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Digitizing Los Millares (Santa Fe de Mondujar, Almería, Spain) through 3-D and geospatial technologies: preserving and disseminating the archaeological heritage

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Abstract

Geospatial and 3D technologies have been successfully employed in archaeological research. Generally used for generating new digital data, they can also serve for preserving the heritage. Drawing on ideas from Public Archaeology, our paper aims to focus on the latter aspect, centered in the site of Los Millares.

Los Millares, located in southeast of Spain, is one of the most important archaeological sites of Iberian Chalcolithic and was the object of intensive archaeological surveys and excavations during the 20th Century. Notwithstanding the usefulness and importance of these researches and later analyses on materials, their results and knowledge remain in grey format. In line with current ethical standards, we aim to reinvigorate Los Millares through digital technologies which can preserve its heritage while outreaching interested audiences. This has taken shape by following a threefold-scale strategy:

- Site-scale: analysing remote sensing data (LiDAR), comparing it with "grey" maps, and geolocalising, for example, as many tombs as possible. This process has been developed using GIS technology.
- Intra-site: creating one 3D-photogrammetry model of the barbican, one of the essential features and prone to deterioration.
- Micro-scale: 3D modelling of unearthed artefacts.

This strategy has proved to be of great aid for reaching our aims. In sum, this research brings the utility of digital technologies for recording and preserving archaeological heritage, not least for disseminating knowledge.

Keywords

3D-modelling; LiDAR; Photogrammetry; Archaeological heritage preservation; Outreach; Legacy data

Introduction

This paper explores the use of geospatial and digital technologies as a mean to preserve and disseminate the archaeological heritage. It deals with how such technologies can be applied in cultural heritage management. The archaeological site of Los Millares is used as a case study which exemplifies one possible path to this aim. The paper explains the process we have followed for converting legacy data from this site to digital formats—which complements other actions carried out for preserving and disseminating the knowledge about the site.

Located in the southeast of Spain (Santa Fe de Mondújar, Almeria), atop a fluvial promontory, Los Millares (Figure 1) stands as one of the most important settlements of the southern Iberian Prehistory. The site comprises a village of 4-5 hectares with 4 concentric lines of fortification walls and an annexed necropolis of over 13 hectares with 83 known burials (Molina, 2018). Andarax River and *Rambla de Huechar*—a ravine—borders Los Milares to the North and East-South, creating a canyon-like path which demarcates its geographical identity (Molina, 2018). Yet, the presence of 13 hill-forts associated to Los Millares indicates the site probably controlled the surrounding lands, while other areas of the Andarax basin could also be dominated by this site (Arribas and Molina, 1987; Molina and Cámara, 2005; Spanedda *et al.* 2015; Cámara *et al.* 2016; Haro *et al.* 2006; Cámara *et al.* 2018).

The available data suggest that both the settlement and the necropolis were concurrently founded around 3.200-3.100 BC. (Molina *et al.* 2020; Molina *et al.* 2020; compare with Aranda *et al.* 2017; Lull *et al.* 2010). The external wall and the hill-forts were built afterwards, respectively around 2.900 B.C. and before 2.500 B.C., according to the dating for the second phase of hill-fort (Molina, 2018). The settlement and its necropolis were abandoned when the hill-forts were burned (*c.* 2.200-2.150 B.C.) or shortly thereafter (Molina *et al.* 2018).

Los Millares' research history is of critical importance because it spans over 100 years. Since its discovery in 1891, 3 different teams have excavated the site (Molina, 2018): Luis Siret and Pedro Flores at the end of the 19th Century (Siret, 1893, 1913), followed by Martín Almagro and Antonio Arribas in 1953-57 (Almagro and Arribas, 1963), and finally, a team led by A. Arribas and Fernando Molina from 1978 (Molina, 2018; Arribas *et al.* 1979, 1981). This can arguably be seen as an account of different theoretical and methodological approaches to the same site.

The surveys directed by Luis Siret at the end of the 19th century mainly focused on the excavations of many tombs at the necropolis (carried out by P. Flores),

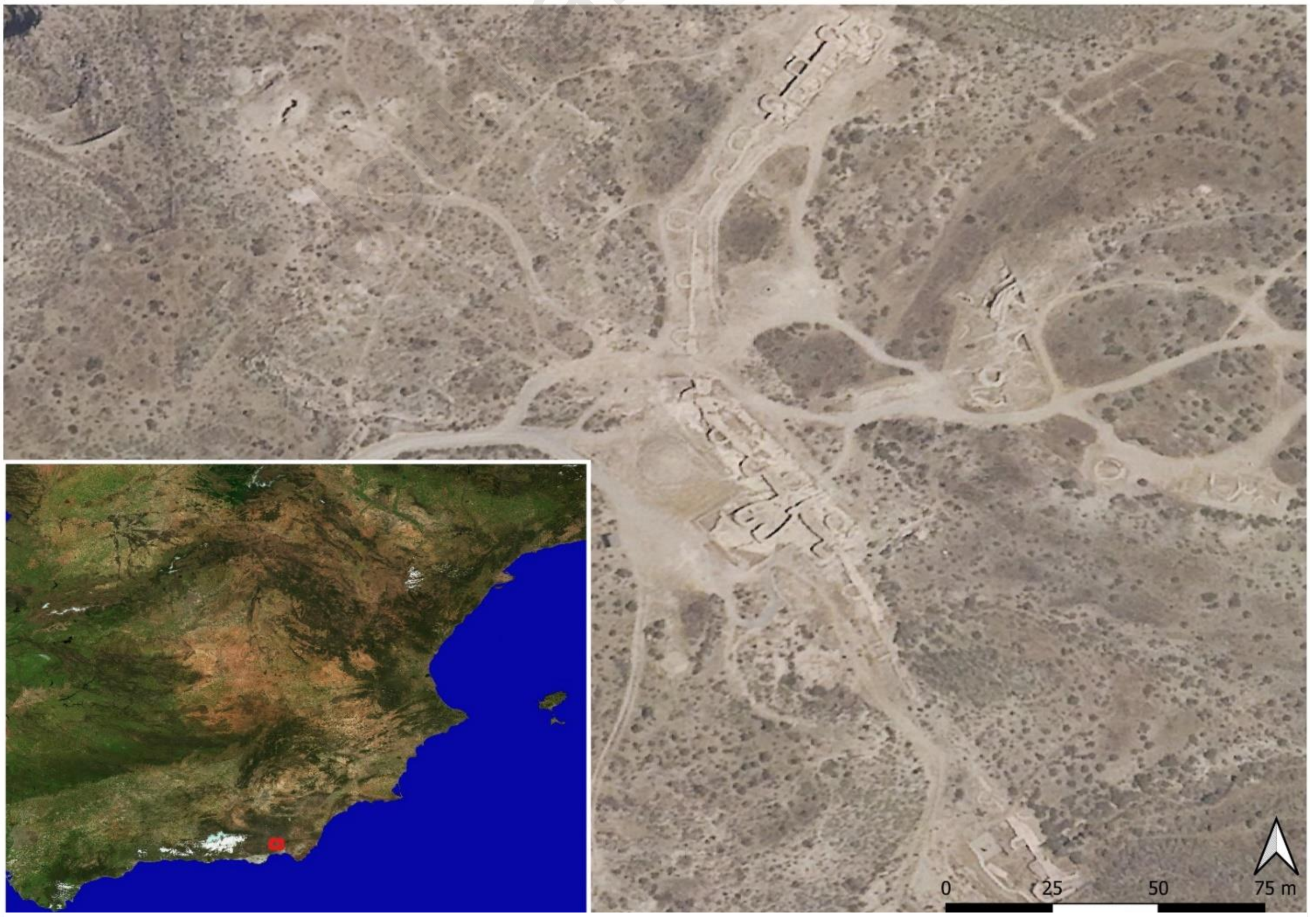


Figure 1. General view of Los Millares (Santa Fe de Mondujar, Almertía, Spain).

limited excavations at the village, and the surface analysis of the external line of walls and hill-forts 1 to 4. (Molina, 2018). Results from these fieldworks were not extensively published by Siret, who instead bequeathed the information to the archaeologists Georg and Vera Leisner (Molina, 2018). They included the information in their 1943's classical corpus of megalithic tombs from the South of the Iberian Peninsula (Leisner and Leisner, 1943).

Between 1953 and 57, Martín Almagro and Antonio Arribas carried out new excavations. They continued with the necropolis, re-excavating 44 tombs, and advanced in the study of the external walls by documenting in the outer one the barbican's gate (Molina, 2018). In 1963, Almagro and Arribas published a monograph with the information (Arribas *et al.* 1963).

New work started in 1978 supervised by A. Arribas and Fernando Molina. This fieldwork shifted the focus towards a regional approach that, on the one hand, privileged an extensive analysis on the necropolis, the hillforts, and the settlement (including excavations in open areas), and on the other aimed to relate Los Millares to its regional context (surface surveys) (Molina, 2018).

The third part of this paper will present a thorough outlining of the ethical issues these approaches have. This would hint at why it is arguably imperative to change some research dynamics—as it is our aim.

Research Aims

As discussed in the next section, Los Millares presents some challenges regarding data and information management. For instance, most of the data is in legacy format—not digitised, not accessible, not reusable, etc. Solving these problems is an ethical[1] issue in Archaeology that must be carefully considered in accordance with recent recommendations—e.g., Historic England Report from 2018 (Will, 2018).

Following the spirit of some recent Iberian scholarship (García Sanjuan *et al.* 2019; Mora Molina & García Sanjuan, 2020; Garçês *et al.* 2022), our paper presents an attempt to change some of Los Millares' legacy issues. This is done by thinking about the site as archaeological heritage, a notion that brings together the imperatives of preservation and dissemination. With this, we aim to push forward the same research agenda that has fostered Museum exhibitions and site guides (Molina, 2018; Molina and Cámara, 2005), data management systems since the 1990's (Molina *et al.* 1996, Esquivel *et al.* 1996), and digital dissemination since 2004 (Molina, 2004).

Geospatial and digital technologies arguably offer opportunities to manage the archaeological heritage for research and dissemination. They, in turn, could help in turning legacy data more accessible and open. We explore this by using Airborne Laserscanning and photogrammetric technology. In sum, we integrate legacy sources in a digital environment in an attempt to reinvigorate a cultural heritage site.

Theoretical considerations

At the core of this paper is a constant interest in finding better curational practices for Los Millares from a cultural heritage perspective. This awareness is also critical from an archaeological ethical gaze, specifically regarding Grey Literature/Legacy Data and the readability of archaeological reports. Both things are, indeed, interlaced and, maybe not surprisingly, addressing the latter might have benefits for the former.

The issues concerning Grey Literature, Legacy Data and archaeological reports have been acknowledged in the last few decades, generating a longstanding debate (Hodder, 1989, 1997; Boivin, 1997; Jones *et al.* 2003; Bradley, 2006; Moore and Richards, 2015; Opitz, 2018). In any case, to understand this debate we first need to address, even if briefly, what Grey Literature is.

3.1.1. Grey Literature: general considerations

There is no exact definition of Grey Literature. In a broad sense, it is defined as every written work, either in print or electronic format, generated in an institutional environment "but which is not controlled by commercial publishers" (McKenzie-Owen, 1998; Schöpfel, 2006). Amanda Lawrence (2012), Childress & Jul (2003), and Vaska (2010) give further details about this definition. In any case, what defines this literature is the elusion of publishing standards (e.g., peer-review, committee agreements, etc.). Legacy Data can be defined as the data stuck/preserved in this literature (Alison, 2008). The dissemination of this literature is one of its significant problems, as in many cases it does not reach the general public. Moreover, in the last years is being increasingly difficult to make this literature impactful in scientific areas dominated by high-impact indicators.

These issues have not passed unnoticed. Different scholars, first mainly from Information and Communication Sciences, have been dealing with them. More recently, new (digital) technologies have foster

[1] Ethics is a complex term with multiple definitions and applications. For this case, the paper finds inspiration in the European Code of Conduct for Research Integrity (2017), especially sections 2.5 (data practices and management) and 2.7 (publication and dissemination).

movements such as Open Access or Open Data—generating thus more attention from other fields, including Archaeology (Moore and Richards, 2015; Schöpfel, 2006; Childress and Jul, 2003; Vaska, 2010; Richards and Hardman, 2008; Schöpfel, 2010; Coble *et al.* 2014; Crossick, 2016). These ethical concerns are fundamental because they put our research ethos in pursuit of what to change for the better.

3.1.2. Grey Literature in Archaeology

Concerns about this literature in Archaeology has grown since the beginning of the 21st Century. The concern focuses on unpublished works, quality, availability, and efficient integration of field-reports into "curatorial and research practice" (Evans, 2015). One stream of this debate is linked to the quality of archaeological reports. These have been criticised for a long time due to their writing style and data management (Hodder, 1989, 1997; Boivin, 1997; Jones et al. 2003; Bradley, 2006; Moore and Richards, 2015; Opitz, 2018). Not without controversies (Sinclair, 1989a and b), this issue is now well-recognised in our field (Moore and Richards, 2015; Evans, 2015; Fellinger and Philpot, 2014; Marchetti *et al.* 2018).

Currently, the interest is mainly focused on how well archaeological reports manage their data. This is not surprising because our reports are the primary source of information, both for understanding excavated archaeological sites and for backing our publications; they contain the data that so often are shortly synthetized in scientific papers and placed in supplementary parts. If we accept that the data justifies the excavation (Lucas, 2001), it is them necessary to strive for data quality. Data quality means both the generation of good data and the accessible preservation of them. One should ask here if accessible preservation mingles well with data held in archaeological archives and old-fashioned reports, as it was our case (see next section). It is the authors' consideration that the latter case means to symbolically lose our knowledge because the reports will not be extensively read nor the data perused or reused (Marchetti *et al*. 2018; Hardman and Richards, 2003). Our knowledge, therefore, eludes the public. This issue has motivated archaeologists to find new ways of preserving and disseminating their primary and secondary results (from preliminary data to interpretations) (Moore and Richards, 2015; Coble *et al*. 2014; Hardman and Richards, 2003; Earley-Spadoni, 2017).

3.2. Dangers beyond grey literature

The ethical issues explained above are aggravated by different local, regional, national, and even global circumstances or threats. One of such is the damage suffered by archaeological heritage due to the effects of accelerating climate change (McGovern, 2018a). Even though some regions are more prone to suffer deterioration from climate change, there is no safe place or scape from climatic effects. For this reason, and considering the alarming consequences of disappearing archaeological heritage (McGovern, 2018b), it is necessary and ethical preserving all the material remains, data, and archaeological documentation.

Moderate to harsh drylands, such as Los Millares, present specific preservation challenges–which vary depending on the kind of element to be preserved (Chemello and Davis, 2014). These risks related to the preservation of archaeological remains add up to the problem of lost information in legacy formats. In fact, the combination of both may put public outreach in serious danger. The mixture of physical damage and data mismanagement is not an ideal situation to look at from the perspective of heritage preservation. We should, therefore, find ways that can ameliorate such situation.

Whilst the preservation in situ of buildings and inner structures is the most common procedure and it has been done at the site before (Molina and Cámara, 2005), another legitimate option is to preserve different archaeological remains digitally. In fact, both things are complementary and offer different prospects. For example, the latter approach can outreach a wider audience and, if implemented with 3D-printing technologies, might surpass accessibility hurdles. This approach can be also applied to mobile items that usually finish at museums—and not necessarily in exhibition areas. Considering this, we argue that digital preservation is a suitable option for handling problems of legacy data, physical deterioration, and outreach. This consideration justifies our methodology (explained in 4.2).

3.3. Los Millares: legacy data and physical threats

The problems of legacy data and physical deterioration are, to a greater or lesser extent, present in the case of Los Millares. Our awareness of these issues is what motivated us to change this dynamic. We deemed the use of geospatial technologies an effective approach for tackling our problems, as they offer the possibility of recording and storing data in standard digital formats. This main concern about data stems from the fact that the most flagrant issue is, precisely, how the data has been managed so far:

- The field notes from Flores are digitised and are accessible at the online archive of the National Museum of Archaeology. Still, this archive gives access to the documents in a pretty raw fashion. The web-portal, moreover, offers scarce details about the documents–preventing the general public from understanding them.

- Access to Lesiner's classical corpus of megalithic tombs from the South of the Iberian Peninsula (Leisner and Leisner, 1943) is strictly limited. This occurs due to the lack of physical copies and inexistence of an easy-to-access digital version.
- The monograph published by Almagro and Arribas in 1963 (Almagro and Arribas, 1963) has also important limitations in terms of use, reuse, and public accessibility, in addition to a limited number of copies of the work that have been published.
- The latest archaeological interventions, directed by A. Arribas and F. Molina, retrieved an enormous quantity of artefacts and ecofacts. Most of these are stored in the Provincial Archaeological Museum of Almería and a limited amount at the Department of Prehistory and Archaeology of the University of Granada. Several papers, which contained the information of these fieldworks, were published (Arribas *et al.* 1979, 1981). Following the hacker ethics, these are now digitised and open, but their data is neither freely available nor reusable. The same applies to more recent papers published in university's repositories (Lozano *et al*. 2010; Cámara and Molina, 2010; Afonso *et al*. 2011; Molina *et al*. 2004) and scientific journal webpages (Molina and Cámara, 2004).

This chronological account reveals a constant, but hitherto unconsidered, feature. Most of the data is still not digitised, and most of the literature remains in grey format. As discussed above, this constitutes an ethical issue that should be amended. The material remains from these excavations, moreover, are physically held at the Museum of Almería and the Department of Prehistory and Archaeology of the University of Granada or preserved in situ. Considering the imperative for doing ethical research, which also includes the dissemination of knowledge, it is desirable to digitally enhance the curation of such heritage. Digital technologies, as this paper shows, make the case for shifting from old to new curational and dissemination practices.

We aimed to do this by digitising a selection of some of the most representative features of Los Millares. Our selection includes tombs, the barbican, and daily-life artefacts. This selection is not trivial, hinting at different aspects of Los Millares: beliefs (tombs), socio-political territorial dynamics (barbican), and the daily life of its population (artefacts). This selection, moreover, is representative of the different issues discussed above: information about the tombs were grey literature and data were in legacy format, the preservation of the barbican is constantly threatened by the natural conditions of the environment–dry, semi-arid, and hot–even after preservation and restoration programs; and the artefacts were only physically accessible.

This approach means to move data from grey to open format. Changing formats is arguably an arduous task that is generally constrained in terms of funding, time, and technology. We opted for a threefold strategy capable of rendering the complexity of the site, at the same time that could be adapted to these constraints. This strategy has been developed at the interface of some ideas from Landscape Archaeology and the themes covered by the archaeological reports. It thus follows a dual logic between our theoretical framework and that from the excavators of the past Century.

Our strategy has followed an approach that envisions the archaeological site as a unit subdivided into different places. This assertion implies that we conceive Los Millares as a whole, divided into different places according to different scales of approaching, from the micro to the site-scale. Such an approach can be seen in the fact that we have recorded the whole settlement and its nearby necropolis, the barbican of the site, and different artefactual remains. From a landscape perspective, this represents a site-scale, an intra-site scale, and finally, a micro-scale. All of which accounts for the interrelationship of different grades and ways to understand Los Millares.

At the same time, our task was constrained by the different excavators' approaches. The selection of what to record was partly imposed by what was already excavated and reported. For example, the necropolis has been subjected to different excavations since the end of 19th century; various interventions focused on or around the barbican; and numerous material remains have been recovered from multiple field seasons. The common denominator is, of course, that none have hitherto been made publicly available in a digital format.

The digitisation needed different approaches and methods, depending on the materials and features. In all the cases, however, the use of geospatial technologies has been of great aid in this, as detailed in the next section. All these digitisation strategies go nonetheless far beyond the simple recovery of information lost in the thread of time, in departmental or research group libraries or museums. Precisely because of their digital format, these digitisations additionally generate new educational tools, more inclusive and with greater potential for disseminating and transferring knowledge. As discussed below, this is possible thanks to Information and Communication Technologies (ICT), such as three-dimensional modelling or/and 3D printers and interactive platforms.

Materials and Methods

As said, our workflow followed a threefold strategy with a focus on different scales. For each scale, we have recorded different significant features. Distinct geospatial techniques have been used to allow us recording the elements: LiDAR for extensive features and photogrammetry for smaller material remains. These techniques are all based on the same principles of 3D recording (Opitz and Cowley, 2013).

The use of GIS approaches and LiDAR technology for documenting sites and large scale remains is a well-established procedure (Opitz and Crowley 2013). Equally, the use of photogrammetry is a well-established practice for precision-recording of artefacts or material remains of medium-to-small size (Frank *et al.* 2021; Andreu and Serrano 2019; Maldonado and Dorado 2020). Therefore, both approaches are accurate for the cases they were applied. We thus considered that their combination, rather than a divided approach, offers quite interesting outcomes due to the recording diversity.

4.1. Site-scale: Grey Sources, GIS, and LiDAR

We have used remote sensing technologies within a GIS environment to record and contribute to the site preservation. Remote sensing technologies, in this case LiDAR, have been used in combination with other sources (detailed in the following lines) for mapping the settlement and its necropolis.

Our first source of information comes from the digital archive of the National Museum of Archaeology. Among the collections preserved in the digital archive are the fieldnotes taken by Pedro Flores during the first excavations at Los Millares[2]. These fieldnotes contain the descriptions of different burials (75 tholoi and 4 cave-burials) and their drawings in a quite naïve style (Figure 2. A). P. Flores numbered these burials following his rather odd criterion. He further indicated the distance between tombs but not the point from which these distances were taken. Unfortunately, he did not provide a map plotting the burials; hence, their identification in the field is constrained by these scarce indications.

Another source of information comes from Georg and Vera Leisner's classical study on Los Millares (1943)[3]. This couple researched the site years after Pedro Flores and Luis Siret, carefully following their indications and drawings. The Leisners made a new set of drawings -sections and plans- for most of the known burials (Figure 2. B-C), which have been used in our GIS. As the Leisners followed many of the indications provided by P. Flores, it is usually taken for granted that their numeration equals to that of P. Flores[4]. For this reason, heretofore this grave numeration is referred to as Flores-Leisner'.

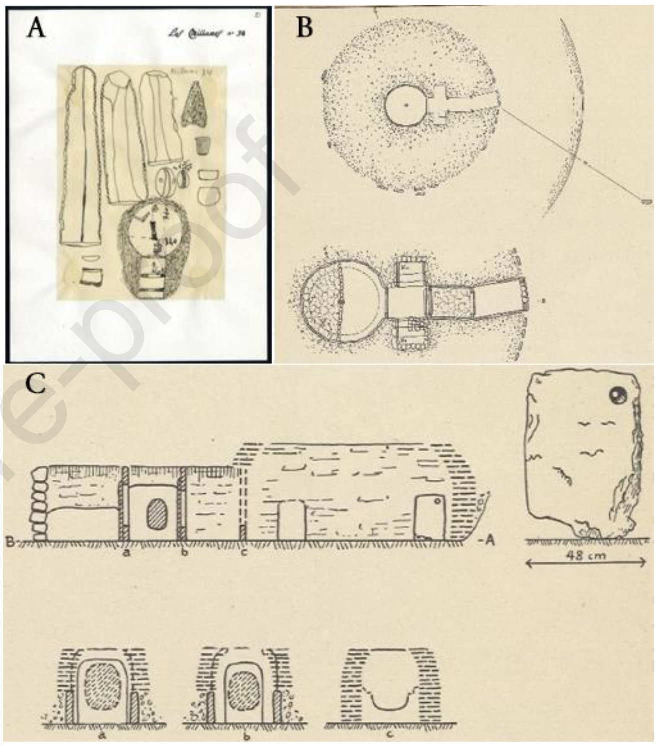


Figure 2. A One of Flores' drawings. B Leisner's drawing: tomb 47, profile drawing. C Leisner's drawing: tomb 17, floor drawing.

Almagro and Arribas's seminal study about Los Millares (1963) constitutes yet another source used in this project. Their book can be considered one of the completest studies of the site, especially for the last cemetery. In this regard, the book offers detailed descriptions, one then-unpublished map from Luis Siret, as well as originals maps from M. Almagro and A. Arribas (Figure 3). The unpublished map by Siret places 63 graves, but the given numeration (totalling 23, in Arabic) is apparently different from that of Flores-Leisner's. The original maps by Almagro and Arribas plotted 61 tombs with high precision, numbering most

[2]http://www.man.es/man/coleccion/catalogos-tematicos/siret.html (accessed: 4 November 2021)

[3] It should be noted the existence of other documents (letters and graphical documentation) from this couple. For instance, the Leisner Archive from the German Archaeological Institute in Madrid (*Deutsches Archäologisches Institut, Abteilung Madrid* – DAI) contains a vast quantity of documentation, including letters about Los Millares (Sousa e*t al.* 2020). The Archive, which is only accesible online, can be found at http://www.patrimoniocultural.gov.pt/en/recursos/arquivos-dgpc/arquivo-leisner/

[4] Also, because unlike for Los Millares, G. and V. Leisner provided double numeration for graves placed in other areas, as the Eastern Granada plateaus (Leisner and Leisner, 1943).

of them (with roman numbers). Perhaps the most helpful insight of this book is that it presents numerical correlations between the numberings of Almagro-Arribas and Flores-Leisner, later completed by R. Chapman (1981).

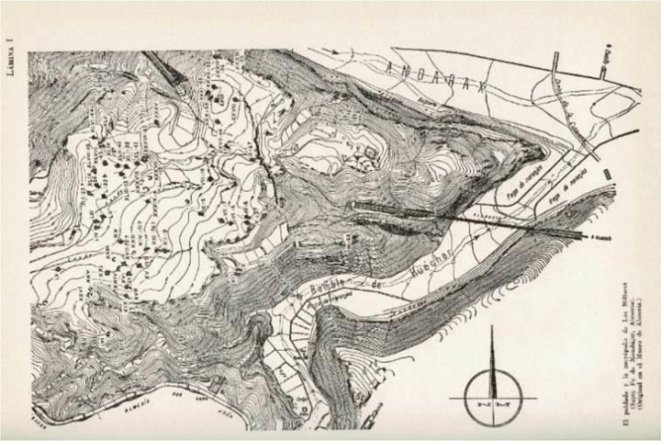


Figure 3. Map from Almagro and Arribas plotting different burials in a dual-numeration system.

Overall, there are three different sources about the necropolis of Los Millares, all in grey format and with uneven readability quality. This means that these sources have some ethical issues, including public unreachability and the difficulty of working with them. As cultural heritage, there is a need to find better curational practices. To ameliorate the situation, we have included these three sources in an ESRI File Geodatabase. The cartographical information was georeferenced, normally following the First Polynomial order criterion, and added as layers. As for the graphical information— Leisner's drawings–, these were added within the Geodatabase as raster data linked to specific points (the tombs). With this, all the grey sources can eventually be displayed on a geoportal accessible to a wide range of users.

Along with this, the project benefits from using geospatial technologies. Aerial imagery (orthophotos) is the base from which we have identify and plot the graves still visible and detailed by the three sources listed above. Airborne Laserscanning, or Light Detection and Ranging (LiDAR), is arguably one of the most valuable GIS-sources offered by geospatial technologies (Opitz and Cowley, 2013) and has been used in an effort to enhance aerial identification. These data have been freely obtained from the National Geographic Institute's online repository[5]. The fact that the geospatial data used was freely available has an obvious benefit, but, on the other hand, it has some trade-offs because, in essence, it is second-hand data. The main disadvantage of using second-hand LiDAR data, at least in Archaeology, is that the image resolution is not as suitable as if it were first-hand data. Yet, the range of resolution is acceptable for our case because we aimed at mapping the site and identify features of considerable size (Fig. 4).

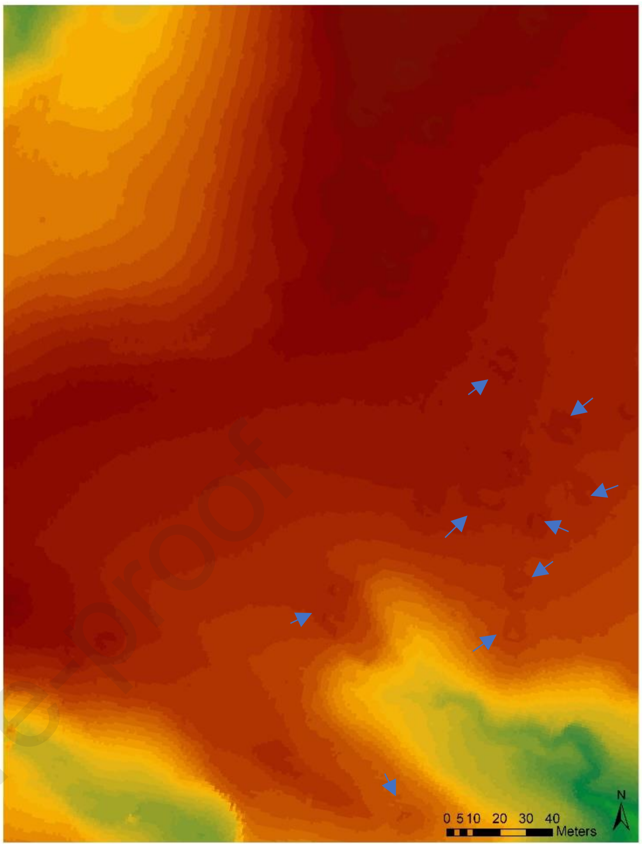


Figure 4. Processed LiDAR (DEM) visualization of Los Millares. The arrows point toward different tombs, which can be correctly visualized after configuring different parameters. The rendering shows these tombs as circular or semi-circular "anomalies".

As described by the metadata provided by the Instituto Geográfico Nacional[6], the raw LiDAR data were acquired between 2009 and 2015 and come in RGB as well as in infrared (IRC). The point density is 0,5 points/ m^2 with an altimetric precision slightly superior to 40 cm root mean square error (RMSE Z). Derived LiDAR data (DEMs) was processed and parametrised in ArcGIS and QGIS for matching our aims. In accordance with other researchers (Štular *et al*. 2012; Kokalj and Somrak, 2019), a set of visualisations have been generated (Fig. 5-6). These visualisations attain the identification of—mainly—excavated tombs from the necropolis, which are typically quasi-circular with an empty interior (almost like a doughnut). However, no significant new results have been obtained so far, which may require either further testing or data with higher resolution.

[5]http://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=LANDS# (accessed 29 November 2021).

[6]http://centrodedescargas.cnig.es/CentroDescargas/linkUnMD

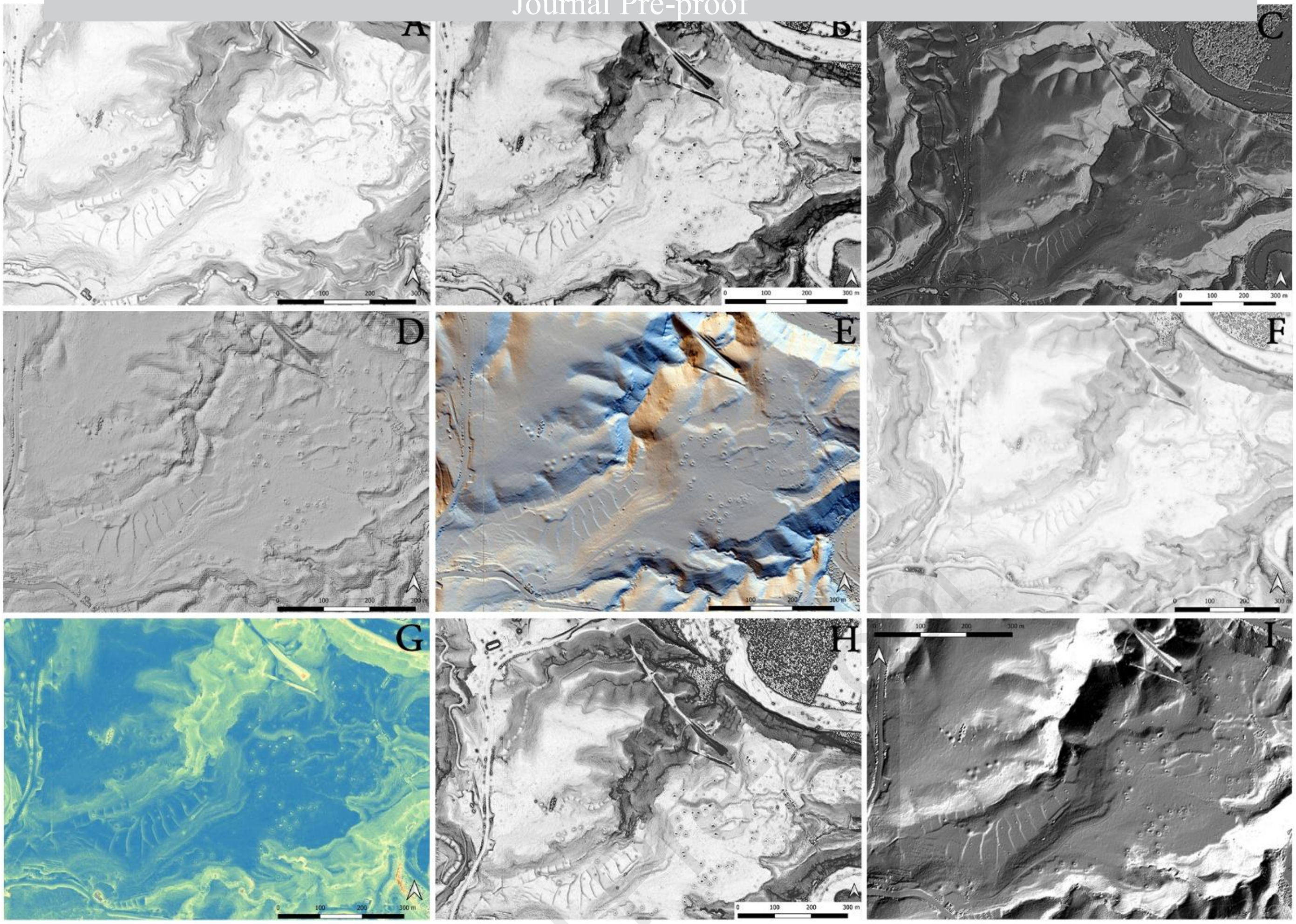
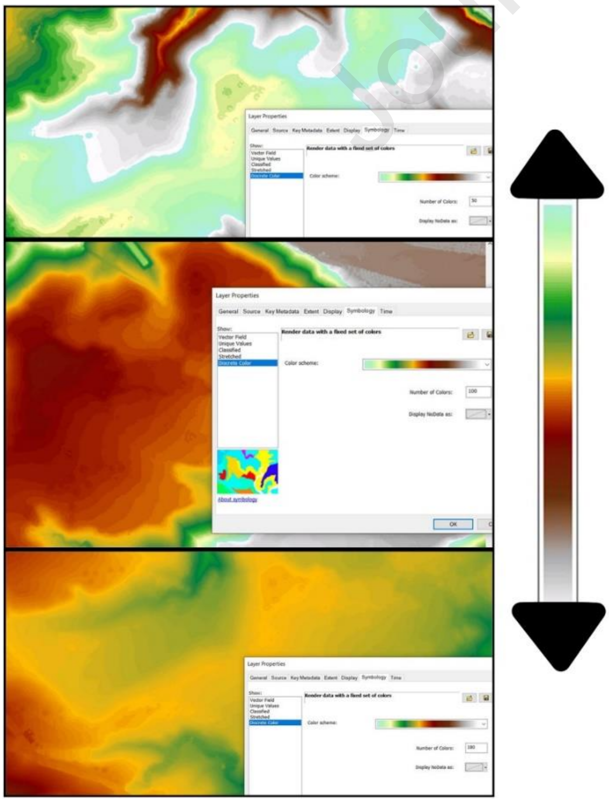


Figure 5 (above). Set of LiDAR-derivated visualisations for Los Millares using QGIS: A) slope gradient; B) the Kokalj-Somrak (2019) blended combination implemented in the ZRC SAZU's Relief Visualization Toolbox (v. 0.9.2); C) manual derivate from Kokalj-Somrak (2019) inverting the grayscale; D) local relief model; E) multihillshade composed in the Relief Visualization Toolbox; F) Skyview factor; G) Skyview factor with spectral renderisation; H) blended skyview factor (multiply and 75% of transparency) with slope gradient (overlay and 100% of transparency); I) hillshade with the colour gradient modified (inverted grayscale).



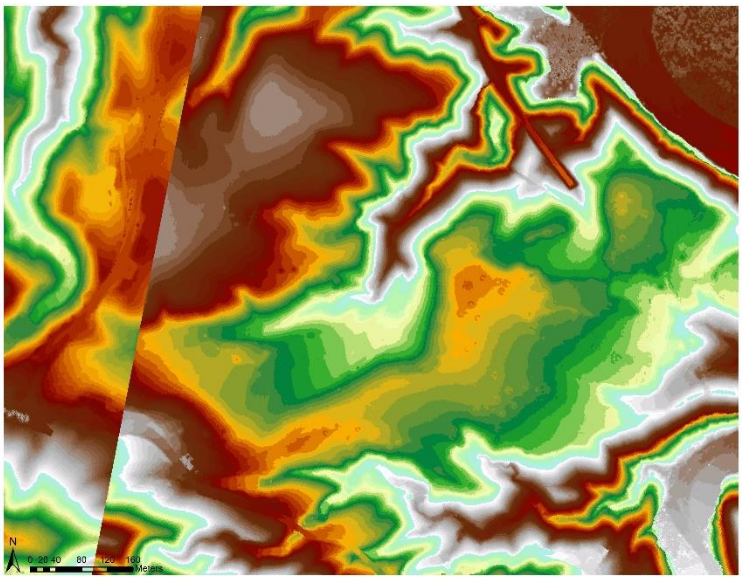


Figure 6. LiDAR-derivated visualisations for Los Millares using ArcGIS. Left: DEM with discrete colours-cast renderisations ranging between 40 to 180. This range responds to different variates such as terrain's topography and altitude or relative remains' preservation. Numbers of colours from top to bottom: 40, 100, 180. Above: map with colour cast ranging between 40 (right side) to 60 (left side).

Aerial orthophoto-interpretation and modern CAD topographical maps, moreover, underpins our LiDAR usage. The aim was to complement our knowledge about the site and, specifically, about the tombs and necropolis. This formalistic and multi-layered approach in GIS combines and interlinks different geospatial sources, allowing thus an understanding of the complex picture of this site (Fig. 7). Specifically, the combination of sources underscores the research carried out in the necropolis and presents a landscape perspective that unites tombs, settlements, and defensive structures.

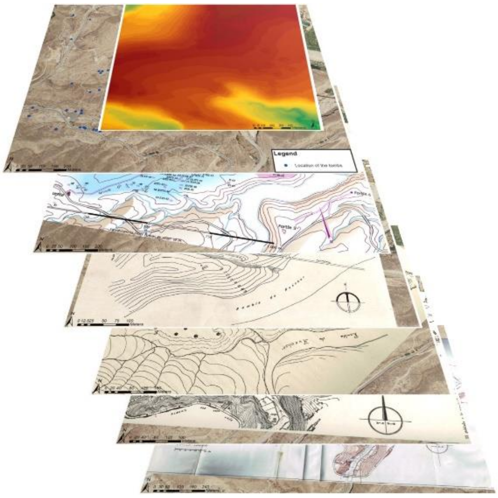


Figure 7. Multi-layered caption of some of the layers used and interlinked in our GIS environment.

4.2. Intra-site and in-site: photogrammetrising the barbican and artefacts

Los Millares' barbican is an important remain for understanding the role of this settlement and its surrounding area. On the other side, artefactual remains reflect fundamental aspects of the social and daily life. Both things have been digitised using digital technologies.

Preserving at the same time than disseminating was mandatory for us[7]. One sensible approach to this end is the use of technology based on the Structure from Motion (SFM) procedures. In this case, we have used photogrammetry aid by the use of similar technologies, such as Reflectance Transforming Imaging (RTI) and Blender postprocessing renderization, when relevant for our aims. Although adapted to our goals, this is in line with current practices in Archaeology, Art History, and heritage preservation, specifically in contexts of potential physical deterioration (Frank *et al.* 2021). This method has also been shown suitable for facilitating effective dissemination and communication (Frank *et al.* 2021; Maldonado and Dorado, 2020).

To speed up field data-capture, 4 Cameras Canon PowerShot SX430 IS, all with the same configurations, were used for the photogrammetrisation of the barbican. The cameras were distributed to 4 people, one per camera. In this process, each person documented one part of the barbican (Fig. 8A): the right side, the entrance and gate, the left side, and over the structures. The next step was the processing of these data in Agisoft Metashape, a software which semi-automatically renders photogrammetrical models from the taken photos. This was then followed by postprocessing modelling through Blender. The final model has now been uploaded to Skectfab and is also accessible through our webpage[8].

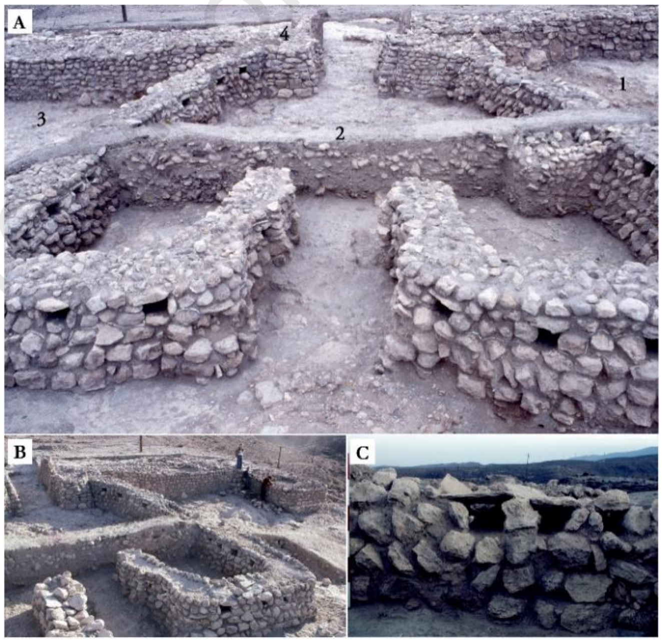


Figure 8. The barbican of Los Millares. A: During its excavation; numeration 1-4 indicates the different places from which the photos for its photogrammetrisation were taken. B: Partly oblique angle of the barbican. C: Details of the barbican's walls.

The photogrammetrisation of ceramics, idols, and loom weights, among others, followed a similar workflow. For these items, we used one Canon EOS 600D, adjusting the lens' parameters on a case-by-case basis: still Yongnuo Focal of 35 mm. for elements of considerable size; the standard Canon lens of 18-55 mm. for pieces of medium size; and one macro-Canon of 100 mm. for the smallest artefacts. We used one tripod to

[7] Other procedures have been used previously at Los Millares for the same aim—for example, the DVD (Molina González, 2004). Our team (Cámara Serrano *et al.* 2021) has also recently photogrammetrised other features for research and outreach purposes. Moreover, Martín Haro Navarro, archaeologist and Project Manager at Los Millares, is currently developing procedures to preserve and render funerary remains at the site in partnership with the Andalusian municipal and autonomic governments.

[8] Virtual3D_UGR. Sketchfab profile where our models are stored: https://sketchfab.com/virtual3Dugr. (Accessed 4 November 2021). Our platform containing the 3D models can be found at: https://virtual3dugr.prehistoriayarqueologia.org/ (accessed 13 December 2021).

ensure image's sharpness. The tripod, moreover, allowed us to use slow shootings that can offset the shutter's minimum openness and the low ISO sensitivity (ISO 100, f/22, 1.6"). In order to prevent from undesired shading-or-shining, we used a light-box with three lightbulbs inside which to place and handle the artefacts. A detailed explanation about the next steps can be found elsewhere (Maldonado and Dorado 2020) and, therefore, this paper only offers a brief overview:

- Range of shots per artefact: 50-70 for medium to big pieces, 100-120 for pieces of small size. Output in raw format (crw/cr2).
- Photographical processing through Adobe Lightroom and Adobe Photoshop, allowing the enhancement of the images and the conversion to an editable format (jpeg).
- Photogrammetric processing through Agisoft Metashape. The result is then exported in .obj or .ply for maximising its compatibility with 3D modelling software.
- Postprocessing rendering with Blender and its engine Cycles. Retropology, which modifies the geometrical mesh, allowed us to obtain high-resolution models in smaller files (see right below). This, along with the use of specific bibliography, opens the possibility of rendering the total or partial digital restitutions of these artefacts.

It is essential to carry out a digital optimisation process after the photogrammetric model has been developed. This workflow process, known as retopology, essentially allows the reduction of geometric load from our three-dimensional objects while maintaining the quality and definition of their details. In other words, this part converts a high-resolution photogrammetric model, which inevitably is quite heavy, into a file with almost the same visual quality but easily disclosable.

Retopology follows two indivisible steps. The first step converts the original mesh of the photogrammetric model into one substantially less geometrically-loaded, more logical and regular—which is mainly composed of quads. The second step focuses on adapting the original texture of the photogrammetric model to the new optimised mesh through 'digital baking'. As there is no actual geometric resolution, we must imitate the model's details through procedural texture maps such as the normal map, the roughness map, and the ambient occlusion map. This procedure is carried out in Blender, applying the modifiers Shrinkwrap and Subdivision Surface to paste the optimised mesh over the original photogrammetric object. Afterwards, the Cycles rendering engine and the Bake tool were used to create the different textures that compose our PBR (Physical Based Rendering) material. This material is made up of texture maps, which are light-in-weight JPEG files that imitate geometric details and arguably improve the finishing of the original model (Fig. 9).

This results in lighter virtual models. As a consequence of this process, these objects can be hosted in online repositories, such as sketchfab, and be viewed from virtually any computing device (smartphones, tablets, laptops, etc.), regardless of its hardware power. Moreover, to ensure metric consistency the models stored in our webpage either integrate a ranging pole or possess metric information in the metadata section.

Overall, the process generates easy to handle and store virtual materials that can be used for multiple ends and by different users or institutions.

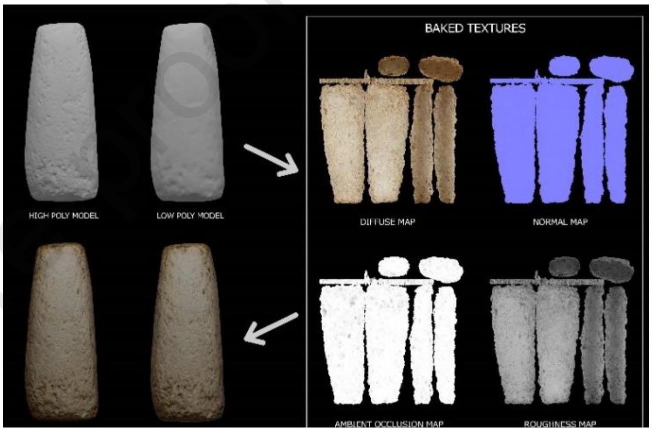


Figure 9. Retopology and texture baking process of an idol from Los Millares. On the left, a comparison of the high-resolution and low-resolution models before and after applying the procedure. On the right, texture maps used to imitate the geometric details of the high-resolution model

Our models have been uploaded to Sketchfab, a standard digital platform for storing and displaying photogrammetric models. People normally access to these platforms via computers. Nonetheless, we also find mobile phones suitable for this, especially considering their portability and capacity for creating immersing VR experiences. In this vein, our team has also developed an additional method for accessing to these materials through mobile-based technology. This has been done by implementing associated QR codes (Fig. 10) attached to the infography of published artefacts (as explained in Maldonado and Dorado, 2020).

Results and discussion

Our work with GIS has retrieved some interesting outcomes. On the first hand, it has organised, related, and united the different sources about the tombs of Los Millares. This is the first time that a dataset correlates and unifies the variate numeration of these burials (Annexe 1). In total, 93 graves have been identified, most of them with identifiable correlations between the different systems of numeration. It is also the first time that legacy maps from the site have been digitally georeferenced, as happens with those from Siret and Almagro and Arribas. LiDAR data, moreover, complement such cartographical information—and it is equally the first effort in combining old cartography with new satellite imagery.

This part of the project also has implications for the heritage sector. Being an ESRI geodatabase, this data is now uploaded and freely available as a Geodatabase (mdb.), CSV, JSON, and as GeoJSON with their respective URI[9]. This conforms to four of the five stars of the Open Data principles developed by Berners-Lee[10]. This part of the project, thus, changes the way of curating the previous material and data.

All in all, the work with GIS results in an important contribution both for researchers and the general public. Our contribution has achieved the combination of these different sources into a single dataset that unifies the different geographical information about the tombs. In other words, the dataset harmonises such information. At the same time, this harmonisation is made open, complying with our commitment with an open, fairer, Archaeology (Marwick *et al.* 2017; Wilkinson *et al.* 2016).

The photogrammetrisation of the barbican and artefacts has also considerable outcomes. In total, the barbican and 13 artefacts have been digitised. The digitalisation of these material remains signifies the movement from physical and grey formats to web-source formats.

As mentioned in the methodological section, our models are now stored in Sketchfab and in our website. These platforms are arguably effective for dissemination because they allow us to present digitised materials in an interactive environment. Normally, the digitised materials contain relevant details – functionality, composition, etc.–, being thus an additional aid for disseminating knowledge. This way of dissemination, we argue, breaks away from physical barriers: now, different users can access to these artefacts without the need of being in the physical archive where they are held or visit the site.

Moreover, the implementation of associated QR codes attached to the infography of published artefacts adds another outcome (Fig. 10). We argue that it is an advancement, at least considering the previous estate of

Figure 10. Processing the photogrammetric model of the barbican in Agisoft Metashape. The first two models show different stages of its processing, and the last one is the final model. Note the QR code attached to the image.

9 https://doi.org/10.5281/zenodo.5783548 (accessed 15 December 2021). Some of the digitised data have also been exported and uploaded as KML for their display through Google Earth.

10 https://5stardata.info/en/ (accessed 4 November 2021).

the data used, because it enables different users to access and manipulate such heritage in a digital format through various mediums. Overall, it changes the previous state of data curation, offering the possibility of outreaching to a greater number of people.

The 3D modelling of these different artefacts opens, in turn, one further outreach possibility. Following the hacking ethic, our artefacts are now digitised and stored in a specific web-portal that allows users to download the models. Moreover, once they are digitised, the models can be printed with specific 3D printers. Considering this, it can be argued that our portal works as a Digital Collection that can, additionally, be used by different users (individuals or institutions) to print replicas of the artefacts for multiple goals (e.g., apprehend and work with them through the sensorial experience of touching). Therefore, our work serves for creating a Digital Collection, that, through tiphlological adaption, enables people to interact with the material heritage without risking the preservation of the originals. Moreover, such tiphlological adaptation and the implementation of ancillary actions (e.g., printing 3D replicas) might help users with diverse impairments to experience Los Millares' cultural heritage in new ways: for instance, our models can be printed and used for creating Virtual Museums, more accessible and attuned to different learning needs. Indeed, recent studies have shown the potentiality of 3D models to create Virtual Museums and improve learning accessibility (Pistofidis *et al*. 2021; Milosz *et al*. 2020; Loaiza Carvajal *et al*. 2020).

Besides these immediate or main results and outcomes, our methodology opens additional avenues, or secondary results, in the form of by-products. Such by-products are equally important and, therefore, the next few lines offer an account of them.

Besides Sketchfab, the models can additionally be accessed through our webpage (Attribution-ShareAlike 4.0 International, CC BY-SA 4.0). On the one hand, this dual channel enables users to interact with, or manipulate, cultural heritage without necessarily accessing the physical copies. This might help in protecting archaeological artefacts from physical damage. On the other hand, the digital treatment and preservation of the materials enable us to record physical details of the originals that otherwise might disappear. For this, it has been argued elsewhere that the modelling of these artefacts allows the digital preservation of the original features of these materials (Maldonado and Dorado, 2020). For this, we argue that our project adjusts to the 2012 UNESCO/UBC declaration, also known as the Vancouver Declaration[11], whose goals are the preservation of the human cultural capital through the digitisation and 3D modelling of material remains (Vancouver Declaration). This societal impact is, arguably, quite a valuable asset that comes out of our project.

Another important result is the usability and applicability of the digitalisation for other projects. Indeed, the Research Cluster of Excellence 'Archaeometrical Studies. Inside the artefacts & ecofacts' of the University of Granada[12] enable this by linking material outcomes from the different projects it fosters. For example, the 3D impression of some of the photogrammetrisised barbican and artefacts has been recently used as a mean to explore new teaching frameworks for people with diverse (mainly visual and mobility) impairments (Contreras *et al.* 2020). In other words, our method potentially generates new teaching possibilities. Therefore, the results presented in this paper aid in generating new strategies which can enhance the accessibility to the material collections curated at the Department of Prehistory and Archaeology of the University of Granada (Maldonado and Dorado 2020).

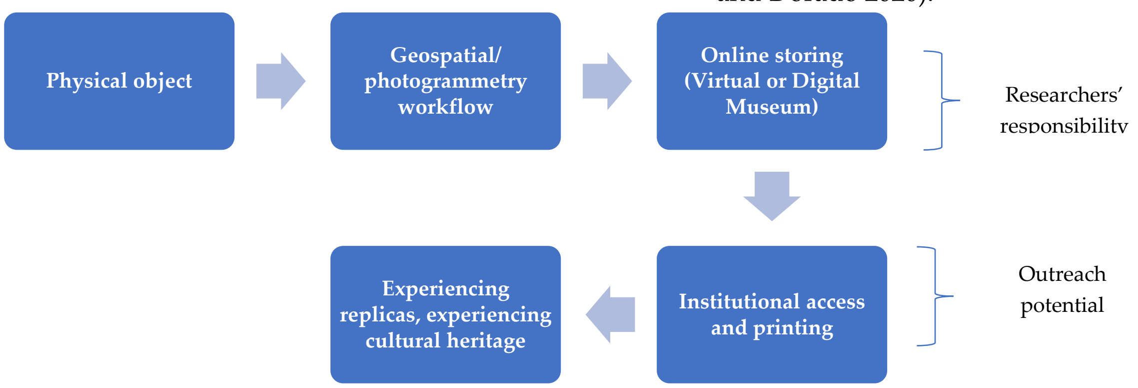


Figure 11. Schematisation of the workflow followed and the prospects it offers.

[11]https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwits9D2hf_zAhVLUxoKHS0_CJYQFnoECAIQAQ&url=http%3A%2F%2Fwww.unesco.org%2Fnew%2Ffileadmin%2FMULTIMEDIA%2FHQ%2FCI%2FCI%2Fpdf%2Fmow%2Funesco_ubc_vancouver_declaration_en.pdf&usg=AOvVaw2-DKMGJCt_rnidDMqkGzoP&cshid=1636040697475216 (accessed 4 November 2021)

[12]https://sites.google.com/go.ugr.es/uearqueolugr/p%C3%A1gina-principal (accessed 4 November 2021).

Conclusions

This paper has brought to the fore some specific concerns related to heritage management and curation. In particular, it has dealt with the ethical issues generated by grey sources and legacy data from the archaeological site of Los Millares. Our paper shows how to challenge and shift this situation—i.e., from legacy to fairer and more open formats. The methodology we explain expounds how to use digital methods based on geospatial technologies to achieve such a change. Thus, the combination of GIS and Photogrammetrisation with digital portals offers an interesting prospect (Fig. 11).

The outcomes of our project are expected to have their echo on different social layers. On a first level, the project has value for the academic community because it eases the access to these data and, therefore, can be used for different ends. A good example is the better co-relationship among the different grave numerations provided through time. On a second level, it represents an outreaching effort in terms of education: it opens new paths towards digital ways of teaching by accessing to these materials as a visual complement to explanations about different chronological periods. On a third level, different regional and local public institutions might find benefits in using our models for 3D printing; these prints can, in turn, be displayed in museums or used as educational tools. On a fourth level, our models may help in outreaching this knowledge to interested people with little to none acquaintance with the archaeological materiality. We argue that such manifold societal impacts conform to the Sustainable Development Goals (SDGs), in especial to Nº 4, 5, and 9[13]. No doubt, this demonstrates the importance of the cultural heritage in our present and future.

In sum, our paper represents an effort in making more ethical our academic ethos. This effort has in its core a specifical preoccupation for the proper curation of the cultural heritage, in this case through the use of digital technologies. The authors think that this approach is suitable and useful to this end. We thus hope other teams can benefit from some of the ideas developed in this paper.

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Annexe 1

Object ID	Siret	Fiabilidad Siret	AyA	Fiabilidad AyA	Flores Leisner	Fiabilidad Flores Leisner	Posibles Flores	Fiabilidad Posibles Flores
1	17	Buena	I	Buena	17	Buena	17	Buena
2	46	Buena	XXVII	Buena	46	Buena	46	Buena
3	16	Buena	VIII	Buena	16	Buena	16	Buena
4	5	Buena	IX	Buena	5	Buena	5	Buena
5	7	Buena	VII	Buena	7	Buena	7	Buena
6	6	Buena	VI	Buena	6	Buena	6	Buena
7	37	Buena	V	Buena	37	Buena	37	Buena
8	8	Buena	IV	Buena	8	Buena	8	Buena
9	4	Buena	XXXIX	Buena	4	Buena	4	Buena
10	22	Buena	L	Buena	22	Buena	22	Buena
11	24	Mala	XLIX	Buena	24	Buena	24	Mala
12	25	Buena	XLVIII	Buena	25	Buena	25	Buena
13	43	Buena	XLVII	Buena	43	Buena	43	Buena
14	13	Regular	XLIII	Buena	13	Regular	13	Regular
15	38	Buena	XLI	Buena	38	Buena	38	Buena
16	41	Buena	XL	Buena	41	Buena	41	Buena
17	40	Buena	XXXVI	Buena	40	Buena	40	Buena
18	12	Buena	XXXVII	Buena	12	Buena	12	Buena
19	44	Buena	XLVI	Buena	44	Buena	44	Regular

Table 1. Part of the data correlating the different numeration from Los Millares' tombs. The correlation has a validation scale (Buena=good; Regular=fair; Mala=bad) which validates the trustiness of the identification of each tomb for every numeration system.

Highlights

- Ethical digital research reinvigorates heritage preservation
- Digital technologies are powerful tools for making more open our research
- Digitisation of databases and information from excavations that have been inaccessible until now
- These data are now fully accessible to use by other researchers (hacker ethic)
- Presents new ways on heritage curation for this site

All the authors have contributed in this paper. PBV came out with the idea and wrote most parts of it. ADA and AMR further contributed with the composition of the text. JACS and FMG revised the text and suggested edits that enriched the paper. PBV carried out GIS and LiDAR analyses; ADA and AMR developed the whole photogrammetry. ADA stored the virtual models in the webpage and PBV uploaded the relevant geospatial data to Zenodo. ADA, AMR, JACS, and FMG provided most of the data pertaining artefacts.

The authors do not find any conflict of or competing interest in this research.