Parallel texts, which are different presentations of identical written content, play a crucial role in various linguistic and research contexts. Aligning these parallel texts involves a meticulous process of matching the content of one text with its corresponding content in another.¹⁷ While feasible for documents in the same language, this task often requires machine learning for aligning documents in different languages, such as aligning Italian text with its English translation. The alignment can occur at the paragraph, sentence, or word level, each level offering unique insights into the text's structure and meaning.¹⁸

In 2002, Mark-Jan Nederhof developed a tool called AELalign to tackle the challenge of automatically aligning hieroglyphs with their transliterations.¹⁹ The method behind the tool successfully aligned encoded texts with various transliterations and translations. However, the input texts needed to be structured in XML format, and anchor points such as line numbers were necessary to facilitate alignment.²⁰ The tool could also handle texts with simpler formats, provided they were divided into alignable sections.²¹ Nederhof also attempted to align encoded hieroglyphic texts with their translations without the anchors in the source files.²² His approach scrutinized individual hieroglyphs and used an annotated sign list. The method assessed the alignment by evaluating the compatibility between the hieroglyphs and their potential transliterations; that is, his method went through the individual hieroglyphs and checked how well their possible transliterations match the existing transliteration. This assessment involved a customized scoring mechanism that assigned different penalties to different readings. The alignment with the least penalty was ultimately selected as the optimal match. Now that we have corpora of machine-readable hieroglyphic texts, it is possible to learn about the intricacies of the language using machine-learning directly on the texts.

¹⁶ Jauhiainen, Jauhiainen 2023; Transliteration Model for Egyptian Words <https://doi.org/10.5281/zenodo.7991240>; MaReTE Transliteration Models <https://github.com/MaReTEgyptologists/TranslitModels>

¹⁷ Owen *et al.* 2000, 100.

¹⁸ Santos 2011, 117.

¹⁹ Nederhof 2002; Nederhof 2009.

²⁰ Nederhof 2002, 6-10; Nederhof 2008, 74.

²¹ Nederhof 2002, 10.

²² Nederhof 2008.

3. Data

The Ramses Transliteration Corpus V. 2019-09-01 (RTC),²³ curated by Serge Rosmorduc from the texts behind the Ramses Online service, served as a resource for training and evaluating the automated transliteration method he was developing.²⁴ This corpus consists of sentences featuring encoded hieroglyphic text alongside their corresponding transliterations, stored in separate files. Original hieroglyphic texts lack explicit word boundaries but, to facilitate word searches in Ramses Online, the corpus has been segmented into words, with underscores used as separators in RTC. With over 71,000 sentences of Late Egyptian texts (1550-1069 BC ca.), the RTC encompasses a wide range of content. However, the sentences are arranged in a random order without indications of the source text. Hieroglyphic texts often suffer from fragmentation and damage, leading to potential transliterations being provided for impaired segments, including individual signs or extended passages. Additionally, transliterations may incorporate grammatical constructs absent in the original hieroglyphic text. In RTC, these insertions are marked with parenthesis or angle brackets around the word. They may also be preceded by an equal sign (=), indicating that a suffix pronoun was meant.

The TLA corpus 2018,²⁵ derived from a snapshot of the database used to create the online version of the Thesaurus Linguae Aegyptiae, serves as another valuable resource. In order to build a dictionary for alignment purposes, a JSON format version of the corpus, known as AES (Ancient Egyptian Sentences),²⁶ was utilized. TLA comprises over 100,000 sentences spanning texts from the Old Kingdom to the Roman period.

The RTC and TLA corpora employ MdC encoding for hieroglyphic signs, consistent with texts produced with hieroglyphic text editors such as JSesh or WinGlyph. This encoding utilizes codes from the Gardiner sign list classification of hieroglyphs.²⁷ However, the hieroglyphic text editors allow for encoding certain signs using MdC (Buurman) transliteration, which employs ASCII representations of special letters, such as A for ʾ and x for h, while the TLA corpus and RTC utilize proper Gardiner sign list codes exclusively.

The need to use a dictionary derived from the RTC in conjunction with TLA corpus arises from the different nature of the two corpora. The texts within Ramses Online predominantly feature Late Egyptian texts from the New Kingdom, resulting in a relatively homogeneous corpus. In contrast, the texts within the TLA corpus span over 2000 years and encompass various content types, including religious pyramid texts, medical texts, and rock inscriptions, resulting in a very different vocabulary than in RTC. Thus, supplementing TLA with as much of the Ramses corpus as possible was necessary to effectively align the RTC sentences that contain editorial insertions.²⁸

²³ Rosmorduc 2021.

²⁴ Rosmorduc 2020.

²⁵ Richter *et al.* 2018.

²⁶ Schweitzer 2021.

²⁷ Gardiner 1957, 438-543.

²⁸ Jauhiainen, Jauhiainen 2023.

4. Needleman-Wunsch Algorithm for Hieroglyphic Texts

The Needleman-Wunsch algorithm,²⁹ initially developed for bioinformatics, excels in comparing long proteins or genomic DNA.³⁰ It has found applications beyond its original domain and has been adapted for aligning natural language text, such as identifying sentence parallelism in student essays³¹ and estimating semantic similarity.³² Its suitability for aligning encoded hieroglyphic words with their respective transliterations lies in its assumption that sequences are in the correct order, allowing it to identify missing items from either sequence.

In order to employ the Needleman-Wunsch algorithm for hieroglyphic sentences, transliterated words must align with encoded words, necessitating a dictionary for comparison. Our alignment method implementation depends, thus, on creating a list of encoded words with all the possible transliterations they can have and employing it alongside the algorithm. In constructing the RTC dictionary, pairs of lines with an equal number of tokens in both versions were utilized. However, word pairs indicating editorial additions by containing characters such as '[', '\', '?', and '<', or those with parentheses around the entire transliteration of a word were excluded. Additionally, words with encoding such as 'SHADED' and 'MISSING' were disregarded. Similarly, in building the TLA corpus dictionary, only tokens with values for both 'hieroglyph' and 'lemma_form' keywords were considered. In the latter case, the transliterations adhering to the Werning scheme were automatically converted to the Buurman-compliant MdC transliteration used in RTC.

LACUNA_I10 D46_I9_M17 G1 Z7 X1 A30 A2_N35 D36 U28 G1 M17 Z7 G37
LACUNA_D d_<n>_f_i A . t w _n - a D A

		+ Bonus or Penalty	+ Penalty	LACUNA	Dd	<n>	f	iA.tw	n-aDA
Bonus = +5 Penalty = -1		0	-1	-2	-3	-4	-5	-6	
LACUNA	-1	5	4	3	2	1	0		
I10 D46	-2	4	10	9	8	7	6		
I9	-3	3	9	9	14	13	12		
M17 G1 Z7 X1 A30 A2	-4	2	8	8	13	13	12		
N35 D36 U28 G1 M17 Z7 G37	-5	1	7	7	12	12	12		

Fig. 2: A Needleman-Wunsch array for an example sentence pair illustrated as a table with the scores and directions the score comes from. Only the green encoded words have matching transliterations in the dictionary (red). The scoring of the first words 'LACUNA' is indicated in blue and is formed by adding a bonus to the score in the cell to the top left.

The algorithm employs an array, essentially a table, where each encoded word is compared with each transliterated word of a sentence (Fig. 2). Initially, the first row and first column are filled with descending numbers starting from zero. Subsequently, the

²⁹ Needleman, Wunsch 1970.

³⁰ E.g. Dayhoff *et al.* 1974 (for an example of aligned letter-sequences see 219, fig. 4).

³¹ Song *et al.* 2016.

³² Itoh 2016; Lai, Hockenmaier 2014.

remaining cells are filled sequentially. Each cell's value is determined as the maximum among three scores: the score in the cell to the top left plus a dictionary score, the score in the cell to the left minus a penalty point (-1), or the score in the cell above minus a penalty point (-1). The dictionary score is assigned based on whether the transliteration is found in the dictionary entry for the word under scrutiny. In our implementation, a match results in a bonus of 5 points, while a mismatch incurs a penalty of -1 point. In Figure 2, as the first words compared, 'LACUNA' and 'LACUNA', are identical, the score in the cell to the top left receives a bonus of 5 points. Consequently, the resulting score coming from that cell becomes 5, which is the highest among the three scores considered. This score is then assigned to the cell under scrutiny. Additionally, the algorithm keeps track of the direction from which the score originated, aiding in subsequent alignment steps.

Once all cells in the array are filled, the actual alignment begins from the far bottom right, starting with the last words of the sentence (Fig. 3). The tokens are aligned if the highest score came from the top left. If it came from above, the left token is aligned with a gap; if it came from the left, the top token is aligned with a gap. The alignment then proceeds to the direction from which the highest score for the cell originated.

For instance, in the figure 3 sentence, when '<n>' is compared to 'I10 D46', and the score originates from the left, '<n>' is aligned with a hyphen, representing an empty slot. Despite not all transliterations being found in the dictionary for the corresponding encoded word, the method aligns the sentence correctly. In cases where the sentence is long or contains many words absent from the dictionary, multiple possible alignments may exist. To determine the optimal alignment, the scores for all pairs on each possible passage are summed up, and the alignment with the highest score is chosen.

	LACUNA	Dd	<n>	f	iA.tw	n-aDA	
	0	-1	-2	-3	-4	-5	-6
LACUNA	-1	5	4	3	2	1	0
I10 D46	-2	4	10	9	8	7	6
I9	-3	3	9	9	14	13	12
M17 G1 Z7 X1 A30 A2	-4	2	8	8	13	13	12
N35 D36 U28 G1 M17 Z7 G37	-5	1	7	7	12	12	12

LACUNA _ I10 D46 _ - _ I9 _ M17 G1 Z7 X1 A30 A2 _ N35 D36 U28 G1 M17 Z7 G37
 LACUNA _ Dd _ <n> _ f _ iA.tw _ n-aDA

Fig. 3: The backward steps (blue) of the Needleman-Wunsch algorithm for the example sentence in figure 2. The alignment of the words starts from the bottom right cell with score 12 and tries first to align the encoding 'N35 D36 U28 G1 M17 Z7 G37' with the transliteration n-d. Underneath the table is the resulting alignment.

Several rules were implemented to handle situations with no direct match in the dictionary due to the variability in Egyptian word representations. These rules were sequentially applied, with each subsequent rule applied if the previous one did not yield a match. Firstly, a word was deemed a match if the transliteration given and any of the possible transliterations for the encoded word started with and completely contained the other. Secondly, the transliterations of all words starting with the first three MdC

codes from the encoding under scrutiny were added to a list of possible transliterations. This extended the list of possible transliterations, allowing for a more comprehensive matching process. Thirdly, all words starting with the first MdC code from the encoding under scrutiny were compared to a list of possible transliterations. These rules prioritize potential matches based on the relationship between transliterations and encodings, expanding the scope of possible alignments to accommodate the variability inherent in Egyptian word representations. Each rule contributes incrementally to the alignment process, with bonus points adjusted accordingly to facilitate accurate alignment.

5. Heuristics

In the pursuit of achieving precise sentence alignments and creating high-quality transliteration models, corpus-specific refinements were added to the alignment method. We adjusted the dictionary score, which is added to the cell in the top left, to be -5 if the transliteration contained parentheses or angle brackets with or without the equal sign indicating insertions by the annotator. This modification yielded significant improvements in alignment accuracy.

Since the end goal was to create a high-quality transliteration model from the RTC corpus, I verified the method's results by aligning all the lines in the RTC corpus and compiling a wordlist that was manually inspected. Broken words and additions were excluded from the dictionary but retained for this validation step. Upon encountering intact words paired with a hyphen, a sign for a gap added by the alignment method, I examined the corresponding sentence to address discrepancies.

During this manual inspection, I identified sentences where the MdC and transliteration did not correspond. Figure 4 exemplifies this phenomenon: the names of certain royal persons were written as a single word in the encoding but as two words in the transliteration. This inconsistency was observed repeatedly with these particular names, prompting the establishment of rules to align them accurately. When building the final transliteration models after the development of the method, the transliterations of these royal names were converted to one word already in the pre-processing stage.



Fig. 4: An example of a sentence pair where the name of the king's son Ramses Maat-Ptah is encoded as one word but written as two words in the transliteration.

In most cases, unrecognized words had in RTC been transliterated with SHADED or such but sometimes a word had been left untransliterated. Furthermore, occasionally longer sequences of transliterations had been deduced from the context without marking them as such and without corresponding entries in the MdC. While the method could often detect missing words, some sentences with several previously unknown words and editorial additions proved impossible to align. Consequently, I compiled a list of sentences to be disregarded. For example, the hieroglyphs marked in red in Figure 5 were divided into two words that were not found in the dictionary using the established rules. The

transliteration of the first word would seem to be p^2 , perhaps the masculine article. The article is not in the encoding, nor is there any indication of editorial insertion; the word would, therefore, seem to be supposed to align with ‘D58 G41 G1’. However, this encoding is elsewhere in the corpus transliterated as b or b^2 and is always part of a longer word. In TLA, the two words ‘D58 G41 G1’ and ‘W11 G1 M17 Ff1 Z9 D40 N35A’ are, in fact, one word b^2-g^2j ³³ from the root bg^2 .³⁴ With all the editorial insertions in the sentence in addition to those two unrecognized words, the alignment was impossible with this method.



Fig. 5: An example of a sentence pair falsely aligned by the method because of the many insertions and the unrecognized words (red). The sentence was added to a list of sentences to ignore while building the transliteration models.

6. Conclusions

The alignment method effectively handles even complex sentences with differences in the number of words between the original encoding and transliteration lines. Out of the 71,000 sentences in the RTC corpus, nearly 57,000 featured an equal number of encoded and transliterated words and were utilized for dictionary creation. However, a considerable number of words in the sentences to be aligned were not found in the dictionary underscoring the necessity for rules tailored to Ancient Egyptian writing conventions.

The dictionary derived from the TLA corpus proved ineffective in aligning RTC sentences,³⁵ highlighting substantial disparities between the corpora compositions. Furthermore, incorporating a penalty for obvious insertions by annotators was essential to achieve perfect alignment between the original lines and the gold standard utilized in validation. To construct high-quality transliteration models, additional corpus-specific rules were indispensable. A more significant number of openly available machine-readable hieroglyphic texts would aid in reducing the heuristics needed to align encoded sentences with their transliteration. While the alignment method presented here is contingent on the unique format of the corpus export by Rosmorduc, the Needleman-Wunsch algorithm itself can be adapted to align sentences in ancient languages even without such a format.

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³³ <https://thesaurus-linguae-aegyptiae.de/sentence/ICICCbNHeTzjNEgJkg3SKQGt9Xk>

³⁴ <https://thesaurus-linguae-aegyptiae.de/lemma/850481>

³⁵ Jauhiainen, Jauhiainen 2023.

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Online Resources

MaReTE	
Transliteration Models	https://github.com/MaReTEgyptologists/TranslitModels
Ramses Online	http://ramses.ulg.ac.be
ORACC	https://oracc.museum.upenn.edu
TLA	https://thesaurus-linguae-aegyptiae.de
Transliteration Model for Egyptian Words	https://doi.org/10.5281/zenodo.7991240
WebGlyph	http://ancientworldonline.blogspot.com/2021/12/webglyph-free-web-version-of-glyph.html ; http://71.174.62.16/Demo/WebGlyph2

Discovering the concealed. Photogrammetry as a 'key tool' for studying ancient Egyptian objects

Stefania Mainieri

Abstract

In the last few years, digital technologies and 3D models have been brought into frequent use within the fields of Archaeology and Egyptology, as well as in Museography. At first, digital models were used as tools for designing, documenting and monitoring objects or for valorisation and dissemination tasks; now their role in scientific research is emerging. The possibility of creating high-resolution and sub-millimetric reproductions of objects and the opportunity to then measure them, detect surfaces and easily compare forms, volumes and geometry allow us to add more elements to the 'traditional' study of the objects and analyse 'undervalued' peculiarities and/or concealed elements, such as the geometry of objects.

This paper will demonstrate that digital technologies and photogrammetric 3D models are 'key tools' for studying ancient Egyptian artefacts. Starting from the main results on yellow coffins within the *Faces Revealed Project*, we go on to explain how these results will inform future perspectives of research where digital technologies and 'human-machine' interactions can be fundamental to reconstructing the history of ancient societies.

Keywords: *Photogrammetry; 'Hidden' features; Production; Egyptian Coffins; Material culture.*

1. Introduction

In 2019, the inaugural edition of the International Conference 'Ancient Egypt - New Technologies' in Bloomington provided an invaluable opportunity to present the inception of a project on ancient Egyptian yellow coffins from the Third Intermediate Period (11th-10th century BCE), that was subsequently awarded funding in 2020.¹

The contribution emphasised the efficacy of photogrammetry in the examination of coffins and the potential outcomes that a study founded on three-dimensional models could have yielded for this class of materials.² However, the applicability of the study on yellow coffins demonstrated the significant potential of photogrammetry not only for these objects, but also for the broader prospects of this application and methodology, especially for comparisons on a geometric basis to identify styles and productions.

The first main utility of photogrammetry is linked to its ability to observe the same object in colour (model with texture) and without colour (model without texture). While this capability is well known to most professionals in the field, its scope is underestimated in Egyptology, having only recently been accepted as adding value to the analysis of

¹ Mainieri 2023a. The project, named *Faces Revealed* (2021-2024), has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 895130. <https://facesrevealed.museoegizio.it/>

² For the specific methodology and technical details regarding the process of photogrammetry used for the study, refer to Mainieri 2024a.

artefacts. Its importance is due to the fact that this technology is capable of making 'invisible' features 'visible', enabling elements that were disguised by decoration, previously overlooked or considered unimportant to be analysed fully. The second main utility is the ability to create a digital twin of an object, including its form and measurements with sub-millimetre accuracy. This allows more precise classifications to be made based on the canons of proportion. Making precise comparisons between different objects based on photographs is risky as different light, position, orientation, as well as lens position and framing can distort the visual evidence.³ These limitations are overcome through rigorously standardised 3D acquisition methods that guarantee measurable visual consistency across diverse objects.⁴

2. Make 'visible' the 'invisible': the coffins

Yellow coffins are perhaps the best example to highlight the importance of using 3D models for the study of production and the material culture of ancient Egypt. The technical characteristics of these objects blend carpentry and pictorial decoration; the objects themselves lie between statuary and decorated surfaces.⁵ The yellow coffins are in fact anthropoid, with a lid that represents the human body of the deceased in which the main features of a human body and face are crafted or modelled. Furthermore, the coffins are decorated, both the inner and outer walls being used as a base for rich textual and figurative programmes. Symbols, vignettes and texts magically embrace and envelop the deceased, helping them on their journey to the afterlife. This rich and polychrome decoration made it impossible to capture the forms and geometry in an objective way or to gain a comprehensive view of the sculpted or modelled features under the decoration.

Although the artistic or aesthetic quality of the coffins differs from one object to another, yellow coffins have a precise scheme of production and decoration techniques now reconstructed thanks to numerous international projects devoted to illuminating the technical aspects of the production during the Third Intermediate Period to give a comprehensive idea of how these objects were produced and how the pigments were applied onto the surfaces.⁶ Today, for example, we know the painting procedure on coffins was based on working the entire surface with one colour at a time, starting from preparation drawings in red or black until the details in black such as pupils, eyebrows, other features of the faces and beards (Fig. 1A-B).⁷

³ Sourouzian 2020, XXXIV.

⁴ Mainieri 2024a.

⁵ For yellow coffins see e.g. Niwiński 1988; Sousa 2018; Sousa 2020; Niwiński, Rigault 2024; Sousa 2024; Vilaró-Fabregat 2024; Vilaró-Fabregat 2025.

⁶ Such as the *Vatican Coffin Project* [<https://www.museivaticani.va/vatican-coffin-project.html>], see Amenta 2014; Amenta, Guichard 2017; Amenta, Iob 2025; and the *Fitzwilliam Museum's Ancient Egyptian Coffins Project* [<https://egyptiancoffins.org/>], see Dawson *et al.* 2016; Dawson 2018; Dawson, Strudwick 2019.

⁷ Amenta 2024.

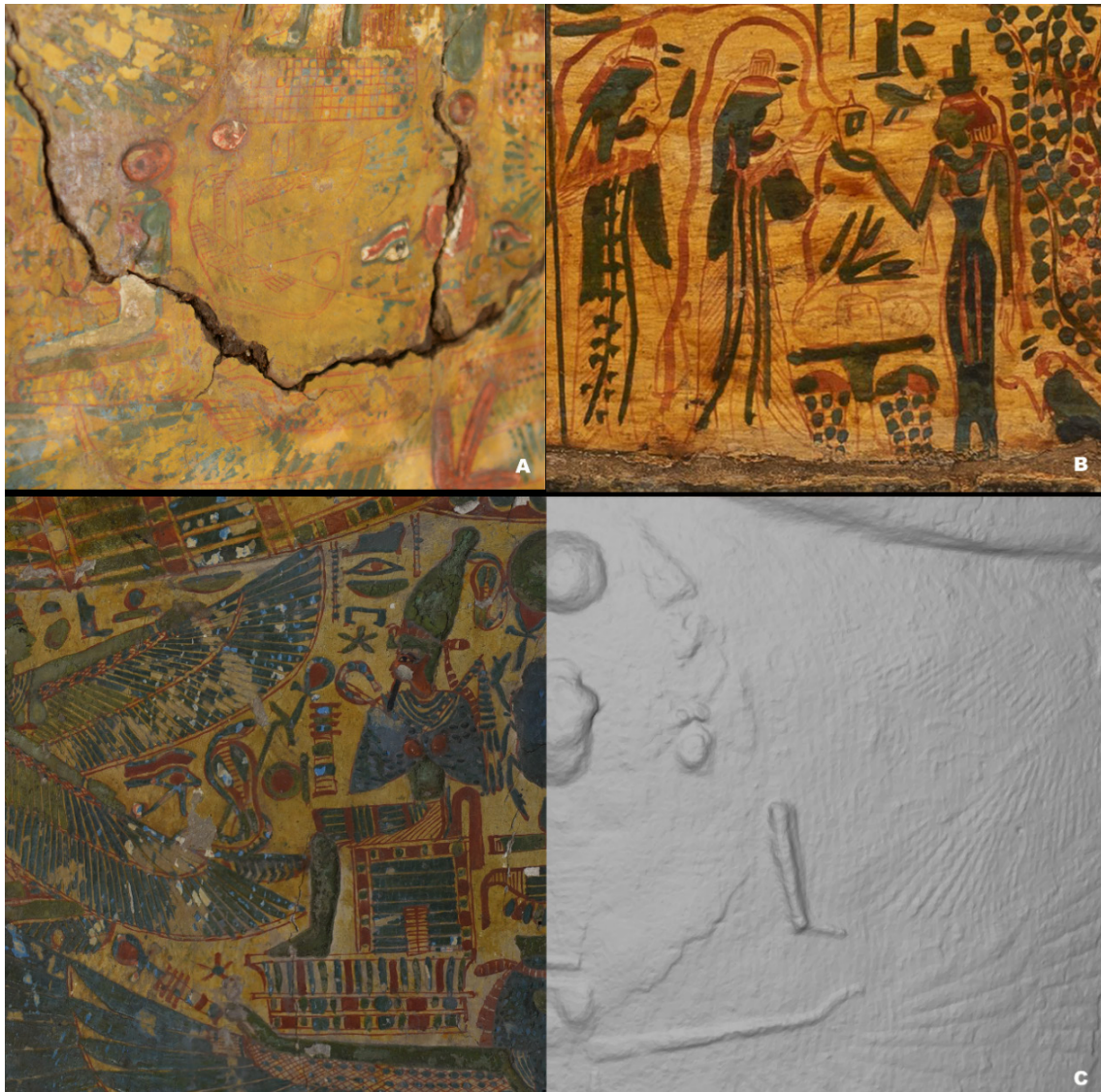


Fig. 1: (A) Detail of the lid of the coffin of Nesra, early 22nd Dynasty (MANN, IG 2348); (B) Detail of the box of the coffin of Tamutmutef, 21st Dynasty (Museo Egizio di Torino, Cat. 2228/01); (C) Detail of the mummy board of Nesypanebawib, 21st Dynasty (RMO, AH1a). 3D Models by Stefania Mainieri within *Faces Revealed Project*.

Limiting our analysis to the most external surfaces, the yellow coffins generally show smooth surfaces sometimes with the addition of a few elements made with the *pastiglia* technique to reproduce low relief.⁸ This technique, added to the use of yellow colour

⁸ The *pastiglia* is a low-relief decoration technique in a white paste, which can be gilded or painted, used on coffin lids for making scarabs, sun discs, and deities in a low relief. See Geldhof 2018; Amenta 2024.

for the background,⁹ was part of a preference to use inexpensive materials to suggest precious ones, such as gold or even precious stones, by highlighting specific iconographic elements such as a crown, bodies of deities, sun disks (Fig. 1C). Moreover, to achieve an effect similar to gold, sometimes a yellow pigment – such as orpiment – was also added to the already yellow paint.¹⁰



Fig. 2: Detail of the outer (A) and inner (B) lid of Khonsu, 19th Dynasty, Deir el-Medina (TT 1), Metropolitan Museum of Art, 86.1.1a and 86.1.2a. (C) Detail of the inner box (outer right side) of Kha and (D) of the inner box (outer left side) of Merit, 18th Dynasty, Deir el-Medina (TT8), Museo Egizio, Torino, Suppl. 08429 and 08470 (for the 3D model: <https://sketchfab.com/3d-models/inner-coffin-of-merit-65e7a6810a58416a86a0b3142422bce9>).

However, it is interesting to note that among the set of coffins analysed in *Faces Revealed*, the coffins of Khonsu¹¹ display a divergent production technique observable in the model without texture. Found in the family tomb of Sennedjem in Deir el-Medina

⁹ The pigments used for yellow colour were yellow ochre and orpiment, the last much more vivid, with a lamellar structure and can reflect the light, creating a gold effect. See Amenta 2024; Brunel-Duverger 2020, 42-43.

¹⁰ On the position of orpiment in the stratigraphy see Brunel-Duverger 2020, 177-255.

¹¹ Metropolitan Museum of Art, 86.1.1a-b and 86.1.2a-b. Cooney 2007; Bettum 2013, 248-255, 3a, d-g.

(TT1) and categorised as a ‘proto-yellow’ coffin of the 19th Dynasty (ca. 1292–1191 BCE),¹² it employs a distinct technique that seems to more closely align it to the methods used for the black coffins of the New Kingdom and the decoration of gold leaf (Fig. 2B).¹³

The delineation of the figures’ forms on the outer surfaces of the Khonsu lids is not merely in red; the figures are finely incised into the wooden surface while hieroglyphic bands and iconographic motifs are modelled in a very low relief (without using the *pastiglia* technique – Fig. 2A-B).¹⁴ The contour lines of the collar bands, the body of the goddess Nut, her plumage, and her dress are finely engraved, thereby rendering their outlines clearer. This technique is of particular interest, given its uniqueness; although it is not already a ‘full’ yellow coffin, it is the only ‘proto-yellow’/ yellow coffin in the *Faces Revealed* dataset¹⁵ to date that features this method of carving. The delicate engravings resemble a technique previously employed with gold leaf, where the object is chiselled or modelled in plaster and is then overlaid with gold leaf (Fig. 2C-D). The technical elegance may be attributed to the preferences of the deceased. It is noteworthy that Khonsu belonged to a sub-elite group. Despite the absence of costly materials in his coffins – such as gold leaf – they exhibit a level of craftsmanship that in many ways eclipses that of contemporary elite burials. It is as if he sought to compensate for the paucity of valuable resources by showcasing his expertise.¹⁶ The use of yellow instead of gold leaf, in addition to the aforementioned technique, suggests the possibility of a deliberate decision on the part of the deceased to create a high-level coffin using ancient techniques, albeit with more economical materials.¹⁷

In addition to a different technique of production, the inner coffin shows two other important features which may be evidence of the passage between two different styles of coffin as well as the autonomy that owners and artists had in their production. The inner lid represents a perfect mix of two different styles: the ‘festive dress’ type coffin, which appeared after the Amarna Period,¹⁸ and the mummiform coffin with the deceased as a *sah* image, the typical form of anthropoid coffins since the Middle Kingdom.¹⁹ The inner coffin of Khonsu represents the deceased as a *sah* image with shroud and forearms crossed over the chest, while maintaining some features of the previous type – the ‘festive dress’ coffins – visible mainly in the duplex wig rather than the striped Osirian head-cloth and the short beard instead of the long and curved one.

¹² Bruyère 1959; Mahmoud Abd el-Qader 2011; Sousa 2018, 37-42; Sousa 2019, 96-127; Gabler, Salmas 2022. Regarding the first known examples of yellow coffins, see Sartini 2024.

¹³ An example is the coffin of Merit (Museo Egizio di Torino, Suppl. 08470), see Sousa 2019, 80-83. For black coffins see: Niwiński 1984; Niwiński 1988, 11-12; Dodson 1998; Taylor 2001; Sousa 2018, 28-32; Sartini 2019; Sousa 2020a.

¹⁴ This technique is visible also on the outer surfaces of the boxes.

¹⁵ For the dataset (ca. 100 coffins) see Mainieri 2024a, Table 1.

¹⁶ Cooney 2007.

¹⁷ Cooney 2007.

¹⁸ Niwiński 1988, type Ia-b; Grajetzki 1996; Bettum 2013, 120, 126-127; Sousa 2018, 32-36.

¹⁹ Sousa 2018, 19-43.



Fig. 3: (A) 3D model of the inner lid of Khonsu (by Stefania Mainieri from *Faces Revealed Project*). (B) 3D model with and without texture of the inner lid of Sennedjem, NMEC JE 27308 (by © danderson4, <https://sketchfab.com/3d-models/mummy-board-of-sennedjem-egyptian-museum-cairo-f42f4c9087804759a15839fb1b625eab>). (C) Detail of the face of Khonsu's inner lid with and without texture (C1) and model without texture with an overlay of the design reproducing the black-decorated features (C2).

Another very interesting feature highlighted by the model without texture is the modelling of the chest muscles under the collar (Fig. 3A). The chest was commonly represented on the male 'festive dress' type coffins, as for example, the one of Sennedjem – the father of Khonsu – testifies to (Fig. 3B). In other 'proto-yellow' coffins, however, this anatomical detail is not realised; a style seemingly disappearing as fast

as it appeared.²⁰ On the lid of Khonsu the mummy-like appearance as *sah* seem to include also the image of the deceased as a living being in a kind of conciliation of both types on the same object before the appearance of ‘full’ yellow coffins.²¹

The presence of these features on the inner lid of Khonsu may suggest not only the autonomy in the artistic or aesthetic quality of the woodwork by single artists but also a kind of autonomy in the creation of new ‘solutions’ during the passage from one style to another one, creating intermediate, hybrid and ‘peculiar’ forms which merge old and new features on the same object.²² Although this aspect has already been considered by researchers,²³ it is important to keep it in mind, as hybrid and ‘peculiar’ forms which overlap periods continue in ‘full’ yellow coffins, as precisely confirmed by the *Faces Revealed Project* and the use of 3D models.²⁴ These peculiarities on coffins have always been considered an indication of reuse.²⁵ However, they may rather bear witness to a change in form between two periods, resulting in a mixture of ancient and new traditions in a single coffin, as, for example, the yellow coffins set of Tanethereret testifies.²⁶

The last feature we observe by deactivating the decoration is how the face and features are carved into the wood and how the decorative layer was applied to it (Fig. 3C1-2). This informs us on its production as the application of decoration can follow the sculpted/modelled traits or can partially or totally modify the original lines to correct errors, adjust asymmetries or, in occasional cases, readapt coffins for reuse.²⁷ On the face of the inner lid of Khonsu, for example, we note that the shape of the carved eye differs from the painted one. It is thinner and more elongated both internally and externally to reproduce the type of eye shape commonly found in Deir el-Medina. Furthermore, we note that the arched eyebrows were initially painted close to the rounded line before continuing upwards to form an arch (Fig. 3C2). However, what needs to be considered is mainly that the modelling of the masks and human parts is executed with a high level of detail, comparable to the ones of the stone statuary. Also, the shape, size, position and proportions of the facial features are consistent with the standard, canon and style of the statues of the period.²⁸ The face on the coffin is oval (ca. 13.8x13.9 cm) with a low forehead, high cheekbones, full cheeks and an oval chin; the eyebrows are rounded and frame two elongated but opened eyes (ca. 2.2x4.1 cm),

²⁰ This conclusion is based on visual observation. However, a more systematic study of ‘proto-yellow’ coffins would be necessary to analyse this data, using a 3D model to facilitate observation.

²¹ A sort of combination between *sah* iconography and details of everyday clothing is also attested on Katebet’s coffin (British Museum, EA6665). Betrò, Miniaci 2018, specifically 179.

²² This aspect, combined with the innovations in decoration on the box - such as the figure of the deceased and the incrementing of scenes generally represented in the tomb - evidence that the change of the style of coffins was performed within a generation and persisted thereafter, evolving into a pervasive trend associated with the socio-economic and political conditions of the era. Cooney 2007.

²³ Bettum 2013, 129; Betrò, Miniaci 2018, specifically 179.

²⁴ For further details on reconsideration of ‘peculiar’ coffin using the set of Tanethereret, refer to Mainieri 2024b; Mainieri forthcoming b.

²⁵ Cooney 2024.

²⁶ Musée du Louvre, Cat. E13027, E13034, E13035. For the coffin set see Niwiński, Rigault 2024, 250-297, Cat. 6a-e. See also Mainieri 2024b.

²⁷ For further details, refer to Mainieri 2024a; Mainieri forthcoming b; Cooney 2024 and relative bibliography.

²⁸ For canons see Robins 1994.

close to each other (ca. 2.4 cm) and located on the upper part of the face; the nose is large (ca. 5.1x3.9 cm), thin at the root and large at the base with visible nostrils; the mouth, naturalistic, has philtrum and upper arch; it is wider than the base of the nose (ca. 4.5 cm) and has full lips. The facial features carved on the coffins, therefore, although ‘concealed’ cannot be considered secondary elements especially if, enlarging the analysis to the entire dataset,²⁹ we see that the care for detail regards all the coffins, including those from the subsequent period.



Fig. 4: (A) Detail of the mummy board of Panebmonthu (Musée du Louvre, E13046). (B) Statue of the High Priest of Amun Ramessesnakht, reigns of Ramesses IV-IX (Egyptian Museum, CG 42163; Wikimedia CC BY-SA 2.0); (C) Statue of Horemheb and one of his wives, late 18th-early 19th Dynasty (British Museum, EA36, The Trustees of the British Museum - CC BY-NC-SA 4.0); Standard-bearing statue of (D) Pashed and (E) Penbuy, 19th Dynasty, Deir el-Medina (Museo Egizio, Torino Cat. 3047 and 3048, CC 01.0).

²⁹ Mainieri 2024a, Table 1.

A close link with the style of the statues of the period is evident not only in the Ramesside ‘proto-yellow’ coffins, but also continues in the early 21st Dynasty (Fig. 4A-E), though there is a gradual but continued modification of them due to a change of style (and/or the socio-economic level of the owner/craftsman). Moreover some coffins of the early 21st Dynasty, show facial features that recall the portraiture style of the Ramesside period (ca. 1292-1077 BCE), a physiognomy style reminiscent, therefore, of the previous statuary style with the surviving of some features over time. An example is the mummy board of Panebmonthu³⁰ whose face shows strong stylistic parallels with the Ramesside sculpture (Fig. 4A-E) particularly in features such as the long, straight nose; the concavity separating the nose from the sloping, low forehead; and the small, almost flat eyes positioned just beneath this depression. The face itself is square-shaped with prominent jaws and high cheekbones, while the mouth displays corner holes along with a clearly defined philtrum and upper lip arch.

2.1 Coffins as Statues: from *Faces Revealed* to *RecoGnISe*, from Photogrammetry to A.I.

Beyond the wealth of information on production revealed by the *Faces Revealed Project*, I would like to draw attention to this close stylistic link between the wooden faces sculpted on coffins and the ones on statuary. This link, together with the evolution of forms over time and the re-evaluation of all ‘peculiar’ coffins as reused,³¹ represents one of the research questions of a new project named *RecoGnISe*.³²

The study of statues and ‘portraiture’ has a long history, and their stylistic forms are important elements in typology and classification.³³ However, when it comes to coffins, such aspects have never been taken into consideration, or at most seen as secondary. Scattered comparisons have been made between stone coffins and statues, but only in a limited context, for example, in the identification of kings, and never between the wooden coffins or between them and the statues.

Russmann³⁴, Bryan³⁵ and Sourouzian were the first to make observations in this area, with the latter identifying the characteristics of the transition between the 18th and 19th Dynasties on the basis of the statues and stone coffins of the vizier Paramessu (later King Ramesses I, ca. 1292-1291 BCE).³⁶ Bryan also reviewed the relationship between statues and coffins, viewing them as the result of a recourse to “available artisans from Western Thebes to work on a broad range of monuments, perhaps crossing artistic forms as a result”.³⁷

³⁰ Musée du Louvre, E13046. For the coffin see Niwiński, Rigault 2024, 60-87, Cat. 1a-c.; for 3D Model: <https://doi.org/10.5281/zenodo.11063613> (CC-BY 4.0).

³¹ Mainieri 2023b; Mainieri 2024a; Mainieri 2024b; Mainieri forthcoming a.

³² *Reconstructing physioGnomy In Sculpture: a comparative analysis of ‘yellow coffin’ faces and the faces of statues* (MSCA2024_0000023 - CUP: C63C25000430001). The Project was awarded by funding in May 2025 and has been running since June 2025 at the University of Naples ‘L’Orientale’ (UniOr), Department of Asia, Africa and Mediterranean (DAAM).

³³ For studies on statues see for example: Bryan 1987; Sourouzian 1991; Bryan 2010; Laboury 2010; Perdu 2012; Bryan 2015; Connor 2018; Sourouzian 2020; Connor 2022; Brügger 2023.

³⁴ Russmann 2001, 210.

³⁵ Bryan 2010.

³⁶ Sourouzian 2020, 2, fig. 230 a-d (statues P1-2, coffins P 3-4).

³⁷ Bryan 2010.

Despite these considerations and sporadic studies, there is still a lack of in-depth research on these relationships, particularly with regard to the strict link and the “cross of artistic forms” between the faces on the coffins and the statues. Moreover, as contemporary studies on yellow coffins are introducing the possibility of the existence of some kind of pre-established model/ training for iconography and texts,³⁸ and *Faces Revealed* identified connection between faces of different coffins regarding physiognomy (Fig. 5), some questions became imperative: could this idea of pre-established models also be applied to the sculptural elements of coffins? Could there be reference models also for the sculpted parts? If so, could they be used indiscriminately for coffins and statues, as well as for sculptures in wood and stone?

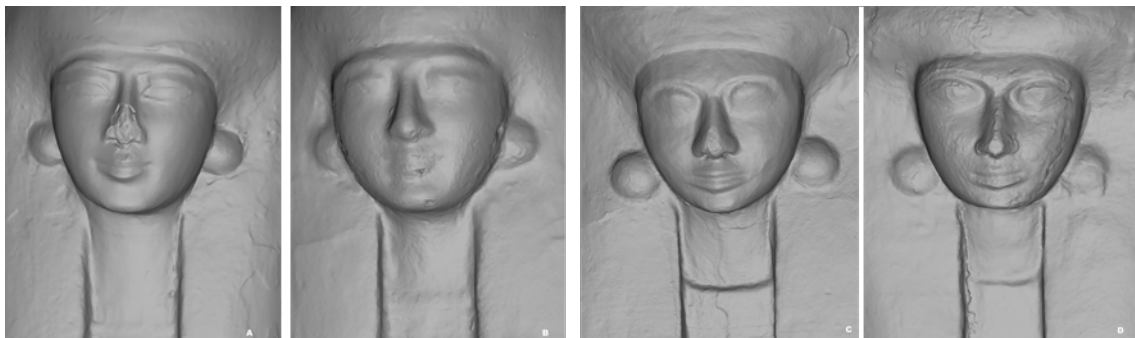


Fig. 5: Example of strict similarities between faces on different coffins which suggests the existence of some kind of model/ training: (A) the face on the mummy board of Tanethereret (Louvre, E13035) with the ones of the (B) mummy board of Henuttawy (MET, 25.3.184); (C) the face on the outer lid of Ikhy (MV, 25035.3.1) with the one on the (D) outer lid of Djedmutiuesankh (ME Firenze, 8524).

To try to answer these questions, to the coffins already analysed between 2021-2024 within *Faces Revealed*,³⁹ a new dataset will be added enlarging the study on coffins from the 19th Dynasty to the first half of the Late Period (ca. 1292- 525 BCE). The increase in the number of objects is crucial for statistical purposes, as an expansion of the dataset will make the outcomes of the analysis more scientifically reliable. At the same time, a group of statues from Thebes and dated to the same chronological range will be selected. The extension of the chronology is due, on the one hand, to the scarcity of evidence relating to statues dating back to the Third Intermediate Period; on the other hand, as already pointed out, the faces on the coffins of the early 21st Dynasty seems to be close to the ‘portrait’ style of older statues, while those of the late 21st and early 22nd Dynasties have characteristics more in line with later objects.⁴⁰ For this reason, become essential to have a larger data set, not only in numerical terms but also in chronological ones.

³⁸ Vilaró-Fabregat 2024, specifically § 2.2.

³⁹ Mainieri 2024a, Table 1.

⁴⁰ The features on *stola* coffins, for example, are completely different from previous productions. See Mainieri 2023b, Mainieri forthcoming a.

The first and second parts of the project will be devoted to the application of the *Faces Revealed* methodology on the selected materials, using the same instruments, the same software and following the same photogrammetric process.⁴¹ An important step will be dedicated to clustering, comparing and cross-checking faces. This step will use the Compare Spreadsheet, the system developed during the previous project, which allows types to be grouped.⁴² Although the Compare Spreadsheet is functional, it is quite complex and difficult to manage and ‘read’ for a larger amount of data, so, during *RecoGnISe* a facial recognition algorithm, capable of automatically identifying the pre-established markers and variables on 3D models, will be developed.⁴³ The aim is to make the grouping more easier, more precise and quick, and to cross-reference and compare the morphometric data of coffins and statues on several levels (Fig. 6).

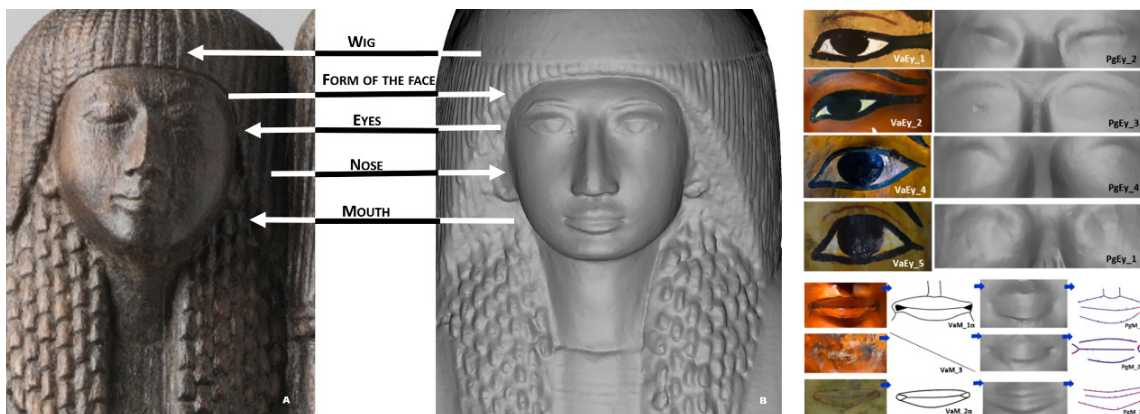


Fig. 6: Comparison of facial features between wooden standard-bearing statue of Pashed (A), Museo Egizio, Torino Cat. 3047, and the mask without texture of the mummy board of Panebmonthu (B), Musée du Louvre, E13046. On the right: types based on the morphometric approach for a vocabulary on facial features (*Faces Revealed Project* – DOI:10.5281/zenodo.11002935).

An initial test of automatic landmarks recognition on bi-dimensional orthophotos was carried out in collaboration with Alessandro Mandelli⁴⁴ at the start of the *Faces Revealed Project* using the Dlib library, an open-source software library module.⁴⁵ Despite very promising preliminary results, it was concluded that to obtain more credible results the algorithm needed to be modified and trained on a large set of similar ‘images’. Now, with the corpus already available and the new datasets, it will be possible to train the

⁴¹ Mainieri 2024a.

⁴² The Compare Spreadsheet is open and free and to use on the project public page: <https://facesrevealed.museoegizio.it/en/section/Compare/Compare-Spreadsheet/>

⁴³ The algorithm will be developed in collaboration with the School of Informatics, Computing, and Engineering and the Virtual World Heritage Lab at Indiana University, Bloomington (USA) in the persons of Gabriele Guidi, Professor in Informatics Virtual Heritage Track Director Studies in Digital Heritage, and Fairman Risch, a PhD student in Computer Science who will devote part of his project to this case-study.

⁴⁴ Specialist senior technician at the Politecnico di Milano (Department ABC).

⁴⁵ Mainieri *et al.* 2022; King 2009. For the software: https://github.com/davisking/dlib/blob/master/python_examples/face_landmark_detection.py. King 2009.

algorithm based on the project's needs and work directly on 3D models (point-cloud) instead of bi-dimensional images.

In this sense, the project will go beyond the state of the art not only in Egyptology but generally for Digital Technologies applied to Cultural Heritage, especially regarding the use of Artificial Intelligence (A.I.) algorithms. The second edition of the 'Ancient Egypt – New Technologies' conference in Naples attests the increasing openness of the Humanities disciplines to Digital Technologies and A.I., particularly for its advantages in simplifying and speeding up the processes of analysis and documentation (in terms of saving time in research) and in supporting the scholar in research and typological classification. Among numerous international projects based on A.I. models,⁴⁶ facial recognition methods represent a more recent, interesting and promising frontier. Experiments in this field are being carried out, for instance, by Alessia Amenta and the Vatican Museums within the *Progetto Sekhmet* for the analysis of the production of lion-headed statues,⁴⁷ and by the University of Twente and Radboud University in the Netherlands, which are developing software able to automatically identify portraits of Roman emperors through physiognomic traits.⁴⁸ Both projects have important and positive potential and demonstrate the international interest in the development of new tools based on 'human-machine' collaboration to facilitate the research by quickly processing enormous amounts of data, which is often difficult to manage with a traditional database. The ultimate aim will be to create a clearly defined evolutionary framework of facial features from the Ramesside period to the Late Period (c. 1292–525 BC) for both coffins and statues.

A comparative analysis of the characteristics of wooden masks and statues will enable an in-depth examination of the relationships between facial features, the identification of any "cross-pollination between artistic forms", and the potential identification of a shared production and/or common models used for different materials.

2.2 Not just coffins

The usefulness of such data for the study of the production of yellow coffins will have major implications for other classes of objects. The importance of observing finds with and without colour is also useful for inscribed or impressed objects. Cases in point are the fragmentary statue of the royal scribe Neferhotep from the now lost Imperial Iseum of Benevento and currently exhibited in the Arcos Museum of Benevento (inv. 1920), and the *cretulae* coming from the archaeological excavation in the Sun Temple of Niuserre at Abu Ghurab.

⁴⁶ Among the interesting projects see in the present volume Gracia Zamacona *et al.* 2026, Avano *et al.* 2026 and Jauhiainen 2026. See also <https://cleo.aincient.org/pages/en/>; <https://datascience.uchicago.edu/research/deciphering-cuneiform-with-artificial-intelligence/>

⁴⁷ Amenta 2023.

⁴⁸ Ramesh *et al.* 2022.

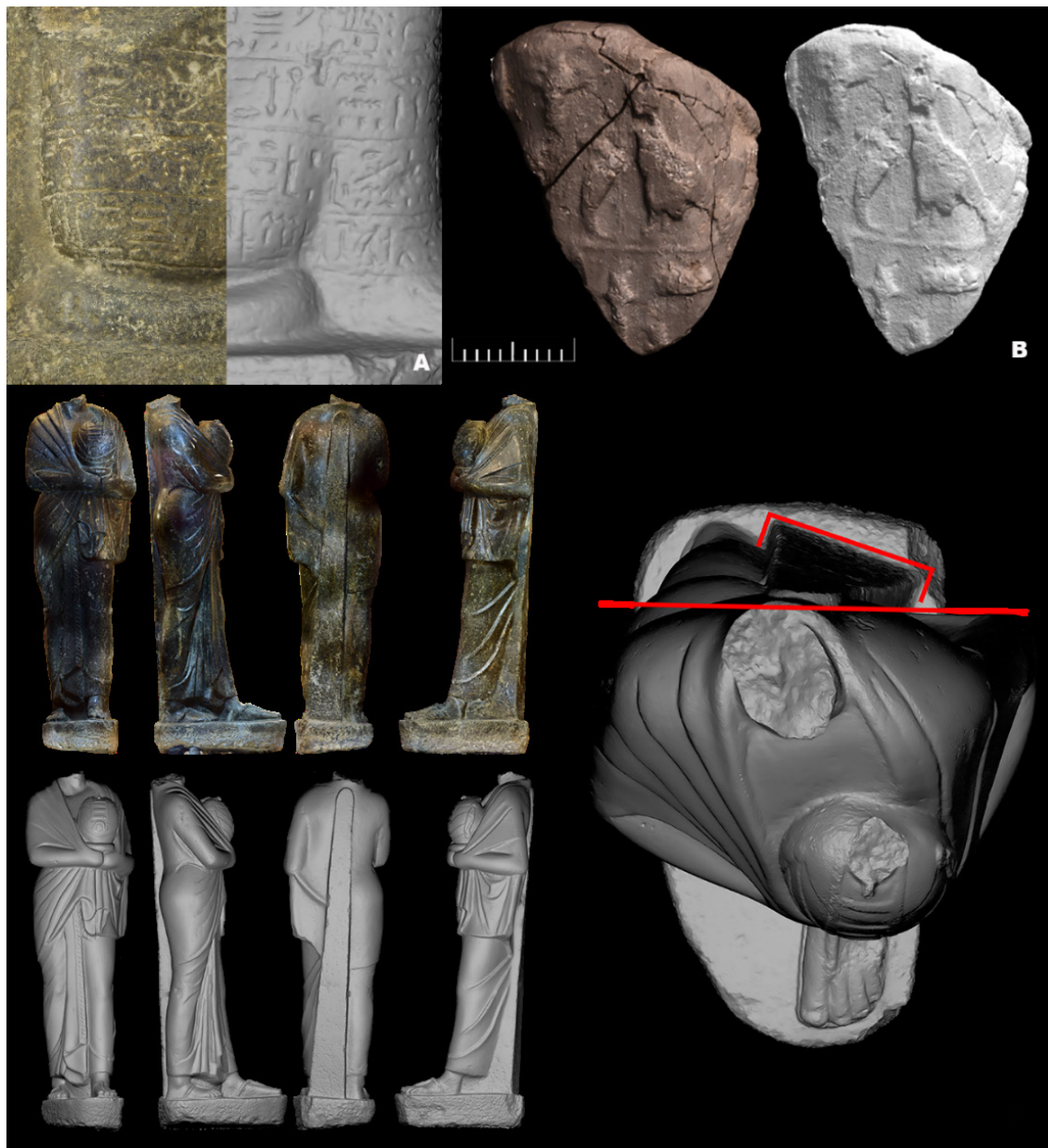


Fig. 6: (A) Orthophoto of the statue of Neferhotep, with and without texture (Arcos Museum of Benevento, inv. 1920). (B) Orthophotos with and without texture of the seal-impression of the king Shepsekara (Abu Ghurab, ST_C1094_4_21). (C) Orthophoto of the Priest carrying 'Osiris-Canopus/Hydreios' (Arcos Museum of Benevento, inv. 1926). 3D models by Stefania Mainieri.

The statue of Neferhotep is a typical block statue characteristic of the Pharaonic period, initially dated to the 22nd Dynasty.⁴⁹ However, a recent re-examination of the

⁴⁹ Müller 1971, 86; cat. 282.

artefact by Elisabeth Frood has led to a re-evaluation of its chronology, suggesting instead a connection with the 19th Dynasty statuette.⁵⁰ During the new study, the scholar faced considerable difficulties when re-reading the text that completely covers the statue. These difficulties were related to the state of conservation of the object, which was fragmentary and corroded. This was aggravated by the characteristic grey-yellow colour of the stone with which it was produced. Although the inscription had been almost entirely deciphered, the observation of the model without textures (Fig. 7A) allowed the scholar to swiftly verify the accuracy of the transcription and, where necessary, integrate signs or parts that she had been unable to decipher with the naked eye or with the aid of grazing lights and photographs.⁵¹

Another interesting example is that of the *cretulae* discovered in the solar temple of Niuserra at Abu Ghurab, objects that vary greatly in terms of size and material. During the latest archaeological mission, a photogrammetric survey of the small artefacts was carried out with the aim of creating a digital archive of all the materials from the temple for conservation and research purposes.⁵² Within the material were dozens of fragments of clay *cretulae*, with associated seal impressions, bearing the names of rulers of the 5th and 6th Dynasty, such as Shepsekara (Abu Ghurab, ST_C1094_4_21, Fig. 7B).⁵³ The photogrammetry of these objects represented the most challenging task of the survey due to their small scale.⁵⁴ However, the photogrammetry confirmed the names and the signs impressed on the *cretulae* and, as in other cases like the Neferhotep statue, allowed a complete reading and, by digitally moving the light source, and decoding hieroglyphs which were difficult to understand due to the colour of the objects and/or the very shallow impression.⁵⁵

Finally, the study of stone sculptures with the support of 3D models is the basis of a new research promoted by Rosanna Pirelli on statues of priests carrying 'Osiris-Canopus'. Comparing five examples – two from Benevento (Fig. 7C),⁵⁶ two similar ones found in Alexandria⁵⁷ and one from Cagliari⁵⁸ – Pirelli noticed significant stylistic differences, which led her to seek more rigorous criteria to better define their chronology

⁵⁰ I would like to thank Elisabeth Frood for our discussion about this statue and for sharing with me the findings of her study, which is due to be published in RiMe, Frood (forthcoming).

⁵¹ On the enhancement of the legibility of inscribed objects through digital models added to other instruments, see Abdelaziz and Elsayed 2025 (in the present volume) and related bibliography.

⁵² The archaeological investigation of the site of Abu Ghurab has been carried out since 2010 by an international research team currently headed by Massimiliano Nuzzolo and Rosanna Pirelli, Universities of Turin and Naples 'L'Orientale', in cooperation with the Uninettuno University of Rome and the Polish Academy of Sciences in Warsaw. For the Sun Temple see Nuzzolo 2018 and the public page of the project <https://www.suntemplesproject.org/the-sun-temples-of-niuserra/>

⁵³ Nuzzolo 2024.

⁵⁴ For the photographic survey a full-frame Nikon D750 camera coupled with a Nikkor 105 mm lens (f/1.16; 1/6 sec., ISO-400) was used. The object was located in a light box on a rotating base equipped with circular markers and using a scale bar for references.

⁵⁵ A comprehensive work on this aspect and photogrammetry applied to objects from Abu Ghurab is in progress.

⁵⁶ Museo Arcos Benevento, inv. nos. 1922 and 1926.

⁵⁷ One statue in Greco-Roman Museum in Alexandria, inv. no. 4309 (Müller, inv. no. 20274), one in National Museum of Alexandria, inv.no. SCA 449.

⁵⁸ Museo del Tesoro di Sant'Eulalia in Cagliari, inv. no. 18004 (probably to be corrected as 18064).

and context of production.⁵⁹ From a comparative autoptic analysis of all the finds, the scholar identified a new type of canopic jar, the one held by the priest of Cagliari, which would be chronologically placed between Weber's type A and type B;⁶⁰ and noted some details relating to the presence/absence, shape and position of the back pillar, which led her to formulate new chronological hypotheses and attribute the three statues found in Italy to local production rather than Alexandrian (as previously believed).⁶¹ Here, the photogrammetry and digital model are valuable in calculating the inclination of the back pillar on which the statues rest, the asymmetrical arrangement of the hips at the back of the figure or to better observe the presence/absence of clavicles and a tunic beneath the cloak.⁶² These enable us to define in a more scientific way the differences between objects, with precisely observed mathematical data. Although the researcher identified these differences with the naked eye, there is no doubt that the observation of these statues with colour turned off, and the possibility to have accurate measurements and then compare the models provide valuable, and sometimes crucial, additional data. This raises important questions about how these objects should be interpreted, particularly concerning the contexts in which the sculptures were produced and used.

3. Conclusions

In conclusion, these examples demonstrate that digital technologies such as photogrammetry and 3D modelling enable researchers to investigate more deeply and explore aspects that were previously overlooked because of the limits of human observation. In this sense, these tools enhance our understanding of the material culture of ancient societies and help to reconstruct the histories of the people behind the objects. In the case of coffins and statues, for example, such technologies help to identify the style and production of artefacts, thereby bringing to 'life' the artisans who created or commissioned them across different periods.

Previously, the *Faces Revealed* project highlighted the importance of 3D models as research tools for their ability to make the invisible visible — an ability undervalued until the project's submission in 2019 — and for enabling morphometric comparisons to reveal connections among objects. Now, the *RecoGnISe* project aims to advance the field of facial feature recognition by developing free, open, and reusable software capable of automatically identifying facial landmarks on 3D models and grouping objects accordingly.

The inclusion of Artificial Intelligence in Egyptological research has the potential to enhance the reliability of results and expand the scope of datasets, thanks to its capacity to process large volumes of information. It remains essential, however, to acknowledge the primacy of human observation and validation. Technology is a means to enrich the research process, not a substitute for intellectual capacity. Human involvement remains the fundamental element at every stage — from initial training to development and application — ensuring that the collaborative interaction between humans and machines always guarantees data quality.

⁵⁹ Pirelli 2024.

⁶⁰ Weber 1911, 32.

⁶¹ Pirelli 2024.

⁶² Pirelli 2024.

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Online Resources

<i>Faces Revealed Project</i>	https://facesrevealed.museoegizio.it/
Compare Spreadsheet	https://facesrevealed.museoegizio.it/en/section/Compare/Compare-Spreadsheet/
Dlib library	https://github.com/davisking/dlib/blob/master/python_examples/face_landmark_detection.py King 2009
Cleo	https://cleo.aincient.org/pages/en/
Deciphering Cuneiform with Artificial Intelligence	https://datascience.uchicago.edu/research/deciphering-cuneiform-with-artificial-intelligence/
Fitzwilliam Museum's Ancient Egyptian Coffins Project	https://egyptiancoffins.org/
Sun Temple Project	https://www.suntemplesproject.org/the-sun-temples-of-niuserra/
The <i>Vatican Coffin Project</i>	https://www.museivaticani.va/content/museivaticani/en/collezioni/musei/museo-gregoriano-egizio/museo-gregoriano-egizio/progetti-scientifici/vatican-coffin-project.html

Digitalising antiquity: the example of terracotta figurines in Ancient Egyptian collections

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Abstract

The production of terracotta figurines as an art form is germane to a number of ancient civilizations and it carries undoubtedly a certain social value. Although their production represented a major activity during antiquity, they have been often qualified as a 'minor' production, being a mass-produced item made from a low-cost material. In the study of ancient terracotta figurines, the rewards are greatest when examining the broadest possible spectrum of production, rather than focusing on one individual figurine. One of the main sources to study these artefacts is represented by museum collections. The projects *SUR.VI.V.E. (SURveying VIRTual Voids in Egyptian collections). A Digital and Cultural Study on Terracotta Figurines and their Lost Molds* and its extension with *SUR.VI.V.E.-Phase 2* stem from the idea of combining the analytical approaches used so far in the study of the terracotta figurines with the innovative digital methodologies. The methodology developed during the first phase of the project and focused on the corpus of ancient Egyptian terracotta figurines kept in the collection of the *Museo Egizio* in Turin, will be applied in the next three years to other groups of objects that, differently from the collection of *Museo Egizio*, will be selected according to different and more specific criteria, like the degree of their preservation and provenance. The application of digital techniques and virtual 3D rendering in a more systematic way on different clusters of materials will facilitate the knowledge and the access to surveyed terracotta figurines, even those preserved in 'minor' collections, in order to implement the comparative study of this category of objects. The methodology applied in the project has the advantage of using non-invasive and replicable techniques, as well as the possibility of spreading the results both to academia and to the general public. It was designed with a triple aim in mind: to be proportional to the available data, to be universally replicable, and to function as repository of information. 3D models may be used for dissemination purposes, but their final aim is to be used for current and future research purposes.

Keywords: *Material culture; Egyptian Collections; Terracotta figurines; Popular cult; 3D modelling.*

1. Introduction (AM, CC)

In the last decade, 3D technologies have become increasingly prevalent in archaeology and cultural heritage, offering numerous applications both in the field and in research labs. Especially, 3D modelling is transforming these research fields, providing a more detailed and accurate representation of artefacts compared to traditional 2D images like photographs and drawings. High-quality 3D models allow researchers to access more precise data and to share these models widely, fostering greater collaboration within the academic community. Applying digital techniques and virtual 3D rendering to different museum collections will also facilitate the study of several categories of objects, including those in less prominent collections, enabling more comprehensive comparative research.

The integration of traditional analytical approaches with innovative digital methodologies represented the foundation of the Project *SUR.VI.V.E. (SURveying VIRTual Voids in Egyptian collections) A Digital and Cultural Study on Terracotta Figurines and their*

Lost Molds and its extension *SUR.VI.V.E.-Phase 2* at Politecnico di Milano.¹ The aim of the project was to systematically apply digital techniques to the corpora of ancient Egyptian terracotta figurines from a museum collection (Fig. 1), in our specific case those of Museo Egizio in Turin, and to explore how 3D models can be applied to a category of artifacts in order to enhance our understanding of their material aspects. This approach could serve as a model for future research in coroplastic studies, inspiring renewed academic interest in the field.



Fig. 1: Display cases of the collection containing the terracotta figurines. *Museo Egizio, Torino* © Caputo.

The production of terracotta figurines was common across many ancient civilizations and held social significance, as reflected in their role in creation myths. Despite their humble nature, terracotta figurines survived better than many more luxurious items, providing a rich and diverse glimpse into religious beliefs, divine representations, and social ideologies. Although terracotta figurines were often dismissed as ‘minor’ art due to the cheap material and mass-production methods, their frequent appearance and the large-scale production suggest they played a significant role in ancient life. As such, their study is essential to gain a deeper understanding of past civilizations, particularly the non-elite populations. To obtain the most from studying ancient terracotta figurines, it is crucial to look at a wide range of production rather than focusing on individual pieces, for this reason museums are one of the primary resources for studying them.

The following paragraphs will focus on the significance of 3D surveying, the technologies involved, and the various applications of 3D modelling in the various research fields, as well as within the Project *SUR.VI.V.E.* However, only a small portion

¹The Project *SUR.VI.V.E.*, conducted under the supervision of Corinna Rossi (DABC-Politecnico di Milano), is funded by the Politecnico di Milano and awarded of the “Seal of Excellence” by the European Commission (H2020-MSCA-IF-2019).

of the collections is usually on display, chosen for their aesthetic appeal, iconography, or known provenance. It is likely that many specimens remain unpublished and unknown to both experts and general public. Given that these objects were produced in large quantities, often in series, and are not always fully preserved, this is understandable. Even when published, they have typically been treated as art objects rather than artefacts related to everyday life, often selected for their completeness and described primarily from an iconographic or artistic perspective. However, since the late 20th century, traditional catalogues that focus solely on descriptive, iconographic, and art-historical aspects are being replaced by more advanced studies. These newer approaches examine the material characteristics, production techniques, and sociocultural contexts of terracotta figurines. This shift has been driven by a growing interest in reconstructing the material culture of ancient societies and by comparing artifacts from well-documented archaeological contexts using modern scientific methods.

2. 3D surveying and modelling technologies (AM)

In recent years, 3D surveying and modelling have become pivotal tools in various branches, revolutionizing the way we approach design, analysis, and reproduction of physical objects. The integration of 3D surveying with advanced modelling techniques allows for the accurate digitization of real-world objects, enabling their manipulation, analysis, and reproduction with unprecedented precision.

More specifically, 3D surveying is the process of capturing the physical shape and appearance of an object using specialized hardware and software to create a digital representation. This digital model can then be used in various applications, such as reverse engineering, quality control, and digital archiving. The data collected by 3D sensors is typically a set of points in space, known as a point cloud, or a continuous surface, known as a mesh, which represents the exterior of an object.²

2.1 Sensors

There are several types of 3D sensors, both cameras and scanners, each using different principles and technologies to capture data. In the first case, the technique related to the use of cameras is called photogrammetry, while in the other cases we speak of 3D scanning. Photogrammetry and 3D scanning are powerful techniques used to create three-dimensional models of real-world objects and environments. Both methods have applications in a wide range of fields, from archaeology and architecture to gaming and virtual reality. Understanding the differences between photogrammetry and 3D scanning, particularly in the context of active and passive sensors, is crucial for selecting the right technology for a specific task. Both methods have their strengths and weaknesses, which are influenced by the types of sensors they use. Sensors are integral components of both photogrammetry and 3D scanning systems. They can be broadly classified into two categories: active and passive sensors. The primary distinction between these types lies in how they acquire information about the environment.

² Remondino 2011, 1104-1138.

2.2 Active sensors

Active sensors emit their energy (such as light, laser, or sound) and measure the response to gather information about the environment. This type of sensor is commonly found in many 3D scanning systems. Active sensors are independent from ambient light, namely they do not rely on external light sources, making them effective in various lighting conditions, including complete darkness. Moreover, they can provide highly accurate measurements, particularly over short to medium distances and can capture detailed information from complex surfaces, including those with varying textures and colours.³

3D scanners can quickly capture the geometry of an object, making them suitable for time-sensitive applications. These sensors have a few disadvantages, in fact: i) they generally require significant power to operate due to the need to emit energy, which can be a limitation in portable or battery-operated devices; ii) the technology behind active sensors can be expensive, particularly for high-end systems like LiDAR; iii) they can be susceptible to interference from other sources of the same energy, such as other lasers or bright lights in the environment; iv) some 3D scanners have difficulty capturing shiny, transparent, or reflective surfaces; v) the use of 3D scanners often requires specialized knowledge and training. There are two main families of 3D scanners: Time-of-Flight (ToF) scanners that emit laser pulses and measure the time it takes for the pulses to return after hitting an object; and structured-light scanners that project a pattern of light (usually stripes) onto an object and use cameras to capture the deformation of the pattern, which is then used to calculate the 3D shape.⁴

2.3 Passive sensors

Passive sensors, on the other hand, do not emit their energy, they detect natural energy that is either emitted or reflected by objects in the environment. Digital, thermal, multispectral and hyperspectral cameras are some examples of passive sensors. Digital cameras capture reflected light from objects. They are the primary tool used in photogrammetry; thermal cameras detect infrared radiation emitted by objects, allowing them to capture images based on temperature differences; multispectral and hyperspectral cameras capture data across multiple wavelengths of light, providing detailed information about the composition of objects. Photogrammetry is a technique that reconstructs 3D models from 2D images. It relies on the principles of geometry, specifically triangulation, to calculate the positions of points in space based on images taken from different angles. Photogrammetry involves capturing multiple overlapping images of an object or scene from various viewpoints. These images are then processed using specialized software that identifies common points in the images and calculates their 3D coordinates. The software uses algorithms to match points across the images, essentially “stitching” them together to a coherent 3D model. The final 3D model is directly related to the resolution of the images captured and the precision of the camera calibration process; photogrammetry is also very versatile, in fact, the same camera can be used to survey a wide range of objects and environments, from small artefacts to

³ Ramos 2015, 359-363.

⁴ Guidi 2015, 321-324.

large landscapes, or indoor scenes. Compared to 3D scanners, digital cameras have some advantages, such as a limited power consumption since they do not emit energy and usually they are less expensive than active sensors. On the contrary, passive sensors are less effective in low light conditions since they rely on external light sources or emitted energy; regarding the data elaboration, the process of matching points and generating 3D models can be computationally intensive and time consuming particularly for large datasets. This makes 3D scanning more efficient for projects with tight deadlines or when large areas need to be scanned.⁵

Photogrammetry and 3D scanning are both powerful techniques for creating 3D models, each with its advantages and limitations. Photogrammetry is a cost-effective and versatile method that excels in applications where high-resolution images and large-scale models are needed. However, it is limited by lighting conditions and may not achieve the same level of precision as 3D scanning.

On the other hand, 3D scanning, particularly with active sensors, offers high precision and speed, making it ideal for applications where accuracy is critical. However, the cost and complexity of 3D scanning technology can represent a barrier to entry for some users.⁶

The choice between photogrammetry and 3D scanning ultimately depends on the specific requirements of the project, including the desired level of accuracy, budget, and environmental conditions.⁷ Understanding the differences between active and passive sensors is also crucial, as it informs the selection of the appropriate technology for capturing the necessary data. Whether preserving cultural heritage, designing buildings, or ensuring product quality, both photogrammetry and 3D scanning offer valuable tools for capturing and analysing the physical world.⁸

2.4 Application fields

3D surveying and modelling have a wide range of applications across various industries, such as manufacturing and engineering, healthcare, entertainment and gaming, architecture and construction, art and design and cultural heritage. In manufacturing, 3D surveying is often used for quality control and reverse engineering. By scanning a finished product, manufacturers can compare it to the original design to ensure it meets specifications. Reverse engineering involves scanning a physical object to create a digital model, which can then be used to produce a new version of the object.

In healthcare, 3D surveying helps in creating custom prosthetics and orthotics. By scanning a patient's body, medical professionals can design devices that fit perfectly, improving comfort and effectiveness. 3D models are also used in surgical planning, allowing doctors to visualize and plan complex procedures.

In the entertainment industry, 3D surveying is used to create realistic characters and environments. Actors can be scanned to create digital doubles, and real-world locations can be digitized for use in movies and video games. This technology allows for more immersive experiences and faster production times.

⁵ Agapiou 2023.

⁶ Baltsavias 1999.

⁷ Melendreras Ruiz 2021.

⁸ Remondino, Campana 2014; Styliandis, Remondino 2016.

Architects and construction professionals take advantage of 3D surveying to capture the details of existing structures. This information can be used to create accurate models for renovation or restoration projects, ensuring that new work integrates seamlessly with the old. Scanning can also be used to monitor the progress of construction projects, ensuring that everything is built according to plan.

Artists and designers use 3D surveying to digitize their work or to create new forms of art. By scanning a physical object, they can manipulate it in digital space, experimenting with new ideas and creating complex designs that would be difficult or impossible to achieve by hand.

In museums and cultural institutions 3D surveying facilitates conservation and documentation of artefacts. By creating digital replicas of objects, they can be studied, shared, and even reproduced without risking damage to the original items. This technology also enables virtual tours, allowing people to explore cultural heritage sites from anywhere in the world.⁹

3. The role of 3D scanning in Cultural Heritage preservation (AM)

3D surveying has emerged as a ground-breaking technology in the field of cultural heritage preservation. It provides a non-invasive, highly accurate method of documenting and analysing cultural artefacts, monuments, and historical sites. This technology has revolutionized the way we approach the conservation and restoration of our shared cultural heritage, offering numerous benefits that were previously unimaginable. One of the primary advantages of 3D surveying in cultural heritage is its ability to capture detailed and precise measurements of objects and sites. Traditional methods of documentation, such as photography or manual measurement, often fall short in capturing the intricate details of ancient sculptures, buildings, or artefacts. 3D surveying, on the other hand, can create accurate digital replicas with sub-millimetric precision. These digital models can be used for a variety of purposes, including research, conservation, and public education. Moreover, 3D models allow for the creation of digital archives of cultural heritage objects. These archives serve as a valuable resource for researchers and historians, enabling them to study artefacts that may be in distant or inaccessible locations. In cases where physical objects are at risk of degradation due to environmental factors or human activity, digital preservation ensures that a detailed record is maintained, potentially aiding in future restoration efforts.¹⁰

Another significant benefit of 3D models is its role in restoration and reconstruction projects. Digital models created through 3D surveying can be used to design and test restoration techniques in a virtual environment before applying them to the actual object. This minimizes the risk of further damage and allows conservators to experiment with different approaches. Additionally, 3D printing technology, which is often used in conjunction with scanning, can produce physical replicas of lost or damaged parts of cultural heritage objects, facilitating their restoration. Furthermore, 3D models enhance public engagement with cultural heritage. Digital models can be used to create virtual reality experiences, allowing people to explore historical sites or artefacts from anywhere in

⁹ <https://www.cyark.org/projects/>

¹⁰ Morgan 2022, 213-225.

the world. This democratizes access to cultural heritage, making it possible for individuals who may never have the opportunity to visit these sites in person to experience and learn about them. 3D models offer precise documentation, support conservation efforts, aid in restoration, and expand public access to cultural heritage. As the technology continues to advance, their role in preserving our shared history will only become more vital.

4. Studying the corpus of Egyptian terracotta figurines (CC)

Egyptian craftsmen used moulds to produce terracotta figurines since as early as the New Kingdom.¹¹ However, some technological practices, such as the use of multiple moulds to cast hollow clay figurines, were first developed in the Greek world before reaching Egypt.¹² These developments highlight the interaction between Greek and Egyptian artistic traditions and how new methods were adapted to create objects for traditional religious purposes.

The study of terracotta figurines poses to the researcher specific problems that require a different approach compared to other forms of ancient sculpture, such as understanding the role of coroplasts, their individual role as artisans and their integration in a wider social sphere as artists. This includes investigating how knowledge and techniques were passed down through generations, the influence of local and external factors, and how the preferences of buyers shaped the production. Often mass-produced, these figurines provide insights into the decisions of the artisans, the economic conditions and the market for these items. The study of terracotta figurines also involves examining the methods used to create them, such as hand modelling or the use of moulds, as well as the various decorative techniques that were employed.¹³ These methods were designed for efficient production, as coroplasts prioritized quantity over creating unique masterpieces. Nonetheless, mass-produced items often feature individual craftsmanship, such as small details added by means of tools or directly by hand.

The analysis of the clay fabrics used to make the products, the style, and the direct comparison with similar pieces from recent excavations can certainly help us to define whether they belong to a specific geographical context. However, determining the origin and dating of terracotta figurines preserved in museum collections can be difficult. Indeed, much of the material in modern museum collections was acquired through antiquities trade or poorly documented excavations from the late 19th century. As a result, precise find-spots and contexts for many figurines are unknown, making it challenging to fully understand their historical and cultural significance.

Recent technological advancements, including 3D modelling and digital analysis, offer new ways to study these figurines. These tools allow researchers to virtually reconstruct missing parts, trace production techniques, and even identify the original moulds used. An example is the *SUR.VI.V.E.* project at Politecnico di Milano, which applies these methods to a collection of 542 terracotta figurines kept in the Museo Egizio and found during the excavations carried out in the early 1900s by Italian scholars and researchers

¹¹ On the techniques applied to the partially moulded pottery figure vases of the New Kingdom, see Bourriau 1987, 81-96; Dormann 2002.

¹² Barrett 2011, 91 and fn. 277-278, and 99, fn. 307, with further references. See also Caubert *et al.* 1998; Blondé, Muller 2000.

¹³ Ballet 1997, 207-213; Ballet 2020, 46-49; Caputo, Mandelli 2023.

in various Egyptian sites.¹⁴ One of the main objectives of the project *SUR.VI.V.E.* was to provide a first systematic and in-depth digital study of a collection of terracotta figurines and to single out criteria replicable in other collections.

5. Surveying the corpus of Egyptian terracotta figurines (AM, CC)

As anticipated in the previous paragraphs, both scanners and cameras could be used to digitalise the corpus of terracotta figurines as the results are comparable in terms of precision and resolution. Regarding the texture it is undeniable that the photogrammetric texture is way better than the texture acquired by the scanner.

The *SUR.VI.V.E.* project considered the use of a structured light scanner, namely the ARTEC EVA,¹⁵ since the large number of figurines and the poor texture that characterises these kind of objects. The scanner is coupled with its proprietary software, ARTEC STUDIO v.17, that follows the operator during the whole process, from the acquisition to the final model. This scanner model is the best choice for medium sized objects ranging from some centimetres up to a couple of meters. The acquisition phase is undoubtedly fast, in a single day it was possible to record up to 20 statuettes, acquiring an average of 5 scans for each object; the operator moves smoothly around the object checking in real time on the laptop screen the alignment of the frames (Fig. 2). This feature helps the surveyor understanding if some parts of the objects are missing, in this case it is possible to improve the survey completing the model.



Fig. 2: Digitalization of a terracotta figurine. *Museo Egizio, Torino* © SUR.VI.V.E.

¹⁴ For the history of the excavations, see Moiso 2008, 199-269; Del Vesco, Moiso 2017. See also Caputo, Mandelli 2023, 79-95.

¹⁵ Keşik 2023; Muminović 2024.

Once the acquisition is completed, the raw data are stored on the hard drive and the elaboration can then be performed at any time, thus allowing to digitise all the objects in a row reducing the time objects are not on display in the museum. Each figurine was digitised setting the acquisition parameters to the maximum value, i.e. accuracy up to 0.1 mm and resolution equal to 0.2 mm. The subsequent elaboration process starts with the alignment of the scans: this step is performed automatically by the software using the ICP (Iterative Closest Point) algorithm, if it fails it is possible to proceed manually. Before proceeding to the subsequent processing phases, it was verified that the overall deviation between scans never exceeded the limit of 0.5 mm. The following step is cleaning the scans to remove unwanted objects, such as the supporting structures of the figurines. Then the data are ready to be converted in a continuous 3D surface that is called mesh. It was decided to apply the sharp fusion to build the mesh since this option is capable to perfectly reconstructs fine features and is suited to both industrial objects and human bodies. The final resolution of the mesh is close to 0.5 mm. The goal is to obtain a regular smooth and sealed 3D geometry so that each photo captured by the camera scanner could be re-projected on the surface. If the mesh respects these characteristics, the area, the volume and consequently the weight could be computed.

6. Deliverables (AM)

The models obtained at the end of the surveying and modelling stages are the digital replicas of the entire corpus. These models are accurate from a metric point of view, and they preserve also the colorimetric information. Once the 3D models are exported in various file formats, such as .obj and .stl, they can be used for several purposes, from detailed digital databases and museum collections to 3D printing and virtual and augmented reality. The digitisation of cultural heritage is making artefacts more accessible and interactive than ever before.¹⁶

6.1 Databases and digital archives

One of the most direct applications of 3D models of cultural heritage artefacts is their incorporation into databases and digital archives. Traditionally, museums and cultural institutions have stored information about their collections in textual or photographic formats. However, 3D modelling offers a more comprehensive and dynamic means of documenting artefacts.¹⁷ A 3D model can capture the object from all angles, allowing for detailed analysis of its shape, texture, and physical features that 2D images cannot replicate. The databases provide accessibility for researchers, scholars and archaeologists can access 3D models of artefacts without having to physically visit the institution where the object is housed. This global accessibility facilitates collaboration between experts across different countries and disciplines. For example, an archaeologist in Germany can study a digital model of an artefact located in a museum in Egypt, using the detailed 3D renderings to conduct analysis or comparisons with local findings. Databases ensure detailed preservation of objects, artefacts, particularly those made from fragile materials such as paper, wood, or textiles, are prone to deterioration over time. 3D models serve

¹⁶ Huggett 2022, 275-304.

¹⁷ Ioannides *et al.* 2018.

as a detailed record of an object's condition at a given point in time, preserving its form digitally even if the original item is later damaged or lost. Moreover, 3D models offer museums and cultural institutions a powerful tool for cataloguing and managing their collections. Detailed 3D scans can be used to create virtual catalogues, which make it easier for curators to keep track of objects, assess their condition, and plan conservation strategies.

6.2 Virtual museum's collections and online exhibitions

Incorporating 3D models into virtual museum collections and online exhibitions is another growing use of this technology. Many museums and heritage institutions have turned to digital platforms to make their collections more widely accessible to the public. This shift was particularly accelerated by the COVID-19 pandemic, which forced institutions worldwide to close their physical doors temporarily. 3D models enhance online exhibitions by offering a more interactive and immersive experience. Visitors to virtual museum websites can explore detailed, photorealistic models of artefacts, rotating them, zooming in to examine fine details, and sometimes even interacting with the objects in ways that would be impossible in a physical museum setting. 3D models enhance the engagement and interactivity with the objects, online visitors can interact with artefacts in ways that go beyond simply viewing a photograph. By allowing users to manipulate 3D models, museums can create more engaging experiences that promote curiosity and deeper learning. For instance, virtual exhibitions may let users "handle" delicate objects like ancient pottery, turning them around and zooming in to see tiny inscriptions or decorative details that would be difficult to observe even in person. Digital collections allow museums to reach a far broader audience than ever before. People who cannot visit the physical museum, whether due to geographic, financial, or physical barriers, can still access the collection online. Furthermore, 3D models are excellent tools for education purposes: history or archaeology classes can use 3D models to study artefacts from ancient civilizations, enhancing the learning experience with immersive and interactive content.

6.3 3D printing and artefact replication

3D printing is another application of 3D modelling technology in the field of cultural heritage. High-resolution 3D scans of artifacts can be used to create accurate physical replicas, which can serve a variety of purposes, from educational tools to conservation aids. Replica artifacts can be used in classrooms and museums to provide a hands-on learning experience. Handling a replica object can offer insights that viewing a photograph or video simply cannot provide. For example, students studying ancient tools or pottery can better understand how these objects were used by physically interacting with a 3D-printed replica. 3D printing can also aid in the conservation of fragile or incomplete artifacts. If an artifact is missing a piece, a 3D scan of the object can be used to create a replica of the missing part, which can then be attached to the original artifact to restore it to its former state. This approach is particularly useful in archaeology, where incomplete artifacts are common. By digitally reconstructing missing elements, conservators can restore the artifact in a non-invasive way, preserving its integrity while also making it more comprehensible to the public. 3D replicas allow museum deciding how to display

delicate or valuable artifacts. Original pieces may be too fragile for permanent display, or there may be security concerns regarding theft or damage. In such cases, 3D-printed replicas can be used in place of the original objects, allowing visitors to view and even handle the replicas without risking the safety of the original artifact.

6.4 Virtual and augmented reality (VR/AR)

Virtual and augmented reality offer some of the most innovative and immersive uses of 3D models of cultural heritage artifacts. These technologies have the potential to transform how people experience and interact with history. VR allows users to enter fully immersive digital environments, where they can explore cultural heritage sites or handle artifacts in ways that would be impossible in real life. For example, a VR experience might transport users to ancient cities, allowing them to walk through its streets, enter their buildings, and examine artifacts in situ. VR can also recreate the original contexts of artifacts, showing them as they would have appeared in their historical environments. A VR simulation of an ancient tomb might show visitors the objects in the positions where they were originally placed by the tomb's occupants. AR offers a different kind of experience, blending the physical and digital worlds. In a museum setting, visitors can use AR devices (such as smartphones or AR glasses) to enhance their experience by viewing additional information or digital reconstructions overlaid onto physical objects.¹⁸ For instance, an AR app might allow visitors to point their phones at an ancient vase and see it reconstructed to its original, complete form, or display information about its historical context. These technologies permit to develop remote virtual tours allowing users to "visit" a museum or archaeological site from their own home. These experiences can be highly interactive, allowing users to move through space, examine 3D models of artifacts, and even interact with digital reconstructions of historical figures or environments. 3D modelling, VR, and AR offer ways to digitally reconstruct important cultural heritage sites that have been lost or damaged due to war, natural disasters, or urban development, preserving their memory for future generations.¹⁹

6.5 Archaeological documentation and analysis

3D modelling is an invaluable tool in archaeological documentation and analysis. Traditional methods of recording archaeological finds, such as sketches or photographs, can be imprecise or incomplete. 3D scanning allows for highly accurate digital documentation of artifacts and excavation sites. Archaeologists can use 3D scanning to document excavation sites in three dimensions, capturing not only the artifacts themselves, but also their spatial relationships to one another. This detailed documentation can be used for later analysis, allowing researchers to revisit the site digitally long after the excavation has been completed, moreover if the 3D surveying is performed at different time thresholds it is possible to go back in time and explore the evolution of the excavation. 3D modelling can assist the reconstruction of fragmented artifacts manipulating and fitting them together in ways that are much more difficult to

¹⁸ Liritzis *et al.* 2021.

¹⁹ Addison 2000, 26-31.

achieve using physical pieces alone. This digital reconstruction can serve as a guide for conservators as they restore the original artifact (Fig. 3).

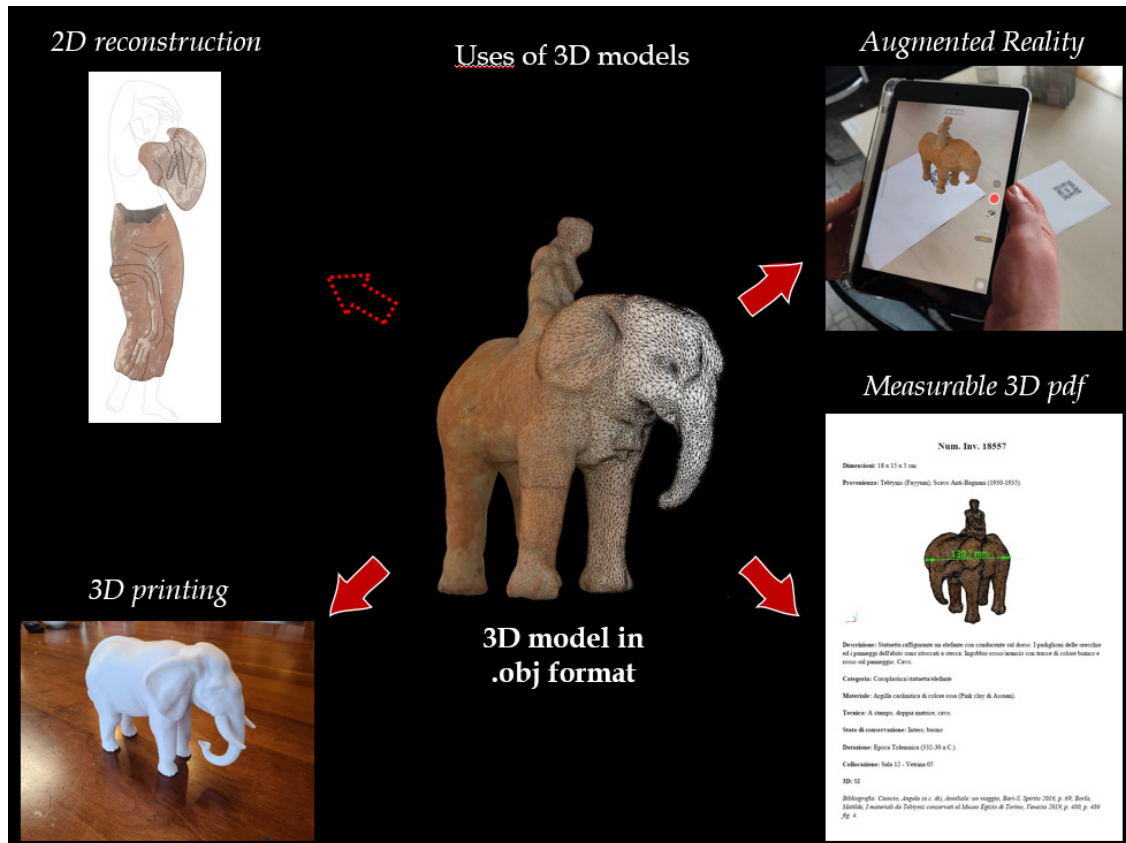


Fig. 3: Some examples of deliverables using a model of the digitized collection. *ABCLab-Eidolon, Politecnico, Milano* © SUR.VI.V.E.

7. Final remarks

In conclusion, the uses of 3D models of cultural heritage artefacts are varied and transformative, ranging from digital preservation and interactive museum collections to educational tools, archaeological documentation, and immersive VR and AR experiences. These technologies are not only preserving our past but are also making it more accessible, engaging, and interactive for people across the world. By leveraging these advances, we can ensure that future generations continue to learn from and appreciate the rich cultural heritage that defines human history.²⁰

As technology continues to advance, 3D surveying and modelling are likely to become even more integral to various fields. The increasing accuracy and affordability of 3D sensors are making this technology accessible to more people and industries. In the future, we can expect to see even more sophisticated applications, such as real-time 3D capturing, which would allow for instant digitization of objects and environments. Additionally, the

²⁰ Dell'Unto, 2014.

integration of 3D surveying with artificial intelligence and machine learning could lead to new ways of analysing and interacting with digital models. For example, AI could be used to automatically identify and classify objects in an environment or to suggest design improvements based on surveyed data²¹. 3D surveying and modelling are powerful tools that have transformed the way we interact with the physical world. From manufacturing to medicine, these technologies are enabling new levels of precision, efficiency, and creativity. As they continue to evolve, they will undoubtedly play an increasingly important role in shaping the future of technology and design.

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²¹ See Moullou *et al.* 2024, 107-121.

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Technical comparison between two ancient Egyptian wooden statuettes of offering bearers from the early 12th Dynasty tomb of Minhotep in Asyut

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Abstract

The multidisciplinary approach presented in this paper centres around a technical comparison of wooden sculptures originating from the same context, with the objective of highlighting characterising elements, in terms of both construction techniques and materials used, of their specific production area.

As a reference point for the research, we decided to study the funerary assemblage from Minhotep's tomb, located in the Assiut necropolis, nowadays preserved in the Museo Egizio, due to its rather clear provenance and historical period, and the high number of wooden sculptures it includes. Among other objects, in fact, it counted three "offering bearer" statuettes, two statues of Minhotep, a bakery model and four boat models, which most likely came from specialised workshops operating in the area during the early XII Dynasty.

The results we would like to present came from a preliminary study, whose results have led to a PhD research, focused on the comparison between two of the three painted wooden sculptures of female offering bearers (n° inv. S. 08795; S. 8796). In light of these results the research will include the technical comparison between artefacts of the same type, that after will be extended to all the objects of the corpus.

X-ray Computed Tomography (CT) has a significant role as an investigation tool in our research and allows us to obtain useful information about the inner characteristics of the wooden structure, besides the thickness of the decoration materials, and previous structural interventions. Despite the same provenance and iconography of the artefacts, we found some important differences in terms of manufacturing techniques, use of materials and state of preservation.

As a starting point for future systematic studies, these specific characteristics could contribute in the correct understanding of finds coming from the same context, but not necessarily produced by the same artisans. Analogies and differences will also support the Egyptological study aiming at the possible identification of different workshops active in Asyut in the early Second Millennium BCE.

Keywords: *Tomography; Funerary assemblage; Assiut; Minhotep; Wooden sculptures.*

1. Introduction

The working group conducted research as part of a PhD project focussing on the examination of funerary wooden sculpture in Ancient Egypt. We initiated our study from the sculptures of the funerary assemblage found in 1908 by the Italian Archeological Mission in the so-called tomb of Minhotep, in the Asyut necropolis. These artefacts are currently housed in the Museo Egizio in Turin.

The project originates from a preliminary study conducted between 2019 and 2021, which enabled us to explore potential outcomes and assess the feasibility of this research.¹ The primary objective of the project is to thoroughly examine the construction

¹ Vigorelli *et al.* 2022a-b.

techniques employed in crafting wooden funerary sculptures in Ancient Egypt. Our aim is not only to enhance current knowledge on this subject, but also to consider how examining construction techniques could aid in identifying different workshops and production areas. The central focus of the research is not to study the evolution of techniques over time, but rather to begin with a group of sculptures that are consistent in terms of provenance and period, in order to have a direct comparison between the objects, their construction techniques and the materials used. This approach enables us to concentrate the study on accurately identifying, as far as possible, the production context, starting with an analysis of materials, technologies and techniques used. By integrating scientific analysis with stylistic evaluation, then, technical aspects that may be attributed to specialised workshops can be highlighted.

Furthermore, the project encompasses two secondary objectives. The first is related to discrepancies observed in some of the objects over time, notably between how they are shown in a historical photograph from the 1920s and their current state. We suspect that a few smaller elements of these objects may have been displaced, rotated, or rearranged over time due to various events that occurred in their century-long history, necessitating their repositioning or even new identification within the collection of the Museum. Considering the modifications that occurred over the past hundred years and the limited information available regarding the condition of the objects at the time of their discovery, this study aims to propose an arrangement of the various elements that respects the one shown in the archive photograph, as much as possible. The second objective is linked to the extensive diagnostic plan outlined for this project, which is conducting a comprehensive assessment of the sculptures' preservation state. This assessment will also aim to define the priority of interventions and facilitate future conservation projects.

2. The Asyut necropolis and the Tomb of Minhotep

Considering the objectives of our project, we have chosen the funerary assemblage discovered in Minhotep's Tomb, in the Asyut necropolis, as the core of our research. This tomb was uncovered by the Italian Archaeological Mission led by Ernesto Schiaparelli, the then director of the Museo Egizio, during the 1908 fieldwork season (Fig. 1). Within the tomb, a total of twelve wooden sculptures were found, alongside a diverse array of other artefacts including coffins, walking sticks, a bow and arrows and numerous terracotta vessels.² Schiaparelli was granted permission to export the whole funerary assemblage, which was then transferred to the Turin museum, where it is still housed today. Although the original funerary context was probably disturbed in ancient times, as noted by Schiaparelli due to the presence inside and in the proximity of the tomb of several coffins and skeletal or mummified remains, all the sculptures seem to originate from the same period. Based on stylistic criteria, they can be dated to the beginning of the 12th dynasty, around 1939-1875 BC. This remarkably homogeneous group of artefacts also share the same history in terms of displacement, exposure to climate conditions, exhibition, and conservation treatments. This shared history makes them ideally suited for direct comparison when considering material ageing.

² Kahl *et al.* 2019, 286-287.



Fig. 1: Asyut Necropolis view from the city (© Archivio Museo Egizio C1078).

The group of sculptures, as listed in the handwritten inventory compiled by Schiaparelli when the objects were accessioned into the museum, includes: three female offering bearers (Museo Egizio, S.8794-7), four boat models (S.8790-3), a model bakery (S.8789), a female statue (currently not identified), and three statues of a Minhotep, actually corresponding to two statues representing Minhotep (S.8787-8) and one statue belonging to another individual called Wepwawetemhat (S.8786).

Considering the presence of at least two male subjects with different names, and the presence of two coffins carrying the name Minhotep, suggest the possibility that the tomb could have been a family or a multiple tomb. Thus, it remains uncertain whether the funerary assemblage belonged to a single individual or comprises multiple funerary assemblages, as may suggest the presence of four boat models. From a stylistic point of view, however, if the assemblage was not a single corpus, the owners probably were not separated by many generations.

3. The three statuettes of offering bearers

While the wooden sculptures belonging to the funerary assemblage are of different types, it was decided to study them by categorising them for typology. This approach facilitates the comparison of materials and techniques, initially focusing on those that are similar. Subsequently, upon completing the study, the gathered data will be synthesised to draw overarching conclusions regarding all the examined sculptures. For this reason, we initially selected the three sculptures of female offering bearers as the subject of our preliminary study and as starting point for our research. In this paper, for clarity, they will be referred to as Bearer A (Inv. S. 8795), Bearer B (Inv. S. 8796) and Bearer C (Inv. S. 8794) (Fig. 2).

The three statuettes share the same iconography and exhibit similar painted decoration. They depict standing female figures, with their left foot forward, carrying food offerings

for the deceased. A truncated pyramid-shaped basket placed on their heads, supported with their left hands, and a poultry offering grasped in their right hand. The yellow baskets are decorated with a grid pattern of black lines: five vertical lines and four horizontal lines for the Bearers A and B, and three horizontal lines for the C one. On the upper section of squares the sculptures A and B have two pairs of lines angled 45° , whereas sculpture C only presents two angled lines along the upper edges. Currently, none of these sculptures hold the poultry offering in their right hand, but the existence of two duck wings in the hands of the bearers A and C, as depicted in an historical photograph of the 1920s, suggests that these elements might still be present in the museum's collection and could potentially belong to the statuettes. The figures have short black hair, adorned with a long ponytail at the back, secured with a white ribbon tied around their forehead and fastened with a knot. They are attired in white dresses consisting of a long skirt that extends from just below the chest to mid-calf. Bearer A and B wear dresses supported by two shoulder straps, while Bearer C has a single strap over the left shoulder.



Fig. 2: From the left to the right: Bearer A, Inv. S. 8795 (h: 60 cm), Bearer B, Inv. S. 8796 (h: 44 cm) and Bearer C, Inv. S. 8794 (h: 64 cm).

All figures have yellow skin and wear the distinctive Egyptian make-up on their eyes. Additional distinguishing features include a mole situated on the right cheek of Bearer C, and a decorative element on the breast area, visible only on the Bearer B. This decoration consists of black dots arranged in a circle with a single dot in the centre, to represent the areola.

A significant contrast among the sculptures lies in their sizes: Bearer A and C share relatively similar dimensions, while Bearer B is approximately seventeen centimetres shorter than the other two.³

As concerns the bibliographic source, it is not possible to reconstruct the original characteristics of the statuettes at the time of their discovery, since the only available information about their condition comes from brief handwritten notes by Schiaparelli in his excavation diary. These notes indicate that Minhotep's Tomb was unearthed on April 13, 1908. Unfortunately, the description of the artefacts found within the tomb is given, in a very sketchy way, just as a list of: "three male sculptures, one female sculpture, one sculpture of maiden, one broken sculpture of maiden, one broken sculpture of maiden, four broken boats, the manufacture of bread, broken [...]"⁴ Regarding the three sculptures of offering bearers, referred to by Schiaparelli as "maidens", it can be inferred that they were discovered in a broken state. However, what exactly Schiaparelli meant with "broken", whether for instance certain elements (arms, ducks, baskets) were missing or the statuettes had cracked parts, remains unclear.

To the best of our knowledge, the earliest photograph showing these objects dates back to the 1920s. This photographic documentation was probably produced for the opening, on the occasion of the Italian King's official visit to Turin and to the Museo Egizio in October 1924, of a new display dedicated to the artefacts and human remains retrieved by the Italian Archaeological Mission in Asyut and Gebelein (Fig. 3).⁵ In this picture the offering bearers' statuettes appear in fairly good conditions. Bearer A is shown complete with her arms (presently detached and with Provisional inventory numbers), and Bearers A and C carrying duck wings in their right hands. This evidence, when compared with Schiaparelli's excavation diary, raises the possibility that between 1908 and the 1920s the objects may have undergone some conservation treatments. It is also plausible that during this period smaller elements, such as the duck wings, perhaps found within the same context but not directly connected with the statuettes, were used to complete them. Keeping this in mind, it becomes significant to compare the structure, materials and techniques of this smaller element with those of the main statuettes, aiming to identify any potential inconsistency. The analytic outcome, particularly for objects such as the duck wings, which are relatively independent from the main sculpture compared to fragments like the arms that are closely integrated with the figure, necessitates a critical assessment of the data from both a technical and stylistic point of view.

³ Bearer A: h. 60; l. 12,5; p. 25,5 cm; Bearer B: h. 44,7; l. 14,5; p. 20,5 cm; Bearer C: h. 64; l. 16; p. 29 cm.

⁴ "tre statue virili, una statuetta muliebre, una statuetta di ancella, una statuetta di ancella rotta, una statuetta di ancella rotta, quattro barche rotte, la fabbricazione del pane, rotta [...]", Kahl *et al.* 2019, 209-210.

⁵ Moiso, Del Vesco, Hucks 2017, 325, 328.



Fig. 3: Wooden artefact found in the Minhotep Tomb, in their first setup in Museo Egizio. Firenze, © Raccolte Museali Fratelli Alinari.



Fig. 4. Selected fragments: above duck wing linked to Bearer A (S. 8165/32), below duck wing linked to Bearer C (S. 8165/33), two arms linked to Bearer A (Provv. 45, Provv. 65).

Another event to be taken seriously into account when considering why some elements might have gone missing between the 1920s and today is represented by the Second World War. During the war period, almost the entire museum collection, including Minhotep's funerary assemblage, was evacuated from the city to the Agliè Castle, in order to protect it from the bombing raids.⁶ Given the challenges of the historical period, not all the artefacts, especially the smaller removable parts, were put together and catalogued comprehensively. As a result, after the war, many objects lost the connection with their original context and given number. The museum staff subsequently re-catalogued

⁶ Moiso 2022, 112-113.

them with new inventory numbers preceded by the term *Provvvisorio* (Temporary, also abbreviated as Provv. or P.), which are currently assigned to some 8200 objects.⁷

The search for the lost parts of the three offering bearers, utilising the 1920s picture as a reference, began with an examination of the Museum catalogue, particularly focusing on objects listed under *Supplemento* originating from Asyut, and those listed under *Provvvisorio*. Through a final morphological assessment of a selected group of objects, the search was narrowed down to four items: two arms probably associated with the Bearer A, sourced from the *Provvvisorio* catalogue (Provv. 45, Provv. 65), and two duck wings catalogued alongside similar objects from the Asyut necropolis. These duck wings were originally linked to Bearer A (S. 8165/32) and Bearer C (S. 8165/33) in the historical photograph (Fig. 4). If their affiliation is confirmed, the Bearer A will be distinguished as the only one adorned with bracelet decorations on the cuffs.

4. First results of the analytic study

During the study, we developed a comprehensive diagnostic plan valid for all the sculptures, which could be supplemented with additional analysis, if needed to explore specific features further. It consists of two phases: firstly, non-invasive diagnostic techniques including image analysis, micro-tomography, XRF (X-Ray Fluorescence) and reflection FTIR (Fourier-Transform Infrared spectroscopy) spots analysis are employed. Secondly, after evaluating the results, the second phase involves the possibility of making some micro-invasive analysis such as sampling of stratigraphies, absorption FTIR (Fourier-Transform Infrared spectroscopy), and gaschromatographies. Sampling areas are defined according to the observation of the object and taking into account the outcomes of the non-invasive analysis.

Regarding the identification of the wood species, sampling can be challenging due to factors such as the size and quantity of samples required. Moreover, sampling may be feasible in certain areas, but it may not be possible for the inner elements of interlocking structures, for example. As an alternative approach, there is a side project underway aimed at identifying wood species using non-invasive techniques such as micro-CT. However, this project is still in its early stages, and there are currently no results available on this matter. The main challenge posed by this research lies in achieving a resolution sufficient for wood technologists to attempt material identification, which requires a voxel size of at least 7 micrometres. Given the overall volume and complex geometry of the artworks, this requirement presents significant issues in terms of imaging performance and the large volume of data that must be managed.

Currently, the execution of a micro-CT scan at a lower resolution played a crucial role in studying the construction techniques, because it made it possible to examine the condition and characteristics of the wooden material, the technical aspects of the assemblies, and the distribution, thickness, and preservation state of the paint layers.

The microtomographic analyses were carried out at the Centro Conservazione e Restauro “La Venaria Reale” (CCR), using the setup developed during the neu-ART

⁷ Kahl *et al.* 2019, 282.

Project⁸, improved with a flat panel detector, which made it possible to reach a better image resolution.⁹ However, as image resolution increases, the amount of data generated by the analysis also rises, leading to corresponding challenges in data storage. For this reason, due to the volumes of the sculptures, this system enabled the acquisition of images with voxels measuring approximately 46 micrometers.

With this analysis we have gathered sufficient data to initiate comparisons between Bearers A and B, from which we have obtained some promising insights into their production techniques. Additionally, we should incorporate some information about the Bearer C, primarily derived from the observation work, as initially analyses on it are still undergoing processing.



Fig. 5: Left: Slice from the head area of Bearer A; Right: Slice from the chest area of Bearer A.

One significant finding pertains to the selection of wood material. Bearer A was carved from a main wooden block, with only a small section of the pith visible in the head area, which was intentionally excluded from the rest of the body during carving. However, the size of the main block was insufficient for carving the entire figure, necessitating the joining of smaller wood portions to construct the head area. This portion comprises three wooden sections joined together with two transversal wooden dowels. At the chest height there is a small wooden portion that was likely detached during the carving phase and subsequently repositioned using a wooden dowel. This relocation may have been necessitated due to a wood ring-shake, as suggested by the overlap between the score

⁸ Nervo 2013.

⁹ Vigorelli *et al.* 2020.

line and the growth ring (Fig. 5). The main figure of Bearer B was carved from a single wood block that includes the pith, visible throughout the entire length of the sculpture. These differences in the wooden support are also reflected in the application of the ground layer. In the statuette A it contributes with a more significant role in defining the volumes compared to sculpture B.

In Bearer A, the larger sculpture, both the basket and ponytail are crafted from separate wooden portions joined to the central body using two wooden dowels in the first case, and one transversal wooden dowel for the hair. However, in Bearer B, these elements are both carved directly into the main wooden support. An observable gap in the painting decoration reveals that in Bearer C, the ponytail is assembled, similarly to Bearer A, but with a different technique, employing a half-wood joint. This choice is significantly more refined than the system used for the Bearer A, as it allows the two elements to be joined in such a way that they are precisely aligned on the same plane. In the case of the Bearer A, the joint used requires making a transition between the surface of the ponytail and that of the head, achieved through the application of a preparatory layer (Fig. 6).

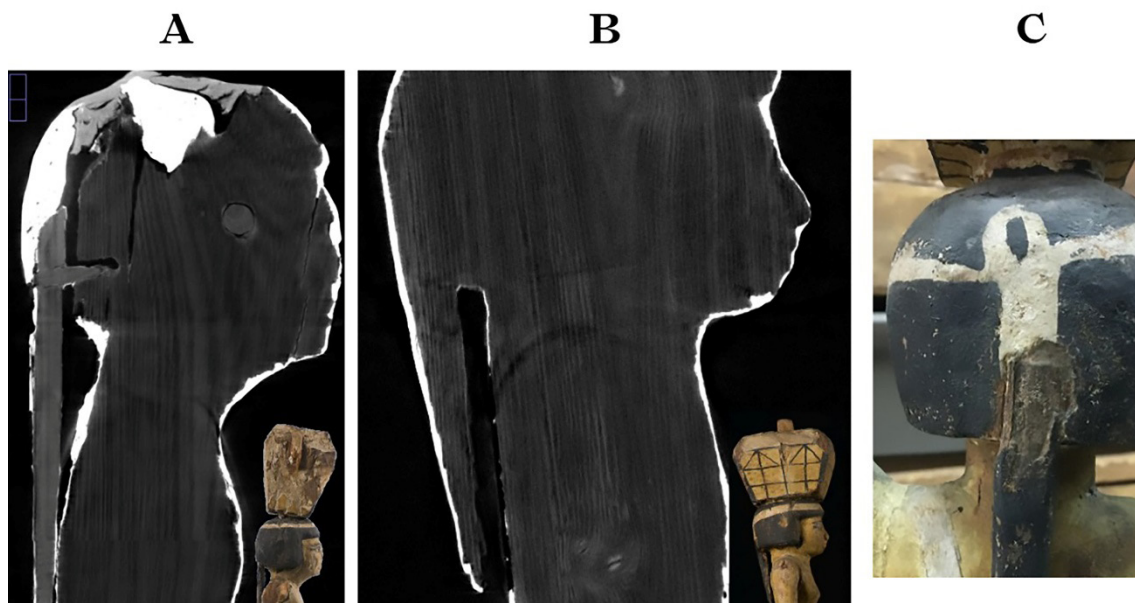


Fig. 6: Detail of the ponytail in Bearer A, B (CT slices) and C.

In all the three sculptures, the arms were individually carved. In Bearer A they were attached to the shoulders using a single dowel each side. For the Bearer B the right arm was assembled using two dowels, whereas only one was used for the left arm. In addition, through CT scanning, we observed a noticeable difference in density between the wood of body and the wood of the arms in Bearer B, suggesting the use of different wood species.

Thanks to an historical photograph it is possible to observe the right arm of the Bearer C disassembled, where it is possible to notice the use of two dowels for the assembly.

In both the A and B statuettes the joints between the lower portion of the legs and the basements have undergone past conservative treatments, making it difficult to discern the original techniques. Nevertheless, the basements exhibit some interesting features

worthy of further investigation: Bearers A and C display a non-functional tenon mortise joint on them, which is absent on the basement of the statuette B. In Bearer A this joint is located on the left side of the basement, while in Bearer C it is situated on the lower face of the basement, in the back area.

Furthermore, the presence of the feet provides valuable insights. Feet are observed only on the basements of Bearer C, where they are well-preserved. Conversely, on Bearer B, only shadows indicating the presence of feet are discernible on the shadows left on the painting decoration. Interestingly, no traces of feet presence can be detected on Bearer A, neither through observation nor via our diagnostic analysis. The information gleaned from the basements introduces various possible scenarios regarding the effective concern of the basements to the sculptures that will be the object of our future studies. The absence of the feet and the presence of a non-functional joint on the basement of the statuette A could suggest the possibility of the use of an unrelated basement. The presence of the feet on the Bearer C, along with a non-functional joint on its base may indicate the utilisation of reused wood for constructing the basement of this statuette in ancient times (Fig. 7).

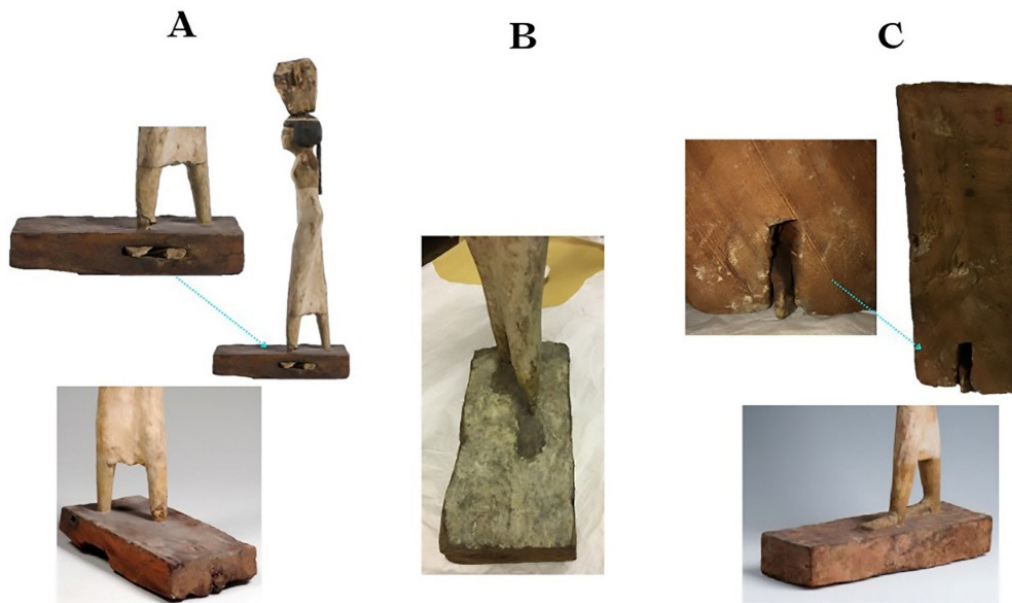


Fig. 7: Details of the basements in Bearer A, B and C. Feet presence and non-functional joints.

The wooden support of the offering bearers is covered with a painting decoration consisting of a ground layer and painting layers.

The ground layer on Bearers A and B is composed of calcium carbonate, applied on the surface of the two sculptures with varying thickness. The micro-CT images enabled us to measure the preparation layers, and observe an irregular layer, sometimes reaching up to 2,3 mm on Bearer A, while Bearer B exhibits a more uniform layer of about 1 mm thickness.

Regarding the pigments, the Visible-Induced Luminescence (VIL) images confirmed the absence of Egyptian blue, even when mixed with black.

Two stratigraphic samples were collected from Bearers A and B, specifically from the hair and garment areas, respectively, in order to be directly comparable. The samples

were primarily analysed using SEM-EDS (Scanning Electron Microscopy with Energy Dispersive Spectroscopy).

The black pigment appears to be carbonium based, whereas an interesting detail emerges from the analysis conducted on the white dress. In both cases the results showed that the white areas were not made leaving the ground layer exposed, but they were painted with a white colour made of calcium sulphate, which to the best of our knowledge is pretty uncommon to find on these kinds of objects. The yellow and the red pigments result to be ochre probably sourced from natural earth.

As of now, we have not yet had the opportunity to analyse the binders used in both the ground layer and of the painted layers of the three sculptures.

UVF (Ultraviolet Fluorescence) images suggest the absence of finishing layers, whether ancient or modern. However fluorescent and non-fluorescent materials indicative of past conservation treatments, such as adhesives, and retouches are visible.

5. Final remarks

In this initial phase of our study, we have demonstrated the numerous technical differences that can be highlighted between sculptures apparently similar and originate from a consistent framework. This suggests that a significant internal variability could be found even in production of funerary wooden sculptures within the same context.

Furthermore, we aim to observe and compare these differences, and attempt to purpose potential causes where feasible. Some variations, such as the use of different wooden portions for carving the main figure of the statuette A, for example could be related to technical aspects concerning the selection of the wooden support. These variations may provide insights into the production process of such artefact. Other features such as the use of calcium sulphate-based pigment for rendering the white portions, may be indicative of a specific workshop or region, offering clues about the production area.

Although we may not always establish clear connections for all the analogies and differences in production techniques, we hope that future systematic studies will provide a more comprehensive framework. These specific characteristics can then contribute to a better understanding of funerary assemblages found in the same context, which may not necessarily have been produced by the same artisans, or for the same purpose and deceased.

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Anthropological and radiological results from the Aswan necropolis near the Aga Khan mausoleum: the EIMAWA experience

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Abstract

We illustrate an interdisciplinary anthropological and radiological approach to evaluate findings from the tombs of the Aswan necropolis on the west bank of the Nile around the Mausoleum of the Aga Khan. Since 2021, the joint mission of the University of Milan and the Egyptian Ministry of Tourism and Antiquities in Aswan (EIMAWA) carried out radio-anthropological analyses on osteological and mummified remains from Room B of tomb AGH26 and AGH032. Bioarchaeological analyses included estimations of sex (using dimorphic traits of the cranium and pelvis as well as metric analysis), age-at-death (through epiphyseal fusion, unfused bone lengths, dental growth and eruption, suture obliteration, and degree of degeneration of the auricular surface, pubic symphysis, acetabulum), ancestry (using morphometric traits of the cranium), stature (with regression formulae based on long bone length) as well as pathological and traumatic analyses. On-site X-rays were performed on the most relevant findings (both bone specimens and some mummified individuals) using a digital portable device (Rextar-X, Posdion), with a fixed tube voltage/current of 70kV/2mA, coupled with a 14"x17" (350mm x 427.25mm) Cesium flat panel detector.

We found over 40 mummified bodies in the Room B of AGH026, whereas 4 bodies were present in Room A. Mummies and commingled remains appeared in different states of preservation. A total of 403 commingled skeletal human remains were recovered in Room B, of which 37 were crania. Bioarchaeological results demonstrate a percentage of female individuals slightly superior to that of male individuals. The 12 juveniles identified ranged between 2 and 6 years. Analyses of mummies and osteological remains showed the presence of diverse pathological conditions. Our results demonstrate the advantage of interdisciplinary collaboration in evaluating osteological samples or mummies. Conventional radiology can still provide important results in the field of paleopathology, thanks to the possibility of using portable radiological devices directly on archaeological sites, thus overcoming technical difficulties in transporting bone mummified remains. More advanced radiological studies with the use of Computed Tomography will be carried out on the on the mummies with the best state of preservation.

Keywords: *Mummies; Anthropology; Radiology; X-ray.*

1. Introduction

The joint mission of the University of Milan and the Egyptian Ministry of Tourism and Antiquities in Aswan (EIMAWA) operate in the Aswan necropolis on the west bank of the Nile around the Mausoleum of the Aga Khan.

Conventional radiology can still provide important results in the fields of bioarcheology and paleopathology, thanks to the possibility of using portable radiological devices directly on archaeological sites, thus overcoming technical difficulties in transporting bone mummified remains.

We illustrate an interdisciplinary anthropological and radiological approach to evaluate findings from the tombs AGH032 and AGH032 directly on site.

2. The archaeological context and the EIMAWA mission

The necropolis, investigated by EIMAWA mission, dated thanks to the numerous materials found between the 6th century BC and the 3rd century AD.¹

At the moment of the discovery the necropolis shows signs of depredation by ancient robbers. For this reason, in many graves the funerary equipment was often found mixed with commingled remains, including mummies (often body parts) and human bones.

Tomb AGH026 (composed by a ROOM A and ROOM B) and tomb AGH032 were excavated (during the 2019 and 2021 campaigns). The tomb AGH026 presents a hypogeal structure accessible by a descending staircase that leads to two different sized chambers called ROOM A and ROOM B. The tomb date to the Ptolemaic and early Roman periods. Tomb AGH026 counted over 46 individuals (both mummies and commingled remains) in different states of preservation; at least 4 individuals were found in in the ROOM A.²

The grave AGH32 consists of an external structure of three mud-brick walls and a hypogeal structure accessible by a descending staircase that leads to a vestibule and four different size rooms (room A, room B, room C and room D). This tomb also dates to the Ptolemaic-Roman period. The tomb AGH032 counted at least 52 individuals, including 20 entire mummies and commingled remains.³

Radiological and anthropological analyses of osteological and mummified remains from these tombs were conducted on site.

3. Anthropological analyses and methods

Preliminary bioarcheological analyses were performed on osteological remains and when possible, on mummified remains *in situ*, due to site constraint. The mummies and skeletal remains from tombs AGH026 and AGH032 were temporarily brought outside the tombs to be photographed and documented.

Concerning the osteological remains, a preliminary classification into subadults and adults was carried out based on morphological traits. The adult remains were subsequently sorted by anatomical region, with the analysis primarily based on macroscopic observation of each bone element. All bones were photographed, numbered, and placed in different boxes inside the tombs.

The mummified material was counted and photographed, but due to the poor state of preservation of some individuals, it was not possible to take them outside the tomb for more accurate photographic documentation. *In situ* radiographs of some mummified remains with specific and interesting characteristics were taken using a portable X-ray device.

The examination of the remains involved identifying each bone according to anatomical region, side, and morphological characteristics. This was followed by the estimation of the Minimum Number of Individuals (MNI), assigning each bone to a specific region and side based on morphological traits and considering the largest

¹ Piacentini, Pozzi, Abd El-Moneim 2020, 21-31. See also in the present volume Piacentini 2026.

² Giudici, Tomaino in press.

³ Piacentini, Tomaino in press.

number of elements per side.⁴ Then biological profiles from the osteological remains were constructed by macroscopical analysis.⁵

For the construction of the biological profile, it is necessary to take into account the assessment of skeletal morphology. Biological sex estimation was performed using morphological and metric methods.⁶ Morphological techniques used for sex estimation consider the analysis of the sexually dimorphic elements in the skull and pelvis. Morphological methods were complemented by metric methods; however, it is important to remember that sexual identification of osteological material is most accurate after the individual reaches puberty.⁷ Conversely, age estimation is easier to establish in subadults than in adults. The development and maturation of teeth have proved to be one of the most accurate indicators of age-at-death, especially in subadult individuals. In addition to dentition, other methods for establishing age-at-death in younger individuals are development and fusion of postcranial epiphyses and the measurements of the immature bones.⁸ Among the most common methods used to establish age-at-death in adult individuals has been count morphology of the symphyseal surface of the pubis and of the auricular surface of the ilium.⁹ To complete the biological profile, ancestry (using morphometric traits of the cranium) and stature (with regression formulae based on long bone length) were estimated. The last step in the construction of the biological profile concerns pathological and traumatic analyses through macroscopic observation and with radiological support on osteological and mummified remains.¹⁰

4. Radiological analysis and methods

Radiographic examinations were conducted on-site, near the tomb, focusing on the most pertinent bone samples and select fully mummified individuals. X-rays were obtained through a digital portable device (Rextar-X, Posdion), with a fixed tube voltage/current of 70kV/2mA, a target angle of 12° and a focal spot of 0.4 mm. This portable x-ray device was coupled with a specific Celsius flat panel detector (14"x17", corresponding to 350mm x 427.25mm) which is necessary to produce the digital images, with a spatial resolution of 3.11 p/mm. It was not always possible to obtain standard two-dimensional projections (typically antero-posterior and lateral) in relation to the peculiarities of the findings, so a single projection focused on the main finding was often favored. The evaluation of the images was carried out on a dedicated workstation using a portable computer with software enabled to read DICOM files.

⁴ Osterholtz, Baustian, Martin 2014, 35-50.

⁵ Cattaneo, Gibelli 2014, 133.

⁶ Methods for sex estimation: Buikstra, Ubelaker 1994; Phenice 1969; Walker 2005; Spradley, Jantz 2011.

⁷ White, Folkens 2005, 395-386.

⁸ Methods for age-at-death estimation of subadults: Alqahtani, Hector, Liversidge 2010; Maresh 1970; Ubelaker 1999; Schaefer, Black, Schaefer 2009; Scheuer, Black 2004.

⁹ Methods for age-at-death estimation of adults: Suchey, Brooks 1990; Lovejoy *et al.* 1985.

¹⁰ Ortner 2003, 227-262; Lovejoy 1985; Lovejoy *et al.* 1985a-b.

5. Findings and results

The bioarchaeological results showed a high proportion of young individuals in both tombs. In grave AGH026 at least 16 subadult individuals of different age groups were identified under the age of 12 years. Additionally, 6 individuals were considered adolescents/young adults as it was possible to estimate from the evaluation of long bones an age ranging from 13 to 30 years old. Within this burial it was also evident, among the 18 adults, that the presence of female individuals was slightly higher than that of male.

In tomb AGH032 at least 23 subadult individuals under the age of 12 years were found., confirming a high proportion of non-adults. A total of 2 individuals were considered adolescents/young adults, while 9 individuals were considered adults (6 females, 3 males). See table 1 for a detailed report of our findings.

AGH026	Female	NC (not classifiable)	Male
Subadult (0 - 12)		11	
Subadult NC ¹¹		5	
Adolescent/ Young adult (13-30)	4		2
Adult	13		5
Indeterminate NC ¹²		8 (complete mummies)	
AGH032	Female	NC (not classifiable)	Male
Infant/child (0 - 12)		16	
Subadult NC		7	
Adolescent/ Young adult (13-30)	1		1
Adult	6		3
Indeterminate NC	1	16 (mummified remains)	1

Table 1: Summary of the demographic distribution of individuals recovered from tombs AGH026 and AGH032.

¹¹ Subadults NC (= Not Classifiable) refers to mummified remains for which the macroscopic dimensions suggest a subadult individual, although it is not possible to provide an accurate age estimation.

¹² Indeterminate NC refers to specimens for which neither age estimation nor differentiation between adult and subadult could be established, and sex determination was likewise not feasible.

Analyses carried out on the sample of mummies and osteological remains revealed the presence of various pathological conditions, in both burials, osteological remains with signs of infectious diseases: some thoracic vertebrae with osteolysis and remodeling on the anterior side of the vertebral body, which can be traced back to possible cases of tuberculosis.¹³

Macroscopic examination of the remains revealed the high percentage of markers of physiological stress in younger individuals, such as cribriotic lesions on various bones, such as femora, humeri, orbits and cranial bones, and Harris lines (Fig. 1) detected by radiological analysis. In particular, these markers were found in individuals whose age at death was between infancy and late childhood, more precisely between 1 and 12 years of age. These markers are symptoms of nutritional deficiencies and metabolic disorders during growth and life.¹⁴

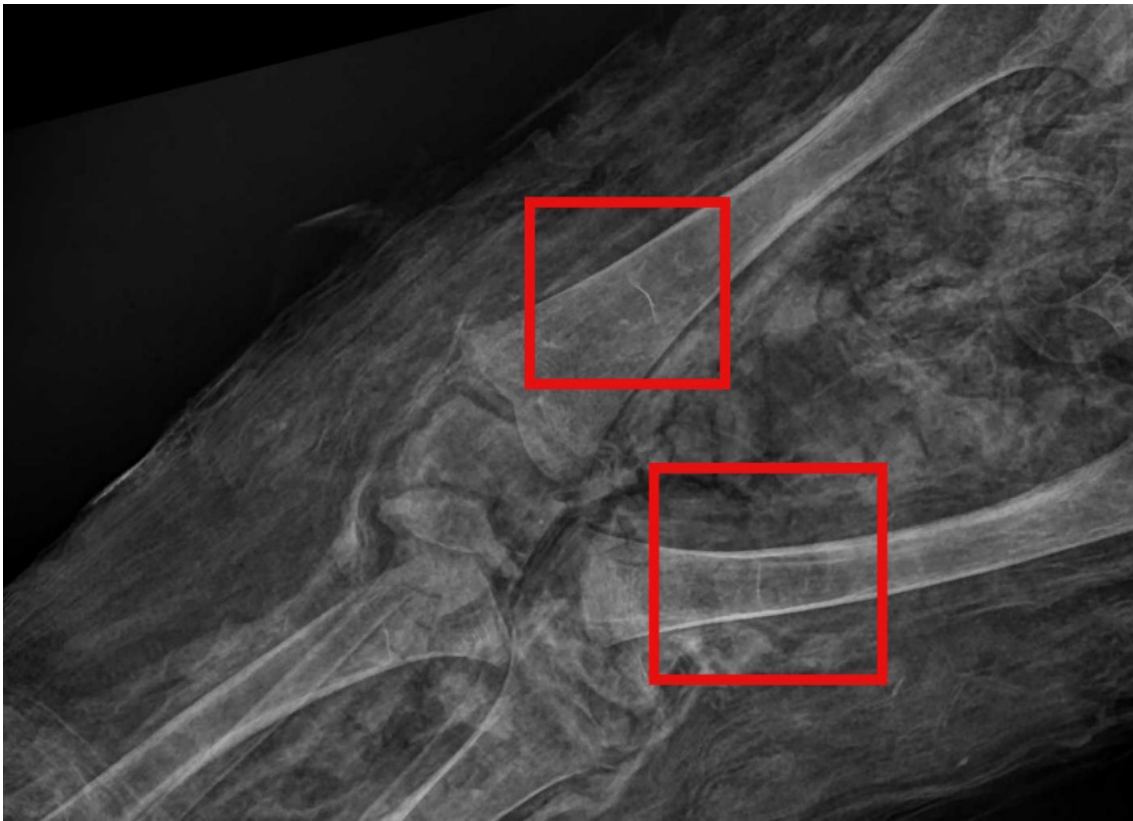


Fig. 1: Individual 71, X-ray showing Harris Lines on both distal metaphyseal femurs (© EIMAWA).

Several bones of pathological and traumatic interest were found, including a right female femoral proximal diaphysis and a right female femoral distal epiphysis characterized by an exuberant bone callus. According to the complete maturation of the bones and stage of fusion of the epiphyses, the individual was aged over 16 years

¹³ Biehler-Gomez, Cattaneo 2021, 42-47.

¹⁴ Lewis 2018, 193-218.

old. Additionally, the sacrum of a male over 20 years of age was found. These remains were analyzed through X-rays and macroscopic examination.

Regarding to the femoral stumps, the type of lesion would appear to be pertinent to amputation with a transverse cut in the middle of the diaphysis (Fig. 2). Macroscopic analysis showed evidence of mid-diaphyseal bone interruption and exuberant reparative callus at the broken stump with woven periosteal new bone, indicating a recent and active healing process at the time of death. In addition, bone outgrowth in the form of osseous spurs with a proximal direction were visible on the anterior and posterior surfaces.¹⁵ Femoral x-ray images confirmed the presence of a slightly radiopaque bone callus but also showed a clear but irregular bony interruption, with sharp margins.



Fig. 2: Femur 28, view of the right femur with the detail of the X-ray performed at the mid-diaphyseal bone interruption (© EIMAWA).

Concerning the sacrum, this bony sample showed fusion of the lumbar vertebrae and partial sacralization of the 5th lumbar vertebra (as anatomical variant). In addition, proliferative signs are visible at the macroscopic level and fusion of the vertebrae, which allow one to establish that this is a pathological subject (Fig. 3). The X-ray image showed an appearance resembling a bamboo spine, which is a distinctive radiographic feature of a disease known as ankylosing spondylitis, related to the fusion of vertebral bodies caused by marginal syndesmophytes. This pathology can be traced back to arthritis and autoimmune inflammation with a genetic predisposition. This disease is predominant in males and occurs mainly in individuals over 40 years of age. Given the morphology of these features, Diffuse Idiopathic Skeletal Hyperostosis (DISH) cannot be excluded as a differential diagnosis, as it is characterized by ossification of the anterior longitudinal ligament of the spine, often presenting with flowing ossifications resembling 'dripping candle wax'.¹⁶

¹⁵ Messina *et al.* 2022, 1-4.

¹⁶ Biehler-Gomez, Cattaneo 2021, 113-115.



Fig. 3: X-ray of individual 69: suspected case of ankylosing spondylitis (© EIMAWA).

6. Conclusions

The results of the EIMAWA study demonstrate the advantages of an interdisciplinary collaboration in bioarcheological and paleopathological evaluations of osteological samples to better understand the funerary context of the remains. In fact, multidisciplinary collaboration and advanced diagnostic techniques are necessary to ensure that data collection and analysis are as complete as possible for a comprehensive study. Also, integrated analyses may also help to overcome the limitations of such a particular context. This study also aimed to find a methodology that can be used for further studies in similar contexts.

From a demographic perspective, the combined analysis of tombs AGH026 and AGH032 reveals a significant predominance of subadult individuals, particularly those under 12 years of age, suggesting a high infant and child mortality rate within this population. A slight prevalence of female individuals was also noted in AGH026. From a paleopathological standpoint, although some isolated conditions were documented—such as probable tuberculosis, signs of physiological stress (e.g., cribra orbitalia, Harris lines), and traumatic lesions—numerous individuals also showed signs of degenerative joint disease. These findings are consistent with early-onset osteoarthritic changes likely related to physically demanding or repetitive labor. Thus, while some skeletal remains did not exhibit major pathological alterations, the general health profile points to a population exposed to both physiological and mechanical stressors from a young age.

A limitation of our preliminary study is that unfortunately, due to the difficult conditions on the archeological site, we had to select only certain samples to examine (especially with the portable x-ray machine). Therefore, we could not fully evaluate other possible disease or conditions (e.g. dental disorders).

In conclusion, only through an interdisciplinary approach is essential to enhance the context and correlate the information provided by historical sources with the results emerged from bioarcheological analyses, radiological imaging, and archeological investigations. Human remains can tell their own story if they are subjected to appropriate in-depth diagnoses, providing important information to better understand health status and living conditions of an entire population.

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Database of burial containers from the Old Kingdom and First Intermediate Period

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Abstract

Burial containers from various materials (stone, wood, plant fibre/"reed" or clay) represented a crucial piece of burial equipment, essential for both practical and symbolical reasons. The excavations of many necropoleis from ancient Egypt have brought to light a remarkable number of containers. However, the ones from the Old Kingdom and the First Intermediate Period (ca. 2592–1980±25 BC) had been neglected in the Egyptological research until recently. Starting from 2023, a project titled "Ancient Egyptian Burial Containers of the Old Kingdom and First Intermediate Period. Evolution, Contextualisation and Significance" has been initiated, with the support of the Czech Science Foundation (project no. 23-04989S). Its holistic approach to the topic leads to the focus on the typology of the containers, technology of their manufacture as well as on the overall social, economic and religious implications. The main prerequisite of the research, and one of the outcomes of the project at the same time, is a freely accessible online database of all kinds of the burial containers from the above-mentioned periods. This paper presents the database and also demonstrates its potential for the study of the burial containers.

Keywords: *Burial container; Old Kingdom; First Intermediate Period; Database.*

1. Introduction

Databases listing a wide range of sources of diverse kind have recently become more widespread in Egyptology, and they indeed offer an incredibly useful tool for data gathering and for further analyses of the material. To mention a few examples for the Old Kingdom, the online database of scene details (*Oxford Expedition to Egypt: Scene-details Database*) created, assembled and permanently updated by Yvonne Harpur¹ is of great significance, or the *Thesaurus Linguae Aegyptiae*,² which includes texts from the Old Kingdom and First Intermediate Period, features among scholars an extensive coverage of material. *The Giza Archives*,³ *Digital Giza*⁴ and the *Giza-Projekt*,⁵ launched by the Museum of Fine Arts Boston, Harvard University and German Roemer- und Pelizaeus-Museum Hildesheim together with the Museum of Universität Leipzig, represent a central repository of finds and archival materials for one single locality that likewise enables access to even unpublished archival material.⁶ In relation to ancient Egyptian burial containers in particular, one can mention, for instance, the project *Painted for Eternity*⁷ or the *Fitzwilliam Museum's Ancient Egyptian Coffins Project*⁸ devoted to Middle

¹ <https://doi.org/10.5284/1000009>

² <https://aew.bbaw.de/tla/index.html>

³ <http://gizapyramids.org/>

⁴ <http://giza.fas.harvard.edu>

⁵ <http://www.giza-projekt.org/>

⁶ See also Manuelian 2016.

⁷ <https://www.meketre.org/>

⁸ <https://egyptiancoffins.org/>

Kingdom and later material. Furthermore, a number of databases remain unpublished, serving thus for personal or internal usage in various institutions, e.g. the Archive of the Czech Institute of Egyptology, Faculty of Arts, Charles University.

As for burial containers from the Old Kingdom and First Intermediate Period (ca. 2592–1980^{±25} BC, Hornung),⁹ these objects stood beyond the interest of Egyptologists until recently, which also went hand in hand with the fact that a collection, let alone a database, was missing.¹⁰ The previous studies of the burial containers neither provided an overall typology covering the whole period under survey, nor did they consider the production of the pieces in more detail. Thus, the AEBC (Ancient Egyptian Burial Containers) project was launched in 2023 with the support of the Czech Science Foundation (project no. 23-04989S).

2. The AEBC project

The main focus of the AEBC project is on the overall typology, production techniques and socio-economic embedding of the burial containers from the Old Kingdom and First Intermediate Period. It represents a completely innovative approach as it aims at a complex study of the burial containers, focusing not only on each material separately. On the contrary, it traces the development, production and religious significance of all types of burial containers made of stone, wood, plant fibres (“reed”) or clay/pottery in the whole Egyptian territory, the Memphite (capital) as well as provincial necropoleis. The creation of a container typology and the contextualisation of the processes encompassing container fabrication are the main goals of the project.¹¹ Moreover, all these phenomena are judged within the framework of the historical and political development of the Egyptian society during the given period.

The project’s main analytical element lies in the reconstruction of the entire process from the origin of a particular burial container to its use and possible reuse. The intention is to trace the whole scale of activities including material acquisition, its transport, methods of manufacture, applied decorative techniques as well as the final burial installation. The social, ritual and economic implications that encompass the production (for instance, religious significance of different materials, questions of specialised workshops or foreign trade in precious materials) are also addressed.

The first step in the study of the burial containers from these periods found in different regions of Egypt is the creation of a comprehensive database. The data corpus of all available finds, collected in the database, has further served as a basis for establishing an overall typology, which had noticeably been missing in Egyptological research. The studied corpus comprises roughly 300 wooden coffins, 250 stone sarcophagi, 50 plant-fibre (“reed”) coffins and 100 clay/pottery coffins. However, these numbers are expected to grow with ongoing excavations in Egypt and further analyses of institutional archives.

⁹ Hornung, Krauss, Warburton 2006, 490-491.

¹⁰ For an overview of the research on burial containers in various periods, see Peterková Hloučová, Nováková 2024, 208-209, fn. 1.

¹¹ For burial container typology, see Peterková Hloučová, Nováková 2024.

As mentioned above, the project investigates three main research questions:

a) Burial container production

This area examines the manufacturing processes, analysing each material separately. Key topics include: raw material acquisition, the role of craftsmen and specialised workshops, the possibility of domestic production, decorative patterns and their regional variations.

b) Socio-economic implications of container production

The study explores how an individual's social status influenced the choice of the burial container materials. On selected material, the distribution patterns of the burial containers are investigated within particular households in the central and provincial necropoleis. Subsequently, the question of the extent of the social dynamics and economic power regarding the acquisition of materials from distant regions (e.g. cedar wood) is studied. Equally important is to investigate to what extent was the king involved in these processes. According to Old Kingdom textual evidence, it was the ruler who often donated some parts of the funerary equipment, including the stone sarcophagus, to his loyal servant,¹² and the same can be proposed for coffins made of more expensive materials, such as *Cedrus libani*. Therefore, texts related to burial containers will be studied in detail in this section, as well as the materials from which sarcophagi and coffins were made.

c) Religious aspects

The third research question investigates: 1. The religious significance of different materials and the influence on the choice of particular materials; 2. How and with what delay religious changes were reflected in contemporary evidence (e.g. the evolution of solar beliefs or the emergence of the Osiris cult); 3. The influence of these beliefs on decorative motifs and the selected colour spectrum; 4. The effects of the change in religious thoughts on ritual formulae inscribed on the burial containers; 5. The development of several protective elements and rituals applied to the containers.

3. The AEBC database

One of the main research tools of the project is a database of Old Kingdom and First Intermediate Period burial containers created in the FileMaker programme. Its main part has been launched using WordPress software and is currently freely accessible to scholars on the website of the Faculty of Arts, Charles University.¹³

The database in the FileMaker programme consists of five parts: The first is called *Burial containers* and gathers the main data for all kinds of burial containers, and this one has been modified for the online version. The other parts of the database in FileMaker designed for internal use only are specific tables for each individual material (i.e. stone, wood, plant fibres/"reed", clay/pottery).

¹² Strudwick 2005, 353.

¹³ <https://aebc.ff.cuni.cz/>

Methodologically, the AEBC database is mainly based on the databases of Old Kingdom material culture and officials created at the Czech Institute of Egyptology, Faculty of Arts, Charles University. Those corpora have remained unpublished, being used only for internal purposes. Their results, however, have been published.¹⁴ Another source of inspiration was the work of Donadoni Roveri (1969),¹⁵ and of Caroline Arbuckle,¹⁶ with their catalogues of burial containers, which provides an overview of the Old Kingdom wooden coffins. Dealing with various materials, and taking into account that the burial containers of the Old Kingdom and First Intermediate Period have not been properly studied yet, the present authors have developed their own classification system for the database entries. The AEBC database was adjusted according to the specifics of the individual burial containers. The material used for the individual container is the major criterion for the selection, but determination of the locality where the individual containers were found is equally significant. To be able to investigate the burial containers from different perspectives, gathering the data about the place where they were uncovered, about their owners and subsequently about the containers themselves is essential.

First, each entry in the AEBC database has received its unique code, consisting of a serial number, and two crucial identifiers: an abbreviation for a locality and an abbreviation for the individual container material (S = stone, W = wood, P = pottery/clay, O = organics, plant fibres, "reed"). In the general *Burial containers* table, the data encompassing three main circuits are assembled. This is the information regarding the place of individual find with all entries associated with the locality, tomb, archaeological context, the preservation and the orientation of the human body inside the burial container. Another group is represented by the records related to the container's owners, their titles, gender and social standing. And finally, details about the containers themselves are provided, describing their shape, dimensions, preserved inscriptions and decoration. The inclusion of bibliographical references to the given find is a standard component of any scholarly work. Regarding the photographs, if we are allowed to publish them, they are added as well, or a link to the relevant museum websites is given.

Given the fact that each material has its own specifics, especially regarding the different production methods and related technical details, four specialised tables in the database (separate ones for wood, stone, plant fibre/"reed" and clay/pottery) were created. Those include, apart from all this basic information, details regarding the individual types, such as decoration, inscription and the construction aspects. For instance, the database for stone sarcophagi contains information about a specific type of stone used for the container manufacture, the type of closure of each find according to Anna Maria Donadoni Roveri,¹⁷ entries connected with the surface treatment or notes on traces of tools left on the material.

¹⁴ Odler 2016; Vendelová Jirásková 2021; Dulíková, Mařík 2021; Brukner Havelková, Dulíková *et al.* 2024.

¹⁵ Donadoni Roveri 1969.

¹⁶ Arbuckle 2018.

¹⁷ Donadoni Roveri 1969.

Ancient Egyptian Burial Containers

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401_Abu_S

Container owner

name	husband of Sheretneby
title	unknown
sex	male

Container findspot

locality	Abusir South
site	Abusir
location	Central Mound
tomb type	rock-cut tomb
code of tomb	AS 68c
material of tomb	limestone
dating	5 (Niuserre)
tomb owner	husband of Sheretneby
social position	without relevant title
title	unknown
shaft	shaft 1 (the southern one)
burial apartment	burial chamber
body inside	no
archaeological context	secondary
remarks on archaeological context	robbers' hole in the E wall of the sarcophagus chest and lid; limestone pedestal for the lid placed to the E of the sarcophagus; remains of the original burial equipment: faience beads, limestone pendants, pieces of gold foil, pottery vessels, canopic jars and animal bones were found scattered to the E of the sarcophagus

« [Previous](#) [Next](#) »



photo: Martin Frouz (CIE FA CU)



photo: Martin Frouz (CIE FA CU)

Search

Container properties

number	AB 218
material	limestone
present location	in situ
state of preservation	good
period	OK
dynasty	5
type	qeresu
updated typology	
shape	rectangular
lid	yes
length	2.45 m
width	1.14 m
height	1.10 m
inscription	no
decoration	no
inner decoration	no
description	undecorated and uninscribed sarcophagus with qeresu type of lid made of fine white limestone nicely polished
notes	

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Fig. 1: Example of one data entry from AEBC database [https://aebc.ff.cuni.cz/database/401_abu_s].

In the case of wooden coffins, determination of wood species plus information about inscriptions and decoration of each wall, but also construction details, such as types of joints, number of planks of one wall, pigments, tool marks, bosses or handles, are included.

Regarding coffins made of plant fibres (“reed”), only a few technical details can be added since they were undecorated and bore no inscriptions, but, for instance, joints and types of binding are of particular importance as well as the determination of plant species used for the construction.

The last database encompasses clay (burnt or unburnt) coffins, again only with a few pieces of additional information. What is important to mention here is that we distinguish between pottery and clay coffins from unburnt mud in order to ascertain how much they differ in their form or their spatial, social and chronological distribution.

The project’s websites (in English and in Czech) were developed in collaboration with the Faculty of Electrical Engineering of the Czech Technical University in Prague. It provides information about the project, our team, and ongoing activities, including our research in Egypt and various European museums, as well as conferences and new articles on the topic. Most importantly, the websites host the online version of the database, which is available in English.

The online database is based on the *Burial containers* table originally created in FileMaker and represents a slightly modified version containing the most essential information (Fig. 1). The homepage serves as an introduction and includes a complete list of all recorded burial containers. Each entry is assigned a unique code that is the same as in the case of the FileMaker version (see *supra*). A list of abbreviations is also provided on this introductory page.

As for the copyright policy, we use photographs and images when we are allowed to publish online by our home institution (the Czech Institute of Egyptology, Faculty of Arts, Charles University) or any other institutions, which is referred to on the websites. In cases of the containers that are published online but without permission to publish, the external links are added. Bibliographical references are noted in each entry.

The search and browsing on the websites is in full text. Although this method is less user-friendly, the required information can still be accessed. The possibility of setting the print mode of individual entries represents a benefit within the current websites for the scientific community. In a following project, we plan to improve this function by updating the entire website.

4. Potential of the database

The AEBC database has its great potential in the study of burial containers, since it gathers into one place a wide variety of information about containers from different materials. It not only allows scholars to obtain statistical data for research within one particular material, whether it is a study of container typology, technical details, their social and spatial distribution, or individual workshops, but it is also beneficial for larger inter-material comparative studies. This database has already served as a useful tool for several case studies using statistical evaluations of various materials. It specifically provided the necessary data for the research of the presence of wooden coffins inside

stone sarcophagi.¹⁸ Moreover, it allowed us to more efficiently assess the typological development in wood and stone as well as to trace the diachronic development of the decoration applied on both types of containers, including the different placement of individual motifs for each type of material.¹⁹ The database also represented an invaluable source of information for a study of the spatial distribution of all types of containers, i.e. wooden, pottery and plant-fibre coffins as well as stone sarcophagi during the Third Dynasty.²⁰

Our future prospect for the database lies in its connection with an interactive map of Egyptian localities that will contain all the containers from the studied period so far published. The intention is to include all the information from the database, which will be displayed with only one click.

5. Conclusion

In the last several decades, innovative methods such as complex network analyses, photogrammetry and 3D modelling or digitalized script and text corpora have flourished in Egyptological research, and this represents a valuable step forward in the documentation of archaeological sites, the reconstruction of individual finds or the translation of preserved textual evidence.²¹ The creation of databases as digitized corpora of information and their forms of open access undoubtedly belong to this rapidly developing trend. In this vein, databases of various types have been used to study various aspects of the ancient Egyptian society more often and more commonly. They represent an absolutely essential prerequisite and tool for any in-depth research into the ancient Egyptian society. Modern database programs, such as FileMaker, provide us with incredibly useful and easy-to-use instruments that makes the research more complex and efficient.

The use of the latest technologies resonates with the authors of this article. Therefore, database of coffins and sarcophagi for the period under study became a natural part of their project. It enabled structured sorting of the data, the statistical evaluation and the material comparison. Given the fact that the database is published freely online, it can also be beneficial to the wider scholarly public.

Acknowledgements

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¹⁸ Peterková Hlouchová 2023.

¹⁹ Peterková Hlouchová, Nováková 2024; Peterková Hlouchová, Eschenbrenner-Diemer 2025; Nováková 2025.

²⁰ Poster Burial containers of the late Early Dynastic Period and early Old Kingdom: adherence to traditions or evolution? presented by M. Peterková Hlouchová, V. Nováková, D. Uhrová at the 8th International Conference ‘Egypt and its Origins’ Predynastic and Early Dynastic Egypt (Krakow, 16-20 September 2024).

²¹ Lucarelli, Roberson, Vinson 2023.

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Online Resources

AEBC	http://aebc.ff.cuni.cz/
Digital Giza	http://giza.fas.harvard.edu/
Fitzwilliam Museum's Ancient Egyptian Coffins Project	https://egyptiancoffins.org/
Giza Archives	http://gizapyramids.org/
Giza-Projekt	http://giza-projekt.org/
Oxford Expedition to Egypt: Scene-details Database	https://doi.org/10.5284/1000009
Painted for Eternity	https://meketre.org/
TLA	https://aew.bbaw.de/tla/index.html

The Palermo Stone and its associated fragments. For a new archaeometric understanding of the Old Kingdom royal annals

Massimiliano Nuzzolo, Chiara Germinario,
Vincenzo Morra & Celestino Grifa¹

Abstract

The Palermo Stone, together with its associated fragments (the 5 fragments kept in Cairo, Egyptian Museum, and the single fragment kept in London, Petrie Museum of Egyptian and Sudanese Archaeology), is the oldest example of royal annals known to us from ancient Egypt. The annals are of pivotal importance for our knowledge of the early phases of ancient Egyptian history, particularly the Old Kingdom, 3rd Millennium BCE. Despite more than a century of study and research, the reading of these annals is still uncomplete on account of the fact that a considerable part of the stones is erased or damaged and not easily readable at the naked eye. Moreover, there is no consensus among scholars on their original location and provenance and some Egyptologists have even casted doubts on the fact that all the fragments originally belonged together.

For these reasons, in very recent years the annals have been investigated by a multi-disciplinary research team by means of a combined set of new technologies, including a new method of 3D photographic documentation and reproduction (Reflectance Transformation Imaging), and a varied set of geo-chemical analyses. While the former were addressed at improving the readability of the annals, and have been the object of previous scientific publications, the latter were aimed at clarifying the geological composition of the stone fragments. This new analytical approach consisted of a fully non-invasive analysis via Digital Microscopy (DM), portable-XRF and ER-FTIR, accompanied by a micro-sampling of the sole Palermo Stone through Polarized Light Optical Microscopy (PLOM) observation and SEM-EDS analyses. The micro-sampling of the Palermo Stone was crucial for the exact determination of the paragenesis and classification of the Sicilian fragment as well as to compare it with the petrographic and chemical data acquired on the other fragments.

These archaeometric analyses are particularly significant for our knowledge of the royal annals, since neither the Palermo Stone nor any of its associated fragments have ever been investigated by means of these technologies.

The present paper will show the main results of our new investigation which, for the first time, provides scholars with a clear geological dataset on the entire annals stones. Based on this, we can now propose a possible provenance for the Palermo Stone and a plausible conclusion regarding the issue of whether the other associated fragments did belong to it or not.

Keywords: *The Palermo Stone; Cairo fragments; London fragments; Archaeometric analyses; Basalt quarries*

1. Introduction

The Palermo Stone and its associated fragments (5 fragments are kept in Cairo, Egyptian Museum, and one fragment is kept in London, Petrie Museum of Egyptian

¹ The authors discussed and agreed on the general content of this paper. Massimiliano Nuzzolo edited the first paragraph (§ 1); Chiara Germinario, Vincenzo Morra and Celestino Grifa edited paragraphs 2-4 (§ 2-4); and all the authors edited the conclusion (§ 5).

and Sudanese Archaeology) are undoubtedly a milestone for our knowledge of the early phases of ancient Egyptian history. Engraved with the names and the “historical events” pertaining to the kings of the first five dynasties, the so-called royal annals represent an unparalleled source of information for the period spanning the last two centuries of the Fourth Millennium BCE and the first half of the Third Millennium BCE, down to the reign of Neferirkara, the third king of the Fifth Dynasty. The pivotal nature of this document is confirmed by the fact that most of the historical-textual data provided by the annals were later confirmed by archaeological investigation, thereby demonstrating the full historical reliability of the source. This is the case, e.g., of the Fifth Dynasty sun temples, whose existence is known from the Palermo Stone much earlier than their archaeological rediscovery and systematic excavation.²

The story of their arrival/acquisition to the archaeological museums of Palermo (1877), Cairo (1910; 1912; 1965) and London (1916), over a time span of around one century, as well as the different stages of the study and publication of all the fragments, have been the object of a few number of articles by the present author,³ and it is therefore not our intention to repeat them here. For the scope of the present article, however, it is crucial to remind the reader that a significant issue remains: there is no consensus among scholars as to whether all the fragments were originally part of the same historical document.⁴ Some Egyptologists have even questioned the authenticity of certain fragments, especially those housed in Cairo.⁵

The main issue relating to whether the 7 fragments were originally a part of a single document is represented by the lack of any information on their provenance. This is in fact totally unknown, with the sole possible exception – yet very doubtful – of the Cairo Fragment 4.⁶ Moreover, none of the 7 fragments has ever undergone any archaeometric investigation; this is a crucial factor in determining whether all the fragments belong to one and the same document or not, since whether they match with one another depends first and foremost on their compatibility in terms of chemical composition and mineralogical features.⁷

For this (and other) reason(s), starting in 2017, the present author set up the *Palermo Stone Project*, a multidisciplinary endeavour – including several scholars with diverse scientific backgrounds and interests – aimed at a comprehensive reassessment of the issue of the royal annals.⁸ Our primary goal was, in fact, not only to attempt a better reading of the hieroglyphic text engraved on the annals (which is still not completely understood) by means of the most modern digital photography technologies, primarily

² Three sun temples are mentioned on the Palermo Stone: Userkaf’s, Sahura’s and Neferirkara’s and only the first one has been so far unearthed (Ricke 1965). The other archaeologically known sun temple, that of Nyusera, was first excavated in the years 1898-1901 (Borchardt 1905) and is currently being re-excavated (Nuzzolo *et al.* 2020), but is not mentioned on the Palermo Stone.

³ Nuzzolo 2020; Nuzzolo 2021; Nuzzolo 2024.

⁴ Wilkinson 2000, 24-28.

⁵ O’Mara 1979; O’Mara 1986.

⁶ Nuzzolo 2021, 58.

⁷ Nuzzolo 2021, 61.

⁸ Nuzzolo *et al.* 2021.

the so-called Reflectance Transformation Imaging (RTI). Rather, our aim was to collect the largest and most diverse set of data on the annals, derived from various disciplines such as Egyptology, Archaeology, Archaeometry, Petrology, Archival Studies, and others. Each of them entails a different methodological approach to the same issue and eventually produces a different type of dataset that, when cross-combined with one another, can provide us with crucial information on the main question from which our research has originated: were all the fragments of the royal annals so far known, part of one and the same document?

2. Analytical techniques of investigation of the royal annals

Between September 2021 and October 2022, the Palermo Stone and the associated fragments from the Cairo Egyptian Museum were investigated to verify their textural, chemical, and mineralogical features. An investigation was carried out using non-invasive microscopic and spectroscopic techniques, combined with invasive micro-sampling of the sole Palermo Stone. The latter was fundamental in setting the starting point of the project, as it is the only way to establish a secure geochemical and petrological definition of the stone. Non-invasive analyses were also conducted on the London Fragment in March 2025.

Non-invasive analyses of the fragments were performed using various devices. Firstly, all fragments were observed through a Digital Microscopy (DM), notably a Dino-Lite digital microscope with a magnification range of 20- 220x and 400- 470x, equipped with a 5.0-megapixel colour CMOS sensor and built-in coaxial illumination and Flexible LED Control (FLC). The DinoCapture2.0 software was used to acquire images.

The chemical composition of the Palermo Stone was further investigated by means of a portable XRF (p-XRF) spectrometer, consisting of an X-ray tube Mini-X - Amptek with a voltage of 35 kV and a current of 80 μ A, a rhodium (Rh) target, and a silicon drift detector (SSD) system (X-123SDD - Amptek). A work distance of 1 cm was used to acquire spectra (acquisition time of 50 seconds per measurement area). On the other hand, the Cairo Fragments were investigated with a portable Bruker TRACER 5G spectrometer equipped with a Rh target X-ray source, SSD system with a 20mm² wide active area, graphene window, and internal camera on areas of 3 mm (spot diameter) with a voltage of 30 kV, 50 μ A, and an acquisition time of 30 seconds. The software ARTAX Spectra 8.0.0.476 (Bruker AXS Handheld, Inc.) was used to process the spectra.

On all the fragments (Palermo, Cairo, and London), a Fourier Transform Infrared Spectroscopy in External Reflectance mode (ER-FTIR) was also carried out by means of a portable BRUKER Alpha FTIR spectrometer. The spectra were collected on a circular area with a 3mm diameter in a spectral range of 4000-400 cm^{-1} with a resolution of 4 cm^{-1} and 128 scans (2 minutes) for each run. The Bruker Opus 7.8 software was used for data acquisition and processing.

IR spectra were further analysed using Principal Component Analysis (PCA), a standard multivariate statistical method that allows for the reduction of dataset dimensionality, retaining only those variables that primarily represent the variance of the data. After pre-processing the data, the analysed spectra were limited to the interval of interest between 400 cm^{-1} and 1300 cm^{-1} , thereby removing signals of

organic origin that could affect the results. PCA, performed using R software version 4.0.0, was applied to the data matrix obtained with the 'files2SpectraObject' function of the 'ChemoSpec' tool, to calculate the scores for the most important components and plot the data.

For a more accurate petrological characterization of the Palermo Stone three micro fragments were also collected and embedded in epoxy resin to obtain a thin section, which was observed using Polarized Light Microscopy (PLM), notably a Nikon Eclipse 6400 POL microscope, equipped with a Nikon DS-Fi camera for the acquisition of representative images.

3. Results and discussion: Palermo Stone

Non-invasive microscopic and spectroscopic analyses allowed us to determine the chemical and mineralogical composition of the rock. DM images revealed a porphyritic texture of the rock, characterized by white crystals scattered throughout a dark grey groundmass (Fig. 1a). Portable-XRF analyses identified predominant Fe and Ca with subordinate Si, Ti, Al, K and traces of Mn and Sr (Fig. 1b). These chemical elements were consistently observed across all spectra obtained from the Palermo Stone's surfaces, including both the Verso and Recto, as well as the side surfaces, indicating a homogeneous rock composition. However, p-XRF also detected the presence of sulfur (Fig. 1b), which can probably be attributed to gypsum residues applied to the stone's surface in the early 1900s by Antonino Salinas, with the twofold aim of taking a high-resolution picture of the stone and creating further casts of it to enhance the readability of the hieroglyphs carved into the stone.⁹ DM further confirmed that gypsum is present in the surface pores and partially fills the grooves of the hieroglyphs (Fig. 1a).

Consistent with chemical data, ER-FTIR of both surfaces identified the diagnostic bands of olivine, plagioclase, and clinopyroxene,¹⁰ which represent the main components of the rock. The intensities of these bands vary, likely reflecting differences in the concentration of these minerals in the analysed areas. Additionally, surface treatments have introduced characteristic peaks of organic materials, observed between 3000 and 2800 cm^{-1} and 1650 and 1250 cm^{-1} (Fig. 1c). These peaks likely result from the application of silicone rubber and epoxy resin used to create casts of the surfaces.

PLM observations confirmed the volcanic origin of the rock, which exhibits a porphyritic texture (Fig. 2a-d). The microcrystalline groundmass is primarily composed of plagioclase and microcrystals of opaque oxides (10–30 μm). Sporadic phenocrysts of plagioclase, olivine, and clinopyroxene, ranging in size from 50 to 150 μm , were also observed. Occasionally, agglomerates of these mineralogical phases are visible (Fig. 2c).

⁹ Nuzzolo 2024, 57.

¹⁰ Izzo *et al.* 2020.

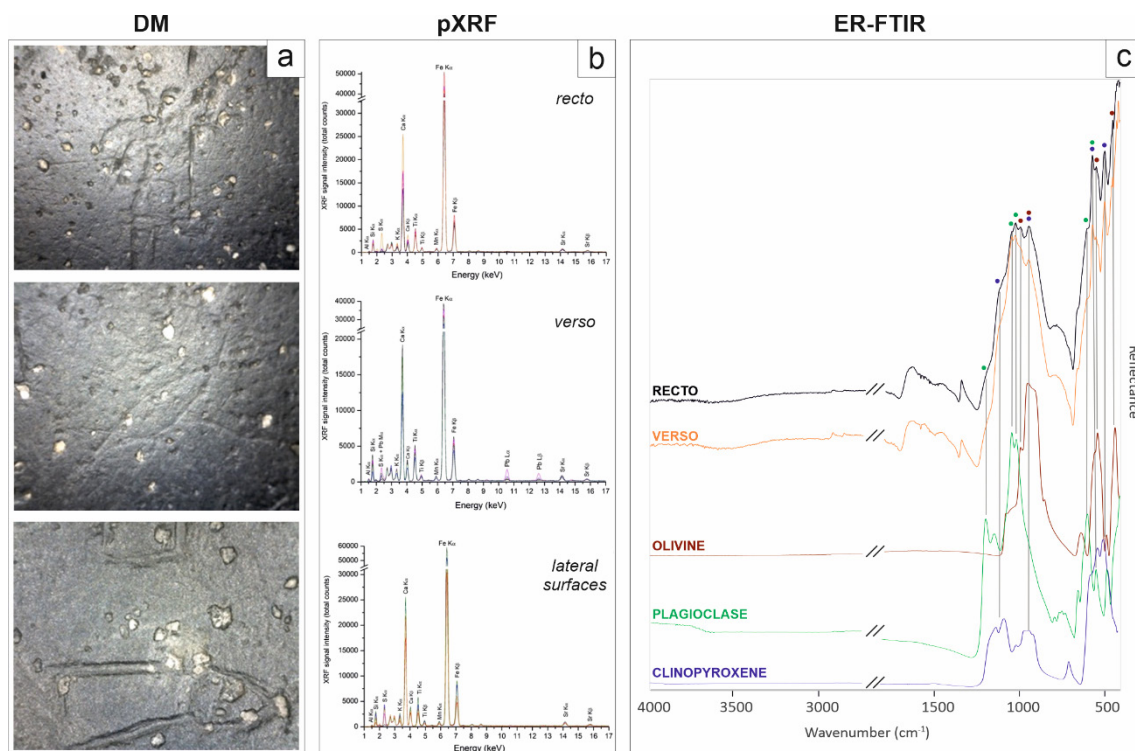


Fig. 1. DM images (a), p-XRF spectra (b) and ER-FTIR spectra (c) of the *Recto*, *Verso* and side surfaces of the Palermo Stone. Reflectance spectra of olivine, plagioclase and clinopyroxene (after Izzo *et al.* 2020) were reported for the identification of the bands in the spectra of the Palermo Stone.

The rock is classified as basalt based on its modal composition and paragenesis.¹¹ The establishment of a secure petrographic classification for the Palermo Stone (and the associated fragments) is crucial because in the early scientific publications, the fragments of the royal annals have been variously – and erroneously – defined as being made of amphibolite, diorite, or amphibolic diorite.¹² It was only in recent times that one of the fragments (Cairo Fragment 5) underwent chemical analysis and microscopic observation, and was eventually defined as “olivine basalt”,¹³ thereby raising questions about the real nature of all the other fragments.

¹¹ Le Bas and Streckeisen 1991.

¹² Nuzzolo 2021, 61.

¹³ De Cenival 1965, 14.

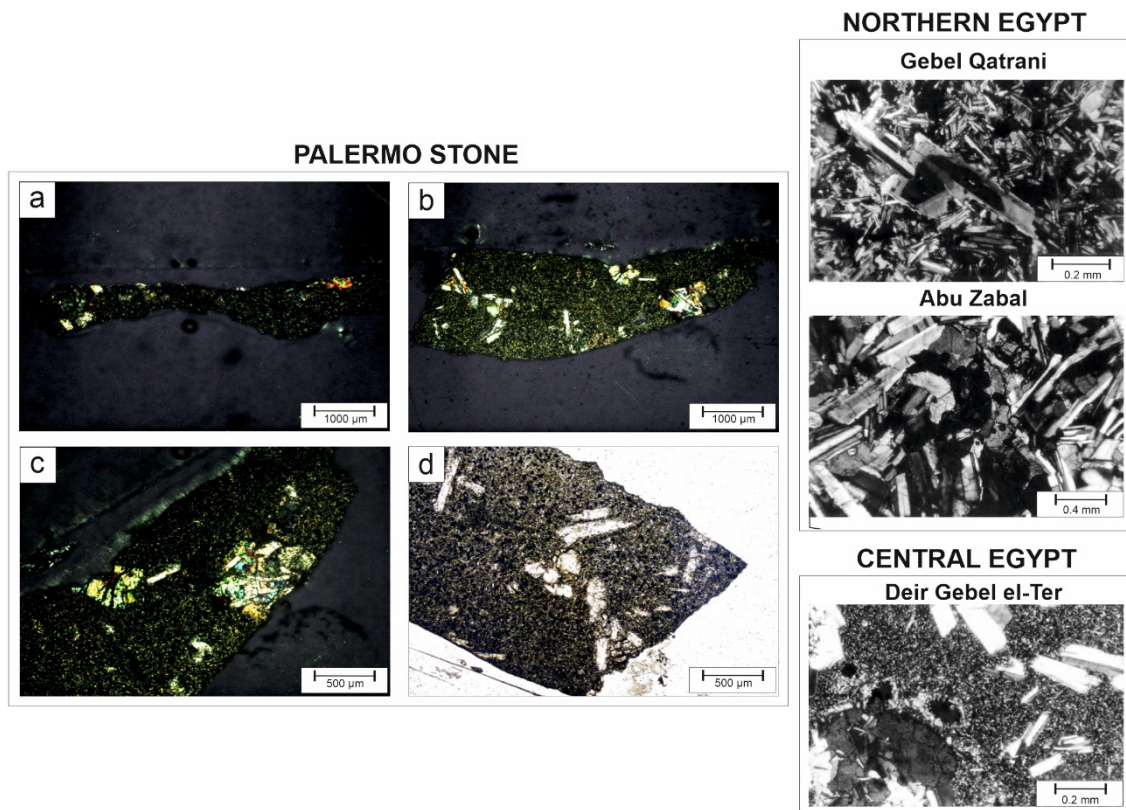


Fig. 2. Four images of the Palermo Stone acquired via PLM in crossed- (a-c) and plane-polarized (d) light, in which it can be observed the porphyritic texture of the rock, featured by mineral agglomerates and single crystals of plagioclase, clinopyroxene and olivine scattered in the microcrystalline groundmass. The thin sections of basalts coming from Northern Egypt (Gebel Qatrani and Abu Zabal outcrops) and Central Egypt (Dier Gebel el-Ter deposit) were also reported for comparison (after Klemm and Klemm 2008).

PLM provided valuable insights for formulating an initial hypothesis regarding the quarrying area of the stone, considering that igneous rocks with basaltic compositions outcrop in various regions of Egypt. The mineralogical and textural features of the Palermo Stone were compared with data on basalts coming from well-known Egyptian quarries, as reported in the reference-text on this subject by Klemm and Klemm,¹⁴ as well as by the more recent publication by Harrell.¹⁵ Crucial similarities were identified with subalkaline basalts from the Minya district, particularly those from the quarries of Deir Gebel e-Ter and Bahnasa (Fig. 2). In fact, basalts from northern Egypt (i.e. Gebel Qatrani Area in Fayum; Abu Zabal and Abu Roash areas to the east and west of Cairo) are characterized by olivine basalts with a “bulky” plagioclase arrangement in the microcrystalline groundmass and scattered phenocrysts of plagioclase, clinopyroxene,

¹⁴ Klemm and Klemm 2008, 315-322.

¹⁵ Harrell 2024, 604-609.

and altered olivine.¹⁶ In contrast, basalts from the Minya area (Central Egypt) are fine-grained volcanic rocks with a porphyritic texture and micro- to cryptocrystalline groundmass containing agglomerates of clinopyroxene and plagioclase, along with olivine and opaque oxides.¹⁷ These textural and mineralogical features align closely with those of the Palermo Stone, suggesting that the rock likely originated from Central Egypt (Fig. 2).

4. Cairo and London Fragments: compositional-mineralogical comparison with the Palermo Stone

To evaluate the chemical and mineralogical similarities between the Palermo Stone and the fragments preserved in Cairo and London, the latter samples were investigated by using the same non-invasive analytical approach described for the Palermo Stone.

Concerning the Cairo Fragments, DM images revealed the rocks' porphyritic texture, characterized by phenocrysts (up to 2 mm) dispersed within a dark-colored groundmass. The phenocrysts consist of white, tabular crystals and subordinate sub-rounded, dark-colored crystals, occasionally bordered by altered rims that have turned red (Fig. 3a, b). Additionally, DM highlighted white-colored material within hieroglyphic traces and thin, regular marks (Fig. 3c), likely caused by the tools used for the polishing of the stone.

From a compositional perspective, our analysis revealed the presence of Fe, Ca, Ti, Si, V, and Mn in all samples (Fig. 3), consistent with the "chemical signature" of basalt. Additionally, the presence of Zn was identified in Cairo Fragments 2 to 4, probably due to surface treatments.

ER-FTIR analysis indicated that Cairo Fragments 3 and 5 display characteristic bands of plagioclase, clinopyroxene, and olivine, likely representing the primary components of these rocks, consistent with the spectral features presented by the Palermo Stone. Spectral acquisitions from different points on both surfaces also revealed the same bands, although with varying intensities. In contrast, Cairo Fragments 2 and 4 exhibited different spectroscopic features. In both cases, the spectra showed intense and narrow peaks at approximately 1020 and 465 cm^{-1} , which, along with the peaks at 795 and 670 cm^{-1} , suggest the presence of a hydrated mineralogical phase, likely resulting from alteration of olivine crystals. These peaks were less intense in Cairo Fragment 1, which occasionally shared the spectroscopic features with Cairo Fragments 3 and 5.

As for the London Fragment, both DM observations and ER-FTIR analyses were performed. The rock is compact, occasionally showing conchoidal fractures. On the smooth surface of the Recto, hieroglyphs are visible, recognizable by fine grooves filled with white material (Fig. 3e). The Verso is way less preserved and largely broken (Fig. 3f). DM photographs reveal a porphyritic texture, characterized by more abundant dark crystals, occasionally turned in red, and transparent prismatic crystals dispersed within the fine-grained groundmass (Fig. 3e, f).

¹⁶ Klemm and Klemm 2008, 317-318, fig. 477-478; Harrell 2024, 605 and tab. 18.2.

¹⁷ Klemm and Klemm 2008, 318-319, fig. 479; Harrell 2024, 608 and tab. 18.2.

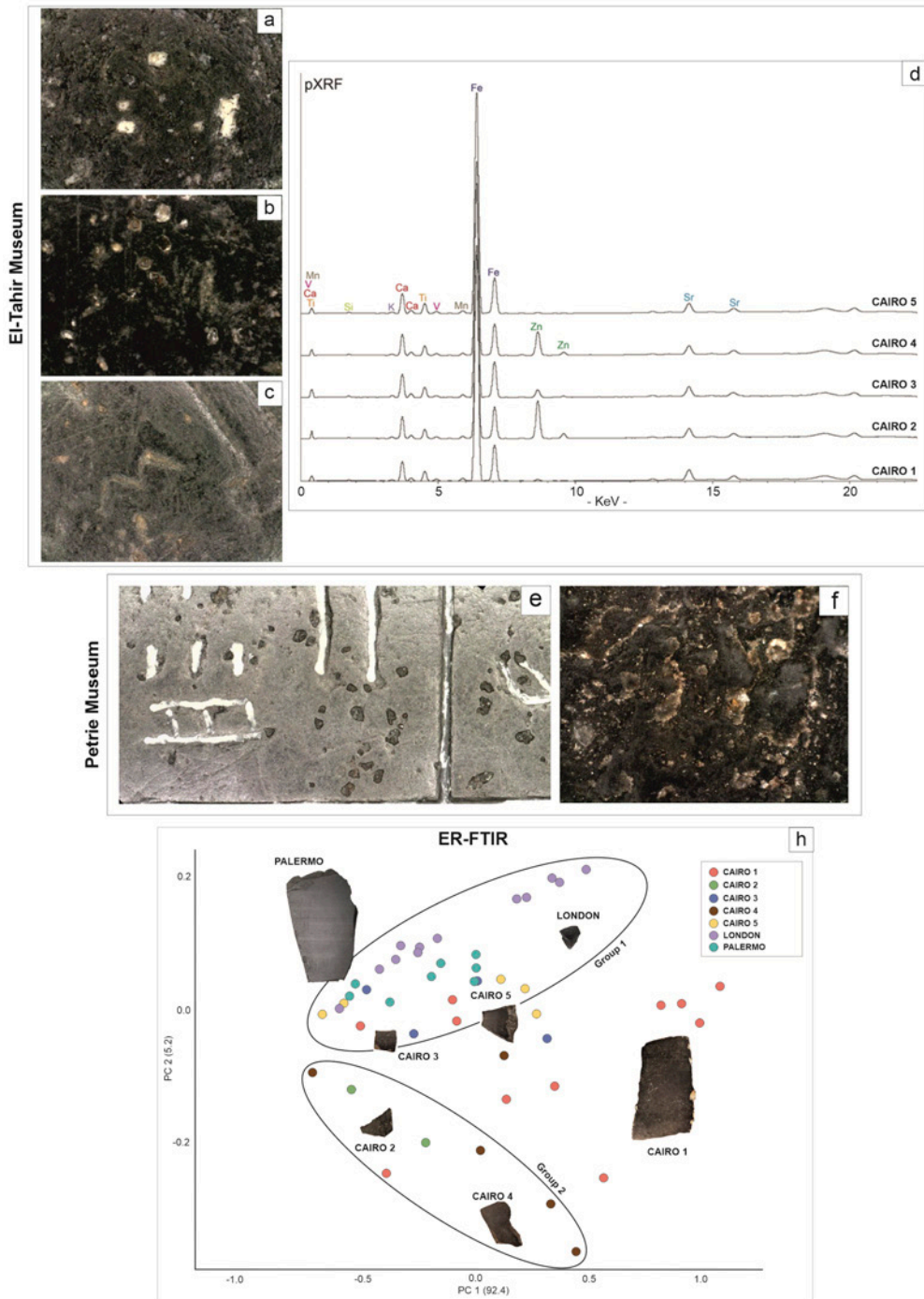


Fig. 3. Microscopic and spectroscopic features of the Cairo and London Fragments: a) DM image of Cairo Fragment 1, showing white crystals with tabular habit scattered in the groundmass; b) DM image of Cairo Fragment 4, in which reddish crystals can be observed; c) DM image of Cairo Fragment 5, showing marks on the surface; d) p-XRF spectra of all Cairo Fragment; e) Collage of DM image of the London Fragment, showing the porphyritic texture of the rock; f) DM image of the London Fragment, showing transparent and reddish crystals in the groundmass; g) PCA graph of the ER-FTIR data of the Palermo Stone and all the associated (both Cairo and London) fragments.

Consistently, the ER-FTIR spectra display intense absorption bands in the 1250 and 800 cm^{-1} as well as from 650 to 400 cm^{-1} regions, corresponding to the characteristic vibrational features of plagioclase, clinopyroxene, and olivine. The spectroscopic evidence, therefore, indicates that these mineral phases constitute the principal components of the rock, confirming the microscopic observations.

To accurately compare the infrared spectral features of the Cairo and London Fragments with those of the Palermo Stone, spectroscopic data were analyzed using Principal Component Analysis (PCA). The statistical analysis confirms significant similarities between the ER-FTIR spectra of Cairo Fragments 3 and 5 and the Palermo Stone. In the PCA graph, these two fragments form a group (Group 1) with the Palermo Stone in the upper-left corner. Conversely, Cairo Fragments 2 and 4 (Group 2) are clustered in the lower part of the graph, corroborating the dissimilarities observed in their spectral features (Fig. 3g).

Cairo Fragment 1 exhibits anomalous behavior; some spectra acquired from its surfaces align with those of Group 1 (Fig. 3g), whereas other spectra display distinct spectral responses, forming a separate group on the right side of the graph (Fig. 3g). This anomalous behavior can be attributed to the presence of absorption bands associated with hydrated mineral phases, which exhibit variable intensities across the spectra acquired at different points within the rock. Spectra in which these bands display lower relative intensities, together with the characteristic peaks of the primary anhydrous mineral phases (i.e., plagioclase, clinopyroxene, olivine), are consistent with the spectral field of the Palermo Stone. Conversely, spectra exhibiting higher intensities of these bands deviate markedly from the Palermo Stone, converging toward the spectral cluster defined by Cairo Fragments 2 and 4, in which the spectral features of hydrated phases predominate at the expense of those of the other mineralogical components.

The ER-FTIR spectra of London Fragment are consistent with those obtained from the Palermo Stone and the Cairo Fragments 3 and 5 (Fig. 3g). However, some spectra acquired from different points on the stone surface appear slightly displaced toward the upper-right region of the PCA diagram, likely due to higher signal intensities and a more distinctly defined band morphology in the 1250–800 cm^{-1} range.

5. Conclusions

The invasive analysis carried out on the Palermo Stone allowed us to determine the nature of the rock, which was identified as basalt. Textural features, compared with those of rocks from Egyptian quarries, suggest an association with the basalts from the Minya district in central Egypt.

Moreover, the non-invasive approach adopted to characterise both surfaces (Recto and Verso) of the Palermo Stone was pivotal for the initial comparison of the Sicilian fragment with both the Cairo and London Fragments, in order to verify the compatibility of all the pieces that compose the royal annals. The microscopic and chemical features of the Egyptian fragments allowed for the classification of their lithotypes as basalt. However, spectroscopic features of the fragments revealed significant differences.

Only Cairo Fragments 3 and 5 can be fully associated with the Palermo Stone from both a chemical and mineralogical point of view. In contrast, Cairo Fragments 2 and 4 exhibited notably different features, such as the presence of Zn, and the intense spectral bands associated with hydrated mineralogical phases, which neatly differentiates them

from the Palermo Stone. Finally, the microscopic and spectroscopic data acquired on the London Fragment suggest the same nature of the rock (i.e., basalt) also for this piece, which is thus consistent with the mineralogical composition of the Palermo Stone, although not fully corresponding to it.

The most enigmatic, and somehow problematic, piece of the puzzle is Cairo Fragment 1. Although its textural and chemical composition is consistent with that of the Palermo Stone and Cairo Fragments 3 and 5, the statistical analysis of its IR spectra revealed that this fragment is only partially comparable to the above pieces. This is in fact quite surprising when we consider that Cairo Fragment 1 joins perfectly Cairo Fragment 3 (fig. 4) and should thus have the same archaeometric features. A possible solution to the puzzle might be that Cairo Fragment 1 underwent a different conservation history with respect to Cairo Fragment 3, but we have no hints in this concern. Further investigations are therefore needed to complete the compositional framework of this fragment and provide more detailed clarification.



Fig. 4. The Recto of Cairo Fragment 1 and 3 (photo: M. Nuzzolo 2022; Courtesy of the Egyptian Museum in Cairo; © The Palermo Stone Project). The photo shows that the two fragments perfectly fit together and should once be one and the same piece.

This is a major point in our investigation of the royal annals, for the Cairo Fragment 1 is the closest to the Palermo Stone in terms of measurements, features of the hieroglyphic text (paleography), and the historical information provided. The matching between the latter two fragments is thus crucial for understanding not only the possible original arrangement of the fragments that compose the royal annals but also the overall size of the annals. This, in turn, can help us determine how much of the original text we still miss and, consequently, how many kings (and related historical events) we should expect to find in the final overall reconstruction.¹⁸

Of course what has been presented in this paper is only a summary of the preliminary results obtained by our work. More detailed analyses, such as Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS), are needed to support these conclusions and will be performed to obtain a specific petrological information as well as to establish a definitive benchmark based on the mineral chemistry. These analyses will in fact facilitate the comparison with previous studies conducted on Egyptian rocks, thereby contributing to improve our understanding of the archaeometry of the Palermo Stone and its associated fragments.¹⁹

Additionally, a specific analytical strategy, that considers all the limitations of the non-invasive analyses, is required. In this regard, what would be really conclusive is a micro-invasive analytical sampling of both the Cairo and London Fragments, as the one carried out on the Palermo Stone. This is the only way to clarify the issue beyond any reasonable doubts, as invasive petrological analyses are essential for classifying the lithotypes and identifying specific quarries and/or supply areas of the fragments.

The latter one is a key-issue also from an Egyptological standpoint, taking into account that the original location of the Palermo Stone and its associated fragments has long been thought to be in the Memphite area. This alleged location clashes with the provenance of the stones (quarries of Central Egypt) as established by our work, considering the presence of at least two large basalt quarries situated not far from Memphis (Gebel Qatrani and Abu Zabal outcrops). The latter quarries would have been much more comfortable for the supply of the basalt needed for the annals, if they were to stand in a temple (or any other type of building/monument) located in the capital area of Memphis or nearby.

We thus hope that more analyses will be soon allowed also for the other fragments of the Palermo Stone in order to try and solve the riddle of the royal annals of Old Kingdom Egypt.

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¹⁸ Compare, e.g., the overall arrangement of the existing fragments of the royal annals presented in Beckerath 1980, 204-205 and Dodson 2021, 115.

¹⁹ Abdel Aal 1998; Abu El-Rus and Rooney 2017; El-Desoky *et al.* 2015; Greenough *et al.* 2001; Harrell and Storemyr 2009; Mallory-Greenough *et al.* 1999.

Nuzzolo; period of work: 2020-2024); B) *Archaeological and Topographical Expedition at the Sun Temple of Nyusera at Abu Ghurab* (grant no. ARC-2980), funded by the Italian Ministry of Foreign Affairs and International Cooperation to the University of Turin, Department of Historical Studies (project director: Massimiliano Nuzzolo; period of work: 2024). A special thank goes to the Essex Egyptology Group for granting funds (Essex Egyptology Group Grant 2024) for supporting the work in the Petrie Museum. The authors would like to express their gratitude to Dr. Caterina Greco, former director of the Regional Archaeological Museum Antonino Salinas in Palermo for allowing them to carry out both invasive and non-invasive analyses of the Palermo Stone. The authors also wishes to thank Salvatore Schiavone and Maria Francesca Alberghina, from “Start-Test Company”, for the rent of the equipment employed for the analyses on the Palermo Stone as well as for the help in the interpretation of the data. Our sincere gratitude also goes to Dr. Sabah Abdel Razek and Anna Garnett, directors of the Egyptian Museum in Cairo and the Petrie Museum of Egyptian and Sudanese Archaeology in London, for allowing the analyses on the Cairo and London Fragments as well as for facilitating the work in the museums and making museum archives and infrastructures easily accessible during all the period of work. A final thanks goes to the anonymous reviewers of this paper for their valuable comments and suggestions.

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A multidisciplinary and innovative approach: the case of the Aga Khan necropolis at Aswan

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Abstract

EIMAWA (Egyptian-Italian Mission At West Aswan) was established in 2018 as a joint mission of the University of Milan and the Egyptian Ministry of Tourism and Antiquities for excavating and safeguarding the Aga Khan necropolis in Aswan. The area investigated covers over 75,000 square meters in which over 400 tombs have been identified and georeferenced. This necropolis served the population living in Aswan between the Late and the Graeco-Roman Period (6th century BC-2nd century AD). The economic and military activities of this population were known thanks to papyrus and findings in Aswan and Elephantine, but not their burial place: this is the missing link that EIMAWA discovered.

From the very beginning, EIMAWA was set up as a multidisciplinary mission with an innovative approach based on the research of new or adapted-to-the-site technologies. The team consists of researchers from different disciplines – from Egyptology to anthropology, radiology, chemistry, topography and geomatics, archaeozoology, archaeobotany, restoration, and informatic sciences. The article will highlight the different aspects of this approach applied in a context made difficult by very high temperatures, wind, lack of electricity, and complex bureaucracy.

Keywords: *Aswan; Graeco-Roman Period; Funerary archaeology; Geomatics; Bioarchaeology.*

1. The history of the discovery and the goals of EIMAWA

Sporadic emergency interventions had begun in the area of the Aga Khan Mausoleum at Aswan in 2015, carried on by Egyptian archaeologists of the University of Aswan and the Egyptian Ministry of Antiquities to counter clandestine activities detected in the area.¹ Then, in late 2016, the Egyptian Ministry of Tourism and Antiquities proposed to the present writer to organize a joint archaeological mission in anticipation of long-term excavation, study, protection, and site-management of the necropolis (Fig. 1). The Egyptian-Italian Mission at West Aswan (EIMAWA) was therefore established, under the direction of the present author and of the Overseer of the Aswan Inspectorate. It is a large team formed by around thirty experts in different fields for the Italian part and a dozen Egyptians, such as Egyptologists, topographers specialized in geomatic, geologists, physical anthropologists, radiologists, archaeozoologists, paleobotanists, chemists, restorers, computer scientists. The team includes skilled Egyptian workers, as well as some Egyptian students at master level, as well as Italian students of the School of Specialization in Archaeology/Egyptology and of PhD programs in Heritage Sciences of the University of Milan. This need for multidisciplinary ended up in the “Mummies Investigation Anthropological Scientific West Aswan Necropolis (MIASWAN)” project, integrated in EIMAWA, grouping eight Departments of the University of Milan and specially financed by it, plus the Department of Civil, Chemical, Environmental and Materials Engineering (DICAM) of the University of Bologna in

¹ El-Aref 2016; El-Aref 2017; El-Aref 2018.

the person of Professor Gabriele Bitelli and his group, as well as the private society of architects Cesare and Carlotta Mari (PAN studio), specialized in heritage and site-management. A collaboration with the Unit of Radiology of Aswan University allows the mission to proceed to the CT-scanning of the mummies, and an agreement with the Institut Français d'Archéologie Orientale in Cairo (IFAO) guarantees the C-14 analysis that, by law, have to be performed in Egypt. In a future perspective, we are planning to collaborate with the DNA-Lab of the National Museum of Egyptian Civilization in Cairo for specific tests.



Fig.1: The area of the necropolis around the Mausoleum of the Aga Khan, view from the Nile © EIMAWA.

EIMAWA started its activity on the site with a survey in 2018 and excavations in 2019. Since 2024, it is an ASOR-affiliated archaeological project.² The research focused on the portion North/East of the Mausoleum enclosure, where a front of rock tombs and, high on the plateau, a concentration of underground graves were detectable. The area investigated until now covers about 25,000 square meters, with an initial mapping of more than 500 tombs, but the extent of the necropolis as a whole is likely to be about 200,000 square meters.³ Preliminary study of the tombs, and in-depth investigation of

² <https://www.asor.org/initiatives-projects/asor-affiliated-archaeological-projects/-egypt>

³ Piacentini, Pozzi Battaglia, Abd El-Moneim 2020, 21-31.

some of them, led to understanding that the necropolis was used mainly in the Graeco-Roman Period.⁴ However, at least one tomb facing the eastern cliff towards the Nile has decorations and inscriptions that allow us to assume the use of the area since the Persian period, during the 6th century BC.



Fig. 2: Photograph captioned "Searching for mummies", Aswan 1902 © Biblioteca e Archivi di Egittologia, Università degli Studi di Milano.

The presence of burials in the area was already known since the beginning of the 20th century at least, as proven by a photograph present in an album created by a tourist in Egypt in 1902, now preserved in the Egyptological Archives of the University of Milan.⁵ It shows a group of ladies accompanied by a dragoman climbing up the sand hill of the south-western bank of the Nile at Aswan; on the back of the photograph is written "Searching for mummies" (Fig. 2). But it was the construction of the Aga Khan Mausoleum (1956-1960) that highlighted the presence of a necropolis. The preliminary

⁴ The tombs carefully investigated by EIMAWA are: AGH026 excavated in 2019 and subject to a more in-depth anthropological investigation in 2020-2022; AGH032 excavated in 2021 and subject to a more in-depth anthropological investigation in 2022; AGH033, AGH034 and AGH035 excavated in 2023; AGH036 and AGH037 excavated in 2024; AGH038 and AGH039 excavated in 2025. In all cases, the artefacts and mummies from these tombs, with multiple depositions, cover a time span from the 3rd century BC to the 2nd century AD.

⁵ <https://archivi.unimi.it/Ente/biblioteca-e-archivi-di-egittologia/>

works of a Swiss-German mission in the 1970s⁶ and of a French one in the early 1990s⁷ were interrupted too soon to emphasize the great complexity of the necropolis and the wide chronological span of its use. Only the ongoing joint Egyptian-Italian mission is actually revealing the place where the large cosmopolitan community that inhabited Elephantine and Syene (modern Aswan) was buried from the Persian period to the Ptolemaic-Roman ones.

In order to study such a vast and complex area, reaching some appreciable results in a reasonable time, there was an immediate need for new technologies applied to archaeological and Egyptological usual methods and to the specific, difficult context of the Aga Khan area. For this reason, the mission was set up with the abovementioned multidisciplinary team and oriented towards implementing everyone's work in an open and inclusive way.

2. Information Technology

Each research and excavation campaign concludes with a substantial volume of documentation, comprising miscellaneous materials provided by numerous researchers. The inherent diversity of information spurred the necessity for a centralized repository to effectively manage and extract insights from the acquired excavation data. To facilitate the organization, sharing, and subsequent analysis of this extensive and varied dataset, computer scientists at the University of Milan supervised by Professor Valerio Bellandi designed and implemented a system using open-source software tools. This system enables the storage and processing of all aforementioned data with efficiency and precision.

The initial search categories were delineated to encompass a comprehensive range of data types, including inventory cards, topographical records, excavation journals, archaeological site details and spatial data, historical documents, archival materials and comparative analyses. Each entity within these categories is accompanied by both structured data, encoded within tables, and unstructured data, presented in free-form text. Moreover, the system allows for the attachment of an extensive array of supplementary materials, such as photographs, images, topographic maps, 3D scans, X-ray plates, relevant literature, and bibliographic references. Advanced search functionalities are integrated into the system, facilitating the discovery, grouping, reordering, and exportation of cards. Additionally, the system enables comparisons with external databases through conventional open data mechanisms. Knowledge extraction features further enhance the system by amalgamating fundamental elements across disciplines, thus offering a comprehensive perspective of the data.

From an IT standpoint, the portal is meticulously structured to manage data in a manner conducive to publication via open data standards and seamless integration with external databases. Consequently, data entries can be exported in punctual or aggregated formats, utilizing a public *Json-LD* schema and REST architecture, to either expose or acquire information from external sources.

⁶ Kaiser *et al.* 1977, 96-100.

⁷ Ballet, Vichy 1992, 113-116.

To uphold data security standards, a dedicated data management module has been implemented to classify confidential information, ensuring its non-exportability. Additionally, a forthcoming data acquisition module is set to be launched, enabling automated querying of public databases to identify pertinent external sources for portal users. This module comprises a sequential process involving: A) translation of English-language cards through calls to public services; B) extraction of keywords and concepts from the cards; C) search across external portals for publications or discoveries utilizing the extracted keywords.

Subsequently, the extracted information is presented to the users who submitted the cards for confirmation of relevance. Following these experimental phases, the repository will be made publicly accessible on the web, with the potential for its model to be replicated across other archaeological sites.⁸

3. Topography and Geomatics

The team of engineers experts in topography and geomatics, headed by Professor Gabriele Bitelli of the University of Bologna (DICAM), has since the beginning of the mission in 2019 a dual focus on research and training. Since then, it has achieved a remarkable feat by producing a high-fidelity 3D model of the tombs, generating billions of points and surfaces utilizing laser scanning technology coupled with an innovative mobile system employing Simultaneous Localization And Mapping (SLAM) technology and close-range digital photogrammetry (Fig. 3). The topographic examination of the site was carried out using Global Navigation Satellite System (GNSS) measurements on some points belonging to the network established with the use of a total station. Subsequently, the collected data were integrated into a Geographical Information System (GIS), providing an optimal geo-reference for the site.⁹

By the end of 2022, the mission acquired a tri-stereo b/h parameter satellite image, employing cutting-edge technology capable of capturing an almost zenithal image, situated between two oblique extremes, thereby ensuring maximum definition. The utilization of satellite technology proves invaluable in a site where drone usage is restricted, yet aerial perspectives remain crucial due to the rugged terrain, characterized by the interplay of *gebel* ridges, *widan* gullies, and plateaus. The introduction of this technology, boasting multispectral resolution with six bands, provides an unparalleled level of detail, offering three-dimensional resolution up to 30 cm from ground level.

Currently, the topographical survey has predominantly focused on the Nord-Eastern quadrant of the necropolis, covering an area of approximately 25,000 square meters, which accounts for about a quarter of the total extent investigated by EIMAWA. Before expanding the survey area, the team of geomatic experts opted to prioritize the mapping of tombs concurrent with their exploration. Notably, tombs AGH026, AGH032, AGH033-AGH037 were successfully located using a mobile laser scanner employing SLAM technology. Despite technical challenges arising from dim lighting within the tombs and the absence of GPS signal, the technology yielded precise three-dimensional point clouds, yielding excellent results.

⁸ Piacentini, Pozzi Battaglia, Bellandi 2023, 335-342.

⁹ Piacentini, Pozzi Battaglia, Abd El-Moneim 2020, 23.



Fig. 3: G. Bitelli and E. Mandanici (University of Bologna DICAM) making GNSS survey of a control point for three-dimensional mapping of the area © EIMAWA.

4. Anthropology and Radiology

The team of anthropologists and radiologists, headed by professors Cristina Cattaneo and Carmelo Messina of the University of Milan, was integrated into EIMAWA just after the first mission at the end of 2019 when it became evident that their skills were necessary for the analysis and comprehension of the characteristics of the numerous individuals discovered in the tombs.¹⁰ Since 2021, they utilized a digital portable X-ray device (Rextar-X, Posdion) on the site, imported among many difficulties from Italy and used under problematic weather conditions because of hard wind or very high temperatures on the site. The obtained images were evaluated on a dedicated workstation using a computer with software enabled to read Digital Imaging and COmmunications in Medicine (DICOM) files. The instrument allowed for internal observation of the bodies still enveloped in bandages and/or covered by

¹⁰ See in the present volume Messina, Tomaino, Biehler-Gomez 2025.

cartonnages, as well as for analysis of bones that presented particular features. It was the case of an adult right femur, with evidence of mid-diaphyseal bone interruption and exuberant osteoreparative callus where the radiographic investigation suggested an amputation.¹¹

In 2023-2024, human remains were scanned directly on the site using an Artec® Space Spider® handheld scanner for 3D imaging.¹² The instrument makes it possible to reproduce a three-dimensional image of the object at high resolution. This is optimal for the long-term preservation of skeletal remains and 'virtual transport' to laboratories in Milan — in our case — where analyses can continue beyond the two-months duration of the mission on site. However, the function of the instrument is to reproduce an image of the surface, so it cannot replace CT scans or X-rays. Moreover, the scanner requires a computer interface and a connection to the power supply, which is not always easy to find and maintain in a desert environment.

Since 2023 there was the possibility of bringing some mummies to the Aswan University Hospital and subjecting them to Computerized Axial Tomography (CT). The scans were performed using a Toshiba Aquilon Prime 160 slice CT scanner with a thin-layer acquisition protocol (slice thickness varying from 1.5 to 0.5 mm, and tube voltage of 100 kVp). Native images were generated for each acquisition and subsequent reconstructions with a window for bone and lung study. The DICOM files of the CT scans were then retrieved and studied both in Aswan and in Milan, using the DICOM viewer "RadiAnt".¹³

In general, all the bodies analyzed showed a good state of mummification, with good preservation of the internal organs. The CT scan made it possible to detect particular characteristics as in the case of two mummies of subadults, found superimposed in Room A of tomb AGH026, the one above aged 4-6 years at the time of death, the other 8-9 years. The presence of wooden sticks placed inside the mummies along the path of the spinal column was seen, to give support and greater stability to the bodies; the under-placed mummy shows also a wooden stretcher at the back to support the body, consisting of three wooden poles, one central and two lateral. Thanks to a 'virtual scrap' it was possible to identify the presence of bracelets on the wrists of both mummies (Fig. 4).

All the analyzes carried out with autopsy analysis and with radiological instruments have offered useful data to complete the anthropological study,¹⁴ allowing the team to draw a biological profile of the human remains identifying sex, the estimated age at the time of death and any pathological or traumatological signs on the individuals found in the investigated tombs.

¹¹ Messina *et al.* 2022, 1-4.

¹² On the different techniques used for 3D-scanning of bones, and the characteristics of the Artec® Space Spider® device, see Otero *et al.* 2020, 1-14.

¹³ The software is a general medical DICOM viewer software, not dedicated to mummies. It is very efficient for loading and managing medical imaging data, allowing for comprehensive examination of images.

¹⁴ Buikstra, Ubelaker 1994.



Fig. 4: Three-dimensional reconstruction of Mummy 2 by means of “virtual unwrapping”. The removal of the superficial layers of the bandage highlights the cuff at the right wrist © EIMAWA.

The minimum number of individuals (MNI) in the larger tombs was very high: 46 in tomb AGH026, and 52 in tomb AGH032. Some were mummified bodies, other skeletonized, while for some of them we have only some bones. We have noticed, at least in one case, that the apparent mummy of one individual was in fact composed, under the bandages, of mixed bones of more individuals. So, counting the bones to determine the number of people buried in one tomb can be misleading, and the MNI is not easy to determine definitively, and could be lower than estimated.

The anthropological study highlighted various diseases. Some vertebrae showed signs of tuberculosis¹⁵ and osteological remains signs of arthritis, a pathology well attested in necropolis with similar chronology and typology.¹⁶ The presence of families and numerous children and sub-adults leads the team to believe that tuberculosis or

¹⁵ For similar cases, see Zink *et al.* 2001, 355-366.

¹⁶ See e.g. Dunand, Heim, Lichtenberg 2010; Dunand, Lichtenberg 2019, 34.

another contagious disease could be the cause of some burial phases which seem to have crowded these tombs, even with entire families.

5. Analytical Chemistry

The team of the analytical chemists, headed by professors Paola Fermo and Alfonsina D'Amato of the University of Milan, carried out extensive color analyses on the findings. In the first measurement campaign carried out in 2021, the aim was to evaluate the possibility of performing on-site analyses using instruments imported from Italy. The decision was taken to adopt light and easy-to-use moveable devices, including a portable Attenuated Total Reflection/Fourier Transformed-InfraRed spectroscopy (ATR/FT-IR) instrument, a colorimeter provided with a visible reflectance accessory, a USB microscope with a 5 Megapixels sensor and an optional polarizing filter (Fig. 5), as well as a multispectral camera with a 28 Mpixel APS-C BSI sensor, 28mm 1:2.8 lens supplied with several excitation sources and specific filters, including the possibility of taking and photographs.¹⁷ The captured multi-band images have allowed the formulation of some insightful considerations on the chemical nature of the pigments employed. Especially, the characteristic fluorescence of Egyptian blue, detected by means of VIL technique, permitted both highlighting its presence/absence on the decorated surfaces and obtaining some unique images of the objects on which that pigment was used.¹⁸

To identify the pigments, the collected spectra were compared with reference spectra present either in the team's database or in the literature. Calcium carbonate due to the substrate of the cartonnages was detected in all the spectra while the pigments were recognized as red ochre, yellow ochre, fine Egyptian blue and madder. The latter is a natural dye of organic origin coming from the root of the madder plant (*Rubia tinctorum*). This compound typically contains alizarin and purpurin, which are two anthraquinones. From the analyses and the obtained spectra, it was possible to confirm homogeneity in the pigments applied on the cartonnages. In addition, the colorimetric data were also processed with Principal Components Analysis (PCA) to highlight possible differences among the different hues. With UV-induced Luminescence (UVL) imaging, it was possible to observe the distribution of the pigmentary drawing hidden beneath the pictorial layer and to investigate the behavior of the different pigments when stimulated by infrared radiation. The analyses performed by ATR/FT-IR revealed the presence of several pigments. Particularly interesting was the pink present on some items: the spectrum itself was found to be different and it is suspected to be an organic dye, probably rose madder. By studying the data obtained by reflectance spectroscopy, it can be stated that the pigments are the same for each color, and the palette remains confined to a limited range of minerals and dyes. With UVL, VIL and IRR it was possible to observe the spatial distribution of some colors; specifically, areas mainly composed either of organic substances or of the abundant Egyptian blue were evidenced. Moreover, the drawing's shape hidden beneath the pigment layer was defined.¹⁹ The investigation revealed the

¹⁷ Guglielmi *et al.* 2023a.

¹⁸ Guglielmi *et al.* 2023b.

¹⁹ Lombardi *et al.* 2023a ; Lombardi *et al.* 2023b.

overall composition of the cartonnages' color palette, which was also found to be in line with the data in the literature.²⁰ In the next campaigns, additional spectroscopic techniques will be used, such as portable Raman spectroscopy that could provide information on the chemical nature of the pigments and binders used on the painted objects.²¹



Fig. 5: Cartonnage discovered in tomb AGH026 scrutinized with a 5 Mpixels sensor-USB microscope equipped with a includable/excludable polarizing filter © EIMAWA.

²⁰ See e.g. Scott 2009, 923-932.

²¹ On the advantages of using Raman spectroscopy, see Ziemann, Madariaga 2021, 8-14.

6. Traditional restoration and innovative virtual restitution

Preservation work was carried out to secure the excavation finds in the magazine. Through a USB portable microscope, it was possible to examine the conservation status of the materials and understand their microstructures characterization. The operations were carried out on pottery, cartonnage, and wooden fragments. For the reassembly of pottery fragments, it was used 50% Paraloid B72 in acetone for adhesion, binding the fragments with strips of paper tape later removed. Sandy deposits were removed on the cartonnages. The fractured areas were reinforced by consolidating the parts with Acril E-411 acrylic adhesive, diluted in water to a concentration of 5%. Decohesive color fixing was carried out by employing a 3% solution of Acril E-411. Deformed portions of cartonnage were smoothed out by moistening the cloth and then applying light pressure to the surface. The cartonnages were then placed back on sheets of ethafoam to bind the detached parts to them through tailoring pins. Sandy deposits were removed also on wooden coffin fragments with brushes and sponges. Encrustations were eliminated with water-supported paper tissues or Japanese paper, removing residues with a scalpel and blitz fix sponge moistened with water. At the end, the coffin fragments were reassembled.

One important find caused much concern at the time of its discovery in 2019. It was a portion of a wooden lid 65 cm long, 36 cm wide and 3 cm thick, found in the lowest part of the sand that cluttered the southwestern part of Room B of tomb AGH026. The wooden membrane of the object was in a state of deep degradation, had lost its cohesive structure and showed an initial state of fossilization with numerous transversal breaks and a surface rich in crystalline aggregates (sand grains). A portion of white plastering, which probably originally covered the entire wooden surface, was preserved although it was severely fragmented. Another still-connected portion showed the depiction of the snout of a *Panthera*, which we interpreted as a *Panthera pardus* (leopard), due to a number of Egyptological considerations.²² The wooden surface was slightly convex, probably serving as a cover for a chest. After careful graphic and photographic documentation aimed at recording the order of the fragments, the removal of the painted surface had to be carried out, as it was impossible to consolidate the wood that had been reduced to a state of total pulverization. The transport of the painted stucco into the magazine was followed by a virtual restitution, in view of the study and interpretation of the artefact (Fig. 6).²³

²² Jéquier 1913, 353-372; Rummel, 2007.

²³ Piacentini, Pozzi Battaglia 2020, 263, fig. 8.



Fig. 6: Virtual restitution of a wooden lid with the depiction of a leopard © EIMAWA.

7. Conclusions

We have seen, through the case-study of the Aga Khan necropolis in Aswan, that many different technologies can be simultaneously used on an archaeological site. They can be updated and adapted throughout the development of the research, to obtain better results decreasing the negative impact on the site itself, on the artefacts and, above all, on human remains. If the study of the latter is of fundamental importance for an in-depth knowledge of ancient populations, we have always to bear in mind that they have to be treated with respect and dignity. Even apparently harmless analysis such as X-ray could damage them, especially as regards DNA preservation,²⁴ and have to be performed with up-to-date devices and just if absolutely necessary, and only new generation CT-scanners have to be used, to better preserve the bodies for themselves and for future research.²⁵

Ethics is a fundamental issue too:²⁶ since we work in a necropolis intensively looted in antiquity and we often find commingled bones or damaged bodies inside the tombs – aside well preserved completely mummified individuals – we have to retrieve them very carefully, to softly clean and recompose them as far as possible, to study and eventually to reconstruct their story, before depositing them in appropriate cushioned boxes and, ideally, reburying them in their cleaned and secured original places.²⁷

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²⁴ Grieshaber *et al.* 2008, 681-687.

²⁵ On this topic, see also Antoine, Ambers 2014, 28-29.

²⁶ Sayer 2010; De Tienda Palop, Currás 2019.

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An Egyptian mummy of the Roman Period with a rare painted shroud: a multi-analytical study of its technical features

In memory of Rita Golfieri

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Abstract

This contribution focuses on the interdisciplinary study of a rare Egyptian mummy housed at the Museo Civico Archeologico of Bologna (MCABo EG 1974), carried out in the frame of the Bologna mummy project (BOmp), an interdisciplinary project promoted by the museum and the Institute for Mummy Studies of Eurac Research (Bolzano). The project started in 2020 with the aim of returning this and other inedited mummies to the scientific community and to the public. Long stored in the museum warehouses, the female adult mummy here presented has a notably preserved painted shroud, which is still wrapped and secured around the body and numerous layers of bandages with textile straps and resin. The pictorial style of the shroud can be traced back to the 1st-2nd century AD (confirmed by 14 C analysis), as evidenced by its similarity to the mummies and coffins belonging to members of the Soter family (53-117 AD), whose tomb was found in 1820-22 in West Thebes. The Bologna shroud belongs to the Soter group, but does not necessarily belong to the same archaeological context and the Soter family. It is particularly rare because only another female shrouded mummy from the Soter group is intact: Cleopatra's mummy in the British Museum. In this context, scientific analysis aimed to deepen our current understanding of the artistic practices of the Roman period through an in-depth study of the painting technique, context of production, and possible provenance of the Egyptian mummy and its shroud, besides reconstructing the biological and the palaeopathological profiles. Moreover, insight into the embalming techniques have been gained. Additionally, the mummy underwent a complex conservation intervention. In particular, the treatments carried on the mummy with the painted shroud needed to include experimental activity to evaluate the performances of innovative materials for conservation.

The study relied on an integrated analytical protocol based on imaging techniques, non-invasive spot analysis.

Keywords: Egyptian mummy; Painted shroud; 'Soternalia'; Interdisciplinary investigation; Conservation treatment.

1. Introduction

This contribution focuses on the interdisciplinary study and conservation treatment of a unique Egyptian mummy (MCABo EG 1974; Fig. 1) as part of the Bologna mummy project (BOmp). This project was promoted jointly by the Museo Civico Archeologico, Bologna, and the Institute for Mummy Studies of Eurac Research, Bolzano, in 2020.



Fig. 1: Female mummy with a rare painted shroud after conservation treatment: front, back, left and right sides, head and feet. © Museo Civico Archeologico, Bologna / Photo Daniele Demonte, CCR “La Venaria Reale”.

The painting style of the shroud, still encasing the mummified body, is attributed to the 1st-2nd century AD, as suggested by the observed stylistic motifs and confirmed by radiocarbon dating (^{14}C).¹ In this context, scientific analysis aimed to enhance our understanding of Roman Period funerary and artistic practices through an in-depth study of the painting technique, context of production, and potential provenance of the Egyptian mummy and the shroud. This research also sought to reconstruct the biological and paleopathological profiles while providing insight into the embalming techniques. The scientific study relied on an integrated analytical protocol based on the combined use of non-invasive spot analysis, mapping, and imaging, as well as micro-invasive investigation of samples from the shroud carried out at the different partnering institutions.² After scientific analyses, the mummy underwent a complex conservation intervention that required experimental testing to assess the effectiveness of innovative conservation materials. Upon completion of the treatment, the mummy was displayed at the 10th World Congress on Mummy Studies, held in Bolzano in 2022,³ before rejoining the Egyptian collection of the Museo Civico Archeologico in Bologna.

¹ Piccirillo *et al.* 2023, in particular 110-111.

² Piccirillo *et al.* 2023.

³ <https://www.eurac.edu/en/exhibition/mummies-unwrapping-the-past>

2. A female mummy with a rare painted shroud: a journey from Egypt to Bologna

The mummified individual was once part of the collection of Bologna artist and collector Pelagio Palagi (1775-1860).⁴ Palagi's collection included thousands of artworks, archaeological finds, coins, medals, books, drawings, and pieces of furniture, which currently enrich Bologna's civic museums and libraries. Among these, his collection of over three thousand Egyptian antiquities, acquired over two decades,⁵ holds particular prestige. Palagi purchased the mummy alongside a thousand other objects in 1831 from Giuseppe Nizzoli (1792-1858),⁶ former chancellor of the Austrian consulate in Egypt,⁷ who documented its provenance as originating from a multiple burial.⁸

The Bologna artist prominently displayed the mummy in his house museum in Milan, as indicated by its floor plan.⁹ This drawing reveals that the mummy was located at the center of the room, alongside another mummy and the coffins of the high-ranking official Usai, son of Nekhet.¹⁰ Palagi's Egyptian collection, including the mummy with the painted shroud, remained in place until his death on March 6th, 1860. In the notarial inventory drawn up in Milan to facilitate the transfer of his assets to the municipality of Bologna, the mummy was identified as belonging to a woman and was described as "wrapped in painted canvas with a plastered and painted hypocephalus, and in poor condition".¹¹

After being briefly exhibited at the 5th International Congress of Anthropology and Prehistoric Archaeology in Bologna in October 1871, Palagi's Egyptian collection was displayed on the first floor of Palazzo Galvani, where the Museo Civico opened in 1881. The museum's first Egyptologist, Giovanni Kminek-Szedlo (1828-1896), did not note the poor state of preservation of the mummy in his *Catalogo di Antichità Egizie* (published in Turin in 1895), instead observing that the inscription on the painted shroud was unreadable.¹²

In the 1970s, during a partial renovation of the Egyptian section, the mummy was moved to the museum's warehouse and placed in a wooden and metal crate due to the shroud's deteriorating condition. Although this decision may seem surprising, given the rarity of a painted shroud still wrapped around an embalmed body, it is important to remember that, at the time, there were no conservators specializing in ancient textiles. Storing the mummy in a warehouse helped prevent it from being treated with unsuitable

⁴ For the artist and collector Pelagio Palagi, see *Catalogo mostra* 1976; Tovoli 1984; Poppi 1996.

⁵ Picchi 2009; Picchi 2011; Picchi 2012; Picchi, Chilò 2021. Further investigation into the history of Palagi's Egyptian collection is underway.

⁶ Picchi 2021, in particular 27-28.

⁷ For Giuseppe Nizzoli and his interest for the Egyptian antiquities, see Daris 2005; Rindi Nuzzolo 2014; Rindi Nuzzolo 2016; Rindi Nuzzolo, Guidotti 2014; Rindi Nuzzolo, Guidotti 2015.

⁸ Nizzoli 1827, XVI.4.

⁹ Picchi 2006, 182-183.

¹⁰ See in the present volume Picchi *et al.* 2026.

¹¹ Translation of "fasciata in tela dipinta con ipocefalo di tela intonacata e dipinta di cattiva conservazione". ASCBo, *Scritture private 1859-1860*, "Antichità Egizie in legno", "Scansia 101", no. 33. The hypocephalus mentioned above is not currently kept at the museum in Bologna, likely having deteriorated over time.

¹² Kminek-Szedlo 1895, 235 no. 1974. The Egyptologist Francesco Rossi (1827-1812), who drew up the first inventory of the Egyptian collection in the 1870s, had pointed out this detail before him.

substances, as occurred in other cases.¹³ The mummy remained there until 2020, when the Bologna mummy project was initiated.

3. Diospolis Magna/Thebes and its necropolises

As stated in the *Catalogo Dettagliato della Raccolta di Antichità Egizie riunite da Giuseppe Nizzoli*, published in Alexandria in 1827, the female mummy with a painted shroud from the Palagi collection was discovered in a collective burial without a coffin, and placed in a row with other mummies of the same type.¹⁴ The pictorial style of the shroud dates to the 1st-2nd century AD, as initially evidenced by its similarity to the female figures painted on the shrouds and coffins of the family of Soter (53-117 AD), Archon of Thebes,¹⁵ and later confirmed by radiocarbon dating. Investigation of the surface deposits and soil residues from the back of the shroud is compatible with a provenance from Upper Egypt, most likely West Thebes,¹⁶ where Soter's family tomb was discovered during the winter of 1820-1821 in the necropolis of Sheikh Abd el-Qurna.¹⁷ On stylistic grounds, other shroud fragments, primarily found in the first half of the 19th century, can be traced to the Theban area and, in part, classified as *Soternalia*.¹⁸

During the Greco-Roman period, the inhabitants of Diospolis Magna/Thebes¹⁹ and nearby villages continued to use the same areas for religious and funerary purposes, preserving and developing local cult and artistic traditions.²⁰

Tradition and innovation are also evident in the embalming practices in the Theban necropolises, which are gradually becoming clearer thanks to increasing tomographic investigations.²¹ Unfortunately, many mummies in the past were unwrapped to study Egyptian embalming techniques, leading to their deterioration. However, by combining historical documentation with modern analytical methods, recurring data have emerged in the embalming practices of the Theban elite.

Papyrus fragments dating from the late 1st to early 2nd century AD contain a funerary text called *The Embalming Ritual*,²² which serves as a fundamental reference document in this context. This text details how to anoint the corpse and wrap the limbs from head to toe before placing the viscera back into the bodily cavities and completing the bandaging of the deceased. It also includes spells to be recited during the deceased's 12-hour vigil prior to burial. While no reference to masks, portrait panels, mummy cases, or shrouds are found in the text, archaeological evidence confirms their use.

¹³ This happened to Usai's mummy (MCABo EG 1975); Picchi, Oliva 2026, 127-142.

¹⁴ See *supra* note 8.

¹⁵ Riggs 2005, 182-205.

¹⁶ See *supra* note 1.

¹⁷ Henniker 1823, 136-137.

¹⁸ Vandenbeuch 2020-2021.

¹⁹ Ancient Waset took on the name Diospolis Magna or Thebes (East) in Greek times; see TM Geo 576 [https://www.trismegistos.org/place/576]. See also Lajtar 2012.

²⁰ Riggs 2002; Riggs 2003; Riggs 2005, 175-244.

²¹ See, for instance, Loynes 2015; Marocchetti *et al.* 2019.

²² For *The Embalming Ritual*, see Töpfer 2015; Töpfer 2017; Töpfer 2020.

For their part, scientific analysis has shown that the deceased was generally anointed with a layer of fluid resin, typically thicker on the head, back, and limbs.²³ The arms were extended along the sides, with palms facing the thighs. The separate bandaging of the head and limbs was a common practice. The final body wrapping could maintain these separate, replicating the body and facial features,²⁴ or enclose them in layers of textiles, often soaked in resin to ensure tightness. Mummies of the Soter family, as well as the one in Bologna, follow this latter practice.²⁵

While embalming methods could differ from ritual practices described in *The Embalming Ritual* according to the deceased's social status and local tradition, the bodies were buried under small chapels, in pits or shafts, often as part of multiple burials within reused ancient tombs.²⁶ The reuse of tombs from earlier dynastic periods, excluding those of sovereigns, was common. This was the case for the Soter family,²⁷ possibly buried in the tomb of Djehutymes (TT32),²⁸ a high-ranking official from the reign of Ramses II, and other nearby tombs.²⁹ The Bologna mummy was found in another multiple burial. Though current evidence is insufficient to determine its exact location or the possible reuse of an earlier tomb, several indicators point to the Theban area as the most probable site.³⁰

In the absence of a dedicated tomb or even a coffin, the surface of the embalmed body became a space for both ritual and artistic expression.³¹ Focusing on female burials, certain iconographic constants characterize most of the masks in *cartonnage* or the goddess-like images of the deceased painted on mummy shrouds, even as styles evolved from the Ptolemaic period to the 3rd century AD. These images often feature voluminous, curly hairstyles cascading down the deceased's shoulders, initially held in place by a laurel wreath and later by a band adorned with gems, or large, helmeted hairstyles with curly hair resting on the shoulders, similar to those worn by men. These goddess-like figures are typically depicted in a sleeved tunic under a feather-patterned sheath with wide straps, sometimes properly *clavi*, and rosettes to emphasize the breasts. Fashionable jewelry adorns the ears, neck, arms, and hands. Mourners, victory figures, snakes, jackals, funerary genii, and other deities, amulets, and flowers, as well as scenes of the deceased on the bier or the weighing of the heart, surround these busts or full-length female figures, offering protection and elevating the deceased toward divinity. Many of these iconographic elements are also present on the Bologna shroud.³²

²³ Töpfer 2017, 27-28.

²⁴ See Raven, Taconis 2005, 191-203; Gessler-Löhr 2012, 10-12.

²⁵ See Raven, Taconis 2005, 179-183; Gessler-Löhr 2012, 12-14.

²⁶ Gessler-Löhr 2012.

²⁷ Herbin 2002.

²⁸ Kakosy 1995, 253-262; Karig 2008.

²⁹ Schreiber *et al.* 2013; Schreiber 2017.

³⁰ Piccirillo *et al.* 2023, 110-113.

³¹ For an overview of burial rituals in Roman times and the relevant bibliography, see Riggs 2005.

³² Riggs 2005, 194-201, 211-213, 217-243.

4. The Bologna-type painted shroud

The mummified individual with a painted shroud housed in Bologna is extremely rare, as only one female mummy of Theban origin from the 1st-2nd century AD has remained intact: the mummy of Cleopatra II, daughter of Soter, now in the British Museum collection (BM EA6706), along with five other fragments showing close similarities to items from the Soter group.³³ Comparing the Bologna shroud with those from females of the Soter family allows for an initial typological classification, which can help map the artistic production of West Thebes and surrounding areas through stylistic groupings.

The Bologna painted shroud (Fig. 1) features a full-length, idealized figure of a woman depicted as the goddess Hathor, Mistress of the West. Her black, curly hairstyle, with thick, long curls descending over her shoulders, is held in place on the forehead by a band adorned with gems, framing the face of this goddess-like figure. Round, red-brown cheeks brighten the pink complexion of the figure's face. Most facial features are outlined in the same red-brown color, except for the black eyebrows, eyes, and round pupils painted over a white background. Round hoop earrings decorated with the head of a hartebeest embellish her ears.³⁴ She also wears fashionable snake armlets on both wrists, rings with stones on each finger except the thumb, and a necklace with a central lunate pendant (*lunula*), characterized primarily by alternating red and blue beads. Her tunic is embellished with two bands on the sleeves and wide straps at the top, each surmounted by rosettes highlighting her breasts. A feather-patterned sheath, which also covers the feet and is arranged symmetrically on either side of a hieroglyphic pseudo-text, decorates the lower part of the tunic. A kneeling mourner holding a folded piece of cloth, a uraeus snake with a sun disc on its head, the amulets *djed*-pillar and *tit*-knot on the right and left side, respectively, as well as a large bouquet of lotus flowers and a sequence of stars and sun discs are painted along the length of the cloth on both sides of the female figure. The lower part of the shroud on the back of the mummy is hidden, as the fabric was folded over and adhered to the body with abundant resin.

A comparison of the Bologna shroud (Fig. 2a) with those of Cleopatra II at the British Museum (Fig. 2c) and Sensaos I (another daughter of Soter, AMM 8-d; Fig. 2b) at the Rijksmuseum van Oudheden in Leiden, along with other similar shrouds in London (BM EA68950) and at the Museum of Fine Arts Boston (72.4723), reveals several recurrent iconographic elements emerge, though the feather-patterned sheaths are different. The feathers on the Bologna shroud are depicted horizontally and visible in their entirety, while those on the Cleopatra II shroud and similar ones overlap vertically.

³³ The British Museum acquired the mummy of Cleopatra II from Henry Salt in 1823, while less is known of the shroud fragments, found uncatalogued in 1978. See Vandenbeuch 2020-2021; Vandenbeuch, Taylor 2024, in particular 117, 154-155. For the conservation treatment of the five shroud fragments in 1980-1981, see Hillyer 1984.

³⁴ Strandberg 2009, 14.



Fig. 2: a) Female mummy with a rare painted shroud, Museo Civico Archeologico, Bologna, MCABo EG 1974. © Museo Civico Archeologico, Bologna / Photo Daniele Demonte, CCR “La Venaria Reale”; b) Painted shroud from the mummy of Sensaos I, Rijksmuseum van Oudheden, Leiden, AMM 8-d. © Rijksmuseum van Oudheden, Leiden; c) Mummy of Cleopatra II, The British Museum, London, BM EA6706. © The Trustees of the British Museum.

Another mummy shroud fragment in the Fitzwilliam Museum, Cambridge (E.GA.5.1943),³⁵ which shows only the face of the deceased, cannot be definitively attributed to the same stylistic grouping as Cleopatra II and Sensaos I. However, they share similarities in the positioning of the headband and the small curls around the forehead at the hairline.

A more precise stylistic correspondence with the Bologna shroud, particularly in the shared feather motif, can be found in other shroud fragments housed at the Museo Archeologico Nazionale di Napoli (MANN 133.159; Fig. 3a-b), the Egypt Center in

³⁵ Fitzwilliam Museum E.GA.5.1943 [<https://collection.beta.fitz.ms/id/object/54412>]. This shroud fragment entered the Fitzwilliam Museum in 1943 as a bequest from Major R.G. Grayer-Anderson.

Swansea (EC38, EC173, and EC175),³⁶ and the Staatliches Museum Ägyptischer Kunst in Munich (ÄS 3266).

The fragment in Naples was received, possibly from Thebes, in 1903 as a gift from Mrs. Acquarulo (widow Canettoli).³⁷ The cloth was wrapped around four mummy feet, with the painted side facing the remains, and enclosed in a glass bell. A recent conservation treatment allowed it to be rediscovered and displayed separately from the feet,³⁸ then wrapped in modern fabric. The fragment features the upper part of the deceased depicted as the goddess Hathor, as indicated by the incipit of the surviving hieroglyphic text.

The shroud fragments at the Egypt Center in Swansea have been on long-term loan from the Wellcome Trust since 1971.³⁹ Henry Solomon Wellcome (1853-1936) likely acquired these and many other painted shroud fragments now in Swansea, after the collection of Robert de Rustafjaell (1876-1943) was dispersed.⁴⁰ Rustafjaell, an antiquities dealer,⁴¹ acquired numerous objects and collections from Upper Egypt, as noted in the preface of Sotheby's auction catalogue. The striking similarities between the Swansea shroud fragments and other textiles from the Theban area further support this.⁴² Ongoing research into the textile properties of the Swansea shroud fragments, along with a series of other painted textiles from the Soter group,⁴³ may help confirm this hypothesis. Fragments EC173 and EC175 from Swansea appear to belong to the same shroud, nearly completing the upper right side of a female figure. The deceased wears a tunic decorated with the same feather motif as fragment EC38 and the Bologna mummy. Additionally, two other fragments, EC176 and EC185, which partially depict the upper part of a female body, seem stylistically related to the same typological group of shrouds. However, this connection cannot be conclusively established at this time without further analytical investigations. A detailed study of the pigments and binding media could also support this. In this context, it would also be essential to analyze the soil residues on shroud fragment EC176 and compare them with those found on the back of the Bologna mummy.

The shroud fragments housed at the Staatliches Museum Ägyptischer Kunst in Munich were discovered at Matmar by Guy Brunton (excavations 1929-1931), inside a Coptic child's tomb (G1011).⁴⁴ This archaeological context, located far from the Theban

³⁶ <https://egyptcentre.abasetcollections.com/Objects?SavedSelections=&Search=Soter+shroud>

³⁷ Mainieri 2021, 37.

³⁸ Guida 2016, 122-123.

³⁹ Wellcome bought "368. Six Cards, with pieces of painted linen from mummies; of varied periods. 369. Six others, similar" at Sotheby's auction in 1906 (Dec. 19-21) for the sale of Robert de Rustafjaell's collection (1876-1943); see Sotheby 1906, 23, lots 368-369, plates XXI and XXIV. The only painted shroud fragments from Roman times published in Sotheby's catalogue and held at the Egypt Center are as follows: plate XXI.1=EC185, plate XXI.2=EC118, plate XXI.3=W1027, plate XXI.6=EC116, plate XXI.7=EC173, plate XXI.8=5971.

⁴⁰ Swansea, Egypt Center EC38, EC115-120, EC131, EC163, EC165-176, EC185, EC483, EC5971-5972, W1027, W1039. See also notes 34 and 37.

⁴¹ <https://ponda.org/people/robert-de-rustafjaell>

⁴² Sotheby 1906, III.

⁴³ This ongoing research is conducted by Jessica Morgan, a current M.Sc. conservation student at Cardiff University.

⁴⁴ Brunton 1948, 93 and LXVII; Schlüter 2018. I would like to thank Melanie Flossmann and Jan Dahms, who are studying the materials from Matmar, as well as Arnulf Schlüter, director of the Staatliches Museum Ägyptischer Kunst in Munich, for the information they have provided.

area, deserves particular attention. Pending a more detailed analysis of the excavation records and materials, it should nevertheless be noted that the reuse of fragments of a female shroud in this context is evident.



Fig. 3: The feather motif on the painted shroud of the Bologna mummy (a: MCABo EG 1974. © Museo Civico Archeologico, Bologna/ Photo Daniele Demonte) and on the shroud fragment in Naples (b: MANN 133.159. © Museo Archeologico Nazionale, Napoli/ Photo Giorgio Albano).

In conclusion, the Bologna shroud can be regarded as the iconographic archetype of a well-established typology of female funerary shrouds, including its variants, which were produced almost certainly in the Theban area or its surroundings during the first two centuries of the current era.⁴⁵ The feather motif is its main distinctive characteristic. An interdisciplinary and comparative study of the shroud fragments discovered so far might offer valuable insights, corroborating the hypotheses put forward based on stylistic, iconographic, and analytical evidence.

5. Recovery activities and conservation

Recovery activities took place on January 20th, 2020, in collaboration with the Institute for Mummy Studies of Eurac Research, which facilitated the rediscovery of the mummy by opening the wooden and metal crate. An initial assessment of the preservation state was conducted using non-invasive water activity analysis. The results (0.50 AW; Temperature 18.45 °C) indicated that the mummy was in suitable thermo-hygrometric conditions, within the safety parameters established for such finds.⁴⁶

The mummified individual was laid on a custom-made multilayer support consisting of closed-cell polyethylene foam (Plastazote®) covered with a layer of micro-perforated

⁴⁵ The same two feather motifs painted on the mummy shrouds also adorn the tunics of two of the Seven Hathors, depicted in Egyptian style on the wall of Shrine I/Mammisi in the main temple dedicated to Tutu in the village of Kellis, Dakhla Oasis. Olaf Kaper (Kaper 2002) dates this fresco to the reigns of Nero (54-68 AD) and Trajan (98-117 AD).

⁴⁶ Samadelli 2013.

polyethylene (Tyvek®). The mummy was then sealed inside a specially designed structure called a Conservation Soft Box (CSB), developed by Eurac in their state-of-the-art laboratories.⁴⁷ The box structure is made of PVC piping wrapped in a multilayer inert, heat-sealable barrier film, which creates an insulated internal environment. Silica gel moisture stabilizers and oxygen removal agents were placed inside the box to maintain an anaerobic atmosphere, ideal for preserving biological remains. Additionally, a passive volatile organic compound (VOC) absorber, composed of a mixture of aluminum permanganate and activated charcoal, was included to ensure optimal storage conditions.

6. Bioanthropological, paleopathological analyses, and embalming techniques assessment

The mummified individual, placed inside the Conservation Soft Box (CSB),⁴⁸ was safely transported to the Sant'Orsola Policlinic Hospital in Bologna. The CSB helped reduce exposure to pollutants, ensuring both the safety of the individual and the hospital environment from potential external contamination. At the Radiology Department of the IRCCS Azienda Ospedaliero-Universitaria di Bologna, the mummy underwent computed tomography (CT) scanning, enabling a thorough virtual examination of the preservation state of both the skeletal structure and the soft tissues (Fig. 4a). Bioanthropological and paleopathological analyses were also conducted, as well as an assessment of the embalming techniques applied to the body.

The CT data were analyzed using dedicated software (i.e. Horos DICOM Viewer -FOSS, RadiAnt DICOM Viewer 64-bit, and Philips - Carestream Vue PACS).

The study revealed that the body is complete and in a medium-to-good state of preservation. The individual was positioned supine, with the arms extended along the sides and the hands placed with the palms facing the thighs. The legs were also extended, with the feet close together in a vertical position and the toes slightly bent. Classical anthropological methods were applied to estimate the sex (e.g. assessment of the presence of genital organs)⁴⁹ and the age at death (e.g., evaluation of pubic symphysis changes;⁵⁰ ectocranial suture closure;⁵¹ third molar eruption stage;⁵² and trabecular bone degeneration⁵³), identifying the individual as female, with an estimated biological age between 35 and 45 years old. Anthropometric analysis suggested a stature of 152.4 ± 2.5 cm, calculated based on the maximum lengths of the femurs.⁵⁴

⁴⁷ Samadelli *et al.* 2025.

⁴⁸ Samadelli *et al.* 2025.

⁴⁹ Ferembach *et al.* 1980.

⁵⁰ Todd 1921.

⁵¹ Rösing 1977.

⁵² AlQathani *et al.* 2010.

⁵³ Acsádi, Nemeskéri 1970.

⁵⁴ Raxter *et al.* 2008.



Fig. 4: a) Virtual unwrapping of the mummified individual with the painted shroud. Software: RadiAnt DICOM Viewer 64-bit. © Institute for the Mummy Studies / Alice Paladin; b) Vertical left incision on the abdomen (white arrows), located between the lower ribs and the iliac crest of the coxal bone, used to remove the internal organs. Software: Horos DICOM Viewer -FOSS. © Institute for Mummy Studies / Alice Paladin; c) Abundant quantity of a radiopaque resinous substance (white area), likely poured over the body, as indicated by the presence of an air bubble on the cranium. Image-making software: Mevis Lab. © Giulio Vara.

Paleopathological assessment revealed evidence of dento-alveolar diseases, including periapical lesions, antemortem tooth loss, and possible periodontitis. Possible signs of abundant dental calculus on the lingual surface of the teeth were also noted. On a skeletal level, degenerative conditions, such as spondyloarthritis and degenerative joint disease (DJD) of the knee, were observed. The presence of prominent skin folds and residual adipose tissue in the hip, buttock, and thigh regions suggested the individual may have been overweight, a factor that could have contributed to the DJD. The CT scan also identified possible calcifications inside the thyroid gland, though their etiology remains unclear. The cause of death remains inconclusive to date.

During the embalming process, the brain was nearly entirely removed through the left nostril. The cribriform plate and the left ethmoidal roof were perforated and fractured. The vomer was also fractured and collapsed to the right, facilitating the removal of the brain. A vertical incision of approximately 7 cm in length was made on the left side between the lower ribs and the iliac crest of the left coxal bone (Fig. 4b). The opening was then packed with resin-soaked tissues, similar to tampons, to provide support. Moreover, CT analysis revealed an abundant quantity of a radiopaque resinous substance, likely poured over the body, as indicated by the presence of an air bubble on the cranium (Fig. 4c). The body was subsequently wrapped in linen bandages, which inevitably became impregnated with the resin. The upper limbs were bandaged separately, as were the lower limbs; however, the fingers and toes were not individually wrapped. The latter were covered with a substantial amount of resin, forming knob-like protrusions. The limbs were then secured with knotted fabric strips at the wrists, under the pubis, and below the knees. Finally, the entire body was encased in what is likely two shrouds.

The Bologna mummy exhibits characteristics that differ from those of Cleopatra II and Sensaos I,⁵⁵ including fewer layers of bandages and textiles soaked in resin, except for those directly adhering to the body. These features provide valuable insights into variations in embalming practices during the 1st-2nd century AD in the Theban area and its surroundings.

7. Technical features and state of preservation

Scientific analysis and research played a key role in understanding the technical features of the shroud decoration and in guiding the design and monitoring of conservation treatments. In line with international guidelines and museums' best practices, the use of non-invasive techniques was prioritized to preserve the remains' aesthetic appearance and physical integrity. Sampling followed by micro-invasive investigations was also employed to address specific questions related to more complex issues. With the assistance of MOLAB, the CCR scientific staff gained access to a wider range of instrumental techniques, enhancing and completing the technical study. The resulting data,⁵⁶ integrated with stylistic and typological considerations, supported hypotheses about the context of provenance and enriched the overall scientific study.

⁵⁵ See Raven, Taconis 2005, 179-183.

⁵⁶ Piccirillo *et al.* 2024.

From a technical point of view, the human remains are covered by linen bandages, an inner shroud, and an outer decorated shroud, which is secured to the body with laces and glued with black resin.⁵⁷ The outer decorated shroud is made of a single piece of linen that covers the entire body, leaving only the upper part of the back exposed. It is folded to conform to the shape of the body. A white, calcium carbonate (CaCO₃)-based ground is applied to the fabric in thin layers to facilitate the application of color over it. The presence of paint remnants within the folds suggests that the shroud was decorated before it was placed on the body. Significant findings from the analytical campaign include the identification of at least two different red pigments used in the shroud's decoration: an earth-based red and a lead-containing red. This contrasts with the almost exclusive use of earth-based red pigments reported in Pharaonic Egypt. Additionally, the use of organic colorants, such as madder lake mixed with calcium carbonate for the skin tone and an unidentified⁵⁸ organic yellow (that is chromatically distinct from iron-containing ochers and warrants further study), was also highlighted. The characterization of binders and other organic residues revealed the coexistence of multiple materials, such as vegetable gums and fatty substances, which likely served both technical and aesthetic purposes.⁵⁹

The mummy displayed several conservation issues (Fig. 5), including fragile materials, structural fragmentation, and general chromatic alterations of the colored surfaces due to the accumulation of superficial soil.

Different types of tears were observed on the painted shroud: more irregular tears in areas where the preparation layer was applied thinly to fill the weaving irregularities, such as the upper part of the head, and more distinct tears in areas with a thicker preparation layer, where the stratigraphy was completely disrupted likely due to specific mechanical stress (such as impacts). Additionally, deformations affected both the textile and the decoration stratigraphy in many areas. The shroud also exhibited fabric gaps of varying severity, with the most significant damage occurring in the upper (head and shoulders), lower (feet, which were entirely missing), and lateral (sides) portions.

The bandaging system, composed of tighter linen bandages (laces), lost its containment function as the laces were displaced from their original location. Finally, all the fabrics appeared dehydrated, indicating an overall deterioration in the chemical and physical properties of the plant fibers. In addition, small tears, deformations, fraying, and gaps further compromised the structural stability of the textile surfaces.

⁵⁷ Characterization of the fibers using optical microscopy. The technical features of the weaving are as follows: Outer shroud: weft 8 t/cm, warp 20 t./cm; Inner shroud: weft 9 t/cm, warp 26 t/cm; Bandages (breast): weft 9 t/cm, warp 26 t/cm; Bandages (feet): weft 8 t/cm, warp 22 t/cm; Laces: weft 8 t/cm, warp 22/24 t/cm. Analysis with gas chromatography / mass spectrometry (GC/MS) of the black embalming material identified oxidized lipid compounds, including animal/human fat and a plant oil, as well as an oxidized Pinaceae resin.

⁵⁸ Liquid chromatography / mass spectrometry (LC/MS) was used to characterize the yellow organic dyes or lake pigments. No markers were detected likely due to colorants degradation and/or their presence in the sample in amounts below the technique's detection limits.

⁵⁹ GC/MS analysis highlighted the presence of animal fats and traces of beeswax in the orange lead based color; polysaccharides of unknown origin, attributed to vegetable gums, were detected in the dark red, earth-based color. For an overview of the scientific results obtained from the analytical campaign on the shroud's painted decoration, see Piccirillo *et al.* 2024.



Fig. 5: Female mummy with a rare painted shroud before the conservation treatment: front, back, left, and right sides, head and feet. © Museo Civico Archeologico, Bologna / Photo Daniele Demonte, CCR “La Venaria Reale”.

8. Conservation treatments

The technical characteristics and state of preservation of the mummy underscored the necessity of considering various intervention methodologies, as well as addressing the key ethical and deontological issues related to the conservation of wrapped human remains—currently a debated topic in the conservation field. These considerations were essential in developing a tailored conservation approach for this specific case study.⁶⁰ The need to preserve the find, both to ensure the stability of the textiles and to protect the painted surfaces in accordance with their original purpose and specific requirements, led to the search for optimized and appropriate strategies. While the general methodology for stabilizing archaeological textiles typically involves incorporating incomplete or fragmented areas within semi-transparent textiles, the unique technical features of the painted shroud required a more nuanced approach, aiming to recover both the structural stability of the fabric and the legibility of the painted decoration.⁶¹

8.1 Cleaning

A preliminary removal of surface deposits was carried out using a vacuum micro-cleaner,⁶² with depression values adjusted according to a series of risk thresholds

⁶⁰ Buscaglia *et al.* 2023.

⁶¹ For more details, see the paragraph below (§ 8.2).

⁶² New Askir surgical aspirator with medium-low depression values ranging between 5 KPa and 10 KPa.

defined for each colored area using an experimental methodology on powdered painting materials.⁶³ To prevent any detachment of fragments from both the textile support and the paint layer, the tip of the micro-cleaner was protected with a narrow mesh net. The possibility of integrating the micro-aspiration method with alternative cleaning techniques was also considered. After excluding dry cleaning due to partial decohesion of the paint, which prevented any direct mechanical action on the surface, a combination with water-based solutions was explored. A specific cleaning process was developed, taking into account the presence of water-sensitive paint materials. The process was designed based on previous experimental studies that demonstrated the effectiveness of innovative high-retention hydrogels⁶⁴ in limiting the release of water-based solutions onto Egyptian painted surfaces.⁶⁵ Preliminary tests were conducted to determine the optimal timing for application, using portable optical microscopy to assess the treatment and Fourier-transform infrared (FTIR) spectroscopy to chemically characterize the material removed from the gel.

The cleaning treatment was also applied to the back of the mummy, where soil deposits were thinned both on the canvas support and decorated surfaces. The handling of the mummy followed a protocol developed in collaboration with FERNO s.r.l., a multinational company specializing in medical first aid equipment. The system used combines an aluminum alloy stretcher and a high-density polyethylene vacuum mattress, which immobilizes all parts of the mummy and limits direct manipulation. This approach minimizes the risks of improper lifting and prevents any rubbing with rigid materials that could damage any exposed element. The vacuum mattress, which rests on the front of the mummy and molds delicately to its shape during decompression, ensures the immobilization of the entire body during its repositioning. Once the stretcher is removed, it allows access for documentation and treatment of the mummy's back.

8.2 Structural intervention

Fragmented and extremely rigid portions of linen laces were integrated into supports made of silk organza, dyed to match the color of the raw linen. Silk organza was also used to contain the portions of the inner bandages at risk, following the recovery of any deformations, and was applied beneath the non-self-supporting areas of the painted shroud. The textile consolidation system aims to contain and stabilize the deterioration of bandages by connecting gaps and fragile areas with a light, transparent protective fabric made of pure silk, specifically dyed to harmonize with the linen. The veil is inserted beneath the painted shroud using spatulas, in a completely reversible and retractable manner. The silk veil serves to support the repositioned bandage areas and provide localized stabilization for the degraded perimeter of the painted shroud, which is secured with small stitching points and silk threads (see shoulder detail in Fig. 6).

⁶³ Cremonesi *et al.* forthcoming.

⁶⁴ Twin-chain polymer hydrogels based on poly(vinyl alcohol), developed within the H2020 European project NANORESTART (grant agreement 646063), were selected. Gels are named Nanorestore Gels® Peggy 5 and Nanorestore Gels® Peggy 6 (CSGI, Florence, Italy). Being more retentive and rigid than the second, the first gel was selected for the intervention.

⁶⁵ Manfreda 2021.

To address the needs outlined above, we adapted the single-thread bonding technique,⁶⁶ originally developed in Germany for paintings on canvas, to archaeological materials: this method was applied by CCR conservators in recent case studies.⁶⁷ The primary goal of the treatment was to restore the structural and aesthetic continuity of the shroud, achieving satisfactory stability and mechanical resistance. To determine the most effective and safe protocol, preliminary tests were conducted on mock-up samples, comparing the behavior of various materials in terms of physicochemical properties (e.g., toughness and elasticity) and load resistance before and after aging.

As cellulose-derived materials are considered the most compatible with textiles and gum-containing binders, and given the desire to use chemically stable products, a series of nanostructured cellulosic materials were tested as adhesives for tear mending with their performances evaluated. These materials included nano fibrillar cellulose (CNF), nanocrystalline cellulose (CNC), and oleic acid-grafted nanocrystalline cellulose (GC), developed by the Center for Colloid and Surface Science (CSGI) in Florence. These materials have previously been successfully tested in the conservation of cultural heritage, particularly for the structural reinforcement of paper, linen, and cotton fabrics. Moreover, these materials have been recently evaluated as suitable for repairing structural damage in paper supports, as the adhesive joint is strong enough to hold the tear edges together without causing excessive stress on the original material. Nanostructured materials have proven effective even at low concentrations, as the smaller particle size in these dispersions increases the specific area and contact surface with the surrounding original materials. Numerous scientific studies have highlighted a significant improvement in the physical and mechanical properties of degraded textile supports following impregnation with crystalline and fibrillar nanocellulose.⁶⁸ This material does not stiffen the fabric, but imparts a durable, tenacious behavior to the fibers. At high loads, the consolidated yarn shows considerable elongation before breaking, indicating that the flexibility of the treated fibers remains largely unchanged. Further studies have confirmed that the strengthening effect is maintained at relative humidity levels of both 80% and below 40%—an essential characteristic for the conservation of a painted artifact in an unconditioned environment.⁶⁹

The experimental process for this case study identified the best performing material as nanocrystalline cellulose, dispersed in water at a concentration of 5,5%, which was used as an adhesive for single-thread bonding in this specific case.⁷⁰

⁶⁶ This technique involves applying glue to attach individual broken threads to the fabric after reweaving the tear. Heiber 2005; Orata 2010; Demuth, 2020; Flock *et al.* 2020.

⁶⁷ Buscaglia *et al.* 2023.

⁶⁸ Kolman *et al.* 2018; Nechyporchuk *et al.* 2018; Palladino 2019; Böhme *et al.* 2020; Oriola-Folch *et al.* 2020.

⁶⁹ Bridarolli 2020; Bridarolli *et al.* 2020; Gastaldelli *et al.* 2021.

⁷⁰ The whole study will be presented in a forthcoming scientific publication.



Fig. 6: Detail of the insertion of the silk veil on the mummy's right shoulder. © Museo Civico Archeologico, Bologna / Photo Roberta Genta, CCR "La Venaria Reale".

9. Conclusions

Painted shrouds held significant importance in the funerary practices of Roman Egypt.⁷¹ They varied in style, iconography, and artistic techniques depending on geographic context or even the workshop. The stylistic features of the rare Bologna-type shroud—supported by radiocarbon dating (¹⁴C) and mineralogical data from soil residues—show close similarities with other female shrouds from the Theban area dating to the 1st-2nd century AD, such as those from members of Soter's family. However, specific characteristics that distinguish the Bologna shroud from these, while aligning it with other shroud fragments, suggest the presence of a second type of female shroud within the *Soternalia*. This second type may not necessarily belong to the Soter family or the same archaeological context. The stylistic differences of the Bologna-type shroud, along with its embalming techniques, may indicate the existence of multiple manufacturing centers or distinct groups of artisans in the Theban area or its surroundings. However, the socio-economic context likely also played a significant role.

The characterization of the binders and the use of organic materials as an alternative to traditional pigments may reflect a deliberate choice by the artisans for specific aesthetic purposes, as seen in other painted textiles. The identification of an organic black or brown material onto the fabric provides insights into the use of oil, resin, and possibly wax mixtures. Overall, the in-depth study of the paint decoration, integrated with stylistic analysis, supported the shroud's attribution, while mineralogical data from surface deposits and soil residues clarified the mummy's previously unknown origin.

The experimental work on nanocelluloses, alongside the results obtained herein through a combination of various conservation approaches, encourages the identification of specific materials and methods tailored to the unique characteristics of the treated

⁷¹ Riggs 2005, 2 and *passim*.

finds. Furthermore, the experiments with nanocelluloses highlight their potential as an ideal material for tear mending in archaeological painted textiles.

The multi-analytical study of this female mummy with its rare painted shroud shed new light on Roman-era funerary practices and artistic techniques. This research could be further expanded through comparative analysis with other embalmed bodies and shrouds from the same period, particularly those of the Bologna-type.

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Imag(in)ing Egyptology. The *Bologna Coffin Project*

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Abstract

The Museo Civico Archeologico of Bologna, in collaboration with universities, institutions, and independent scholars, has recently launched an interdisciplinary research programme on a group of six Egyptian coffins dating to the 1st millennium BC, mainly to the 25-26th dynasty (c. 746-525 BC), aimed at their study, conservation, and public valorisation. This contribution focuses in particular on the project carried out (October-December 2022) in partnership with the Politecnico di Milano, ABC Department, and financed by the Fondo Cultura of the Italian Ministero della Cultura consisting of a laser scanning and photogrammetric survey of these coffins.

The geometrical features were surveyed by means of a laser scanner with a significant degree of accuracy, thanks to the fact that the adopted instrument (Artec Eva HD) allows the acquisition of a large quantity of data in a very short time. On the other hand, the photogrammetric survey carried out with a Canon reflex camera allowed the best chromatic result, achieved thanks to the employment of a professional colour checker.

The potential of the application of these technologies lies in the fact that different objectives can be achieved: for convenience they can be organised in four categories, bearing in mind that they are often quite permeable and dynamic. First of all, the digital objects produced are crucial for study purposes entailing a vast range of operations that can be carried out *on* the digital object without involving the original. It could serve, for instance, for morphological, philological and iconographical studies. Moreover, the 3D model may play a role in a museum installation, displayed beside the material culture to enhance specific aspects and features – e.g. information on the decoration process. Additionally, another important contribution that the digitisation of these coffins could provide concerns their conservation: relying on accurate 3D survey, restorers could realise custom supports and mounts for these fragile and complex objects. Finally, replicas can be printed at full or very small scale for dissemination, educational, and commercial reasons.

In this paper, the activity carried out on the coffins of the Bologna collection will be presented starting from their theoretical framework, in order to underly the great potential that the digital realm can offer in conjunction with the material realm.

Keywords: *Coffin; Photogrammetry; Laser-scanning; 3D modelling; Digitization.*

1. Introduction

The Museo Civico Archeologico of Bologna (MCABo), in cooperation with prestigious Italian universities, institutions, and independent scholars, has undertaken a research programme on a homogeneous group of six Egyptian coffins and two lid fragments dating to the first millennium BC – in particular to the 25th-26th dynasty –, coming mainly from the Theban area. The project “Imag(in)ing Egyptology”, in partnership with the Politecnico di Milano, ABC Department, consisted of a detailed three-dimensional laser and photogrammetric survey of these artefacts¹ and represents an outcome of the Bologna

¹ The authors would like to thank the museum staff, in particular Augusto Arrigo, Luca Andreini, and Elena Canè with the support of Alessandro Galli; Eugenio De Marsico and Emiliano Antonelli (CROMA conservazione e restauro opere e monumenti d'arte srl); Simone Galli and Michela Morandi (Politecnico di Milano, ABC Department).

Coffin Project. The objectives of this still ongoing research program, methodologically akin to *The Vatican Coffin Project*² and *The Egyptian Coffin Project* of the Fitzwilliam Museum in Cambridge,³ are to characterize the painting layers and relate the colour palettes of the coffins to their decorative program and stylistic development; to provide new data for a chronological sequence and the identification of a possible workshop; to identify and distinguish the original materials and pictorial layers from the ones applied subsequently on the occasions of conservation treatments or pictorial retouching, challenging to see and not always explicitly documented;⁴ to evaluate their assembling technique and conservation status, a useful preliminary stage to any conservative work; to collect detailed information on the wooden structure, texts, and iconography and to make it easily accessible to scholars and the general public. Achieving these objectives will facilitate their classification, help trace their archaeological provenance, complete their museum history by integrating archival research, and create contemporary storytelling.

Within the framework of this project, the museum has already completed the archival research, multidisciplinary study, and conservation treatment of two coffins, those of Mes-iset and Un-Montu, while waiting to proceed with the others. The coffins of Mes-iset, Ta-shaâ-kheper, Usai, and Un-Montu were investigated by the Politecnico di Milano team between October and December 2022: the geometrical features were surveyed both by scanner to acquire the geometry in detail and by photogrammetry to achieve the best chromatic result. The current paper starts with a description of the technical work and presents the state of the art and the latest results of this project, coffin by coffin.

2. The 3D survey

The acquisition of raw data at the Museo Civico Archeologico in Bologna took five days for the five coffins and involved two techniques employed for different purposes. Within the framework of this research, digitising cultural heritage (imaging) does not solely involve the creation of 3D models; it encompasses all procedures that ultimately produce a digital object, including photographs. Just as in the production of a material object, where matter is manipulated to obtain a product following a project, the purpose of creating a digital object must also be evident in advance. For example, in photography, if the goal is to show a detail of a relief, a wide-angle lens would not be used; instead, the focus would be on a more specific and defined portion of 'reality'. Similarly, every 3D model should have specific characteristics depending on its intended use. This purpose-based approach is reflected in the workflow and the equipment adopted and used in each instance. In this project, a structured-light 3D scanner was employed to capture shape and geometry, while photogrammetry was used to obtain more accurate information regarding colours and textures. This dual approach ensures that the structural and aesthetic details of the coffins are meticulously documented and preserved.

² Amenta 2017; Prestipino 2017; Prestipino *et al.* 2025.

³ Egyptian Coffins, available online: <https://egyptiancoffins.org/about>; Strudwick, Dawson 2016; Strudwick *et al.* 2025.

⁴ During the 20th century, the coffins in Bologna underwent conservation maintenance in the 1960s by Ancilla Cacace and in the 1970s by Ottorino Nonfarmale. Documentation on the first intervention is almost non-existent.

For the first stage of the survey, an Artec Eva HD structured-light 3D scanner was employed.⁵ This scanner allows for extremely fast data acquisition compared to photogrammetry and ensures a high degree of accuracy regarding the geometry of the object. The scanner captures up to 16 frames per second, processing 18 million points each second with an accuracy up to 0,1 mm. This rapid acquisition capability is particularly beneficial when dealing with delicate artefacts, as it minimises the time spent handling and potentially disturbing the objects.

The process adopted for these coffins is the standard procedure, fine-tuned by the team's previous experience: the raw data were subsequently processed in specialised software where individual scans were coherently assembled to form the correct shape of the artefact, providing information on the accuracy of the produced 3D model. This initial result still contained a few issues, particularly excess data; the first step, therefore, was to remove the portion of the supports used to hold the coffins. The resulting model allowed for a highly accurate analysis of the surface of the artefacts, especially if visualized in one colour only, as it enabled observations that are not possible when the pictorial layer is shown. A photogrammetric survey was conducted in parallel by means of a Canon EOS 5DSR Mark III camera with a fixed 35mm focal lens. Approximately 350 photos were taken for each of the two components of each coffin, lid and case; they were imported into the photogrammetric software Agisoft Metashape, where they underwent an alignment process to construct the 3D models. To ensure appropriate geometrical precision, a calibrated bar was used to act as a metric reference and ensure the proper orientation and positioning of the digital object in the space. The integration of photogrammetry with data from the scanner thus provided a comprehensive digital representation of the coffins, combining precise geometrical information with rich chromatic details.

The potential of the application of these technologies lies in the fact that different objectives can be achieved: for convenience, they can be organised into at least four categories. First, the digital objects may be used instead of the originals to perform morphological, philological, and iconographical studies. Then, the 3D model may play a role in a museum installation, displayed beside the material culture to enhance specific aspects and features (e.g. information on the decoration process). Additionally, conservators could construct (or even print in 3D) custom supports and mounts for these fragile and complex objects, as well as produce virtual models for structural integrations or replicas.⁶ Finally, replicas can be printed at full or very small scale for dissemination,⁷ educational,⁸ and commercial reasons.⁹

The following pages summarise the current knowledge on these coffins, including the information derived from the 3D survey and its application.

⁵ Keşik *et al.* 2023; Muminović *et al.* 2024.

⁶ See, for instance, Bonora *et al.* 2021.

⁷ See, for instance, the replica of the coffin of Butehamon at the Museo Egizio in Turin.

⁸ See, for instance, Wilson *et al.* 2018; Kantaros *et al.* 2023.

⁹ The Museo Civico Archeologico in Bologna has small-scale replicas of other Egyptian antiquities for sale in its bookshop and intends to increase their number.

3. The coffin of Mes-iset (MCABo EG 1963)

The first multidisciplinary conservation project of a Bologna coffin, which has undergone integrations and pictorial retouches at least three times since the 18th century, was part of the Intesa Sanpaolo Restituzioni project¹⁰ and was presented at the First Vatican Coffin Conference in 2013.¹¹

Cardinal Alessandro Albani (1692-1779) donated this anthropoid coffin and its mummy with *cartonnage* to the Istituto delle Scienze in Bologna.¹² This coffin, belonging to Mes-iset (MCABo EG 1963, formerly University Collection), likely arrived in Bologna before 1751.¹³ The guide of the Istituto delle Scienze of Bologna *Dell'origine e de' progressi dell'Istituto delle Scienze di Bologna e di tutte le accademie ad esso unite, con la descrizione delle piu notabili cose, che ad uso del mondo letterario nello stesso istituto si conservano*, published by Giuseppe Gaetano Bolletti (1709-1769) in that year, might mention it: "Firstly [in the fifth room of Natural History section, of the Istituto delle Scienze] there are various ancient Egyptians embalmed corpses ... The one enclosed in a noble custody, well visible and very loosely clothed, is believed to be the body of a very distinguished person among these nations. Another one is placed on a kind of funerary bed, supported by some Egyptian animals. The others [mummies] are enclosed in wooden boxes, one of which expresses well the shape of an Egyptian dead body".¹⁴

The 3D survey (Fig. 1) allowed us to provide extremely precise dimensions: the outer anthropoid coffin of Mes-iset is 198 cm long, 63 cm wide at the shoulders, and 39 cm tall at the feet. Its original shape, decorations, and hieroglyphic inscriptions can be traced back to the late 22nd/early 25th dynasty – also confirmed by radiocarbon dating – and linked to Lower Egypt. As for the lid, two lappets of a massive tripartite wig frame the pink-coloured face, characterized by big eyes, a small mouth with red lips, protruding ears, and a long blue beard on the chin; a large polychrome *wesekh*-collar decorates the shoulders; the Goddess Nut, holding the *ankh*-sign in each hand and stretching her wings, sits on her right heel on the abdomen of the coffin; five columns of polychrome and retouched hieroglyphics embellish the central decorative panel on the legs, while three pseudo hieroglyphics stand out on the white side decorative panels. On the underside of the floorboard of the box, two columns of hieroglyphics in bright colours decorate the dorsal pillar, which connects the wig with the pedestal. The interior of the coffin – box and lid – is without decoration.

¹⁰ This two or three-year program for the conservation of Italian artworks was launched in Vicenza in 1989 and is now about to celebrate over three decades during which over 1300 works of art have undergone conservation treatment for the benefit of the Italian cultural heritage; Picchi 2013.

¹¹ Picchi 2017.

¹² Winckelmann 2003, 151, note 1. This coffin with its mummy was considered a gift to the Istituto delle Scienze by pope Benedict XIV (1675-1758) in Picchi 2013, Picchi 2016, and Picchi 2017, but new archival documents seem to refer to Luigi Ferdinando Marsili (1658-1730) as the recipient of the gift to the Institute; see Giovetti *et al.* 2025, 330-331.

¹³ Kminek-Szedlo 1895, 227-228, no. 1963. See also Picchi 2016, 458-259, 563-264.

¹⁴ Translation of: "Sonovi in primo luogo varj antichissimi cadaveri di Egizj imbalsamati ... Uno ve n'è in nobile custodia racchiuso, ed a tutti visibile, e molto vagamente vestito, e cadavero credesi di personaggio molto fra quelle genti distinto. Altro di questi quasi posto sul feretro, è sostenuto da certi egizj animali. Gli altri sono chiusi in iscatole di legno, una delle quali esprime essa pure la forma dell'egizio cadavere", in Bolletti 1751, 86-87. Bolletti does not seem to refer to the anthropoid coffin of a child also kept at the Istituto delle Scienze.



Fig.1: 3D model of the coffin of Mes-iset: orthoimages from five sides and perspective view.

From the 18th century onwards, this coffin underwent heavy conservation works that modified the lid from a structural and pictorial point of view. These alterations are visible from the X-ray surveys, the rather unusual shades of the colour palette, and the numerous over-paintings, which sometimes give a glimpse of the original iconographic layout.¹⁵ Dane Georg Zoëga (1755-1809) was the first to document these interventions, during his visit to the Istituto delle Scienze in 1789. He copied the five columns of hieroglyphics and some iconographic details from the lid in his travel notes. Thanks to him, we know that a winged female figure, no longer extant, was painted on the feet decorative panel.¹⁶

¹⁵ Picchi 2013; Bracci *et al.* 2015.

¹⁶ Picchi 2011, 61-63, 65.

4. The coffin of Ta-shaâ-kheper (MCABo EG 1961)

The time of arrival in Bologna of the inner anthropoid coffin of Ta-shaâ-kheper (MCABo EG 1961, formerly University Collection) is presumably November or December 1841.¹⁷ Felice Cocchi from Bologna, a physician then stationed in Egypt at the court of Ibrahim Pascià (1789-1848), donated a mummy in a poor state of preservation and its coffin to the Museo delle Antichità della Regia Università di Bologna through his brother-in-law Giuseppe Ferlini (1797-1870). The donation was publicly announced by the *Gazzetta privilegiata di Bologna*: “Sir. Dottore Felice Cocchi, Bolognese, who with honour practices in Upper Egypt the healing art learned in this University, has kindly donated to our Museo di Antichità a Mummy closed in its case, painted on all sides. ... The case is of wood, in the figure of a body, but bandaged and ornamented according to Egyptian custom”.¹⁸ The mummy and coffin arrived in Leghorn before November 16, 1841, and, together with another mummy and its coffin, were examined by Ippolito Rosellini (1800-1843) as an exchange of letters between the latter and Ferlini confirms.¹⁹ The scholar defined both mummies [and coffins] as being of little interest to science but in a pretty good state of preservation. Unfortunately, the mummy sent to Bologna was opened from head to abdomen at customs for fear that it contained contraband goods; after that, Ferlini removed the rest of the bandage and the underlying palm-fibre mat, discovering the skeletonized remains of the deceased and tissue envelopes, presumably containing organs, placed in the lower abdomen. According to the museum director Girolamo Bianconi (1772-1847), the acquisition of this mummy with its coffin was functional to educate the public and enrich the museum with a female figure.²⁰ The skeleton and parts of a mummified body handed over in 1869 to Luigi Calori (1807-1896), director of the Museo di Anatomia, likely correspond to the mummy donated by Felice Cocchi.²¹ Considering that Ta-shaâ-kheper’s coffin is not included in the inventory compiled by Filippo Schiassi in 1835, while it is present in *Ministero della Pubblica Istruzione. Regia Università di Bologna. Inventario delle proprietà mobili dello Stato esistenti al 31 Dicembre 1870*

¹⁷ Kminek-Szedlo 1895, 226-227, no. 1961.

¹⁸ Translation of: “Il sir. Dottore Felice Cocchi, Bolognese, che con onore esercita nell’alto Egitto l’arte salutare imparata in questa nostra Università, ha donato graziosamente il nostro Museo di Antichità di una Mummia chiusa nella sua cassa, dipinta da ogni parte. ... La cassa è di legno, in figura del corpo, ma fasciato e ornato secondo il costume egiziano”, in *Gazzetta privilegiata di Bologna*, no. 6 (January 14, 1842), “Bologna, 14. Gennaro”. See also Brizzolara 1984, 163.

¹⁹ Biblioteca Universitaria di Pisa (hereafter BUPi), *Fondo I. Rosellini*, Ms.294.1.53.4–5; Museo Civico Archeologico of Bologna (MCABo), Historical Archive, *Fondo Università*, b. 60, fasc. H, transcription with integrations made by Ferlini of a letter from I. Rosellini to G. Ferlini, Pisa, 10 December 1841, in MCABo, Historical Archive, *Fondo Ferlini*, b. 1, vol. 6, “Corrispondenza dei Professori Ungarelli, Rosellini e Migliarini”, f. 81-82. Ferlini adds in the copy of Rosellini’s letter that the mummies are inside coffins. It was common at the time to denote by the word mummy both the body of the deceased and the anthropoid coffin.

²⁰ MCABo, Historical Archive, *Fondo Università*, b. 60, fasc. H, copy of letter from [G. Bianconi] to [cardinal C. Opizzoni, archchancellor of the University], December 1841, requesting authorization to accept the donation by bearing the transport costs from Livorno. See also Brizzolara, 1984, 162-163. Bianconi was director of the museum from 1836 to 1847.

²¹ MCABo, Historical Archive, *Fondo Università*, b. 58, “Corrispondenza 1869-1872”, authorization for the transfer of these human remains from the Rector of the University to the then museum director F. Rocchi, 24 November 1869, and declaration of receipt from L. Calori, 1 December 1869. See also BUPi, *Fondo I. Rosellini*, Ms.294.1.53.5. This research deserves further investigation.

nell'Archeologia,²² its acquisition must occur within those 35 years. So far, no document has been found attesting any other acquisition of an anthropoid coffin.

Ta-shaâ-kheper belonged to a well-known Theban family, which retained identical religious and administrative titles from the Libyan to the Saitic period.²³ She was the daughter of the Princess Sopdet-em-hââwt and of the Prophet of Amun-Re, king of the gods, scribe *t3* and *imy-st-ꜥ* of the estate/domain of Montu, lord of Thebes, Pa-di-Amon-neb-neswt-tawy.²⁴ The accurate facial features and the richness of the iconographic and textual layout of the coffin, inner and outer sides, document the privileged social status of this lady, who bore the title of Mistress of the house.



Fig. 2: 3D model of the coffin of Ta-shaâ-kheper: orthoimages from five sides and perspective view.

²² Both inventories are kept in the historical archive of the Museo Civico Archeologico in Bologna. Filippo Schiassi was director of the museum from 1810 to 1835.

²³ Pernigotti 1990; Meffre 2015; Meffre 2016. See also Taylor 1984.

²⁴ Pernigotti 1990, 18-21; Meffre 2015, 11-15.

According to the 3D survey (Fig. 2), the coffin is 178 cm long, 53 cm wide at the shoulders, and 44 cm tall at the feet. It corresponds from a stylistic point of view to a variant of Theban design 3 of Taylor's classification, which Meffre identifies with design 3C.²⁵ This kind of inner coffin with a dorsal pillar and plinth represents a key feature of the 25th-26th dynasty. Still, the vulture headdress painted over long, flowing locks with the addition of a fringe of curls at brow-line, and the presence of piercings in the earlobes allow us to more precisely attribute the coffin to the 26th dynasty.²⁶ The same dating is confirmed by Meffre's genealogical study of her family.²⁷

Further down the winged figure of the Goddess Nut sitting on a door, the lid has a central panel with seven columns of text running to the ankles. On the side decorative panels, the son of Horus and forms of Anubis are symmetrically arranged among bands of texts in a sequence suggesting the *Stundenwachen*. An image of the mummy on a bier with a Ba bird flying away is depicted at the top of the central panel. A *djed*-pillar wearing the double feathers crown and holding the *heka*-scepter and the *nekhekh*-flail with the hands side by side decorates the underside of the floorboard. It is flanked by horizontal inscriptions in black on yellow and white backgrounds. A snake biting its tail represents the top frieze of the outer side of the box. A frieze of *ankh-neb-was* symbols is represented on the front of the plinth. The Goddesses Isis and Nephtys are painted on the feet decorative panel and on the end head, respectively, while Isis and Nut are painted in black on white background in the interior of the lid and the floorboard, respectively.

As far as we know, the coffin underwent two conservation treatments during the 20th century. While almost nothing is known about the former, which was carried out in the 1960s by Ancilla Cacace – only a generic list of materials used by the conservator and a few photos preserved in the Historical Photographic Archive 'FOTOWALL' of Walter Breveglieri are available –,²⁸ we know that about a decade later the conservator Ottorino Nonfarmale applied a series of investigation techniques to this coffin (XRF, UV, and IR) before his conservative intervention.²⁹

5. Coffin assemblage of Usai (MCABo EG 1957, EG 1962, EG 1964)

Other coffins arrived in Bologna in 1861 via the testamentary bequest of the Bolognese painter Pelagio Palagi (1775-1860).³⁰ In 1831, he bought four coffins dating to the 25th-26th dynasty by Giuseppe Nizzoli (1792-1858), former chancellor at the Austrian consulate in Egypt.³¹ These coffins are listed in the catalogue of Nizzoli's collection, published in Alexandria, Egypt, in 1827,³² making them available for sale.³³

²⁵ Taylor 2003, 114-115; Meffre 2015, 50-53.

²⁶ Taylor 2013, 547-548, specifies second half of the 26th dynasty. The coffin was dated to the 22nd-23rd dynasty by Cesaretti 1990, 208-211, no. 158.

²⁷ Meffre 2016, 55-56.

²⁸ I thank the Minerva publishing house for informing me of the existence of these photos.

²⁹ This documentation and an unpublished summary conservation report are kept in the museum's archives.

³⁰ As for Pelagio Palagi, see Catalogo mostra 1976; Tovoli 1984; Poppi 1996.

³¹ As for Palagi's acquisition of the Nizzoli collection, see Picchi 2011; Picchi 2021, in particular 27-28, including bibliography. As for Giuseppe Nizzoli and his interest for the Egyptian antiquities, see Daris 2005; Rindi Nuzzolo 2014; Rindi Nuzzolo 2016; Rindi Nuzzolo, Guidotti 2014, Rindi Nuzzolo, Guidotti 2015.

³² Nizzoli 1827.

³³ As for the sale of this Nizzoli's collection to Palagi, see Picchi 2021, with earlier bibliography.

The author first highlights in Chapter XVI the excellent state of conservation and the extraordinary iconography of the *qrsu* coffin belonging to Usai or Wesy, son of Nekhet and Herib-Bastet.³⁴ After two pages of a detailed description of the outer coffin, Nizzoli moves on to the anthropoid coffins and Usai's mummy inside, on which he dwells more briefly.³⁵ These coffins are said to come from Thebes, where similar assemblages are well-attested. In 1878, Giovanni Kminek-Szedlo (1828-1896) published only the *qrsu* coffin, focusing on its complex iconographic and textual apparatus,³⁶ which gathered all the mythological elements needed for the rebirth of Usai. More recently, John Taylor has considered the Usai coffin assemblage in an inspiring article, highlighting the presence of social patterns in Theban coffins of the 25th dynasty and arranging them in approximate chronological order by generation.³⁷ The 'higher elite' coffin assemblage of Usai is believed to date to the half/late 25th dynasty.³⁸ Radiocarbon dating of a fabric sample, taken from the deep layers of the mummy and a wooden sample of the intermediary coffin provided preliminary chronological data, which need further investigation.³⁹



Fig. 3: 3D model of the *qrsu* coffin of Usai: orthoimages from four sides and perspective view.

According to the 3D survey, the outer coffin (MCABo EG 1957)⁴⁰ is 240 cm long, 93 cm wide, and 97 cm tall (Fig. 3). It consists of a rectangular four-sided box with corner pillars, above which are placed three *akhem*-falcons – one is missing –, and a vaulted lid.

³⁴ Nizzoli 1827, 29-31, no. XVI.1.

³⁵ Nizzoli 1827, 31, no. XVI.1. A bead net in faience was on the mummy.

³⁶ Kminek-Szedlo 1878.

³⁷ Taylor 2018.

³⁸ Taylor 2018, 361.

³⁹ Picchi *et al.* 2022; Picchi, Oliva 2026, 127-142.

⁴⁰ Kminek-Szedlo 1895, 219-223, no. 1957. See also Cesaretti 1994, 211-212, no. 159; Picchi 2016, 468-469 and 565, no. VII.48, with earlier bibliography.

The lid features two facing jackals and, in the centre, an *akhem*-falcon on an axial text line, which divides the vault surface into two decorative panels. On each panel, a bottom *kheker*-frieze and two lines of text frame images and spells (*Book of the Day*) concerning the sun god's journey in the sky on a boat towered by deities and drawn by boatmen. The exterior wall of the box concerns the nocturnal vigil over the body of Osiris. A line of text runs along its top border, while a palace facade frieze runs along the bottom one. Canopic divinities inside shrines and columns of texts (*Book of the Night*) are in sequence on the longer outer sides, watching over the deceased. The goddesses Isis and Nephtys, flanked by columns of text, are depicted on the shorter outer sides, respectively. The interior of the coffin does not show any decoration.



Fig. 4: 3D model of the intermediate coffin of Usai: orthoimages from five sides and perspective view.

The intermediary anthropoid coffin of Usai (MCABo EG 1962), according to the 3D survey (Fig. 4), is 206 cm long, 69 cm wide at the shoulders, and 73 cm tall at the feet.⁴¹ A tripartite wig with parallel stripes frames a face that is dark brown in colour – the beard on the chin is missing – in contrast to a polychrome *wesekh*-collar made of several rows of beads that surrounds the upper body. The remaining exterior surface of the coffin is monochrome except for an axial column of text running to the feet on the lid, and a line of text running around the box in the middle of the exterior wall. The floorboard is decorated with the figure of Imentit, the Goddess of the West. The lid corresponds to design 1, while the box to design 1 of Taylor’s classification of the intermediary Theban coffins dated to the 25th-26th dynasty.



Fig. 5: 3D model of the internal coffin of Usai: orthoimages from five sides and perspective view.

⁴¹ Kminek-Szedlo 1895, 227, no. 1962. See also Cesaretti 1994, 212-214, no. 160; Picchi 2016, 468-469, 565, no. VII.48, with earlier bibliography.

The inner coffin of Usai (MCABo EG 1964), according to the 3D survey (Fig. 5), is 187 cm long, 52 cm wide at the shoulders, and 40 cm tall at the feet.⁴² The male figure wears a wig with parallel stripes: blue and yellow on the front and blue, yellow, and red on the back. The face, brown in colour and endowed with a long beard, is enlightened by a polychrome *wesekh*-collar covering the shoulders. Further down, in a sequence of registers, it is possible to see: the Goddess Nut stretching her wings and sitting on a door, the judgment and presentation of Usai to Osiris, the mummy on a bier, the solar barque with adoring cynocephali, Sokar as a wrapped falcon between Isis and Nephtys, and an axial image of the Abydos fetish with lateral decorative panels containing the son of Horus and two *wedjat*-eyes. A large *djed*-pillar flanked by horizontal inscriptions is on the underside of the floorboard. The foot board with the Apis bull carrying the mummy to the tomb pairs with a scarab beetle on the head end and the solar disk on the head wall. The lid corresponds to design 4B, while the box to design 1 of Taylor's classification of the inner Theban coffins dated to the 25th-26th dynasty.⁴³ The interior of the coffin is without decoration.

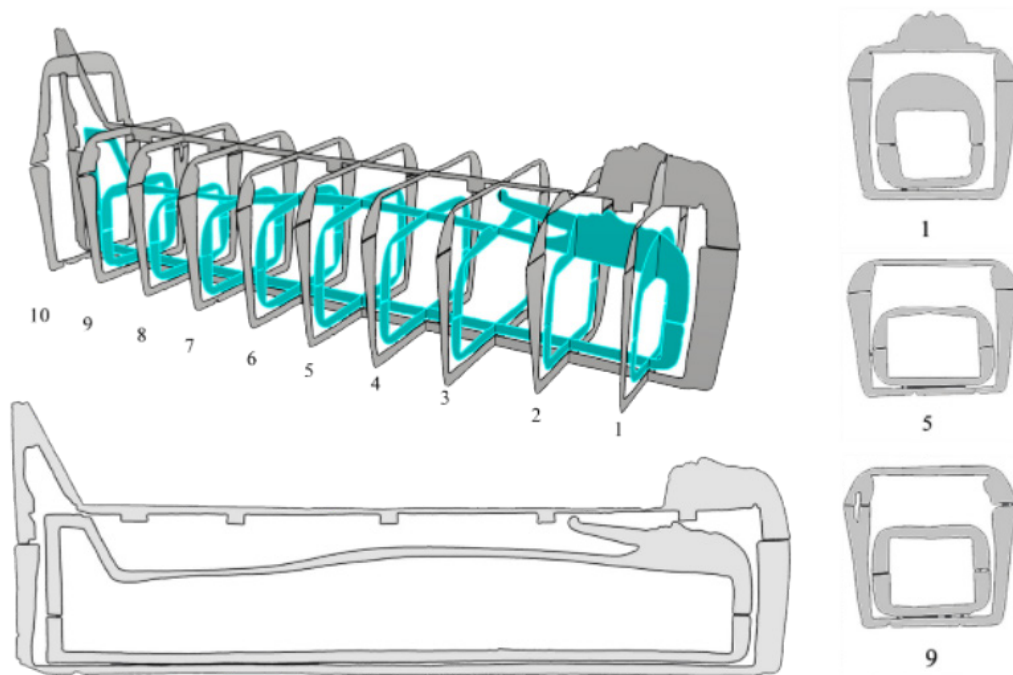


Fig. 6: Sections of the 3D model of the intermediate and inner coffins of Usai.

During the 20th century, this coffin was not recognized as part of the assemblage of Usai and was displayed separately from the *qrs*w and intermediary coffin.⁴⁴ One of the aims of this project was to virtually include each coffin inside the others and recompose

⁴² Kminek-Szedlo 1895, 228-229, no. 1964.

⁴³ Taylor 2003, 115. See also Taylor 2018, 362-365, who attributes this kind of decoration to 'lower elite' burials.

⁴⁴ Cesaretti 1990, 215-216, no. 163, where the coffin is not attributed to the same assemblage, as well as in Picchi 2016, 469, 565, no. VII.48, with earlier bibliography.

the coffin assemblage as described by Nizzoli. Elaborations of the 3D models constructed from the 3D survey allowed us to verify that the third coffin fits perfectly well into the second, thus confirming that they could be part of the same assemblage (Fig. 6).

Modelling the survey in 3D also allowed us to identify weak areas: the central portion of the chest of the intermediate coffin consists of only a very thin layer of modern gypsum used to keep it assembled. These coffins underwent three conservation treatments during the 20th century, in the '60s, '70s, and '80s, but need a more detailed interdisciplinary diagnostic investigation, especially on the intermediate one, where these areas of weakness have been now clearly identified.

6. The coffin of Un-Montu (MCABo EG 1960)

Palagi acquired from Nizzoli a fourth anthropoid coffin in 1831. Nizzoli's description of a reddish coffin with a long beard in the *Catalogo Dettagliato della Raccolta di Antichità Egizie riunite da Giuseppe Nizzoli* allows its identification as that of Un-Montu, whose genealogy and titles are unknown.⁴⁵ The artefact is enthusiastically considered "beautiful" and "well-preserved" by the author, who appreciates its "beautiful paintings, inscriptions, hieroglyphics, representations, allegories, and emblems".⁴⁶ This coffin is then mentioned in the inventory of the Palagi house museum, which was drawn up in 1860 after the painter's death and before moving his collections from Milan to Bologna. The inventory reveals that the coffin was both painted and varnished, providing valuable information for reconstructing its conservation history.

The coffin of Un-Montu (MCABo EG 1960), according to the 3D survey (Fig. 7), is 184 cm long, 52 cm wide at the shoulders, and 43 cm tall at the feet. This male coffin is characterized by a tripartite wig with parallel stripes, a dark-brown coloured face, and a beard presumably not original. The lid features on the breast the Goddess Nut sitting on a *nbw*-sign and further down a horizontal register representing the weighing of the heart and the presentation of the deceased to a series of deities. On the lower part of the body, there is a central panel consisting of seven columns of inscriptions running to the foot and flanked by a symmetrical sequence of deities inside shrines and lines of text. The orientation of the texts on the left and right sides, as well as that of the deities, is the same as those on the central panel. On the top of the panel, there is a mummy on a bier. The exterior of the box features five columns of text on the pillar, on white and yellow backgrounds, flanked by horizontal lines on the same backgrounds. The foot board and the head end of the lid represent two different moments of the cycle of the sun. The interior does not show any decoration. Based on stylistic comparisons, the lid corresponds to design 3 and the box to design 2 of Taylor's classification of the inner Theban coffins dating to the 25th-26th dynasty.⁴⁷ A date to the very early 26th dynasty has been also considered because the wings of Nut on the upper part of the lid are divided into four sections, and there is a repeated frieze of *ankh-neb-was* symbols on the front of the pedestal.

⁴⁵ Nizzoli 1827, 31, XVI.3; Kminek-Szedlo 1895, 228-229, no. 1960.

⁴⁶ Nizzoli 1827, 31, XVI.3.

⁴⁷ Taylor 2003, 114-115; Taylor 2017, 547.



Fig. 7: 3D model of the coffin of Un-Montu: orthoimages from five sides and perspective view.

The coffin of Un-Montu underwent a conservation treatment in 2016–17 as part of the Intesa Sanpaolo Restituzioni project.⁴⁸ The integration of radiocarbon dating, wood species identification, and CT imaging enabled a deep understanding of the coffin's wooden structure.⁴⁹ The tomographic investigation was performed in museum in collaboration with the Department of Astronomy and Physics of the University of Bologna.

⁴⁸ Picchi 2018.

⁴⁹ Fauzia *et al.* 2022. See also Thomas 2022, 196 note 93, 201-202 note 112.

7. Next steps

The collaboration with the University of Bologna, whose imaging techniques complement those of the ABC Department of the Politecnico di Milano, will continue: the plan is to perform a CT scan of four more coffins to investigate the construction technique of the 25th-26th dynasty coffins of Theban provenance. Additionally, it may be interesting to study two lid fragments (MCABo EG 1966 and MCABo EG 1965) in light of the conclusions drawn for the entire coffins illustrated above.

The lid fragment MCABo EG 1966, corresponding to the upper right part of an anthropoid coffin feet decorative panel, was presumably donated to the museum between 1885 and 1895 by Federico Amici Bey (1828–1907).⁵⁰ Born in Rome to a Bolognese family, Amici lived from 1875 to 1885 in Egypt, where he was appointed Director of Statistics.⁵¹ He was responsible for the first national census of Egypt.⁵² After his return to Italy, he donated various Egyptian antiquities and the mummy of a child with three tunics to the museum, following the tradition of donations by citizens, to which we owe the formation of the Egyptian collection in Bologna. This small fragment (41 cm long, 31,5 cm wide, and 3,3 cm deep), presumably belonging to an outer coffin, retains part of the right wing of a goddess sitting on a door and, further down, the figures of three cynocephali worshipping the solar barque behind the Goddess Isis. At the moment, it is generically dated to the Late Period.

The provenance of the lid fragment MCABo EG 1965 is unknown. From the documents found so far, it is unclear when and from whom Pelagio Palagi acquired this wooden fragment, which corresponds to the central panel of the lid of the anthropoid coffin belonging to Pa-bik-nen / Pa-Hrw-nen, son of Tash.⁵³ This carefully polished wooden fragment with five columns of carved hieroglyphs (*Book of the Dead* spell 72) is 85 cm long, 24 cm wide, and 4,5 cm deep. It can be generically dated from the Late to Ptolemaic period in the absence of the rest of the coffin, particularly the head.⁵⁴

Hopefully, the integration of archival research and a detailed physical survey of these objects will provide helpful information to reconstruct their provenance and guide future operations of conservation, re-display, and re-contextualisation. The future of research on these complex objects lies in an integrated multidisciplinary approach.

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⁵⁰ Kminek-Szedlo 1895, 230, no. 1966.

⁵¹ [Amici Bey] and Fachinelli 1885; Bono 1983.

⁵² Amici drafted the *Décret, règlements et instructions relatifs au recensement général de la population de l'Égypte, 3 mai 1882*. He also published *Il commercio dell'Italia coll'Egitto: memoria dell'ingegnere Federico Amici direttore della statistica egiziana* [1880].

⁵³ Kminek-Szedlo 1895, 229-230, no. 1965, who dates the fragment to the 26th dynasty.

⁵⁴ Moser 2019.

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Fitzwilliam Museum's Ancient Egyptian Coffins Project

<https://egyptiancoffins.org/>

An online-only publishing experience: the *Rivista del Museo Egizio*

Federico Poole

Abstract

The *Rivista del Museo Egizio* (abbreviated *RiME*) is an academic journal published online by the Museo Egizio, Turin. Founded in 2017, it is now in its seventh year. Its main aim is to publish Egyptological research on the collection of the Museo Egizio in Turin, as well as on archaeological sites the museum is investigating today or investigated in the past. Its scope, however, has expanded over the years to also encompass studies not specifically concerning the Museo Egizio.

The paper will use the experience of *RiME* as a case study to address the following topics: open-access policies; “paper-boundedness” (the incorporation in digital publications of certain limitations and features of paper ones); and the advantages of the digital format, as well as its disadvantages – most notably risks inherent in online publication, such as link volatility and website demise.

Keywords: *Open access; Paper boundedness; Link rot; Multimedia; ANVUR.*

1. Introduction

The *Rivista del Museo Egizio* (henceforth “the *Rivista*”, or *RiME*)¹ is a yearly double-blind–peer-reviewed academic journal published online-only by the Museo Egizio, Turin. Founded in 2017, it is now – as of this writing in 2024 – in its eighth year. Its main aim is to publish research on the vast collection of the Museo Egizio, as well as on archaeological sites the museum is investigating today or has investigated in the past. Its scope, however, has expanded over the years to also encompass Egyptological studies not specifically concerning the Museo Egizio.

The *Rivista* holds a special place among Egyptological journals for its intimate connection with the museum that publishes it and the research going on in it. The editors are also among the museum’s curators.² As such, they can offer an especially high degree of cooperation with the authors, most of whose articles are about individual artifacts, or corpora of artifacts, held in the Museo Egizio. As may be expected, several of the museum’s curators have published in *RiME*, including some of the journal’s editors.

The present author has acted as editor-in-chief of the journal since its foundation. Here I use the experience of the *Rivista* as a case study to address the following topics: open-access policies; “paper-boundedness” (a self-coined expression by which I mean the incorporation in digital publications of certain features and limitations of printed publications); and the advantages of the digital format, as well as its disadvantages – most notably risks inherent in online publication, such as link volatility and website demise.

¹ <https://rivista.museoegizio.it/>

² In addition to the author, the *Rivista* is edited by Divina Centore, Johannes Auenmüller, Susanne Töpfer, Federica Facchetti, Paolo Del Vesco and Sara Cianetti; formerly also by Caterina Ciccopiedi and Valentina Santini. It has an international advisory board comprising 30 academics and/or museum professionals, all Egyptologists (list available at <https://rivista.museoegizio.it/chi-siamo/>). The journal is a publication of the Museo Egizio, but is laid out and put and maintained online by the Franco Cosimo Panini publishing house, represented by Paolo Bonacini and, recently, Alice Previte. The *Rivista del Museo Egizio* was founded at the behest of the director of the Museo Egizio, Christian Greco.

2. Open access

The *Rivista* is free and requires no registration. Its articles are published under a Creative Commons license (CC BY 4.0) allowing all the visual material published therein to be freely used, as long as appropriate credit is given, any changes made are indicated, and the terms of the license continue to apply. High-res versions of the images in each article can thus be freely downloaded and reused.

This open-access policy is part of a general policy of the Museo Egizio, notably as regards images of its objects, which can be freely downloaded from the museum website or requested from the museum's photographic archive. This policy also applies to images of the museum's archive documents and to its historic photographic archive.³

3. "Paper-boundedness"

The tradition of paper publication still weighs heavily on online academic publication.

The *Rivista* is published in two formats: a single column scrolling webpage and a downloadable PDF laid out in two columns. The webpage format offers several advantages, most notably faster navigation of text, endnotes and images, the viewing and downloading of images in their native high-resolution quality, and direct access to multimedia content (on which further below). PDF is the for-print format, but it is worth remarking that it has also become the choice medium for collections of digital publications and bibliography management software (such as Zotero, Endnote, Mendeley and Citavi, among others). Several of the main natively online scholarly Egyptological journals are PDF-only.⁴ And PDF is obviously the medium of choice for the digital version of paper journals.

With the PDF format comes another holdover of the paper medium, namely, pagination. In *RiME*, once the pdf has been laid out, its pagination is also applied to the web version by inserting page numbers between brackets in the text. Doing so is another bow to the world of paper journals and books, where page numbers are the most efficient means to reference a locus. As Lit puts it:

(...) the page number (...) functions in the print world as the ultimate neutral decider of the place of a text (...). Page numbers have assumed such great power that their functionality has been projected onto the manuscript and the digital world when referring to a source from either world.⁵

In the *Rivista*, for the sake of consistency of citation irrespective of whether the web or PDF version is cited, the pagination of the downloadable PDF version is carried over (as much as possible) to the webpage version. I am not aware of any other dual-format journal that does this, although there very well may be others.

Originally, we paginated each article individually within each issue, i.e., the page numbers of every new article started over from 1. This was changed from issue 4 (2020)

³ Moiso, Montonati 2021.

⁴ Including the pioneering *BMSAES* [<https://www.britishmuseum.org/research/british-museum-publications/bmsaes>], *NeHeT* [<https://www.nehet.fr/>], and the brand-new *Hieroglyphs* [<http://www.hieroglyphs-journal.org/>]. A dual-format journal that offers a quite smooth online reading experience is *Aegyptiaca* [<https://journals.ub.uni-heidelberg.de/index.php/aegyp>]. A list of digital Egyptological journals is available, as of this writing, at <https://www.egyptologyforum.org/EEFDigijournals.html>

⁵ Lit 2019, 15.

onward, when the switch was made to continuous pagination across the whole issue. The main reason for this “paper-bounded” change was compliance with the regulations of the ANVUR, the Italian agency for the assessment of the quality of research, from which the *Rivista* sought the coveted (in Italian academia) inclusion among “Class A” journals for disciplinary sector L OR/02, Egyptology and Coptic Civilization. This inclusion – granted in 2022 – improves the Italian academic rating (in the said disciplinary sector) of authors publishing in the *Rivista*, extending retroactively to all articles published since issue 2 (2018). At the time, the ANVUR norms specified that “electronic publications are regarded as journals only on condition that each issue” have “a progressive numbering of pages”.⁶ This requirement was emended in 2023 and is now more flexible: contributions within publications should be identifiable “through progressive numbering of pages and/or a DOI code assigned to each article”.⁷

Publication in print brings with it a constraint: Once a work is printed and acquired by libraries and individuals, there is obviously no possibility for the author or publisher to make any changes, corrections or additions to the text. This constraint is inherent in the medium. The best one can do to emend an already printed text is to slip *errata corrigé* sheets between the pages of volumes before they are distributed. Hoping the sheets will not fall out and get lost, and that readers will bother to consult them.

These material limitations of the paper medium play a role in shaping the rules of the academic game. Once a book or article is published, it is carved, as it were, in stone. Any corrections, new findings or new ideas by the author will need a new publication – or at least, in the case of a book, a new edition – to gain official acknowledgment.

An online text obviously has no such constraints. Potentially, it can be updated, corrected and improved at any time at little or no cost – as one does with the object entries of a museum’s online database, or with natively digital forms of publication such as the blog, or Wikipedia. So then, do we do the same with the articles published in the *Rivista*, making them better and better? Of course not. We treat them as if they were articles printed on paper: Once published they cannot be changed. Authors who cite them at different times will all be citing the same words and the same content. Should we allow this content to change over time, the rules of the game would be distorted. Publications are the unmovable steppingstones of academic dialogue and interaction: so-and-so made this statement, put forward this argument, or offered this information, in this year, on this or that other page in their work, where readers can be sure to find it. It is largely on publications abiding by these rules that the reputation of a scholar and their career opportunities are based. The great majority of electronic academic journals (for some exceptions see the last chapter below) thus purposely give up the possibility of using the whole potential of online publication to remain within the limits dictated by centuries of paper-bounded academia. As a full-fledged

⁶ “Le pubblicazioni elettroniche sono considerate riviste esclusivamente a condizione che ciascun fascicolo... risulti... con numerazione progressiva delle pagine”, ANVUR *Regolamento per la classificazione delle riviste nelle aree non bibliometriche* [<https://www.anvur.it/sites/default/files/2024-11/Regolamento-classificazione-riviste.pdf>].

⁷ “[T]ramite numerazione progressiva delle pagine e/o codice DOI assegnato a ciascun articolo”, ANVUR *Regolamento per la classificazione delle riviste nelle aree CUN 8a, 10, 11a, 12, 13 e 14*, [<https://www.anvur.it/sites/default/files/2024-11/Regolamento-classificazione-riviste.pdf>].

academic journal, the *Rivista del Museo Egizio* has made the same conservative choice (a few years ago we actually took the first steps to publish it on paper – as well as online – but did not go through with this, mainly for financial considerations).⁸ We currently have no plans to attempt to break (or wiggle) free of the constraints of the paper world.

It is worth noting, in this regard, that unchangeability is also an ANVUR requirement for the recognition of journal status to electronic publications, whose every issue should be “concluded in itself, not open to further updating”.⁹

The temptation to emend offered by the digital medium can be sometimes hard to resist, but we have succumbed to it only in very few instances, and only to address merely cosmetic flaws, such as when belatedly discovering that the wrong font had been used for some characters. We strictly refrain from replacing or altering content.

We do, however, make one important exception to the no-change-after-publication rule, and we stand by it. We allow ourselves this breach of the rules to make up for an inherent weakness of digital publication – a weakness I will discuss below, in the sections on “link rot” and “website demise” (5.1 and 5.2).

Let us now look at some advantages and disadvantages of publishing a journal online.

4. Advantages

4.1 Accessibility

This is certainly the most important advantage of the online format for an academic journal, and is so obvious that it is hardly worth dwelling upon. In the case of Egyptological journals such as the *Rivista*, the general advantages of free online access are compounded by the scarcity of well-stocked Egyptological libraries around the world, and the often high cost of Egyptological publications.

4.2 Linking

The accessibility of a digital journal is extended seamlessly to other online resources (articles, museum databases, etc.) by means of external links. Internal links to other parts of the article – footnotes, figures, and indexed sections – speed up the consultation process.

4.3 Multimedia content

Inclusion of multimedia content is another obvious advantage of the digital format. But this requires a caveat. We are in an age when there is ever more emphasis on the application of new technology in archaeology. I am concerned that we are still at a stage when the medium easily becomes more important than the message: a fetish. We will eventually get to the point when multimedia becomes a mere tool and we can focus only on the research objectives we are using it for, but right now using 3D reconstructions

⁸ The library of the Collège de France in Paris does print and bind *RiME* and make it available on its shelves (Elsa Rickal, personal communication, Nov. 8, 2024). So do several libraries in Germany, or at least have done in the past (Susanne Töpfer and Johannes Auenmüller, personal communication, Dec. 4, 2024).

⁹ “In sé concluso, non aperto ad ulteriori aggiornamenti”. https://www.anvur.it/wp-content/uploads/2019/02/REGOLAMENTO-PER-LA-CLASSIFICAZIONE-DELLE-RIVISTE_20022019.pdf. Interestingly, the updated 2023 version still specifies “in sé conclude” (concluded in themselves), but leaves out the “not open to further updating” part. <https://www.anvur.it/wp-content/uploads/2024/01/Regolamento-classificazione-riviste.pdf>

or multispectral images in an article can still sometimes be a way to increase its appeal or stress its innovativeness, whatever their actual usefulness may be (it used to be like this for studies relying on computers in the years when they first became widespread, whereas they are now taken completely for granted).

There is no special emphasis on multimedia, or applications of new technologies to archaeology, in the *Rivista*. Its digital format, however, allows for the inclusion of multimedia in articles – only a few so far – whenever there is an obvious benefit in doing so.

We included 3D models of objects in two articles in the very first issue of the *Rivista* (2017). One is about a shabti box,¹⁰ the other about a fossil sea urchin bearing an inscription.¹¹ In the latter case, in particular, the model does far more justice to the complex geometry of the object than the photographs do.

3D models by technicians of the Politecnico of Milan are used to great advantage to document the Museo Egizio's excavations in Saqqara, on which two reports have appeared in the *Rivista* so far¹² (one more is in preparation).

A link to a historic film in the archives of Italy's Istituto Luce recording the king of Italy's visit to Egypt in 1931 is included in an article about statues which at the time were newly excavated and appear in this film.¹³ The usefulness of video is particularly borne out in Gabler and Soliman's article on an Eighteenth Dynasty hieratic letter on papyrus that was folded several times in an elaborate way.¹⁴ While trying to understand the folding procedure from the punctilious written description and the drawing provided in the article can be something of a chore, everything becomes immediately clear when one watches the included videos, which show a one-to-one paper replica of the papyrus being deftly folded by Gabler's hands.

Finally, a recent article illustrating the use of Reflective Transformation Imaging (RTI) to observe tool marks on ancient Egyptian statues includes links to the original RTI images.¹⁵

In these cases, we are breaking through the boundaries of paper, exposing the contradictions of the schizophrenic, as it were, nature of *Rivista* articles, in whose PDF version, when they are printed, access to linked resources and any multimedia content is, of course, lost. We have addressed the issue of the discrepancy between the web vs. the PDF version, or the web and digital PDF vs. the printed PDF version in various ways. For example, in the above-cited article by Gabler and Soliman (2018) there is a notice on the first page of the article that the web version includes additional multimedia content, and a link to the video is provided (p. 4). The 3D model of the tomb of Meryneith in Del Vesco et al.'s report (2020, 74) is replaced by an axonometric view of the tomb taken from the model. Our latest expedient to bridge the digital-paper gap was to include in the PDF version, next to the (linked) image of the 3D model, a QR code allowing readers of a printed copy to visualize the model on their mobile device.¹⁶

¹⁰ Marini 2017, 3-4.

¹¹ Karlshausen, Putter 2017, 1.

¹² Del Vesco et al. 2019; Del Vesco et al. 2020. See also C. Rossi 2026 in the present volume.

¹³ Cafici, Deotto 2017, 5, note 26.

¹⁴ Gabler, Soliman 2018, 4.

¹⁵ Serotta 2023.

¹⁶ In Girardi 2024, 65.

5. Disadvantages

5.1 Link rot

We speak of “link rot” when a link ceases to work. The issue may be merely that the web address has changed. At the *Rivista*, we carry out regular checks of the links in all the published articles and correct any changed web addresses. For example, a considerable number of the links are to objects in the British Museum and these all had to be updated after a major revamp of the BM website in 2020 that entailed a change to all the object URLs.¹⁷

The last check we performed as of this writing (17 September 2024) revealed 35 broken links. 30 of these were fixable, being due to changed URLs, which we replaced. In five cases, we could no longer find the website and had to mark the URL as no longer available. Three of these we should soon be able to replace, as they are to objects in the Manchester Museum, whose collection website is down as of this writing (November 13, 2024), but is envisaged to be back online in a matter of months.¹⁸ The other two links, instead, appear to refer to a no longer available resource.

Allowing ourselves to intervene on these problems inherent in the medium is the main exception we make to the paper-bounded limitations we, and the academic world, have imposed on ourselves.

The *Rivista* itself adopts DOIs to ensure the long-term permanence of its articles.¹⁹ How these and other systems having the same purpose work, and how much durability they actually grant over time, would be an interesting subject to pursue here, but falls outside the scope of this article.

5.2 Website demise

The worst instance of link rot is when the linked resource no longer exists.

Out of the above-mentioned 35 broken links revealed by a recent check (see previous subchapter), two we had to pronounce dead and consequently delete. In both cases, the deletion fortunately had a negligible impact on the article and will go unnoticed.

An extreme case is Jurjens’ article on an ancient Egyptian manuscript in the Turin museum, where she cites as an important source an article on a long defunct webpage, of which she was lucky to receive a copy in print (!) from a colleague.²⁰

An article on a figured Coptic jar to be published in the *Rivista*²¹ included a footnote with a reference to parallels for this jar in a most valuable online resource, the Clémence Neyret database of Coptic pottery in the Louvre. During editing, we found that the link was dead. I wrote the Louvre to inquire and received an apologetic reply informing me the database had been taken offline due to a hacker attack, and there were no plans to make it publicly available again.²² I therefore asked the author to find other parallels in a

¹⁷ Wild 2020.

¹⁸ Susan Martin and Campbell Price, personal communications, Nov. 8-9, 2024.

¹⁹ Detailed information at <https://www.doi.org/>

²⁰ Jurjens 2021, 110-111, note 5.

²¹ Incordino 2019.

²² Marie Delassus, personal communication, Nov. 28, 2019.

printed source, which she did.²³ We then published the article, leaving out the reference to the Louvre database.

Ironically, I checked while writing this paper and found that today the Neyret database is available again.²⁴ My paper-bounded conscience prevents me from modifying the Coptic jar article by putting back into it what would be a useful link to another parallel. Although I cannot deny I am tempted. ANVUR would probably never notice.

6. Making the most of the medium: alternative approaches, and a failed attempt

The Museo Egizio's library holds a copy of Jean-François Champollion's *Lettres au duc de Blacas-d'Aulps*²⁵ – a description of a number of highlights in consul Drovetti's outstanding Egyptian collection, drawn up by Champollion in epistolographic form shortly after its arrival in Turin, where it formed the original core of the Museo Egizio. This specimen contains pen and pencil annotations, mostly giving the current inventory number of several of the described artifacts. Many of these annotations – which are most useful – are in the handwriting of Silvio Curto, director of the Museo Egizio from 1964 to 1984 (the only one that could be identified).²⁶

Such handwritten annotations make the printed book also a manuscript, lending it some of the latter's capability to change and evolve as text is added in or deleted. They also lend the book some of the manuscript's uniqueness, since another feature of the manuscript that sets it off sharply from the printed work is that every copy of the latter is, as a rule, identical, whereas we can expect almost every copy of the former, whether made by the same author or by a copyist, to incorporate additions, corrections, variations, omissions (deliberate or otherwise), etc.

This is one feature of texts in the manuscript world that they share with texts in the digital world, which have it to a much higher degree, as they can be – and often are – edited, added to, copied and reproduced with unprecedented speed and minimum effort. The question then arises of whether, how, and to what extent it would be useful or desirable to change the rules of the game – as set out above – to allow academic publications to exploit the flexibility and possibilities for improvement offered by the digital medium – short of the extreme case of Wikipedia entries, with their renouncing of authorship.

Within academia, a small, cautious step in this direction has been taken, for example, by the journal *PLOS ONE*, which allows authors, subject to editorial approval, to correct or retract statements in their articles post-publication. This is usually done by linking a correction notice to the article; however, “[i]n rare cases, PLOS may choose to republish a corrected version of an article, replacing the original online version”, usually with “an accompanying correction notice that [...] documents the changes”.²⁷

²³ Incordino 2019, 7, note 11.

²⁴ Catalogue des céramiques coptes du Musée du Louvre – base Clémence Neyret, <https://corpus.louvre.fr/s/catalogue-des-ceramiques-coptes-du-musee-du-louvre-base-clemence-neyret/page/accueil>

²⁵ Champollion 1824.

²⁶ Thanks to Silvia Mosso for assistance and to Beppe Moiso for identifying Curto's handwriting.

²⁷ <https://journals.plos.org/plosone/s/corrections-and-retractions>

Another interesting approach is that of the *Bulletin of the History of Archaeology*,²⁸ which allows registered readers to annotate and comment articles in a column on the right of the text.

Looking beyond the confines of the online journal *sensu stricto*, an approach that is game-changing, but still guarantees academic accountability, has been taken by the Open Research Europe portal, which leaves earlier version of revised articles available, along with their reviews.²⁹

The *Rivista*'s own attempt to exploit the digital medium's possibilities to extend an article's growth beyond its publication was, I regret to say, unsuccessful. Until recently, the web version of every article in the *Rivista* included, alongside the Index and Gallery columns on the right of the main text column, a Comments column. This was meant to host any comments on the article – additions, criticism, new evidence, etc. –, including the author's, to be published subject to approval by the editors. This possibility failed to draw interest from either readers or authors. Not having received a single submission of a Comment in six years, starting last year (2024) we decided to do away with this feature, which had looked useful on – er – paper.

The entrenchment of paper-bounded academic practices is still so deep and has such a strong *raison d'être* that it will probably take some time before the research publication world fully embraces the potential of the digital medium.

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²⁸ <https://archaeologybulletin.org/>

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Online Resources

Aegyptiaca:

<https://journals.ub.uni-heidelberg.de/index.php/aegyp>

ANVUR

<https://www.anvur.it>

ARKs

<https://arks.org>; <https://docs.dasch.swiss/2025.01.02/DSP-API/05-internals/design/api-v2/ark/>.

BMSAES

<https://www.britishmuseum.org/research/british-museum-publications/bmsaes>

BHA

<https://archaeologybulletin.org/>

Catalogue des céramiques coptes du Musée du Louvre – base Clémence Neyret

<https://corpus.louvre.fr/s/catalogue-des-ceramiques-coptes-du-musee-du-louvre-base-clemence-neyret/page/accueil>.

E-Journals and Digitized Paper Periodicals (Egyptology)

<https://www.egyptologyforum.org/EEFDigi-journals.html>

Hieroglyphs

<http://www.hieroglyphs-journal.org/>

NeHeT

<https://www.nehet.fr/>

ORE

<https://open-research-europe.ec.europa.eu/>.

PLOS One

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RiME

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The contribution of the immaterial realm to the study of the material culture

Corinna Rossi

Abstract

The digital revolution endowed us with new tools to study the material culture. We are learning to use them, but with uneven results: the issue is not technical and not even simply methodological, it is philosophical. Unless we clearly define the parameters we cannot clearly define the parameters. The research into the relationship between material objects and immaterial information must be made of theory and practice, of trials and errors. The aim is to identify a shared field of action, which is new and unexplored: what works on one realm, may not work in the other. This paper will present the research carried out in this direction in the last few years at Politecnico di Milano, in collaboration with Museo Egizio, Torino.

Keywords: *Digitisation; Digitalization; 3D survey; 3D model; remote investigation.*

1. Context

A wide range of new technologies are being applied to the realm of Egyptology. They have the power to make visible things that were, until recently, invisible: some were hidden, others were lost; some were known to the ancient Egyptians, others were not. These distinctions are crucial as they define the limits and characteristics not only of our knowledge, but also of that of the ancient Egyptians.

When discussing the relationship between material and digital culture, the contraposition between 'real' and 'virtual' may be misleading, as the virtual realm is also real. My preference goes to using the terms 'material' and 'immaterial', and to considering as a duality, rather than as two opposing elements. If we place material and immaterial realms in contraposition, the objects and their digital versions may be perceived differently, depending on the point of view. Objects may be seen as bad-looking, incomplete, breakable, fixed, whereas their digital versions may be perceived as good-looking, integer, unbreakable, transformable. The opposite may also be true: objects may be considered as true, real, original, tangible, whilst their digital counterparts as false, unreal, copied, intangible. If, instead, we consider the immaterial realm as a mirror in which the material object can see itself in a different light, then both realms may contribute to our knowledge of the object itself.¹

One of the most obvious contributions of the immaterial realm in archaeology is to make up for the destruction. Not only to integrate missing parts, but also to address the destructive nature of the archaeological excavation itself: archaeological sites are physically demolished by excavations, finds are separated from one another and from their context, objects are stored in magazines, or placed on display in museums; in the past, groups of finds coming for the same context were often scattered among several

¹ Rossi 2019a.

museum and collections. In the immaterial realm, reality-based 3D models of each stratigraphic unit can precisely record the connections that are inevitably lost once they are dismantled; some aspects of sites and objects may be studied through their digital twins; finds and contexts can be re-connected; *disjecta membra* can be reunited.² Of course, this is easier to say than to do in an effective way: the theory is clear, but several practical aspects still await a solution.

The transition to the digital realm implies two types of operations: digitisation and digitalisation. The term 'digitization' refers to the transformation of analogical data into digital data, whereas the term 'digitalisation' describes the passage from analogical to digital processes. Not all data have the same origin and have been digitised following the same path. The current situation of the digital realm, therefore, is a combination of digitised data, digitalized processes, native digital data and native digital outputs. In the field of archaeology, it is unlikely that the situation will change in a significant way: there will always be inaccessible places or objects of which only paper record exists, or out-of-date digital data to be revived. It is important to accept that digital data are heterogeneous and will remain so.

The digital realm thus offers new tools and solutions to three areas of the archaeological field: documentation, research and dissemination. Politecnico di Milano has been active on all these fronts alone and in strict collaboration with Museo Egizio, Torino³ and the following paragraphs describe some activities, their issues and the solutions that have been adopted.

2. Documentation: archaeological/architectural survey

Performing 3D surveys of objects is a relatively common activity nowadays, even if not always at the same level of precision and accuracy that one would wish for. In particular, the importance of producing metric models must be stressed, that is, measurable models that reflect the actual dimensions of the original object. As methods, techniques, hardware and software improve, it is important to move on from the production of data and ask ourselves what can be done with these data. Obviously, 3D surveys and models can be used to obtain the same, traditional results that could be obtained by hand-drawings and photographs, and just achieve this in a quicker and more precise way. But new tools offer also new possibilities, that can and must be taken into account and exploited.

An interesting example is the 2018 3D survey of the external coffin of Butehamon, held at Museo Egizio.⁴ The software offers the chance to switch off the colour of the surface and see just its geometry: this allowed to see, thanks to a click, the geometrical facial features of that coffin, significantly different from those painted over. This is probably due to the re-use of older components of other coffins, that were re-painted according to the wishes of the new owner. This was the same principle that led to the creation of the

² Greco 2019.

³ Rossi 2019b; Greco, Rossi, Della Torre 2020; Mandelli, Gobeil, Greco, Rossi 2021.

⁴ Mandelli *et al.* 2019.

project *Faces Revealed*, that investigated in detail the facial features of a large number of yellow coffins by exploiting just this software option.⁵

Equally promising is the survey and modelling of archaeological excavations. Since 2018, Politecnico di Milano has been in charge of the survey of the concession of the joint Dutch-Italian archaeological mission to Saqqara of Museo Egizio (Torino) and Rijksmuseum van Oudheden (Leiden), that includes a number of New Kingdom tombs.⁶

Two types of surveys have been performed on the field: those of already excavated structures and those of the ongoing excavation. The first type concerns more or less fixed situations (even if small variations occur more frequently than one would perhaps expect), whereas the second type is, by definition, a situation in continuous evolution. This sequence of reality-based models constitutes a 'double' digging diary: as the excavation proceeds, it captures the progressively older layers but also the daily evolution of the excavation with a hitherto unavailable degree of precision and accuracy. A widespread, effective way to visualise and handle such a sequence of contexts is, however, still missing, thus holding back the spread of this method to record the excavations.

3. Research

3.1. Digital models

Surveys and models of 'fixed' structures are easier to handle as individual, digital objects. The interesting and challenging part of the work starts when we wish to use them all together and for a purpose that goes beyond turning them on a screen. The collection of surveys and models of the various parts of the Saqqara concession represents an ideal case-study to experiment with these issues.

A first, and rather obvious operation, was to digitally remove the most invasive modern superstructures from the individual models of the tombs. The decision was taken to limit this activity to a minimum: going back to the original state in which the tombs were found would be impossible without a substantial operation of deconstruction and reconstruction, that would fall beyond the scope and interest of our research. Therefore, modern shelters and roofs were removed, along with the doors of the wooden lockers which protect the decorated orthostats, in order to show them inside.⁷ Only one tomb is endowed with a different type of modern structure, that of Meryneith, that being smaller than the others was encapsulated into a box-like building. The latter was digitally removed and the tomb exposed like the others (Fig. 1).

⁵ Mainieri, Mandelli, Rossi 2022; Mainieri 2024a; Mainieri 2024b.

⁶ Del Vesco, Greco, Müller, Staring, Weiss 2019; Del Vesco, Greco, Soliman, Weiss 2020; Del Vesco, Greco, Rossi, Soliman, Weiss 2020.

⁷ Rossi 2019b.

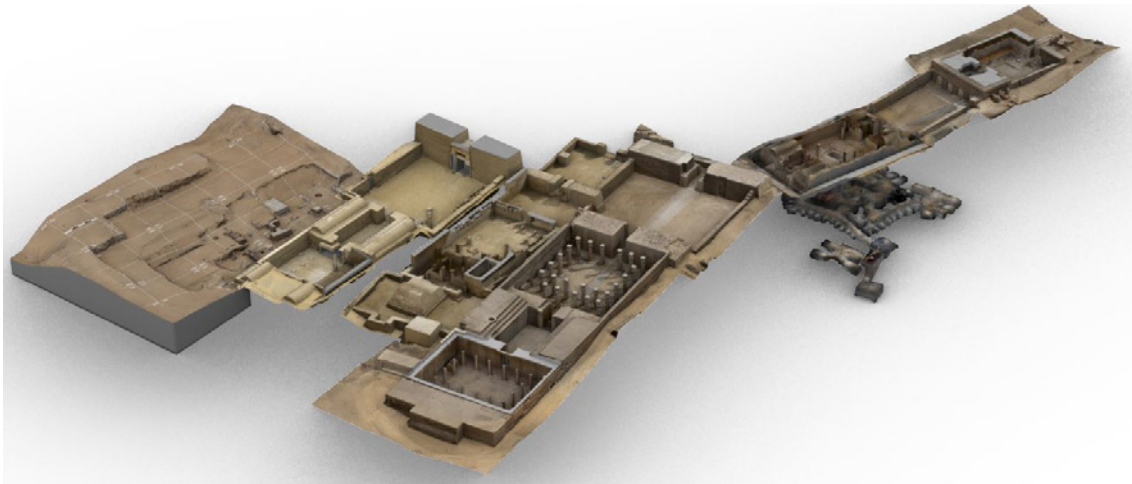


Fig. 1: 3D models of five tombs of the Turin-Leiden concession, plus the area under excavation, as of 2020 (elaboration by A. Mandelli, 2021).

Once all the reality-based models were addressed, we turned to the issue of the inaccessible parts. Our ongoing project focuses on constructing an overall model, joining together the above-ground structures and the underground portions of the tombs. This general model cannot be achieved on the basis of reality-based surveys only, as most of the underground parts are inaccessible for various reasons, either because they are closed by the authorities or because they were backfilled or blocked. These parts are being modelled in a different software, starting from the two-dimensional plans and sections published by the archaeologists who excavated them in the recent past (Fig. 2).

Being able to deal with this type of composite model, in which data are derived from different sources, represents a significant step in a future perspective: combining data from different sources will allow us to combine data gathered in different historical moments, thus giving us the chance to construct a really comprehensive model, able to go beyond the range of the currently visible remains. A parallel project is also being carried out: it consists in attempting a geometric reconstruction of the missing parts of the tombs. This is being achieved without any mimetic intent: the bare geometry of the missing parts, accurately designed on the basis of a metrological study, is added to the point-cloud.

Finally, it is worth mentioning that digital handling of 3D models is starting to gain space also in the field of epigraphy, even if with some limitations. The possibility to digitally regulate the light in the 3D models may offer a significant help to epigraphists and archaeologists to improve their study of reliefs and inscriptions, especially in case they are faded and barely visible with the naked eye. The software Real-Time Suggestive Contours (RTSC) by Princeton University,⁸ for instance, was used to enhance scenes on a sequence of orthostats from the tomb of Meryneith and to register the state of the blocks located in the courtyard, on the east wall, to the left of the entrance, that are suffering from weathering.⁹

⁸ De Carlo *et al.* 2003.

⁹ Lori, Rossi 2020.

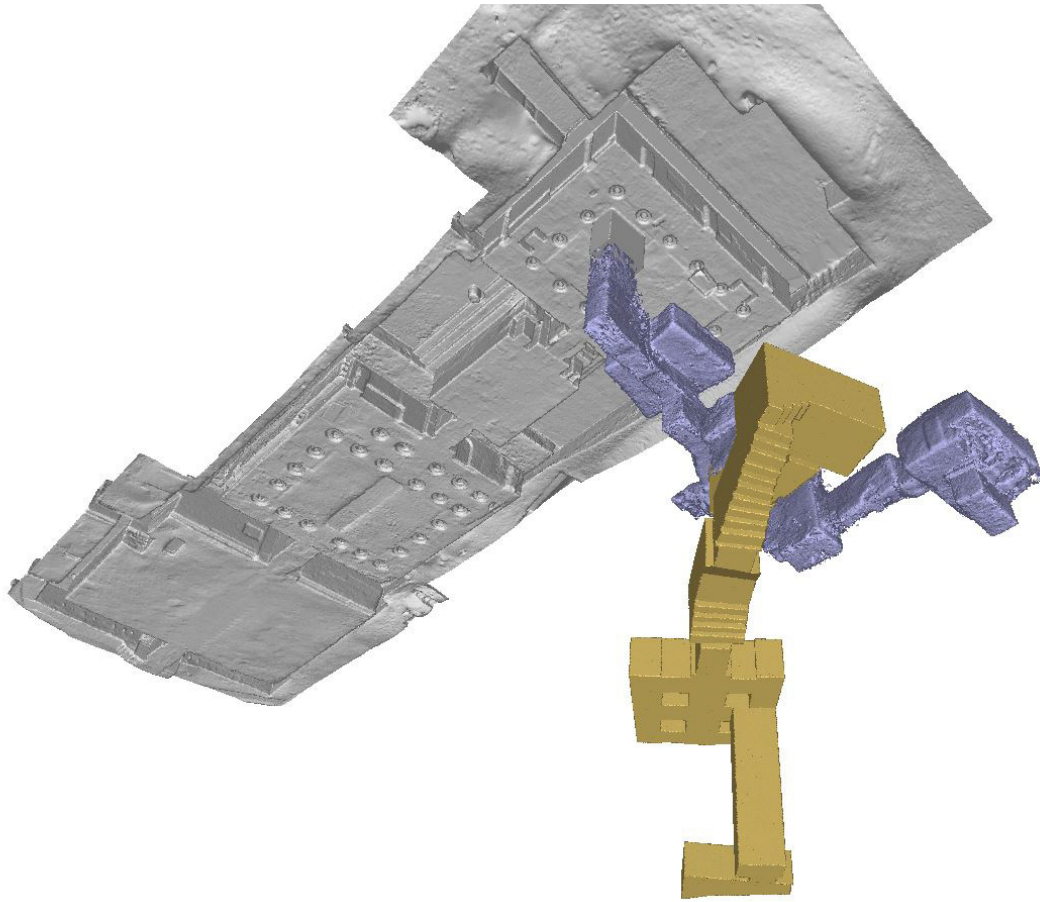


Fig. 2: Composite 3D model of the tomb of Horemheb, combining reality-based (grey and lilac) and reconstructed (yellow) models (elaboration by A. Mandelli, in Rossi 2020).

3.2. Remote investigation

The digital realm offers also the chance to implement what we named ‘remote investigation’, a combination of remote sensing and archaeological study carried out on digital data, to be attempted when the actual site is not accessible. This methodology was envisaged during the ERC-funded project LIFE,¹⁰ dedicated to the Late Roman site of Umm al-Dabadib, located at the northern outskirts of the Kharga Oasis, in Egypt’s Western Desert, dating to the Roman Period. The deterioration of security in the Western Desert led to the interruption of any archaeological work from 2016 to 2022 and forced us to adopt alternative methods to continue to investigate the site.

Remote sensing is not new in archaeology, but here it was necessary to work with already available material: the most productive source of information was represented by Google Earth images, that provided evidence and inspired several lines of investigation. One was the study of the orientation of the chain of Late Roman forts, to which Umm al-Dabadib belongs. From the study of the satellite images, it became clear that all these sites had the same

¹⁰ ERC CoGrant 681673, www.life.polimi.it

orientation as the barchan sand dunes that flow across the oasis in a north-south direction: this means that the forts were aligned to the prevailing northern wind¹¹ (Fig. 3). This can be clearly see not only at Umm al-Dabadib, but also at other contemporary fortified settlements built in the Kharga Oasis: beside their orientation, they share a number of architectural features that suggest that they were part of a single strategic design of control of the oasis.¹²



Fig. 3: Orientation of Umm al-Dabadib on the prevailing northern wind (Rossi, Magli 2019).

The 3D survey of the Fort allowed the construction of a precise and accurate model that was instrumental to perform a metrological study of this building¹³ (Fig. 4). The study demonstrated that the Fort was built using the ancient Egyptian cubit as unit of measurement; to be precise, the reformed cubit, divided into 6 palms, larger than the older 7 palms into which the cubit was divided from the beginning of the Egyptian history until the 26th Dynasty.¹⁴ This is, at the moment, the latest attestation of the use of the ancient Egyptian cubit in architecture.

¹¹ Rossi, Magli 2019.

¹² Rossi *et al.* 2022.

¹³ Fiorillo, Rossi, Galli, 2020; Fiorillo, Rossi, Morandi 2021.

¹⁴ Fiorillo, Rossi, 2018; Rossi, Fiorillo 2018.

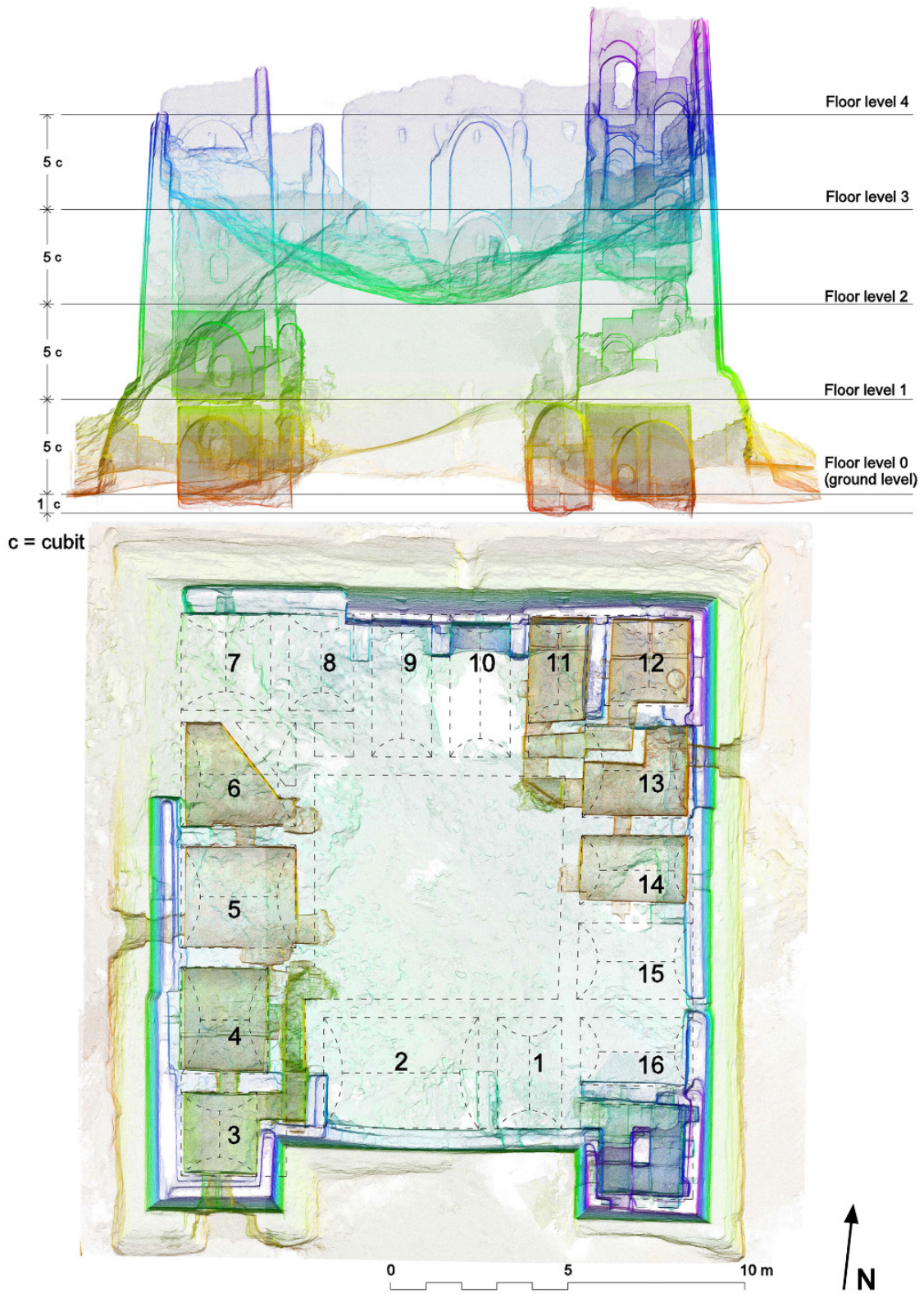


Fig. 4: Elaboration of the 3D model of the Fort of Umm al-Dabadib (elaboration by F. Fiorillo, in Fiorillo, Rossi, 2020).

It was later possible to demonstrate that the same unit of measurement was also used in the construction of the Fortified Settlement, as well as of the other forts that punctuate the northern portion of the Kharga Oasis.¹⁵ The subsequent metrological analysis of the house of Serenos in the nearby Dakhla Oasis revealed that also in that case, the unit of measurement was the same.¹⁶ Future studies are likely to reveal further instances in which the cubit was used in the constructions dating to the Late Roman Period.

Another possibility offered by the level of accuracy and precision achieved by the computerized 3D model, that would be extremely difficult to achieve by eye and hand, was to perform a geometric analysis of the vaults of the Fort. It was possible to demonstrate they are elliptical, and to suggest the actual method that was used by the workmen to draw their outline of the back wall of the rooms in which they were constructed.¹⁷

The metrological study of the Fort and the geometric analysis of its vaults opened the way to an overall study of the entire Fortified Settlement from an architectural point of view. We developed an *ad hoc* conceptual and operative approach that we defined ‘semantic and parametric modelling’: each element of the building is named and defined from a (geo)metric point of view. In this way, each named element is reconstructed according to precise parameters: this system allowed us, starting from the visible portions of the buildings emerging from the debris, to make precise hypotheses on the portions that lie still buried (Fig. 5).¹⁸

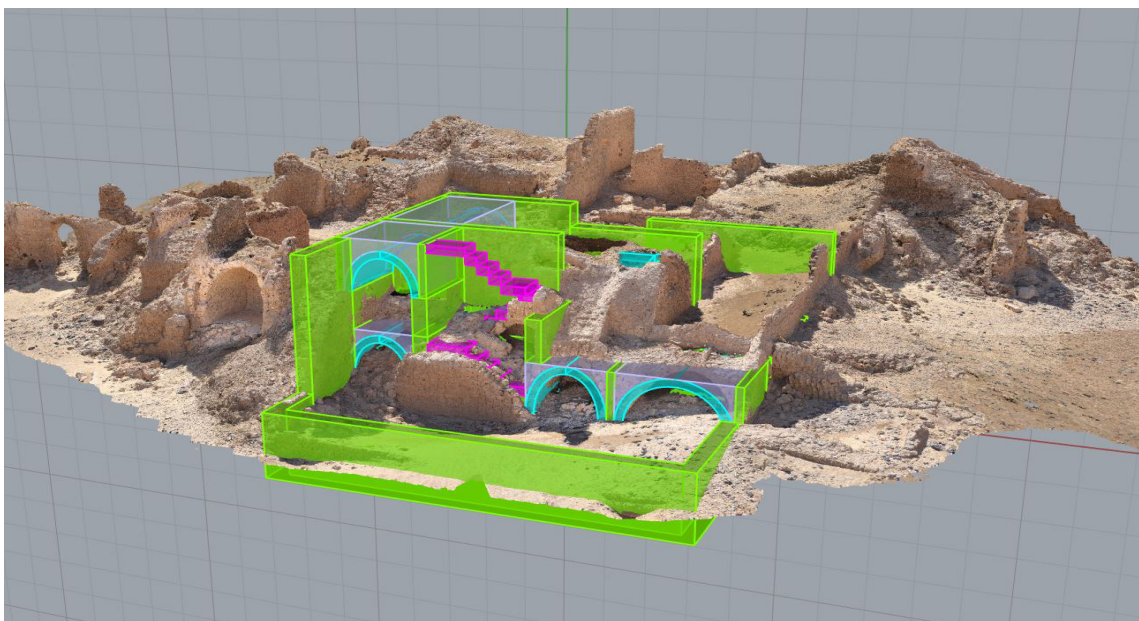


Fig. 5: Semantic and parametric modelling applied to Unit C at Umm al-Dabadib (elaboration by F. Fiorillo, in Fiorillo, Rossi 2021).

¹⁵ Rossi 2019c.

¹⁶ Davoli 2022, 44-6.

¹⁷ Fiorillo, Rossi 2020; Fiorillo, Rossi 2023.

¹⁸ Fiorillo, Rossi 2021.

As we worked on the construction of these models, we realized that the 'recipe' to construct and model that eventually 'clicks' together is to proceed following the same steps that the ancient builders made: starting from the plans drawn on the floor level, then building the back wall up to the top, then building the lateral walls up to the impost of the vault, then add the vault, etc. The digital model thus mirrors the construction process and can provide interesting information also on that subject.

4. Dissemination: combination of material and immaterial components

3D models may be very useful to disseminate the results, not only among the academic community but also for the general public. The multimedial installation centred on the external coffin of Butehamon prepared for the temporary exhibition *Archeologia Invisibile* (Museo Egizio, 2019-2022)¹⁹ represented a significant example. The submillimetric survey and the ensuing model allowed the creation of a video explaining the construction of the coffin that worked in connection with an operation of videomapping of the decoration of the coffin projected onto a 1:1 physical model of the coffin itself.

The final product was the result of a long and complex work that saw the participation and the collaboration of different specialists, including Egyptologists, surveyors and videomakers. The installation was so effective and successful that it was re-presented on the occasion of the temporary exhibition *I creatori dell'Egitto eterno* at the Basilica Palladiana, Vicenza, and is now an integral part of the permanent exhibition path of Museo Egizio, located at a short distance from the set of coffins of Butehamon himself.

In order to achieve a successful result it is important to stress that experts from different fields must be involved, as none of them, alone, would be sufficient. In this respect, the fields of augmented and virtual reality can offer a wide range of possibilities to further explore and elaborate new and innovative ways to disseminate the results of scientific research to the wider public.

5. Conclusions

The immaterial version of a material object is made of its digital image and of all the information that may be attached to it. One way to define this combination of elements is 'digital twin'. Material object and digital twin have a number of elements in common, but they are not equivalent: digital twins are tools, instruments, ways to represent and describe the physical object, that remains the original source of information, progressively retrieved as technologies and knowledge evolve.

In the digital realm, known, 'old' operations (such as archaeological and architectural surveys) may be performed quicker and better. But in order to really exploit the potential of the digital realm, we need to operate a shift of paradigm, leading to the identification and implementation of new operations, inspired by the newly available tools. Examples are composite models, as well as the semantic/parametric modelling described above.

The results illustrated above demonstrate that the collaboration between museums, where the material culture is held, and universities, where experimental research can be performed at controlled costs, represents a successful example of joining forces to achieve

¹⁹ Ciccopiedi 2019.

result that neither of them could have otherwise obtained. Hopefully, more institutions will follow this example and increase the number of collaborative projects able to push the boundaries of our knowledge further. This means performing ground-breaking specialistic research, as well as dedicating the same amount of energies and time to the dissemination of these results to the wider public: knowledge can only advance if both aspects are properly addressed.

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The King's Chamber: a digital publication prototype

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Abstract

This article provides an overview of the history, evolution, and potential future trajectory of a Digital Publication Prototype: the King's Chamber, developed under the auspices of the Epigraphic Survey in Luxor, a long standing project under the Institute for the Study of Ancient Cultures (ISAC) at the University of Chicago.

The prototype explores the convergence of digital technology with traditional epigraphic practices, focusing on creating a web-based platform that seamlessly integrates photography, drawing, and philology. While rooted in the Epigraphic Survey's original vision, the project leverages digital advancements to enhance accuracy and accessibility. Central to the endeavor is the development of a modular digital publication format that accommodates layered drawings, 3D models, and comprehensive commentary.

Key features of the prototype include a Scene Selector for navigating through chambers, a layered IIIF-compliant viewer for examining orthophotos and epigraphic illustrations, and an Archive tab for accessing historic images. Thematic priorities encompass accessibility and archivability, emphasizing user-friendly design, adherence to web standards, and future-proofing strategies.

Future development plans entail refining the site's structure for more intuitive navigation, incorporating citation methodologies, and exploring advancements in AI, computer vision, and 3D data processing. The article underscores the prototype's role as an experimental endeavor in response to a dynamic technological landscape, aiming to inspire innovative approaches to digital publication that merge tradition with sustainability.

Keywords: *Digital publication; Documentation; Epigraphy; Photogrammetry; Archivability.*

1. Introduction

This article will serve to present a summary of the history, development, and potential future of this Digital Publication Prototype: the King's Chamber. The core function of this project has been to explore the process of creating a web-based digital publication platform that is purpose-driven and sustainable. This work is based on the system and projects of the Epigraphic Survey in Luxor (aka Chicago House) of the Institute for the Study of Ancient Cultures (ISAC) at the University of Chicago.

The Epigraphic Survey's original vision and mandate originated with its founder, James Henry Breasted. His early fieldwork in Egypt made it clear that many hieroglyphic inscriptions were rapidly deteriorating and at risk of becoming lost forever. Although a number had been drawn in the late 19th and early 20th centuries by artists and scholars alike, not all of these copies were accurate, and they often did not include important paleographical details. His dream was to provide a published volume that could stand in place of the original, making these ancient records widely available for scholarly research and preserving them for the future. The method devised to produce these volumes — a rich combination of photography, fine art, and philology — yielded

precise, accurate, and information-rich facsimile drawings through a process that came to be known as the Chicago House method.¹

Though the techniques used to obtain the results have changed, our objectives and goals remain faithful to the Epigraphic Survey's origins. The current process and disciplines can now be done digitally, and this has the advantage of allowing the epigraphic drawings to be matched seamlessly to the base photography used in the process. With print publications, 3D data is something of a by-product, used to reproduce a traditional 2D workflow, but this 3D space has also enabled the 2D data, both current and archival, to become reused in a 3D publishing context. We knew something more could be done with this data and desired to explore the possibilities. However, fundamentally, our project is intended less as a solution, and more as a tool for evaluating what a meaningful digital publication could be; and crucially, it has been about identifying where the most significant challenges lie before diving into a slew of technology and a sea of ambition.

2. History and development

This project grew out of a series of conversations amongst colleagues about the potential for sharing the data inherently created through the digital collation process. The digital drawing and collation process was initiated and developed by Egyptologist and Epigraphic Survey artist Krisztián Vértés, and made accessible for a larger audience through the DigitalEPIGRAPHY website.²

It was the method of producing the final drawings, with all of their nuance and meaning, that helped inspire this project. A brief (and simplified) review of digital collation will help illustrate why the idea of having a digital publication platform arose. The first step of the epigraphic process, whether digital or analog, is photography. For digital drawing, the foundation is a rectified orthographic photo extracted from 3D datasets. The area that requires documentation is photographed, the images are rendered as a model using photogrammetry, and a complete image of the area in question can be created with next to no distortion and as high a degree of accuracy as the practitioner desires. The acquisition of the images is undertaken with professional DSLR and medium format digital backs as well as professional grade lighting equipment.

Once the rectified orthographic photo is prepared, the artist employs it to create a Photoshop file that will be used for all of the subsequent steps in this process. This file can be put onto a tablet and taken into the field so that the artist can do the initial drawing (called 'penciling') in front of the actual scene. The orthophoto forms the base layer for penciling; however, archival images can also be added into 3D datasets and used to create properly rectified historical references (which is imperative if the archival photographs contain details that have since been destroyed or lost). When the artist has finished this initial work, they then render the drawing in two different line weights

¹ Johnson 2014, 9-20.

² <https://www.digital-epigraphy.com>

(called 'inking'), which helps convey whether the relief is sunk or raised, thus creating a drawing that is not only a technically correct copy but also reflects the more subtle artistry of the original inscriptions. Once this is complete, the artist passes the file along to an Egyptologist who does a first collation, which involves an intensely thorough examination of the original scene alongside the drawing. The epigrapher also does a transliteration and translation of the relevant texts, and, where possible, identifies useful parallels to provide context and aid in finding any elusive carved elements in damaged areas. This first collation is then checked, reviewed, and supplemented by the observations and knowledge of a second Egyptologist. The final steps of the process include multiple conversations and verification assessments amongst the epigraphers and artists (including a final inspection by the field director). The documentary fruits of these myriad observations, interpretations, and conversations are all collected in the same multi-layered file, which affords everyone involved the ability to see the drawing and its base photo (including additional reference material) in stacked layers that can be turned on and off. Once the artist has made any final changes to the drawing, it is considered complete, and it, along with the translation and commentary of the epigrapher, awaits publication in a volume on the larger area in which the scene is located.

As may be apparent from this description, there is a substantial amount of material generated in the process of creating a final publication, not all of which is possible to present in a print volume. The initial focus of this project was to develop a method to present the overlapping layers of photos and drawings in a way that was as close as possible to their native capture, observation, analysis, and production.

Although it is often thought that a photograph should be sufficient documentation, this has been known to be a fallacy since the inception of the Chicago House method of epigraphy. A photograph's inherent weakness — objective impartiality — places equal emphasis on all surface elements, as dictated by the lighting source, direction, colour, and intensity of the light. What carries meaning, and can be selected and highlighted by careful study in the field — damaged hieroglyphs, eroded internal details of signs or figures, traces of earlier decorative stages, or faded paint lines — can remain invisible in a static photo that one cannot alter. While techniques such as 3D capture and RTI³ go beyond the static nature of traditional photography, the information they may record requires significant time and interaction to present the salient features of the subject. This is one of the reasons that makes the drawing on its own essential, as it is created while examining the actual inscribed surface. Additionally, it has been verified by professionals and internally peer-reviewed, such that the final drawing can be seen as the cumulative knowledge of multiple specialist disciplines, and is thus more accurate than any one person assessing a photograph. Lastly, the drawing allows the imagery to be viewed through a different 'lens' than the photo, providing the viewer with clear, concise visual data free of ambiguous marks, obtrusions, and noise, thus

³ Reflectance Transformation Imaging; for further information on this technique, see the discussion provided by Cultural Heritage Imaging (CHI) 2025 [<http://culturalheritageimaging.org/Technologies/RTI/>].

making comparisons with other inscriptions much more straightforward. This being said, removing the inscription from its context comes with its own set of problems (such as the lack of paint information). Thus, the ideal option is to have the drawing and the photo together, but also the ability to see each on its own.⁴

While creating a platform for presenting these layered drawings and photos was the initial focus of this work, it quickly expanded as we examined all of the useful elements of the epigraphic pipeline that were not sharable in a traditional publication format. One of the more evident elements that we wanted to integrate was the 3D model. At least part of a complete model has to be created for an orthophoto to be generated, and this seemed like an ideal way to help the reader not only navigate the decoration of the monument, but also to see all of the decorative schemes, as well as the final epigraphic illustrations, in context.

It was the conversations around these ideas that supplied the framework for the entire project. Working on this highlighted a number of questions about long-term solutions for presenting and archiving epigraphic documentation. Thus, the overarching question for our work became: can one publish a descriptive volume in a modular format that is visually cohesive, highly functional, and presents the many layers (both literal and figurative) that are created by the epigraphic process in a sustainable and accessible format?

3. Prototype

For the prototype, we chose a small subsection of the Epigraphic Survey's latest publication, *Medinet Habu IX, the Inner Sanctuaries of the 18th Dynasty Temple*, and more specifically, one room in the temple called the King's Chamber.⁵

The organization of the beta site as it currently exists begins with a landing page that contains some of the backstory of the project, along with a number of links pertinent to the various elements utilized in the project.⁶ Clicking on the *Launch Prototype* button immediately moves the user to the first page of the set that has been generated for this text. There are only a small number of sample plates in the current beta site, but each one is in a slightly different stage of completion in order to help present the process and the potential for a modular publication format (not all of the pages would have to be finalized for the site to be functional). One of the most complete is Plate 87, showing the south wall of the King's Chamber (Fig. 1). This example will be used to highlight the various features included in the prototype.

⁴ Note that something similar was done in the early days of developing the Chicago House method, in which lines were inked onto the photo and the whole image was published; these were called enhanced drawings. The downside to this method was that it did not allow for the photo or the drawing to be seen on their own.

⁵ The Epigraphic Survey, 2009 [<https://isac.uchicago.edu/research/publications/oip/medinet-habu-ix-eighteenth-dynasty-temple-part-i-inner-sanctuaries>].

⁶ The King's Chamber [https://ommphoto.ca/kings_chamber-v01/].

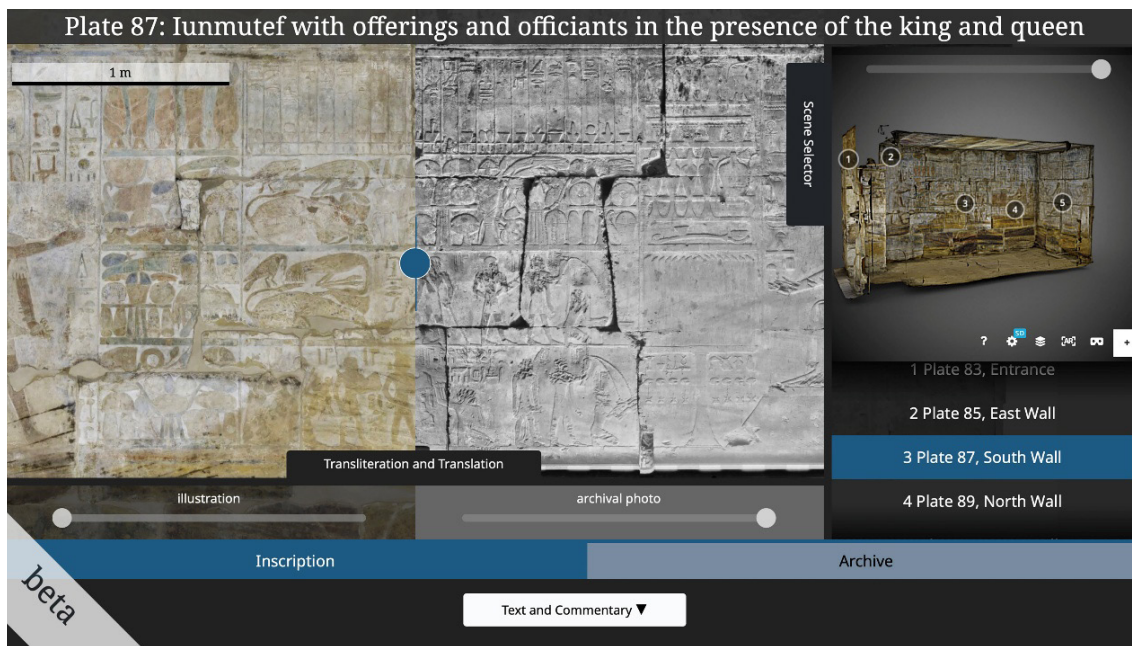


Fig. 1: Plate 87 of the current beta site, showing the south wall of the King's Chamber, with the layered IIF image and the Scene Selector.

The first has been designated as the *Scene Selector*. Located in a sidebar at the far right of the screen, this tab can be minimized by clicking on its label tab. When visible, the *Scene Selector* has two primary features: displaying a model of the entire chamber and serving as a traditional table of contents that allows the viewer to navigate content. At the top is a 3D model of the entire chamber. This is hosted on Sketchfab, and so has the standard utilities provided by that site. It can be interacted with by grabbing the model with the cursor and moving it around, by clicking on the number annotations displayed over each scene (which takes the user to the respective plates for that scene), or by cycling through the plates for the scenes using the arrow buttons to the right and left of the model. The model can also be expanded to full screen, with the final epigraphic illustrations done by the Epigraphic Survey layered directly onto the model, at any degree of desired opacity with the standard base photo texture (Fig. 2). This can also be viewed using an AR/VR headset, allowing the user to stand inside the temple as it has been interpreted, documented and drawn. The ability to view these illustrations in context is something no other technology affords and is, in and of itself, perhaps one of the most important uses of 3D data created during the digital epigraphic process.⁷

⁷ Murray, Pantos, and Singer 2023 [<https://sketchfab.com/blogs/community/api-spotlight-kings-chamber-prototype/>]. Many other projects are working in the area of digital humanities in Egyptology, although none, to our knowledge, are using IIF and 3D models in the same way. Some of the other projects that have done very interesting work (most tied strongly to landscape and GIS work) include: Digital Karnak [<https://digitalkarnak.ucsc.edu/>]; Sullivan's Constructing the Sacred: Visibility and Ritual Landscape at the Egyptian Necropolis of Saqqara [<https://constructingthesacred.org/>]; the Theban Mapping Project [<https://thebanmappingproject.com/>]; Digital Giza [<http://giza.fas.harvard.edu/>]; the Wadi el Hudi Expedition [<https://wadielhudi.com/3d-modeling->



Fig. 2: A view of the 3D model of the King's Chamber, with the epigraphic drawing layered over it.

Although this is one way to navigate the pages, there is also a more traditional list of contents in the sidebar, just below the 3D model. This mirrors the *Table of Contents* page that will be discussed in the Future Development section below, but it is essentially designed to provide a limited selection of links to various other parts of the publication.

The main focus of the prototype is a layered IIIF-compliant viewer⁸ of whatever scene has been selected. Currently, there are three layers to this image: two orthophotos, along with the final epigraphic illustration. One of the photographs is a recently-made full-color orthomosaic image created by Owen Murray; the other is a rectified black and white orthomosaic image made with film photographs from the early 1930s taken by Henry Leichter. The slider in the center allows one to see more or less of either orthophoto by moving it from right to left. Although these are the two images that were relevant to this scene and the epigraphic documentation process in general, any images could be loaded and used in this IIIF viewer, depending on the context of the work (conservation damage mapping, Near Infrared Colour imaging, etc.). Below the image is a slider bar labeled *Illustration* that shows the feature at the root of this project: it allows the user to place the third layer with the epigraphic drawing over the photos. The slider bar controls the transparency of the image, so the user can see a version of the drawing at any degree of opacity over the two photo layers beneath or, by dragging the bar all the way to the right, just the epigraphic drawing on a white background.

at-wadi-el-hudi/]; and of course *Puzzling Tombs*, the AI-driven project based at KU Leuven and presented at the first Ancient Egypt, New Technology conference (Sykora *et al.* 2023, 532-550). For a more comprehensive list of articles on various digital projects, see the Digital Egyptology site [<https://digitalegyptology.org/>]. There are also a large number of projects outside of Egyptology doing innovative work with IIIF, in particular, the work with the Madoc platform (for a useful grouping of projects utilizing this, see the Ghent Center for Digital Humanities [www.gcdh.ugent.be/projects/madoc-iiif-transcription-annotation-and-crowdsourcing-platform]).

⁸ IIIF 2025; for a thorough explanation of the format, see <https://iiif.io/get-started/how-iiif-works/>. Additionally, in this case, we used Open Seadragon [<https://openseadragon.github.io>] and a modified version of the excellent plugin *openseadragon-curtain-sync* [<https://github.com/locomo/openseadragon-curtain-sync>].

There are two other elements of this IIIF viewer that are valuable. The first is the scale bar in the upper left corner, which is helpful for understanding the general sizes of various elements (a direct measurement tool hasn't been implemented yet, but is a possibility). The other is a *Translation and Transliteration* tab, placed just above the *Illustration* slider (Fig. 3). When this is opened, it reveals the translation and transliteration line by line. The particular advantage of this is that when a line is selected, the same line in the drawing is highlighted with a blue box. In a scene with lengthy inscriptions, this can add clarity when searching for a specific section of the text, and, more generally, it could be a valuable aid to those learning to read hieroglyphs.

The transliteration and translation are also given below in a more traditional, text-box format. Included here are the epigraphic and iconographic comments, essentially as they would appear in a print publication. However, one advantage of the digital format is that pop-up footnotes can be easily added so that the user does not have to scroll all the way to the end of the document to see them (although, of course, they are included there as well).

The final element of the original beta site is the *Archive* tab, located just below the inscription viewer. Clicking on this takes the user to a collection of historical images related to the plate — presently, these are limited to the original photos taken for the epigraphic process but could include excavation photos, historical paintings, etc. The current layout for this includes a thumbnail gallery of the images that can be easily scrolled through. Additionally, in this section, there is a *Comments* tab below the selected photo, which, when clicked, shows all of the pertinent metadata for the image (such as the name of the file, location of the photo, photographer, etc.). The basis of this archival gallery is again IIIF compliant, and the system has the potential to aggregate images and datasets hosted via different institutions without infringing on copyright or reproduction permissions.

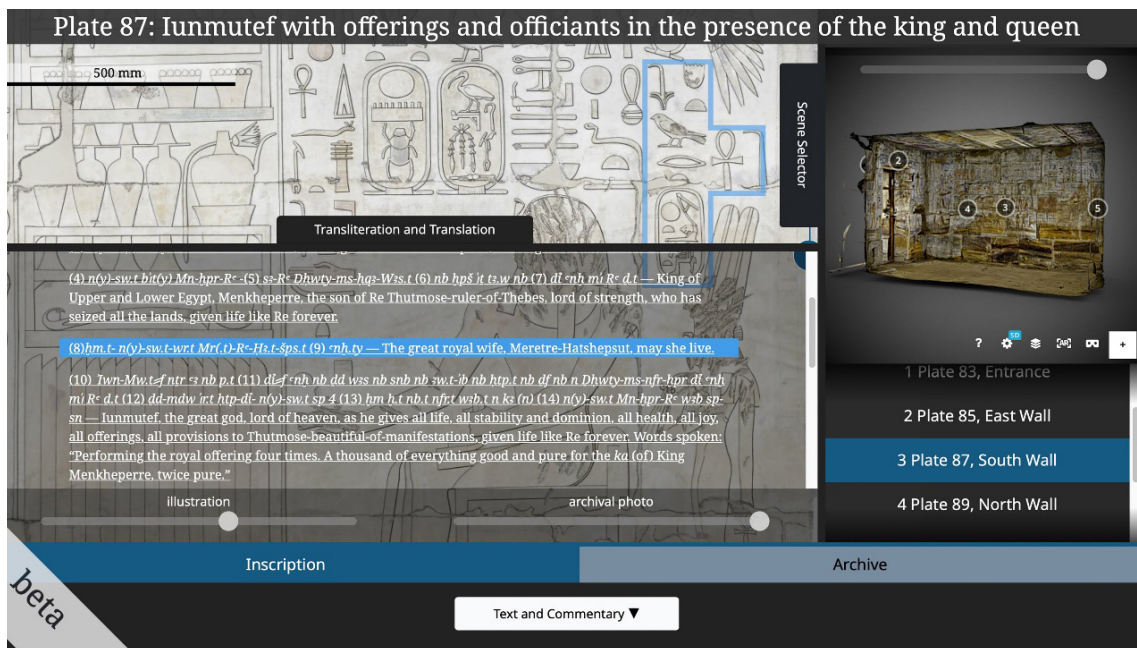


Fig. 3: Plate 87 of the current beta site, showing IIIF image with the epigraphic drawing and with the *Transliteration and Translation* tab selected, highlighting in a blue box one line of the text.

4. Thematic priorities

Throughout the development of the beta site and in future development, there have been two core themes: accessibility and archivability.

Accessibility: This term has a variety of meanings and functional associations, but for this work, the first objective was to create something that was fundamentally easy to use. This means that it has intuitive interactive elements and simple, but multifaceted, navigation. The second was, as much as possible, to apply the standards and guidelines of the World Wide Web Consortium (W3C).⁹ This would ideally include such features as built-in support for screen-readers and other assistive technologies, although such attempts are still very much at a basic level in the beta site. Additionally, the goal is to have full multilingual integration, and while this is not currently implemented, with some of the advances in AI, automatic translation will likely become more realistic in the near future. Finally, in order to make the site as accessible as possible for those who do not have the advantage of fast and stable internet, we aimed to make the site easy to load. Thus, it was a priority to take a 'degrade gracefully' approach to system design from the beginning. For example, the core content of the site is based around plain text description and annotation, large images are streamed, and the 3D model is designed as an expansion to basic navigation tools, such that if it works, it can provide extra information, context, and usability, but is not essential. It was also hosted on a platform with some ability to deliver different quality data depending on the bandwidth capabilities of the person viewing. Many of these goals require considerably more work for implementation, and as such, it is important to constantly circle back to them so that they remain a priority.

Archivability: As is well known, technological solutions can be delicate and time-sensitive, and websites require at least a minimal level of maintenance in order to remain functional, much less updated and renewed as new technologies develop. There are a few ways in which this project aimed to help mitigate this issue. First was having a large institution, such as a university or museum, as the hosting and storage platform. This means that the website is less dependent on the attention of an individual and their ability to keep the site up-to-date. Second was ensuring that the code is future-proofed as much as possible and attempting to minimize the number of dependencies and links to sites that may not be maintained or that do not have stable URLs. Third was only putting data into formats that are commonly used and ideally open source (such as .jpegs, .objs, and plain text), so if systemic changes are made in the way we access data, there will also be systems created to transition that data. One of the most important, but also most challenging, elements of archivability is developing a downloadable offline form of the publication (such as a pdf and accompanying dataset). The primary complication here is the variety of media that would ideally be included in this downloadable version of the digital companion. Although some variety of 2D image is feasible to include along with the text, the layer function used in the beta site is not transferable, nor is a functional, well-integrated 3D model. Obviously, this is an area that is in continuous development

⁹ W3C [<https://www.w3.org>].

with more complex long-term file formats such as OpenUSD¹⁰ and glTF¹¹ increasing in use in recent years.

Currently, the project is centered on other archiving concepts with a focus on the preservation of the scholarly knowledge presented in the site, over the preservation of the site itself. While we can see the content published online as the data = text, models, and images, a considered layout and structured organization still play a part in knowledge construction and communication of ideas, at least for the human audience of this work. Maintaining these relationships in ways that function on and offline still provides a challenge, especially when we consider the greatest strengths of digital publication over traditional print — that of flexibility and updatability. With this in mind, we have looked toward platforms such as Quire, an open-source multi-format publishing tool developed specifically to allow for high-quality, well-formatted print alongside web accessibility.¹² It uses a single set of plain text files and creates a document that does not require maintaining a complicated server. This model of web publishing means that HTML files are static rather than database-driven, which makes versioning, and so referencing, simpler and also less at risk of failure due to changes in technology and has the added benefit of reducing the energy footprint of the website. Unfortunately, integration of the system would require significant investment to implement. Nevertheless, investigating the process did have the benefit of causing a re-assessment of the underlying structure of the text on the site and the adoption of a standard Markdown format, which is gaining in popularity in some academic circles.

Markdown is a markup language based on plain text that also permits simple and limited formatting to be added without too much complexity, i.e., without having to add full HTML tags or CSS style formatting. This has a number of advantages, in particular, that the text remains readable, even in its source code form (in other words, when it is not formatted for a website), and it does not require any paid programs to create content. Another benefit is that it is remarkably easy to learn, and a basic understanding allows the user to be relatively high-functioning with limited time investment.

One final issue of archivability (and also accessibility) is that the current system relies on the Sketchfab API service. While this is a well-established and popular option, now part of the Epic Games family, no service is guaranteed to last in perpetuity. It also brings with it some questions over data sovereignty — where in the world these 3D models are saved, and who has jurisdiction over these servers and by whom the data may be used? The choice to use Sketchfab in the prototype was largely a practical one, as the Epigraphic Survey already hosted data on this service and it provided tools that were needed, though other open source alternatives have been considered and could be substituted in the future.¹³ The rest of the site is based around open-source technologies, so the basic structure would be available for anyone who found it useful for presenting their own work.

¹⁰ Open USD (Universal Scene Description) 2012 [<https://openusd.org/release/index.html>].

¹¹ glTF (a 3D asset delivery format) 2025 [<https://www.khronos.org/glTF/>].

¹² Quire [<https://quire.getty.edu>].

¹³ For example, Google's 3D Model Viewer would essentially allow institutional self-hosting of the 3D model content, in the same way that the IIIF servers work with 2D images.

5. Future development

One of the primary areas of future development is a plan for the overall structure of the website — essentially, what the 3D publication of an entire monument or site might look like and how it could be navigated. A large part of the process thus far has been identifying priorities, and simplicity has been our mantra. One of the best ways to future-proof the site is to keep it as simple as possible — focusing on content with meaning over fancier features that may require more time, resources, updates, and maintenance. Of equal import is maintaining a consistent aesthetic and layout for the site that reinforces its core objectives, and that of the Epigraphic Survey's origins, without sacrificing a clean and functional experience for the user. In the same manner that the medium of book publication forces one to make choices about source material, so it is true of digital publication. These are not decisions to be arbitrarily made, or as is more often the case, driven by technology alone, but rather, intentional and considered choices that underscore the interrelatedness of digital publication with traditional print publications.

The current mocked-up plans for the overall flow of the site are still based on the original beta site but with a number of modifications. The launch page in the next iteration would essentially be the cover if this were a physical book, so it is designed to look like a combination of the front pages of the book. From here, the user would click on a *Table of Contents* button, which would be the only interactive element, making the navigation path clear. This would lead to the *Table of Contents* page, which would include a complete 3D model of the area covered by the volume at the top of the page. The user could interact with this page in a few ways, the first of which would be by clicking on letters on the model, similar to what is currently possible on the beta page. Alternatively, if the user scrolled down, they would also find a more traditional layout, very similar to the one in the book version. There is one modification to this part: since there are a lot of plates in each volume, it seemed useful to add a subhead for each chamber (already given names and identification letters in the original volume). In the traditional *Table of Contents* section, these can simply be clicked to see the list of plates in that chamber. However, this also ties in well with the organization inherent in the 3D model, so each chamber in the model can be selected to be taken to the same list of plates for the chamber (Fig. 4).

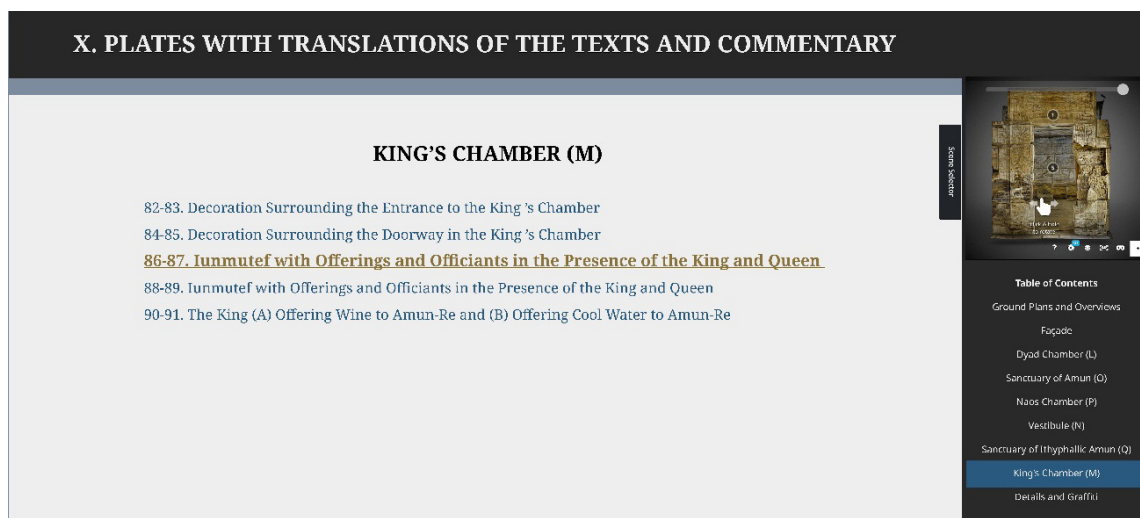


Fig. 4: The King's Chamber section of the proposed future *Table of Contents* page, showing the modified Scene Selector at the right.

There would be three primary types of pages: those with the front matter (the lists, concordances, and essay format material), those with IIF images (the plates with translation and commentary in the analog book), and the glossary. On the right side of each page, these would have the unifying element of a modified version of the *Scene Selector* navigation panel. This would still be hide-able by clicking on the tab and have the 3D model at the top with links to the different pages below, but it would also follow the user as they scrolled down the page, making it easy to jump to another section without having to return to the top of the page. Additionally, the *Table of Contents* link would always be present at the top of the list, making returning to that primary point of navigation quick and easy, and the page that the user was currently on would be bolded and in a different color, so they would always know where they were in the publication.

The front matter would be very similar to the analog versions, with only a few modifications in format. For example, the preface would have a standard text layout, but would also benefit from added features, such as clickable footnotes (Fig. 5). Where useful, the lists (such as the List of Figures) would have links to the pages they reference. The plate pages would all have the same layout as in the current iteration of the beta site (with a few minor aesthetic modifications). The glossary page would reflect the layout of the lexicon of ancient Egyptian terms in the more recent print versions of the Epigraphic Survey volumes. This includes most of the ancient Egyptian words found in the plates in transliteration and could be enhanced in the digital format by having clickable links to the plate on which the Egyptian words appear.



Fig. 5: A section of the Preface from *Medinet Habu IX*, showing the clickable footnotes, the modified Scene Selector, and the proposed citation formatting.

With this mock-up, the aim has been to develop a site design that is simple and has a clear association with the original material, but would also allow for flexibility and future development. In this process, a number of complicated issues have become evident,

but one of the more challenging is how to design a functional citation methodology, particularly for the translation and commentary or the essays, most of which are at least moderately long. In one of the early attempts, which can still be seen on the beta site, Roman numerals were employed; however, after working through the flow of the overall site, it became clear that this was not the most useful place to add further numbers. Fortunately, at the Ancient Egypt, New Technology conference in Naples, there was an excellent talk by Federico Poole on the digital publication of *Rivista del Museo Egizio*, and he addressed their system for citation. Inspired by this, the proposed structure for the epigraphic digital companion is to have the page number from the book noted in brackets in the line with the text where the page break would have occurred in the physical copy. Additionally, a list of the pages in the section is available in the *Scene Selector* panel so that it is easy to jump to a specific page if looking up a citation identified in another source (Fig. 5).

Thus, the modifications we think would be advantageous cover a broad range of areas from aesthetics to functionality, and although it has not yet been possible to implement these on our original beta site, we remain optimistic that such future work will be possible.

6. Conclusion

Overall, the current beta site is best considered as an exploration of design approaches set against the prevailing backdrop of a rapidly (and sometimes rabidly) changing technological landscape. Systems for managing complex 3D data of historical buildings (HBIM¹⁴) and VR experiences for the public are well-established, but dynamic output that satisfies the requirements of traditional scholarly output is still an area of development.¹⁵ This project was begun during the Covid pandemic, and we have since seen the explosion of AI systems. These include Large Language Models that may simplify multilingual functions, improved computer vision and image recognition tools that can enrich image search-ability and association, as well as developments in 3D data processing and presentation, such as automated BRDF¹⁶ acquisition and NeRFs¹⁷ that may provide richer ways to interact with source data and new levels of complexity to the data we would like to publish in the years to come. All of these features, and undoubtedly others that have yet to be developed, will significantly impact the future of digital publication, so we feel the best approach to the development of a site such as this is to remain flexible and open-minded about any possible advancements.

Thus, it is our hope that the themes and ideas underpinning this digital publication prototype and our collaboration inspire others in their efforts and explorations of how

¹⁴ Heritage Building Information Modelling; see, for example, Penjor *et al* 2024.

¹⁵ See, for example, the PURE3D project [<https://pure3d.eu/about/>] and Dynamic Collections [<https://www.darklab.lu.se/digital-collections/dynamic-collections/>].

¹⁶ Bidirectional Reflectance Distribution Function – a mathematical model of how light reflects of a surface, allowing for a more detailed model of a surface, which may provide additional meaningful information to the epigrapher. See, for example, Chitnis *et al.* 2025.

¹⁷ Neural Radiance Fields – a deep learning technique that allows for new views to be synthesised. In contrast to ‘conventional’ 3D reconstruction, this technique also models the complex interactions of light with a surface, resulting in more realistic scenes. See, for example, Mildenhall *et al* 2020, 405–421.

3D datasets can find meaningful publication alongside traditional 2D print publications that are both purpose-driven and sustainable.

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Online Resources

CHI	https://culturalheritageimaging.org/Technologies/RTI/
Digital Egyptology	https://digitalegyptology.org/ .
DigitalEpigraphy	https://www.digital-epigraphy.com
Digital Giza	http://giza.fas.harvard.edu
Digital Karnak	https://digitalkarnak.ucsc.edu .
Dynamic Collections, Lund University	https://www.darklab.lu.se/digital-collections/dynamic-collections/
The Ghent Center for Digital Humanities	www.gcdh.ugent.be/projects/madoc-iiif-transcription-annotation-and-crowdsourcing-platform

IIIF	https://iiif.io/
Open Seadragon	https://openseadragon.github.io
Openseadragon-curtain-sync	https://github.com/locomo/openseadragon-curtain-sync
Pure 3D	https://pure3d.eu/about/
Quire	https://quire.getty.edu
The Theban Mapping Project	https://thebanmappingproject.com
The Wadi el Hudi Expedition	https://wadielhudi.com/3d-modeling-at-wadi-el-hudi/
W3C	https://www.w3.org

Appendix

Programme of the International Conference *Ancient Egypt – New Technology (2nd Edition)* DAAM UniOr Naples, 5-7 July 2023

Keynote lectures

- *Archaeological data and digital society.* Andrea D'Andrea
- *TT8 Project: Decoding the materiality of the intact grave goods of Kha and Merit (Egypt, ca. 1400 BC).* Enrico Ferraris
- *Faces Revealed Project (MSCA: 895130). Discovering the concealed. Photogrammetry as a 'key tool' for studying anthropoid coffins.* Stefania Mainieri
- *A multidisciplinary and innovative approach: the case of the Aga Khan Necropolis at Aswan.* Patrizia Piacentini
- *The contribution of the immaterial realm to the study of the material culture.* Corinna Rossi
- *Digital trends in the study of Egyptology.* Stephen Vinson & Gabriele Guidi

Wednesday 5th July 2023

Session 1/ Texts (Chairman: Stephen Vinson)

- *A glossary of ancient zodiacal terms.* Christian Casey
- *OCR-PT-CT: proof-of-concept project on OCR applied to hieroglyphs from the earlier Egyptian mortuary texts.* Carlos Gracia Zamacona
- *Aligning encoded hieroglyphic and translated words with Needleman-Wunch Algorithm.* Heidi Jauhiainen

Session 2/ 3D modelling (Chairman: Gabriele Guidi)

- *Digital and cultural study of terracotta figurines in Egyptian Collections. The Project SUR. VI.V.E. – Phases 1-2.* Clementina Caputo, Alessandro Mandelli
- *Underwater archaeology in Alexandria-Egypt: New methods for documentation through the use of three-dimensional technology.* Mohammed Abdelaziz, Mohamed Elsayed
- *Imag(in)ing Egyptology: the Bologna Coffin Project.* Andrea Pasqui, Daniela Picchi

Session 3 / Fieldwork (Chairman: Corinna Rossi)

- *The Abu Ghurab landscape: from total Station to GIS and GPR.* Marco Anzalone, Emanuele Brienza
- *Database and burial containers from the Old Kingdom and First Intermediate Period.* Marie Peterková Hloučová, Věra Nováková
- *Reconstructing ancient monuments: from excavations to BIM. The study case of the Sun Temple of Niuserra at Abu Ghurab.* Patrizia Zanfagna, Massimiliano Nuzzolo

Thursday 6th July 2023

Session 1/ Chemical and Imaging Techniques (Chairman: Patrizia Piacentini & Maria Diletta Pubblico)

- *A Ptolemaic mummy from Akhmim: the first case of fatal mastoiditis and the ancient physician's treatment.* Dina Faltings, Roman Sokiranski
- *Chemical investigation on organic and inorganic materials present on the five cat mummies of the Società Africana d'Italia.* Maria Diletta Pubblico, Leila Birolo, Alessandro Vergara
- *From macro to micro: pottery production in Predynastic Heliopolis.* Federica Ugliano, Silvia Amicone, Jade Bajeot, Vanessa Forte, Giulio Lucarini
- *An Egyptian mummy of the Roman Period with a painted shroud: a multy-analytical study of its technical features.* Daniela Picchi, Paola Buscaglia, Anna Piccirillo, Roberta Genta, Federica Pozzi, Michela Cardinali, Marco Samadelli, Alice Paladin, Claudia Caliri, Francesco Paolo Romano, Claudia Conti, Costanza Miliani
- *Analysis and comparison of two Middle Kingdom wooden statuettes from the tomb of Minhotep, Asyut.* Nicole Manfreda, Luisa Vigorelli, Paola Buscaglia, Paolo Del Vesco, Tiziana Cavaleri, Marco Nervo, Sabrina Grassini, Laura Guidorzi, Alessandro Re, Alessandro Lo Giudice.

Session 2/ Artificial Intelligence & Virtual Reality (Chairman: Andrea D'Andrea)

- *Artificial Intelligence for Egyptology.* Heleen Wilbrink
- *A digital archive for religious texts from the Nile Valley and beyond.* Federico Maria Avano, Angela Bosco, Andrea D'Andrea, Gilda Ferrandino, Zied Mnasri
- *"Sekhmet Project". Research and development of innovative investigative methods.* Alessia Amenta
- *Integrating virtual heritage projects in educational curriculum: the case of Reviving Karanis in 3D.* Eiman Elgewely
- *Virtual reality as "Virtual Traveling": re-imaging the sarcophagi of Psametek and Padinese in their 26th Dynasty tombs in Saqqara.* Elaine Sullivan, Rita Lucarelli, Matthias Lang, Eiman Elgewely

Friday 7th July 2023

Session 1/Museum and Public Engagement (Chairman: Enrico Ferraris)

- *Predynastic lithic production at Heliopolis, Egypt: new light on a forgotten Museum Collection.* Adelaide Marsilio, Francesca Manclossi, Donatella Barca, Mohamed Hamdan, Federica Ugliano, Giulio Lucarini
- *An Online-Only publishing experience: the Rivista del Museo Egizio.* Federico Poole
- *The Palermo Stone and its associated fragments. New technological approaches to old data.* Massimiliano Nuzzolo, Celestino Grifa, Vincenzo Morra, Salvatore Schiavone, Maria Francesca Alberghina, Chiara Germinario, Mohamed Osman
- *Digital heritage and community-engaged research.* Willeke Wendrich

Session 2/ 3D modelling (Chairman: Stefania Mainieri)

- *The role of laser scanning and photogrammetry in investigating geographical provenience and regional craftsmanship: graeco-roman cartonnage from the Egyptian Western Desert.* Carlo Rindi Nuzzolo
- *3D visualization of fourth-century Christian monuments and archaeological sites of Egypt.* Victor Ghica, Mohamed Abdelaziz
- *Breathing new life into ancient fragments: 3D models and automated reconstructions of private statuary from Qau el-Kebir.* Tommaso Montonati, Federico Taverni

Session 3/ Documentation & Digital Publications (Chairman: Stefania Mainieri)

- *The King's Chamber: a digital publication prototype.* Ariel Singer, Murray Owen, Pantos Alexis
- *Insights of the Egyptian artists: documenting Theban funerary painting in situ. A new approach.* Vivas Sainz Immaculada, Gema Menendez
- *Documenting stone structures in the west bank of Aswan (Egypt): from mobile 3D recording to GIS spatial analyses.* Facciani Sara, Alessia Brucato, Alberto Urcia, Antonio Curci, Maria Carmela Gatto

Poster Session

- *Anthropological and radiological results from the Aswan Necropolis near the Aga Khan III Mausoleum: the Eimawa experience.* Carmelo Messina, Patrizia Piacentini, Alice Tomaino, Lucie Biehler-Gomez.
- *Bringing colour back to the page: publishing polychrome palaeographies of Egyptian Manuscripts.* Marina Sartori
- *The Nag El- Hamdulab interactive hyperbook: a new way of communicating egyptological research.* Alberto Urcia, Alessia Brucato, Antonio Curci & Maria C. Gatto.



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