THE VIRTUAL HORN: DIGITAL STRATEGIES FOR THE DOCUMENTATION AND DISSEMINATION OF THE ARCHAEOLOGY OF THE HORN OF AFRICA

El Cuerno Virtual: Estrategias digitales para la documentación y difusión de la arqueología del Cuerno de África

JORGE DE TORRES RODRÍGUEZ *,
MANUEL ANTONIO FRANCO FERNÁNDEZ *,
PABLO APARICIO RESCO ** y JORGE ROUCO COLLAZO *

ABSTRACT The StateHorn project aims to understand, from a multidisciplinary perspective, the origin and consolidation of the medieval Muslim states of the Horn of Africa, to compare its stability between the 11th and the 16th centuries, in contrast to the current tensions throughout the region. To deal with a complex scenario that includes several countries, different academic traditions and languages, the StateHorn project has developed a series of strategies and tools to document and integrate archaeological and archival information into resources. This paper presents three of these strategies used in our research. The first one is the Ibapp Beta software, a mobile application designed by one of the members of the project to collect field data from different contexts, linking photographs, GPS data and archaeological information. The second one is the virtual reconstruction, applied to the case study of a medieval mosque from Somaliland using old archive photographs, photogrammetry and archaeological and ethnographic information. Finally, a third strategy will address the reconstruction of the plan for the town of Amud, a medieval town now disappeared but where some old aerial photographs of the 1930s. Combined with orthophotos and satellite images, it has been possible to reconstruct the urban layout of this important but extremely damaged site.

Keywords: Horn of Africa, Remote Sensing, Digital Reconstruction, Historical Photographs, Mobile Applications, Photogrammetry, Satellite Imagery.

* Instituto de Ciencias del Patrimonio (INCIPIT), Consejo Superior de Investigaciones Científicas, Edificio Fontán, Bloque D, Monte Gaias s/n, 15707 Santiago de Compostela (Spain).
jorge.detorres-rodriguez@incipit.csic.es https://orcid.org/0000-0001-8687-9332
manuel-antonio.franco-fernandez@incipit.csic.es
jroucocollazo@gmail.com https://orcid.org/0000-0002-9111-397X
** 3D Stoa – Patrimonio y Tecnología.
pablo.aparicio@3dstoa.com https://orcid.org/0000-0003-0752-7027
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RESUMEN El proyecto StateHorn busca entender, desde una perspectiva multidisciplinar, el origen y la consolidación de los estados medievales islámicos del Cuerno de África, para comparar su estabilidad entre los siglos XI y XVI con las actuales tensiones en la región. Para manejarse en un complejo escenario que incluye varios países, diferentes tradiciones académicas y lenguajes, el proyecto StateHorn ha desarrollado una serie de estrategias y herramientas para documentar e integrar datos documentales y arqueológicos. Este artículo presenta tres de las estrategias usadas en nuestra investigación. El primero es el programa Ibapp Beta, una aplicación móvil diseñada por uno de los miembros del proyecto para recoger datos en campo en diferentes contextos, añadir fotografías, datos GPS e información arqueológica. El segundo es la reconstrucción virtual, mostrada con el caso de estudio de una mezquita medieval de Somalilandia, empleando antiguas fotos de archivo, fotogrametría y documentación arqueológica y etnográfica. Finalmente, una tercera estrategia se aplica en la reconstrucción de la planimetría del asentamiento de Amud, una villa medieval ahora desaparecida, pero con algunas fotografías aéreas de la década de 1930. Combinándolas con ortofotos e imágenes satelitales, ha sido posible reconstruir el trazado urbano de este importante yacimiento, pero muy dañado.

Palabras clave: Cuerno de África, Teledetección, Reconstrucción digital, Fotografías históricas, Aplicaciones móviles, Fotogrametría, Imagen satelital.

INTRODUCTION

There is little doubt that the advances in digital technologies applied to archaeological research have revolutionized the ways archaeologists do their job, store their data and even think about their discipline. From photogrammetry to LIDAR, from 3D reconstructions to cloud storage, digital practices have become so imbricated within the archaeological work that have reshaped the way we approach our profession (Remondino, 2011; Remondino and Campana, 2014; Crutchley, 2015; Carreño *et al.,* 2024; Martínez *et al.,* 2024). Although this revolution has also been accompanied by serious challenges related to data curation and storage (Anderson, Torres and Galvin 2018), it is undeniable that digital techniques of data acquisition have opened a new era of archaeological practice around the world. This is especially true in the case of archaeological work in remote areas, where digital technologies have made it possible to overcome serious logistic challenges that decades ago severely biased the acquisition and management of data (Karauck *et al.,* 2021). This paper analyses the specific case of the fieldwork conducted in the Horn of Africa since 2015 by a team of the Institute of Heritage Sciences of the Spanish National Research Council (INCIPIT-CSIC). It will analyze how several digital strategies have been implemented to deal with the challenges the team has found throughout the years while conducting research in the region (fig. 1).

The work of INCIPIT staff in different areas of the Horn of Africa started as early as 2001, with research being conducted in the regions of Gondar (Fernández *et al.*, 2017), Beni-Shangul (González-Ruibal, 2014) and Gambella (González-Ruibal *et al.*, 2014), all areas located to the north and west of Ethiopia. In 2015, research moved to Somaliland, where different projects were conducted until 2020 (de Torres, 2022). In 2021 research was extended to Djibouti, and in 2020 part of

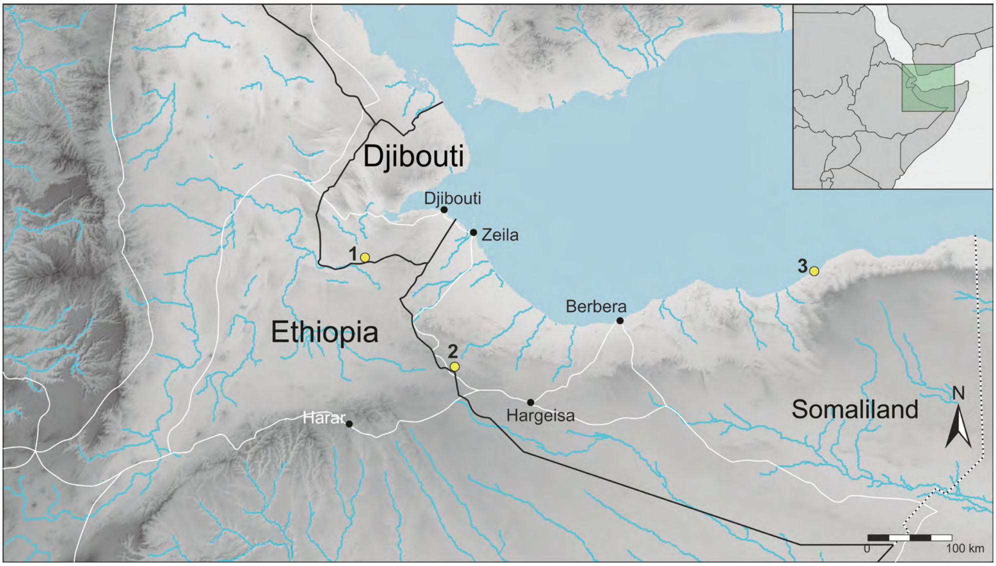


Fig. 1.—Map of the region studied by the Incipit team with the location of the three sites presented in the paper: 1, Handoga; 2, Amud; 3, Xiis.

the team started research in Ethiopia, close to the Somaliland Ethiopian border. So far, a total of twelve campaigns have been conducted in Somaliland, Djibouti and Ethiopia, and the INCIPIT project is currently the most enduring project ever launched in the territories occupied by the Somali. Through the years, research has been progressively focused on two historical periods —Antiquity and Medieval archaeology— and in 2020 a new project —StateHorn— was launched to study the medieval Muslim states of the Horn of Africa. Funded by the European Research Council (ERC) and the Galician Innovation Agency (GAIN), this project will continue research in the region until 2029, making of the INCIPIT research in the region one of the longest archaeological research initiatives in the Horn of Africa.

Since its beginning in 2015, the research conducted by the INCIPIT teams in the east of the Horn of Africa has faced two major issues in building a coherent, solid corpus of data (Gutiérrez de León, 2022:19). The first one is directly related to the logistical challenges of recurrently working in areas with poor infrastructures, difficult physical access, lack of basic services and sometimes unstable environments. These challenges have a direct impact on the ways research is conducted: an intensive acquisition of information is prioritized as it is very difficult to return to the sites to correct or improve the data sets. In many cases, the lack of electricity to recharge batteries for drones, cameras or laptops makes it necessary to maximize the ways information is acquired and managed.

While these logistic problems are shared with many archaeological projects around the world, the second challenge faced by the INCIPIT team has deeper roots, which have to do with the history of the Horn of Africa and the artificial borders created during the colonial period in the 19th century. The division of the territory occupied by the Somali into five different territories (Kenya, Ethiopia, and the French, Italian and British somalilands) set the foundations of political instability and conflict until today. Wars, *coups d'etat*, famines and other episodes have seriously prevented the development of long-term strategies —although they existed, if weak, since the 1970s (de Torres, 2018). Moreover, the impact of the colonial borders has reached far beyond the political and physical separation of the communities: it has seen the development of independent research traditions rooted in markedly different colonial occupations, using distinctively different research strategies and with information published in several different languages (Italian, English, French, Russian or German). Also, historical documentation is scattered through different museums and institutions outside Somalia, in countries such as United Kingdom, France, Italy or Kenya. This fragmentation has biased our understanding of the historical dynamics that took place in the region, limiting the collaboration and integration of archaeological data. Despite these problems, there is still a significant amount of information that can be used to improve our knowledge.

This paper presents three initiatives developed and implemented by the INCIPIT team in different regions of Ethiopia, Somaliland and Djibouti in the last five years. They have been used in radically different contexts, with the combination of several methodologies and aiming for different goals. However, they all share a common objective: to recover, process and integrate as much information as possible from archaeological or archival contexts with severe restrictions on the access of information.

DOCUMENTING THE HORN: IBAPP

One of the main logistic challenges faced by INCIPIT teams while working on the field is related to the temporal restrictions imposed by the remote areas where the fieldwork is conducted. Many of the campaigns consist of surveys where sites are identified for the first time and are usually documented for one or two days at the most (de Torres, 2022). In some cases, the team has only several hours to collect as much information as possible about the site, including plans, photographs, 3D models and notes of the main architectural and archaeological features, and a sample of archaeological materials. These time constraints have led to the development of a well-oiled system that relies on the use of digital technologies which allows the fast collection of data that can be easily integrated into a single database. One of these technologies is Ibaap, a mobile application specifically designed by one of the authors of this paper (Manuel Antonio Franco) to collect archaeological data on the field and to build inventories that combine archaeological, photographic and GPS data[1]. Ibapp has been recurrently used in different archaeological contexts

1. The Ibapp app is open access and can be downloaded here: http://www.ibappbeta.eu/inicioI.html

from Somaliland, Ethiopia and Djibouti to document archaeological materials and different types of archaeological features, providing a fast, mobile-based tool to gather and organize information[2].

Ibapp is organized around three key layers of information: a "project" upper level which corresponds to the upper level of data and usually relates to an archaeological site, sector, trench or materials' sample. A second organizing level corresponds to the categories, that is, the different criteria selected to document and organize the concrete archaeological features of each project. These categories are prepared in advance and therefore can be adapted to the specificities of the site or sample studied and the availability of time to document it. Finally, a third level corresponds to the data themselves, which are introduced according to the different categories set. The fact that Ibapp is managed from the mobile provides great flexibility in preparing and modifying the categories, adapting them to the real situation on the field and the availability of time and resources[3]. An important asset of Ibapp is its ability to incorporate photographs, videos, voice and written notes and GPS coordinates into the dataset: it even allows to drawing of simple sketches on photographs to differentiate specific parts of archaeological features or strata, facilitating the understanding of the collected data (Franco, 2018:21). It also offers the possibility of linking the data to Google Maps or similar web services. Of course, the quality and availability of these additional data depend greatly on the characteristics of the mobile used for the recording and the context in which the data are collected: in many areas of the Horn of Africa internet access can be tricky and therefore GPS coordinates and links to Google Maps can be unreliable. Despite this, Ibapp offers a flexible and comprehensive solution for the documentation of archaeological data in contexts where time is one of the key limiting factors.

In the case of the INCIPIT team, the fact that archaeological sites studied correspond to three or four types (cairnfields, medieval settlements, cemeteries, etc.) has led to the implementation of "site templates" that can be quickly adapted to the specific features of the site that is studied at any moment. In this paper, we present three brief examples from Somaliland and Djibouti which show how Ibapp has been adapted to the different archaeological contexts from the region, which type of information has been collected and how it has been integrated into the general data management of the archaeological sites. Rather than describing the results of the research, these cases aim to show the range of possibilities that Ibapp offers and its potential to manage different levels of information. The first case comes from the site of Fardowsa, a medieval town located in central Somaliland,

2. The minimum requisites of the smartphones to run Ibapp are Android 9 or superior and 500 MB of RAM memory. The storage used by the app varies on the projects, specially when photos and videos are taken with the app. If it is not the case, the app works with plain text (.txt) with minimum storage necessities.

3. With the current version of Ibapp app, it is not possible to work simultaneously with several devices on the same Ibapp project. Therefore, for several archaeologists recording in the same project, will be necessary manually merge the final data.

close to the contemporary village of Sheikh, 60 km south of the important coastal town of Berbera. The site (and Sheikh now) is located at the exit of a strategic mountain pass that connects Berbera with the interior of Somaliland and the Haud plains, and was one of the major stops in the trade routes between the 13th and the 16th centuries (de Torres *et al*., 2022). The place was briefly visited in 2001 by the archaeologists François Xavier Fauvelle-Aymar and Bertrand Hirsch (Fauvelle-Aymar *et al*., 2011:41), but it wasn't until 2015 when comprehensive research on the site started, including two test pits conducted in 2016 and a large excavation in 2020 (de Torres *et al*., 2020).

One of the characteristics of Fardowsa is the variety of archaeological materials that can be found in the different buildings and layers, especially imported materials which confirm the idea of the town as one of the major trading centres in Somaliland. During the 2020 campaign, an Ibapp project was designed to document the materials that appeared in the most relevant strata. This project included inventory information about the materials, the topographical coordinates and strata in which the objects were documented, and photographs of the pieces taken with the mobile. For the categories, two different levels were established: a first, higher level describing the type of material and a second one describing the characteristics of the different pieces, if necessary. These categories were defined following the previous experience of the INCIPIT team in Fardowsa and other medieval sites in Somaliland, and therefore it was a comprehensive summary of the material culture of the site which can be extrapolated to any other medieval site with little effort. The results can be seen in figure 2, which shows the different levels of the database, from the project to the type of piece found. The result is a database that not only is systematic but also relates the materials to their stratigraphic position and incorporates a photograph that provides basic information about the archaeological context in which the object was found.

The second case study refers to one of the most common types of sites found in Somaliland, the cairnfields which are ever-present throughout the territory (González-Ruibal *et al*., 2017b). These types of sites are characterized by high variability in types and shapes, a variability which likely obeys territorial and chronological parameters although it is not fully understood. In 2018 and 2019, the INCIPIT-CSIC team had to approach the study of the cairnfield of Xiis, a site situated on the eastern Somaliland coast close to the village of the same name (fig. 3). It is an extensive cairnfield of more than 300 structures lying at the foot of Majilin Hill, a steep, long escarpment about 145 meters high that runs north-south parallel to the coast and then turns to the east (fig. 1). Xiis was documented as early as 1881 by Georges Révoil (1882), but it wasn't until the 1970s that the site was briefly revisited by Neville Chittick during a survey along the coast of Somalia (Chittick, 1979). Fieldwork wasn't resumed until 2018 when the INCIPIT team visited the site, and in 2019 a full field campaign was undertaken, one of whose objectives was to the identification and cataloging of all tumuli in the main cairn field (de Torres *et al*., 2019; Fernández *et al*., 2022; González-Ruibal *et al*., 2017a, 2022).

This cataloguing was based on a combination of drone flights and inventorying through Ibapp, and required a more complex organization of the information than

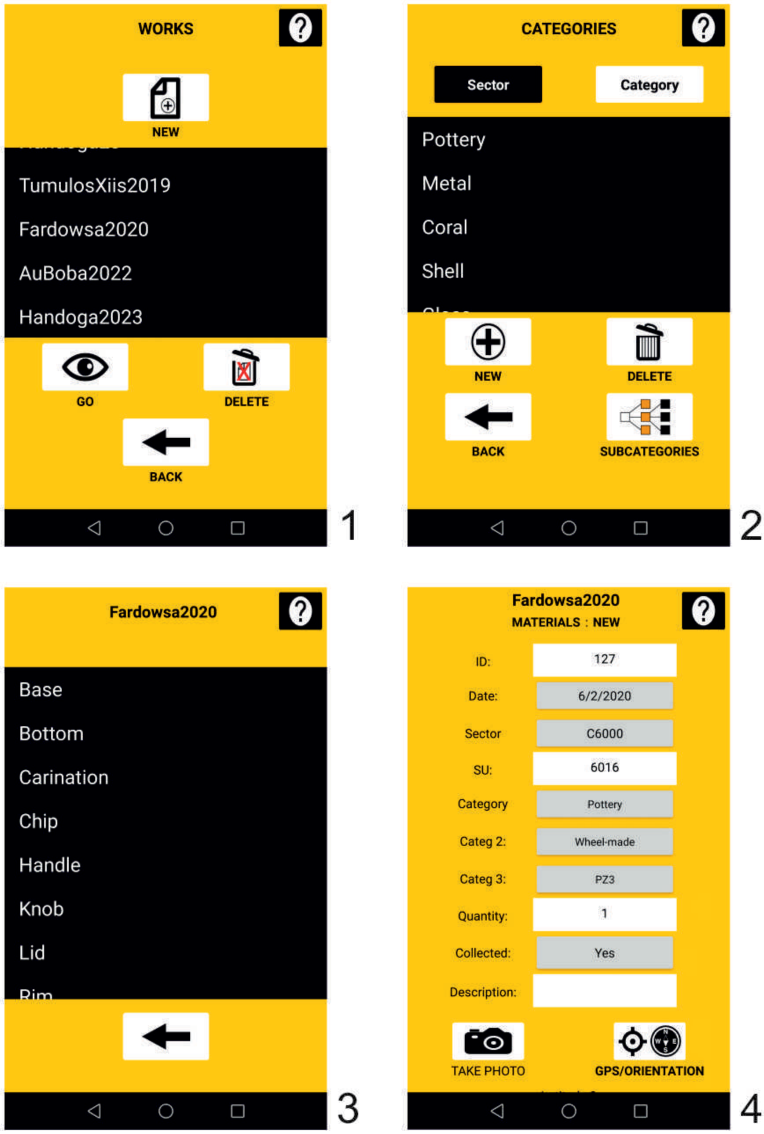


Fig. 2.—Interfaces of the Ibaap project developed for Fardowsa indicating: 1, Project; 2, Type of materials; 3, Parts of pottery; 4, Individual entry.

the previous project, given the high number of categories considered during the inventory of the structures. To do so, a list of categories with the different options was prepared, including Yes/No categories such as "looted", or categories described with a number (1-4) for different types of stones. As the Ibapp display has a limited number of categories, the "description" space was used to include a line of answers to the different categories, separated by commas, which will appear in the project .txt

Fig. 3.—View of Xiis cairnfield seen from the Majilin hill.

file once it is downloaded (see fig. 4). This text file can be then exported into an Excel document where a full analysis of the results can be conducted. The database for the Xiis cairn field is one of the most complex designed for Ibapp, and has been fundamental for a proper analysis of the site (González-Ruibal *et al.*, 2022)

The last case comes from the medieval settlement of Handoga (Djibouti) (fig. 1), a site where the INCIPIT team started working in 2021 (Torres *et al.*, 2023) following research made in the 1970s-1980s by French archaeologists (Grau 1979a, 1979b; Gutherz *et al.,* 2007; Cauliez and Gutherz, 2020; Cornax-Gómez, 2023). Following a brief survey in 2021 and an excavation in 2022, a systematic documenting of all the structures started in 2023, including the extensive cemetery to the south of the site with a wide variability of types of tombs (fig. 5). A specific project was developed with Ibapp to document the tombs systematically, using mobile photographs and drone flights. A typology was built based on the information collected during the surveys, which included seven main categories corresponding to the main types, with additional subtypes in some cases (fig. 6). The inventory of the funerary structures was complemented with individual photographs taken with the mobile, and with drone flights which helped to identify each structure and provide accurate coordinates for each tomb. The project is still ongoing but once finished, it will allow a fast —the first two hundred tombs were documented in three days— and accurate control of the hundreds of tombs of Handoga cemetery, while classifying the tombs at the same time.

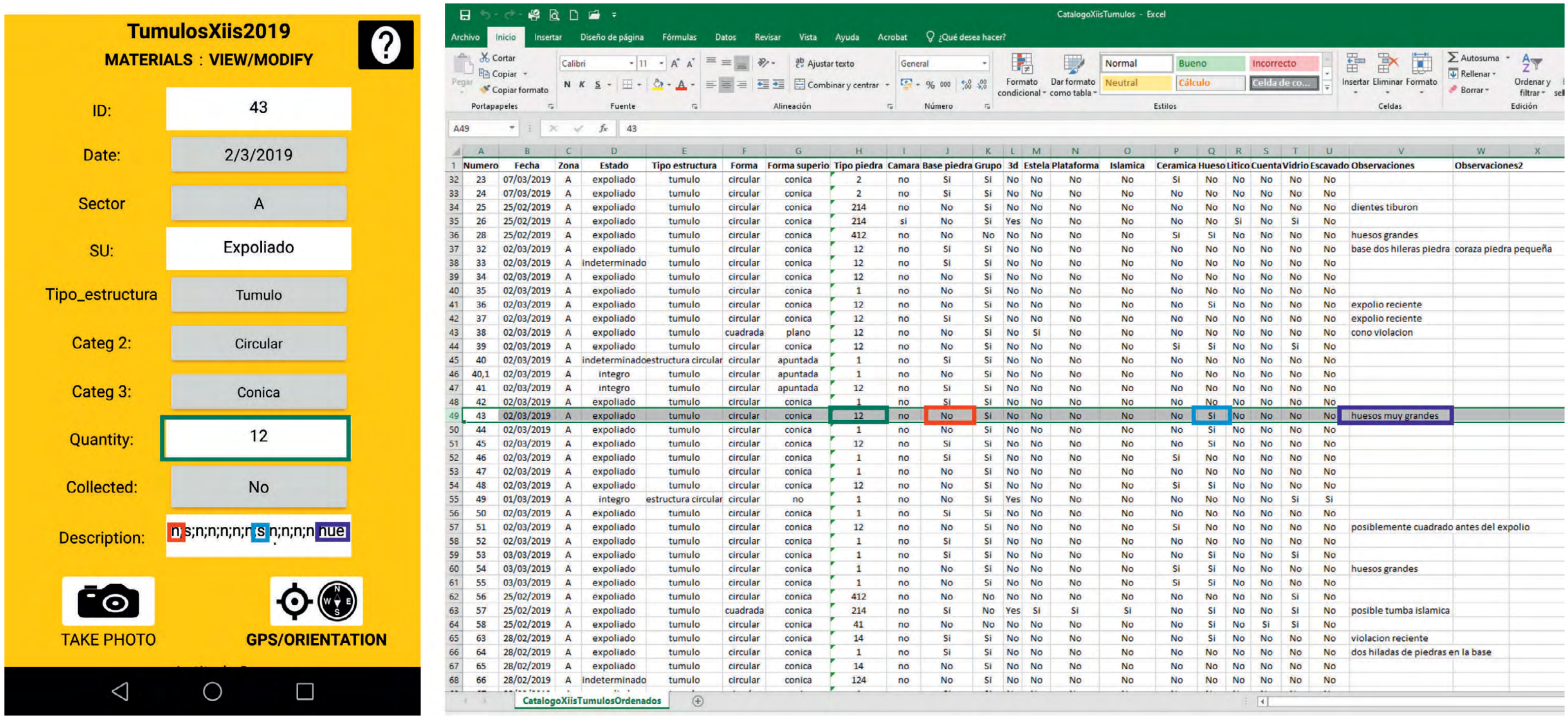


Fig. 4.—Interface of the Xiis database, with the Excel file and some categories marked.

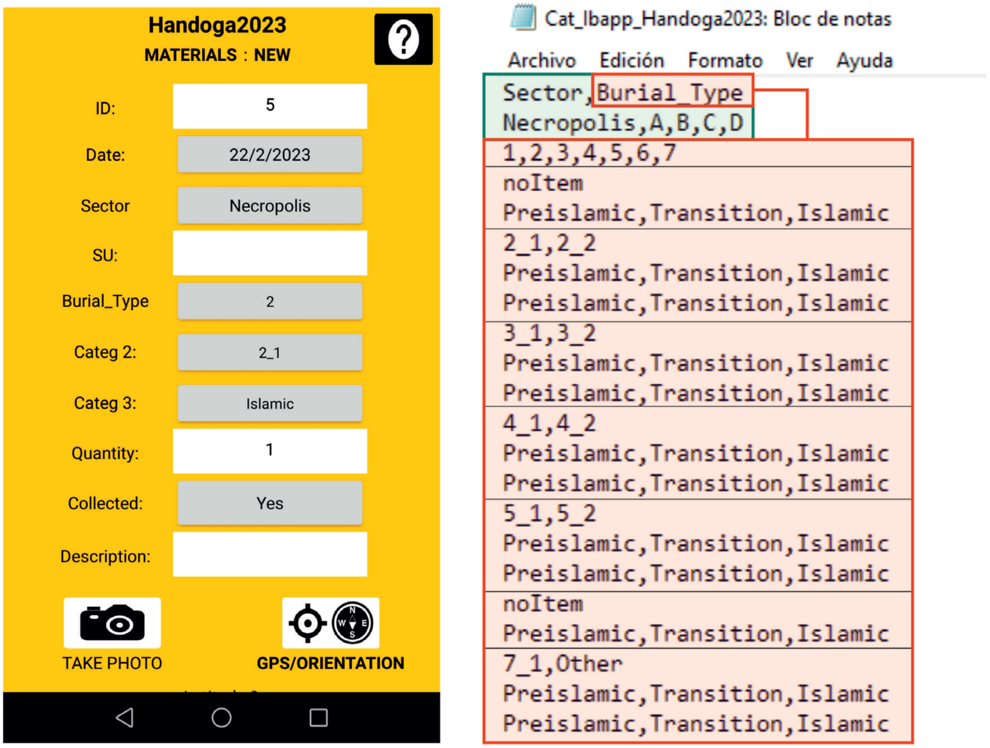
Fig. 5.—View a tomb at the Handoga cemetery. Specifically, it is a cairn with flatslab cist, stelae and an outer stone ring.

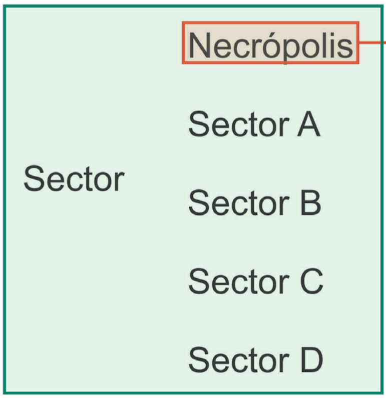
In the last five years, the Ibapp application has proved its usefulness in different archaeological contexts throughout the Horn of Africa, allowing fast and comprehensive documentation of archaeological materials and structures. It has been especially useful in contexts where the main characteristics of the site are already known (and therefore, the project can be created before the archaeological work). When combined with drone flights, it can provide accurate and rich basic information about newly discovered archaeological sites, setting the foundations for further research (González-Ruibal *et al.*, 2017:154-155). Some of the most complex aspects of the app —such as the organization of hierarchies in the .txt files— are currently being addressed to generate a more intuitive way of organizing categories and data options. It is also noteworthy the capacity of integration of the app whit geodatabases thanks to these outputs in .txt files with geographic coordinates, very useful in Archaeology (Mafredas and Malaperdas, 2021).

THE MEDIEVAL MOSQUE OF ABASA

The project

One of the most common misconceptions about the archaeology of the Somali territories is that the archaeological research has been extremely poor and grew in





Burial type	Burial subtype	Cronology
1		Preislamic, Transition, Islamic
2	2_1	Preislamic, Transition, Islamic
	2_2	Preislamic, Transition, Islamic
3	3_1	Preislamic, Transition, Islamic
	3_2	Preislamic, Transition, Islamic
4	4_1	Preislamic, Transition, Islamic
	4_2	Preislamic, Transition, Islamic
5	5_1	Preislamic, Transition, Islamic
	5_2	Preislamic, Transition, Islamic
6		
7	7_1	Preislamic, Transition, Islamic
	Other	Preislamic, Transition, Islamic

Fig. 6.—Interface of Handoga individual entry, and graphics showing the different levels of hierarchies in the database.

an anarchic, weak way due to political instability and lack of interest. Although political instability has undoubtedly influenced the development of archaeology in the region, the truth is that there are more resources available than usually thought, especially regarding collections based at museums and archives which are largely unexplored (de Torres, 2018). If properly used, these collections can provide invaluable information to complete ongoing research, incorporating data now lost due to the passing of time and the disappearance of archaeological sites. One of these cases is the project conducted at the medieval mosque of Abasa, where the combination of archaeological fieldwork, archival research and 3D technologies has allowed the digital integration of now-disappeared archaeological data which will be used for research and dissemination purposes.

Abasa is one of the most important medieval sites in eastern Somaliland, already mentioned by Richard Burton when he crossed the region in 1852 on his trip to Harar. Burton described accurately Abasa's mosque, referring to a well-built mihrab and the existence of twelve stone pillars. The first visual document came a century later, when the British officer Alexander T. Curle visited the place and took a photograph of the mosque which shows the building in a —relatively— good state of preservation (Curle, 1937). Subsequent brief visits to the site (Chittick, 1976) recorded the progressive deterioration of the mosque: for example, the photograph taken by the Soviet-Somali expedition in 1971 shows how the arch of the mihrab had already collapsed at that time (Warsame *et al.*, 1974). In 2018, the INCIPIT team visited the site and confirmed the degradation of the building (fig. 7). To gather as much information as possible before its complete collapse, the INCIPIT team did a full photogrammetry of the building and a small test pit inside, which reached the original floor of the mosque and documented the base of the pillars (de Torres *et al.*, 2018).

Although research in Abasa was interrupted after this survey campaign, the interest in the mosque was never abandoned, especially after the discovery of a set of photographs of the mosque taken by Neville Chittick in 1974 and deposited at the archive of the British Institute of East Africa (Nairobi)[4]. Combined with some other old photographs from publications and the British Museum online collection, the photographs offered the possibility of retracing the original shape of the mosque. Moreover, when merged with the photogrammetric data collected in 2018, the opportunity arose to build an accurate model of the original building, based on real archaeological data but useful to offer a glimpse of how an actual medieval building could have looked like.

The sample consisted of 22 old photographs, one published by Curle (1937), six from the British Museum Collection Online (1930s), one from the Soviet-Somali expedition (1971) and 14 from Chittick's collection at the British Institute of East Africa archive (1975). The photographs were oriented using the plans and 3D models

4. The INCIPIT team would like to thank the directors and staff of the British Institute of East Africa, who generously provided the photographs from the archive.

Fig. 7.—Photograph of the Abasa mosque in 2018.

available, and then the full process of digital reconstruction started (fig. 8). After that, the photogrammetry was remade with high-quality standards, scaled and oriented to obtain the most accurate starting point for the building reconstruction. This included the information provided by the small test pit dug in 2018. Although small, it provided a key piece of information: the depth at which the floor was, and therefore the possibility of establishing the real height of the building.

Over this initial 3D model and with the use of the Blender software, preliminary work on three-dimensional volumes was conducted to evaluate the basic structure of the building and its most relevant architectural features: doors and windows, pillars, *miḥrāb* and so on. This stage was also relevant to propose a hypothesis about the height of the building and the structure of the roof. Once this volumetric draft was finished, the historical photographs collected in archives and publications were incorporated into the study, and a set of cameras was virtually disposed of following these photographs' perspectives. This allowed us to complete some architectural hypotheses and to enrich the reconstruction of the mosque. The final step of the process was to obtain a detailed model of the interior and exterior of the mosque, accurately adjusted to the original 3D model, the volumetric hypothesis and the historical photographs (figs. 9 and 10).

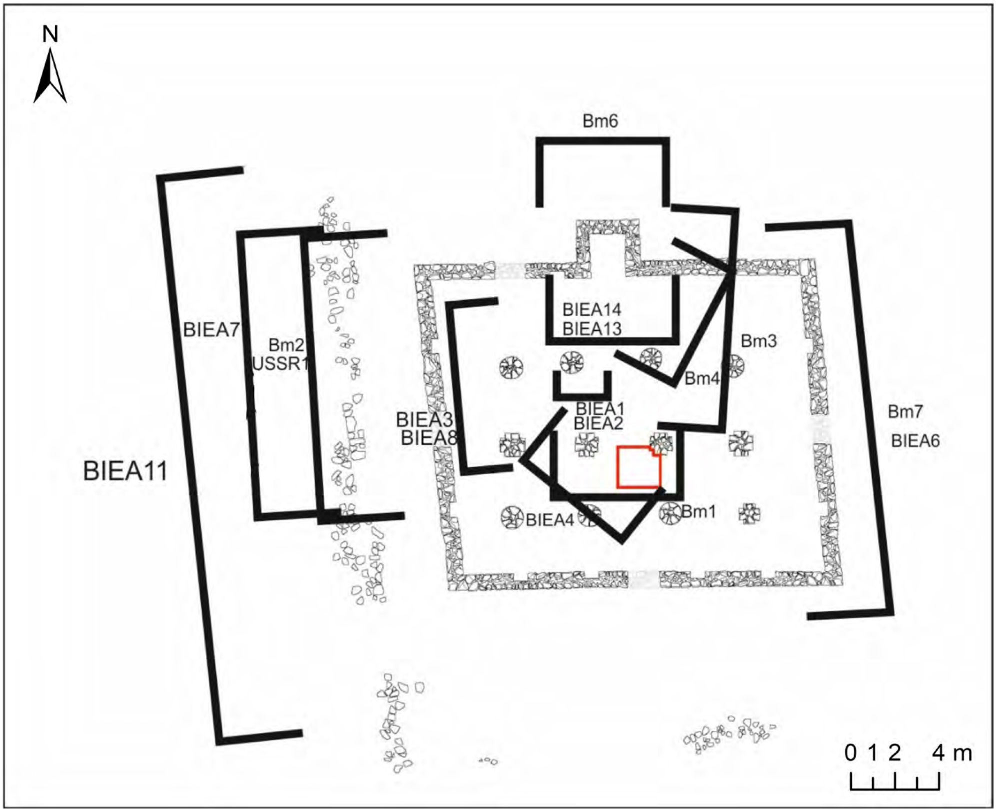


Fig. 8.—Perspective of the different historical photographs from different archives, using the plan generated in 2018 as a reference.

The second step consisted of the texturing and coloring of the virtual reconstruction through the use of Adobe Substance 3D Painter, one of the most advanced software for the creation of realistic materials and textures for virtual scenes. The data for the texture and color came from the 3D model and the photographs taken by the INCIPIT team during their visit to the site in 2018. Finally, several contextual elements were included in the model, to increase the realism of the model and to provide a scale to the building (figs. 11 and 12). These additions were including attending to architectural and archaeological parallels and ethnographic and historical information, aiming to provide the most accurate context for the digital reconstruction and recreation.

The scale of historical-archaeological evidence of the Abasa mosque

Despite having a significant amount of reliable data from first-hand documentation and historical photographs, some parts of the building had to be reconstructed

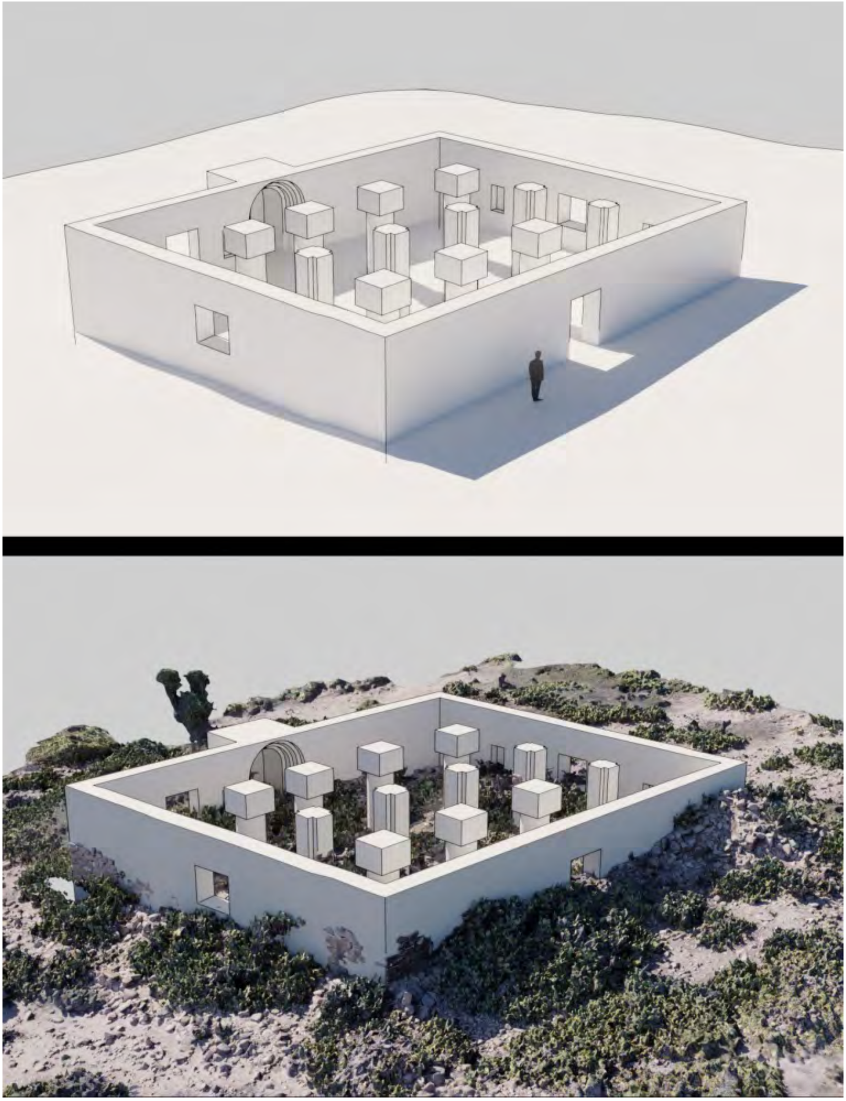


Fig. 9.—Hypothetical volumetric reconstruction of the mosque.

based on weaker evidence —either parallels from other buildings, historical texts or ethnographic information. To ensure scientific transparency (Sociedad Española de Arqueología Virtual, 2012) and to make clear the veracity of the work that had been carried out, the historical-archaeological evidence scale was set, based on cold and warm colors. In this system, warm colors indicate a higher level of evidence, while cold shades refer to weaker evidence of historical or archaeological data. The combination of colors provides an immediate, visual tool to understand the reliability of digital reconstructions. Based on these premises and in the context of the

Fig. 10.—Integration of historical photographs within the volumetric reconstruction.

Byzantium 1200 project[5], the historical-archaeological evidence scale was developed by C. Figueiredo and P. Aparicio (Aparicio and Figueiredo, 2017), implementing a precise color code and describing comprehensively each of the evidence levels. The last modification of this scale has been applied in the Abasa mosque, where the lowest level of evidence marked as purple (#472583) has been substituted by a light grey (#808281), which seems to represent the lowest level of evidence (fig. 13). Purple was considered too strong to represent a low level of evidence —something contradictory— and includes a red hue which can give a feeling of warmth, thus contravening the principle of less evidence-cool tones, more evidence-warm tones. The result of this change has been a clearer understanding of the scale and the different levels of veracity in the virtual reconstruction.

The scale of historical-archaeological evidence of Abasa mosque is complemented with a second tool used to reinforce the scientific traceability of the reconstruction: the Reconstructive Units (RU). The RU was developed in 2015 by the Virtual Heritage

5. Byzantium 1200 is a 3D reconstruction Project of the city of Byzantium in 1200 AD, launched by Parick Clifford, Jan Kostenec and Albrecht Berger. It can be accessed here: https://www.byzantium1200.com/

Fig. 11.—Final reconstruction of the mosque

team of the University of Alicante (Molina Vidal *et al.,* 2021), and they facilitate the identification of each element of a virtual reconstruction. They also provide additional information about the archaeological, historical, ethnographic or literary sources used in each of the elements. In the case of Abasa's mosque, the RU has been combined with the colors of the scale of historical-archaeological evidence to summarize all the information regarding the different levels of reliability of the reconstruction (figs. 14 and 15).

The reconstruction of the main mosque of Abasa has achieved three main objectives. It has incorporated and integrated lost archaeological data into a coherent, scientifically reliable reconstruction that can be compared with other similar buildings throughout the Horn of Africa. Moreover, it has brought to light some interesting architectural data such as the shape of the windows or the mihrab design, which were previously available only to a reduced number of experts. Secondly, the 3D reconstruction can be used in several dissemination and educational activities to show in an easily understandable way the shape and size of the building. Finally, the digital reconstruction allows modifications of the model if further evidence is obtained (for example, if a comprehensive excavation of the mosque is conducted in the future), something that would be reflected in the scale of historical-archaeological evidence. In a context where many buildings have been destroyed by conflicts or lack of proper preservation —such as the lighthouse of Mogadishu or the Quiblatain mosque in Zeila—, the use of historical photographs can help to reconstruct —at

Fig. 12.—Final recreation of the mosque: exterior, upper image; interior, lower image.

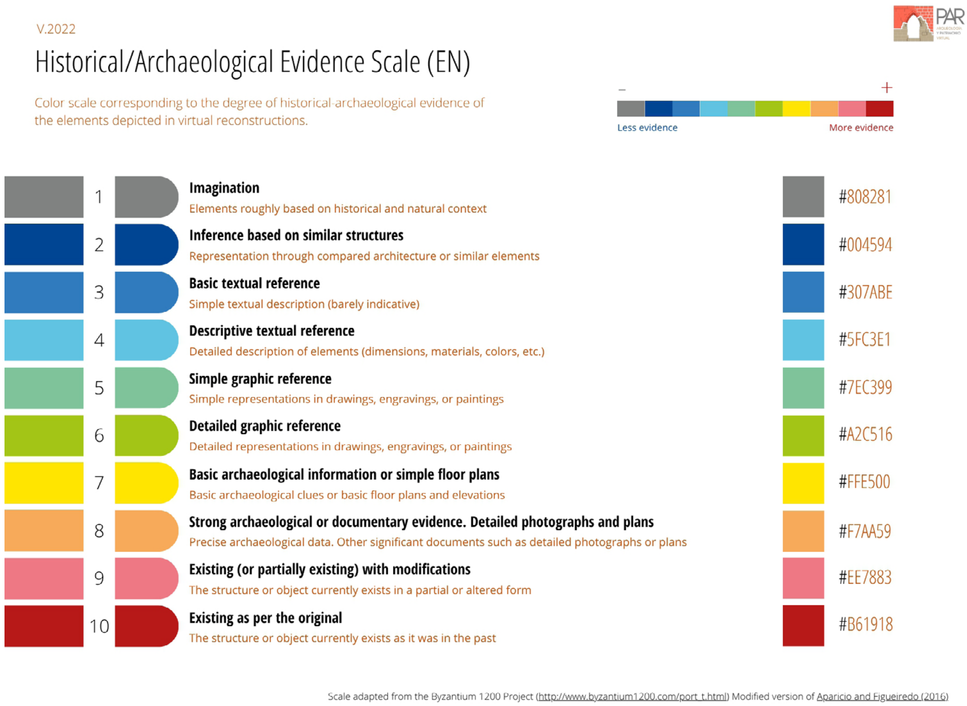


Fig. 13.—Scale of historical-archaeological evidence.

least, digitally— some of the most important buildings of the Horn of Africa which have been damaged in past decades.

DIGITAL URBANISM: THE VIRTUAL INTERPRETATION OF AMUD LAYOUT

Until recently, the state of preservation of archaeological remains in the areas of the Horn of Africa inhabited by Somalis was pretty good due to the nomadic lifestyle of the majority of the population. That reality implied that most of the archaeological sites have never been reused after their abandonment, and therefore in general the remains have endured remarkably well with time, as the few photographs taken in the 1930s can attest (Curle, 1937). In the last decades, however, a rapid process of deterioration has been documented in many areas of the region due to uncontrolled urbanism, vandalism and looting. One of the —unfortunately— best examples is Amud, a major medieval town close to the border with Ethiopia, 6 km southeast of the present-day town of Borama (fig. 1). The site was first described by A. T. Curle in 1934 (1937), and later visited in 1943 by G. W. B. Huntingford (1978), being described as one of the major medieval towns in the region along with Abasa, Gogesa and Aw Bare (Curle, 1937). The site has been traditionally referred to as one of the

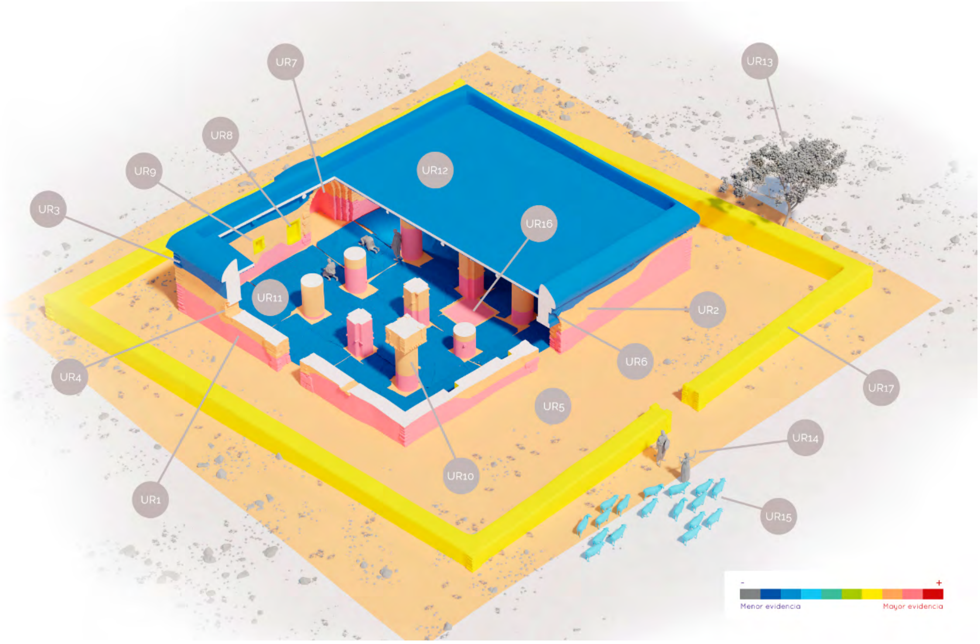


Fig. 14.—The scale of historical-archaeological evidence applied to the mosque reconstruction and indicating the Reconstructive Units (RU).

main archaeological sites in Somaliland, and was usually included in travel guides as a tourist destination (Briggs, 2012). The few photographs, aerial photographs and sketches made by the British show a very good state of preservation, with elevations up to 3 m high. In particular two aerial photographs[6] show a complex urban layout, with well-defined structures standing well above the ground.

In 2017, a visit to the site by the INCIPIT team showed a radically different view: absolutely all the structures had been razed to the ground, with the stones removed to be used as construction materials for modern buildings (fig. 16). The level of destruction was so high that trenches were dug to remove the buried walls of the buildings. During that visit, a drone flight was made to document the few remaining structures, and given the dramatic state of preservation, a strategy was prepared to collect as much information as possible about the site, combining satellite images, drone flights and the few available aerial photographs taken when the site was better preserved. The reconstruction followed a similar process to that of the mosque of Abasa, combining historical photographs and modern data to reproduce the most accurate possible plan of the town.

6. Inventory References Af,B9.10 and Af,B9.11

RU	LEVEL	NAME	DESCRIPTION AND SOURCES
1	9	Architectural remains documented in situ	Archaeological remains documented during the 2018 archaeological fieldwork (Torres et al 2018)
2	8	Walls of the mosque preserved between the 1930s and the 1970s.	Published historical photographs (Curle 1937 y Warsame et al 1974) and archival collections from the British Museum and the BIEA archives
3	2	Reconstruction of the elevation of the mosque walls	Reconstruction after published historical photographs (Curle 1937 y Warsame et al 1974) and archival collections from the British Museum and the BIEA archives
4	8	Windows	Extrapolated after one of the historical photographs kept at the British Museum online repository
5	8	Orography of the terrain adjacent to the mosque	Documented during the 2018 archaeological campaign
6	2	Doors	Base of the door documented through a plan (Chittick 1976), upper part was reconstructed following the style of the only medieval window known through historical photography from the British Museum online repository
7	8	Archivolts of the mihrab	Historical photography published by Curle (1937), Photographs stored at the BIEA archive
8	7	Niches	Location through plan (Chittick 1976), upper part was reconstructed following the style of the only medieval window known through historical photography from the British Museum online repository
9	7	Northern side window	Historical photography stored at the British Museum online repository
10	8	Reconstruction of columns, pillars and capitals	Historical photographs published by Curle (1937), Photographs stored at the British Museum online repository and the BIEA archive
11	2	Mats	Reconstruction following ethnographic parallels stored at the British Museum and shown in the online repository
12	2	Roof	Reconstruction following archaeological parallels (Poissonier et al. 2011), ethnographic parallels and information about local timber
13	1	Acatia, rocks and other natural, contextual elements	Reconstruction based on photographs of the site taken in 2018.
14	1	Characters	Reconstruction based on historical photographs and engravings (late 19th-early 20th century) of Somali people
15	4	Sheep	Reconstruction based on medieval descriptions (Varthema1863) and current sheep breeds
16	9	Original floor of the mosque	Remains of the original floor documented during the 2018 fieldwork campaign (Torres et al 2018)
17	7	Perimeter wall	Remains of a wall documented during the 2018 fieldwork campaign (Torres et al 2018)

Fig. 15.—Summary of Reconstructive Units (RU) with the corresponding colors and the sources used for the reconstruction and recreation.

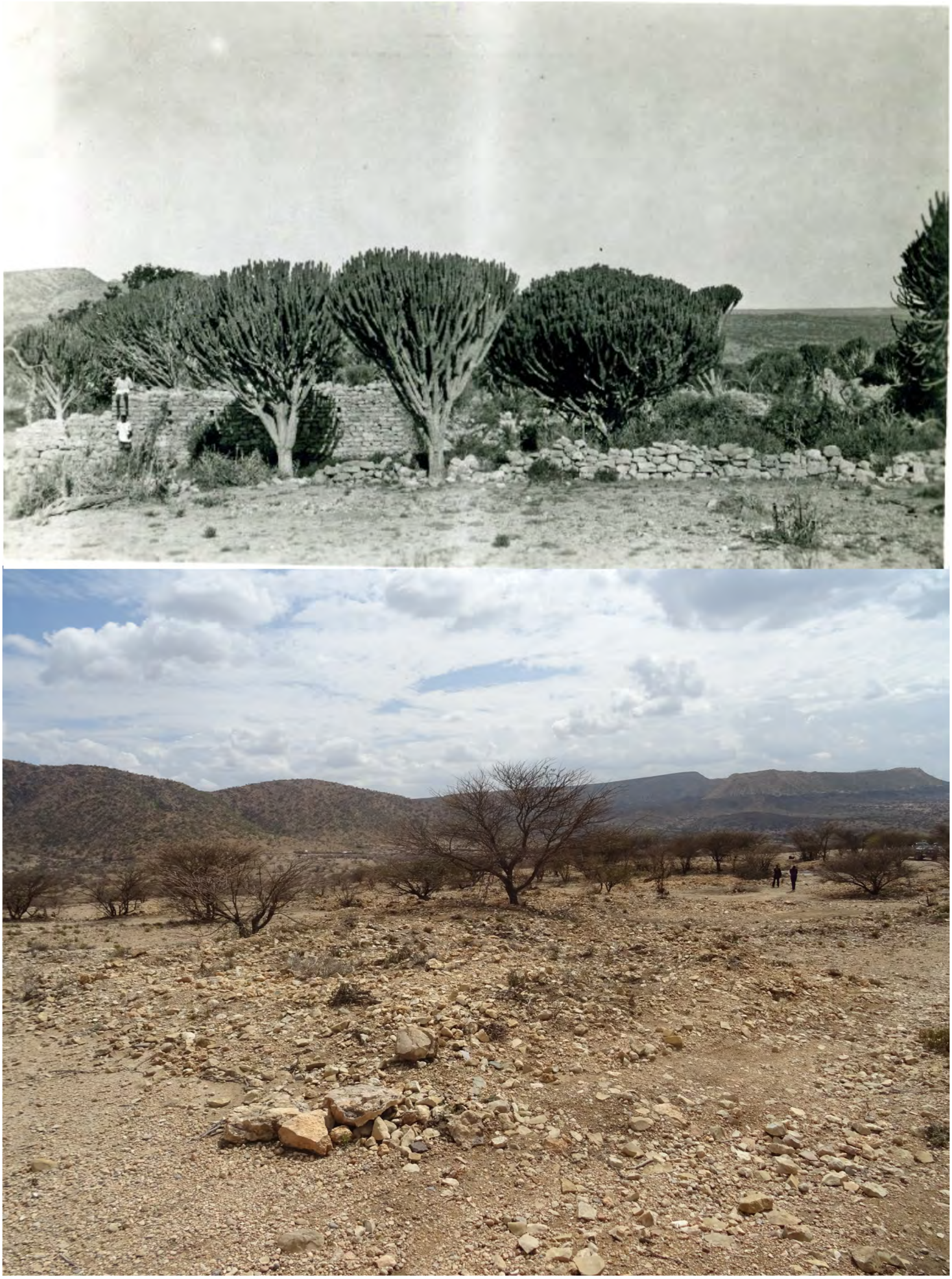


Fig. 16.—Upper photo, the site of Amud in 1934 (Curle, 1937). Bottom photo, the site of Aumd in 2017.

Of course, the use of remote sensing in Archaeology has a long tradition, from aerial photographs to the most modern techniques of the last decades, including the application of photogrammetry, LiDAR and satellite imaging (Parcak, 2009; Crutchley, 2010; Fowler, 2010; Remondino and Fabio, 2011; Remondino *et al.*, 2011; Lasaponara and Masini, 2012; Mlekuž, 2013, 2018; Nex and Remondino, 2014; Remondino and Campana, 2014; Opitz and Herrmann, 2018). While these techniques are now routinely employed in archaeological research across a range of chronologies and regions, there is still a long way to go in African archaeology (Davis and Douglass, 2020). This is largely due to the limited availability of open-access data that can be used by archaeologists compared to other areas. Nevertheless, it has seen considerable progress in recent decades (Klehm and Gokee, 2020:2-3). Moreover, within the broad field of archaeology in Africa, there are also regional differences (Khalaf and Insoll, 2019). Thus, more archaeological projects apply remote sensing in North Africa (Rayne *et al.*, 2017) than in sub-Saharan contexts (e.g. Mason, 1968; Seddon, 1968; Clark *et al.*, 1998; Schmid *et al.*, 2008; Katsamudanga, 2009; Sadr and Rodier, 2012; Grenier *et al.,* 2013; Harrower and D'Andrea, 2014; Hunt and Sadr, 2014; Sampson *et al.*, 2015; O'Regan *et al.*, 2016; Reid, 2016; Sadr, 2016a, 2016b; Biagetti *et al.*, 2017; Rayne *et al.*, 2017; Bergstrom *et al.*, 2019; Khalaf and Insoll, 2019; Klehm *et al.*, 2019; Thabeng *et al.*, 2019; Thabeng *et al.*, 2019; Davis *et al.*, 2020; Ochungo *et al.*, 2022; Fitton *et al.*, 2023; Gutiérrez de León, 2023).

In the case of Amud, three different techniques were used to reconstruct the urban fabric. On the one hand, aerial photographs taken by the Royal Air Force in 1935 (British Museum, Af,B9.10 and 11) and referenced by A. T. Curle in his account of his 1934 visit (1937). On the other hand, in 2017, as part of the Spanish Archaeological Mission in Somaliland of the INCIPIT team, a photogrammetric flight was carried out with a UAV of the preserved remains, which had already been largely obliterated by the construction material by the nearby population, compared to A.T. Curle's visit. Finally, we reviewed the satellite images of the site, mostly open source, available nowadays.

Going into the specific methodology, the photogrammetric flight was carried out following the usual parameters of height over the site and speed of the drone to ensure the correct visualization of the photographs and the overlap (Benavides *et al.*, 2016; Benavides *et al.*, 2020). The UAS used for this was a Mavic Air 2, with a 48 MP 1/2" CMOS sensor and an aperture of f/2.8. The model was referenced using Ground Control Points measured with a total station in local coordinates to obtain a reliable metric result. As for the satellite imagery, the entire historical series from different open-source sources was reviewed to try to pinpoint the moments of destruction since Curle's visit. To this end, images from Landsat, Copernicus and Google Earth were reviewed. The images captured by the US government's Corona program of spy satellites were also used because of their relatively good resolution and earlier start in the 1960s, and their application in archaeology since their declassification has yielded interesting results (Fowler, 2005).

The Landsat program began in 1972 with the launch of Landsat 1 by NASA and the US Geological Survey (Short, 1982). The various sensors of the program's successive satellites have had records of the Amud area since 1973. Regarding the Copernicus program, started operations in 2014 with the Sentinel 1A satellite by the European Space Agency (Jutz and Milagro-Pérez, 2020). The program already started with a higher resolution of only 15 m on the ground, although its much more recent coverage does not provide the same historical collection as the Landsat program. Finally, among open source sources, the Google Earth historical series has also been reviewed, which includes satellite images from both open source, such as the aforementioned Landsat and Copernicus, but also from commercial satellites, such as MAXAR. In the case of Amud, the first satellite image on Google Earth dates from 2004, jumping later to 2012.

In addition, the historical series of the CORONA program has been consulted. This was carried out by the Central Intelligence Agency (CIA) of the United States between 1959 and 1972 to obtain aerial images of the whole world for intelligence purposes, using Keyhole satellites with cameras that reached a high resolution of up to 7.5 m (Ruffner, 1995). The consultation of the historical satellite images has made it possible to delimit the period of destruction of the site, although it has not been possible to determine how the process took place with precision due to the low resolution up to the turn of the millennium. This process would have taken place after the visits of A.T. Curle (1937) and G.W.B. Huntingford (1978) between 1934 and 1943 and before 2004 when we have the first satellite image of the site of sufficient quality. The destruction could be related to the construction of Amoud University, which was founded in 1998 and is not far away from the site. From this time to the present day, degradation has slowed down, with no major changes in the structures and collapses (Mire, 2011).

Given the poor accuracy of the satellite images, it was decided to manually reference the RAF aerial photographs using the orthophoto taken with UAS as a basis (fig. 17). For this purpose, topographical references visible in both the historical aerial photographs and the orthophoto were used to obtain the most accurate planimetry possible. Once the RAF aerial images had been georeferenced (fig. 18), they were photo-interpreted. To define as many structures as possible, it was decided that three of the authors of this work, with experience in photo interpretation, should separately sketch the structures that were visible in the historical photos (fig. 19). With the three resulting sketches, the results have been crossed to obtain a definitive planimetry, with the greatest number of reliable structures documented in it (fig. 20).

The combination of different remote sensing methods has made it possible to obtain a reliable planimetry of a site that has already disappeared. The large number of structures reported by visitors to Amud, up to two hundred houses (Curle, 1937; Huntingford, 1978), could not be documented due to the presence of vegetation. But the planimetry does tell us of a high density of structures and a poorly ordered urbanism, with a great variety of sizes and typologies in the structures. Both domestic structures and other types of constructions, livestock enclosures and other types of small buildings whose functionality is still uncertain, are visible. Particularly noteworthy is the existence of a large structure in the central part of the site, partially

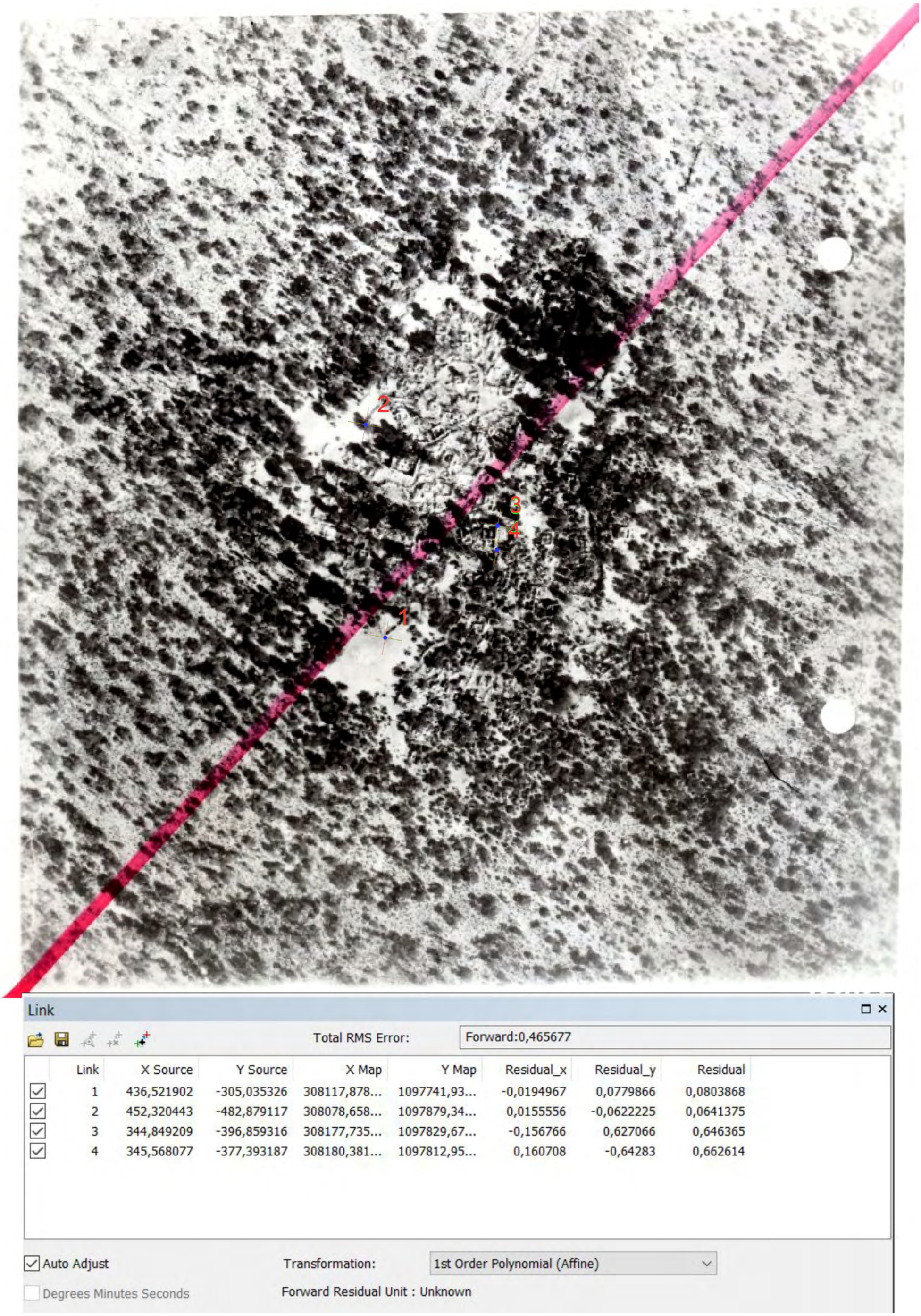


Fig. 17.—Referencing points on the aerial photo of Amud taken by the RAF in 1935 (Af, B9,10).

Fig. 18.—A drone flight made in 2017 overlapped an aerial photograph taken in the 1930s.

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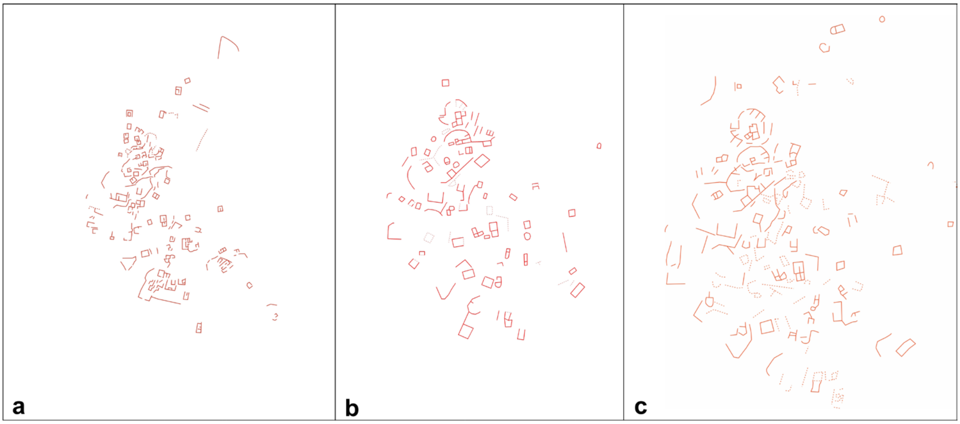

Fig. 19.—Planimetries from photointerpretation made by three different observers.

Fig. 20.—Proposed plan of Amud.

hidden by the trees, whose dimensions seem to correspond to the supposed mosque described by various authors on their visits (Curle, 1937; Warsame *et al.*, 1974; Huntingford, 1978; Cornax-Gómez and de Torres, 2023). The internal structures indicated in their sketches also seem to be visible, and the orientation to the north (8°) reinforces this identification (fig. 21). Furthermore, on the outskirts of the city are visible several large stone enclosures with radial internal compartments (Image Af, B9.11). These appear to be animal structures, perhaps camel pens for trading caravans (Lewis, 1961:73). Although these structures have now also disappeared, we cannot know whether they are of medieval origin.

In short, remote sensing has made it possible to draw a much more complete plan of Amud from historical aerial photographs than the previous sketches in the bibliography. However, given the vegetation and the destruction of the structures, we will not be able to obtain a definitive plan of the site without excavation. Nevertheless, new technologies are proving very useful for recovering heritage information in the face of rapid degradation in many parts of the African continent (Davis and Douglass, 2020). Their development and application open important avenues for future work in African archaeology.

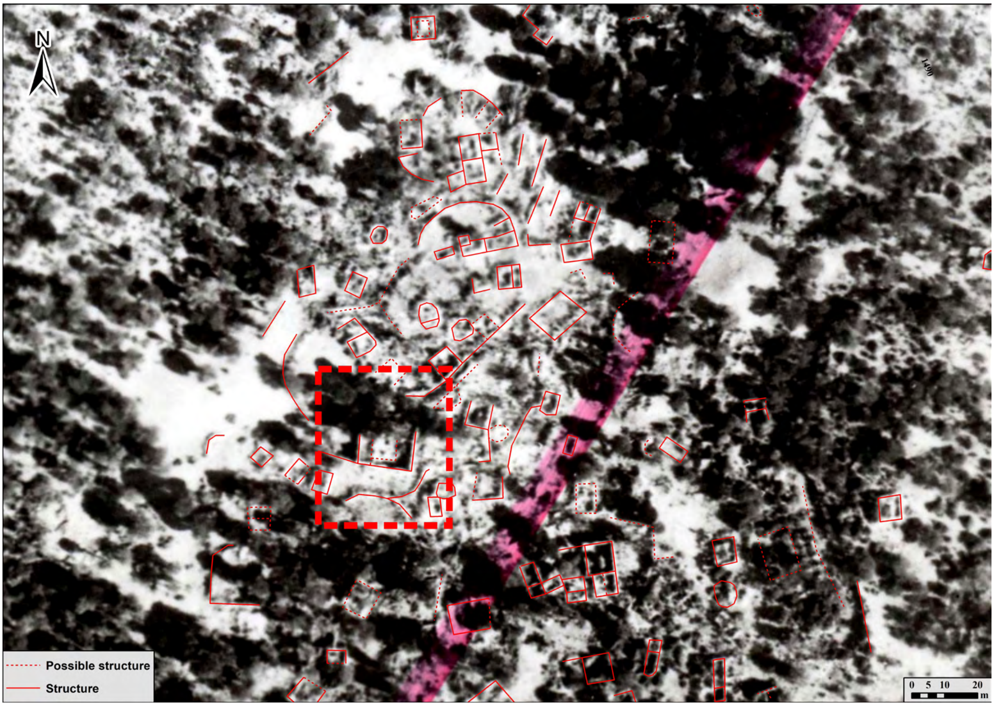

Fig. 21.—Possible mosque of Amud.

CONCLUSIONS

The great development in the last two decades of a wide range of technologies and their application to the Humanities, and to Archaeology in particular, has triggered a big step forward in archaeological methodology and theory. It has also bolstered the interdisciplinarity of the field.

The introduction of diverse digital methods for the gathering, management, and analysis of the data into archaeological workflows has supposed a remarkable increase in the quantity and quality of the data. Nevertheless, this increase leads to new problems, making more difficult data management and custody, especially concerning how these data must be open access to the scientific community and the society as a whole. It is also worth noting that the learning and application of all these new technologies make compulsory a greater specialization of the archaeologists, and also strengthen the collaboration with other fields.

The three examples presented in this paper evidence the usefulness of digital technologies in obtaining and managing archaeological data through a wide range of techniques and applications. This usefulness is manifest even in a geographic area with so many logistical limitations such as the Horn of Africa. Although with different approaches and research contexts, all these examples aim for the same objective: integrate information from different sources and optimize resources (time, available archaeological data) which in our specific research context are often scarce.

In that sense, the experience of the INCIPIT team in the Horn of Africa shows that digital technologies are useful in different contexts, and having a good knowledge of the capabilities of these techniques is mandatory to implement methodologies and workflows for the successful gathering and analysis of archaeological data.

This experience has meant the establishment of a workflow in which digital technologies have a core presence. These span from applications that are getting more widespread in Archaeology, such as Structure from Motion photogrammetry, the use of drones, or in-field database applications, to satellite imagery or 3D reconstruction.

This combination of techniques has allowed us to survey and analyze the archaeological remains still in place in the Horn of Africa. But it has also provided the basis for a strategy —in challenging environments such as the Horn of Africa— to reconstruct —at least digitally— archaeological sites currently lost, which will be returned to the scientific community and the Somali people. These technologies have generated interest in local institutions and archaeologists, and a process of training in their application has begun, which we hope will bear fruit in the near future.

The good results reached in all three case studies show the great versatility of these technologies in analyzing different types of archaeological contexts and sites. In this way, the experience of the INCIPIT team in the Horn of Africa clearly shows the great contribution of digital techniques to Archaeology. Despite their use in the field of African Archaeology is still a minority compared to other geographical contexts, their progressive application will have a core role in the study and preservation of this continent's heritage and material culture. The use of digital technologies is, therefore, one of the big ways of future development of Archaeology in Africa.

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