

RESEARCH ARTICLE

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Emergent heritage: the digital conservation of archaeological sites in reservoirs and the case of the Dolmen de Guadalperal (Spain)

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Abstract

The dolmen of Guadalperal (Spain) became well known in 2019 when the waters of the reservoir in which it had long been submerged became so depleted as to leave it above water and highly visible. This gave rise to great media and social polemic. In this study, we deal with the 'recovery' of the dolmen using digital techniques, including a strategy of geometrical documentation of long, medium and short-range through the use of terrestrial laser scanning (TLS) and photogrammetry. The result is a set of products that trace the changes that have taken place in the monument since its excavation in 1925, the identification of conditions affecting it and the acquisition of new information on the decorated supports that formed part of the megalithic architecture. To do so, the time during which it was accessible (i.e., not underwater) was used to acquire the only heritage information currently available on the monument. This new information offers a complete assessment of a megalithic monument using a protocol that is exportable to other sites submerged in lakes or reservoirs.

Keywords: Digital recording, Submerged archaeological heritage, Megaliths, Climate change

Introduction

Megalithic heritage can be seen as global imagery made up of symbols [1] chronological developments and similar landscape notions across Western Europe [2, 3]. It has the unquestionable capacity to determine the meaning of the landscape beyond its prehistoric uses to produce a shared perception [4]. Under this premise, the protection of and research into megalithic sites must relate to the cultural peculiarities of each region [5–10]. This study responds to the need to harmonize these social requirements by the incorporation of digital geometric documentation in an unusual case as is the conservation of archaeological assets lying over the waters of reservoirs.

The case chosen, the dolmen of Guadalperal, made the media headlines during the summer of 2019 when the fall in the water level of the reservoir of Valdecañas (Spain) led to the emergence above the water of this famous monument (Fig. 1). The assessment of the preservation of the dolmen was undertaken by the Spanish Ministry of Culture, specifically the Spanish Institute of Cultural Heritage (IPCE), and a group of specialists, including the undersigned. Although the archaeological site was already well known to professionals in the field, the media presented it as a discovery and an opportunity to promote cultural tourism in the region. Despite the evident error, the national and international media compared it with Stonehenge promoting a vivid social debate on the convenience of relocating the sepulchre to a place somewhere out of the reservoir.

Thus, the current scenario in which the management of hydric resources and climate change is creating an unprecedented need to safeguard cultural heritage in

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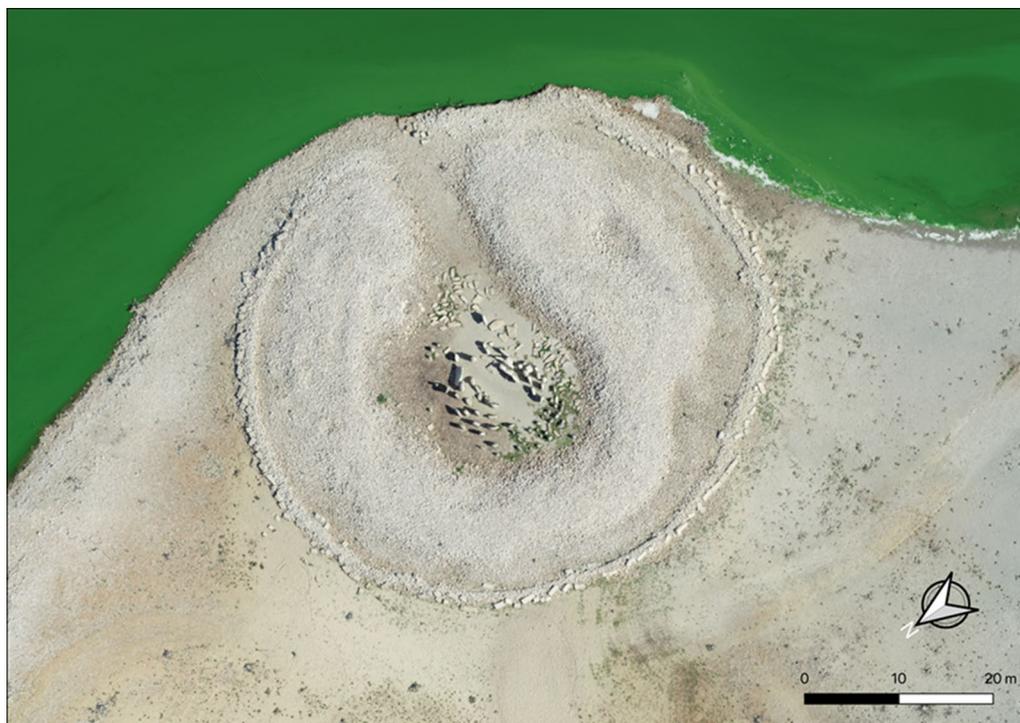


Fig. 1 Orthoimage of Dolmen de Guadalperal, images taken during September 2019. The image has been composed using the procedures described in this paper

coastal areas of Western Europe [11–14]. Situations such as that of the dolmen of Guadalperal will be repeated in the future and make it necessary to design research strategies that improve knowledge of cultural goods in affected territories and consolidate management heritage policies under the pressing needs of conservation [15, 16]. This is a complex issue, which involves social and legal aspects associated with archaeological knowledge and heritage management.

Geometric documentation of cultural heritage in the face of any risk that threatens its preservation is certainly not new [12, 17, 18]. Some of this work includes the use of photogrammetry on coastal sites in the face of erosion due to climate change [19, 20]. However, there is no previous literature on the geometrical documentation of submerged archaeological assets in reservoirs. Additionally, the digitalisation of European megalithic heritage is a line of work that has been pursued at different levels. On the one hand, initiatives have been developed to document the architectural elements of megaliths using photogrammetric [21–23] and laser scanning techniques, sometimes using BIM technology [24] to unravel aspects of their construction. On other occasions, digital products have been used to simulate the relationship between the monuments and the natural lighting [25]. Finally, perhaps the

most exploited field is that of the analysis of engravings and paintings found on the slabs of the megaliths, where there is a certain tradition of analysis developed in recent years in countries such as Spain [26], Portugal [27], France [28] or Ireland [29].

Looking beyond the final decision on the conservation of the site, a line of work is put forward to provide a model interpreting the site of the dolmen of Guadalperal in a reliable way as possible and as it would have appeared in its original state, together with the transformations caused by its flooding. This line of works comprises the generation of high-quality geometric documentation as well as monitoring the damage produced on the monument by different agents like weathering. In this case, the study we present here aims to use geometric recording techniques to establish continuous monitoring of the Guadalperal Dolmen. The novelty lies in the establishment of a control system in which each of the parts of the monument can be individualised in order to observe the changes that changes in conditions may cause. This includes the documentation of the area surrounding the monument, of its slabs, but also of the engravings found on some of them. This approach involves a combination of different techniques that are brought together in this work for the purpose of research but also for monitoring of the changes that the monument may undergo.

The archaeological and historiographic context of Guadalperal

The megalithic sites from the inner basin of the Tagus River have been the object of archaeological research programs for decades [30]. A chronological diversity of monuments built from the end of the 5th to the end of the 3rd-millennium cal BC are available, corroborated by absolute dates, such as those obtained in the monuments of Azután [31] or Guadancil 3 [32] (Table 1). This is not so for Guadalperal, whose chronology was established in three phases: prior to the megalith, megalithic and Bell-Beaker period from the information compiled by Leisner and Leisner [34] which must be confirmed.

Throughout the Tagus basin (Fig. 2) we find varying concentrations and dispersions of tombs in different units of landscape [41]. In this case our interest centres on the dolmens (Fig. 3). Upstream the monument of Navalcán is located [42] also covered by the waters of a reservoir. The similarities between this site and that of Guadalperal are clear, particularly located at the entrance of the chamber). The workflowthe presence of conceptually similar decorative and architectural elements [43]. In an intermediate position between the two, although not flooded, the dolmen of Azután [31] is located, cited by H. Obermaier [33]. This monument presents an architecture of a similar nature to that of Guadalperal, with inner stones and a chamber made up of 14 slabs [31]. Finally,

Table 1 Absolute datings of the dolmens of the Spanish Tajo basin

Site and reference	Absolute date (BP)	Lab reference	Material	Calibrated (2 σ cal BC)
Azután [31]	5750 \pm 130	Ly-4578	Human bone	4904–4862 4856–4344
Joaniña [36]	5400 \pm 210	Sac-1380	Charcoal	4712–3771
Azután [31]	5250 \pm 40	Beta-157731	Charcoal	4231–4194 4170–3975
Azután [31]	5060 \pm 90	UGRA-288	Human bone	4041–4016 3995–3649
Montehermoso 8 [37]	5040 \pm 70	Ua-17768	Charcoal	3968–3699 3686–3654
Tremedal [38]	5000 \pm 60	GrA-15903	Charcoal	3946–3653
Portillo de las Cortes [39]	5000 \pm 30	Beta-334952	Human bone	3943–3865 3811–3701 3681–3655
Guadancil 3 [40]	5000 \pm 40	Beta-328111	Charcoal	3946–3856 3846–3834 3820–3696 3690–3653
Montehermoso 11 [37]	4965 \pm 75	Ua-17766	Charcoal	3946–3640
Montehermoso 11 [37]	4920 \pm 70	Ua-17763	Charcoal	3945–3857 3818–3622 3583–3531
Tremedal [39]	4860 \pm 50	GrA-15941	Charcoal	3765–3727 3715–3526
Azután [32]	4620 \pm 40	Beta-145277	Human bone	3522–3336 3211–3193
Azután [32]	4590 \pm 90	Ly-4500	Human bone	3626–3576 3571–3561 3534–3074 3066–3025
Trincones 1 [40]	3600 \pm 60	Beta-197160	Sediment	2138–1868 1850–1771
Joaniña [36]	3480 \pm 170	Sac-1381	Charcoal	2287–1422

Calibrated datings using the Software OxCal 4.4.2 [35] and atmospheric data [36]

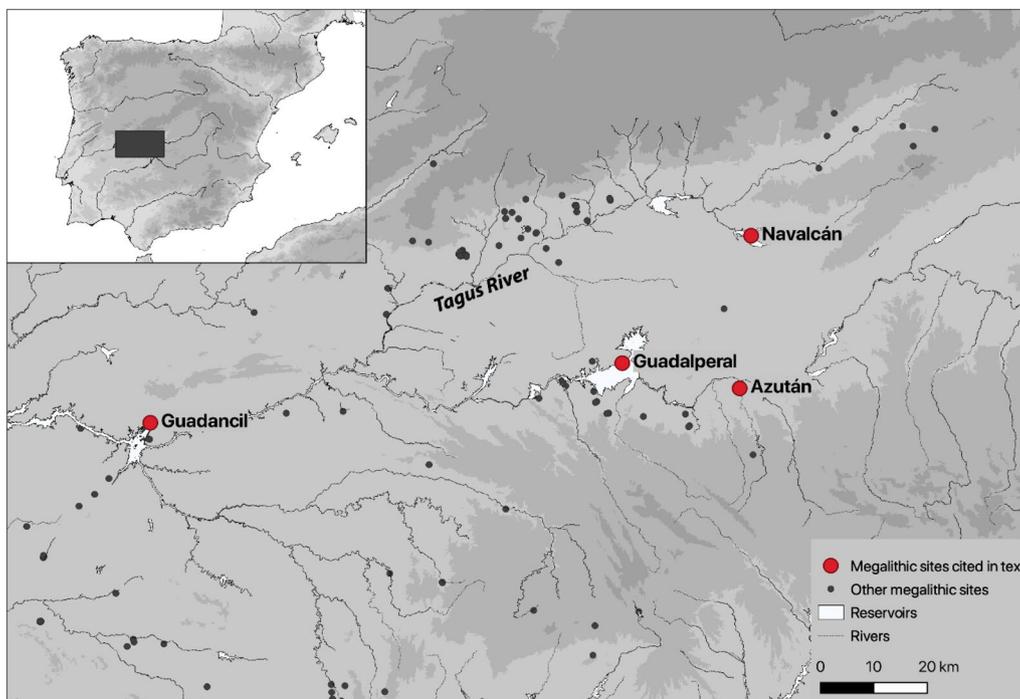


Fig. 2 Map of the section of the river Tajo (Spain) showing Guadalperal and other megalithic sites mentioned in Fig. 3. The cartographic representation is comprised between the following geographical coordinates (WGS84 datum): 6.78 W, 40.08 N (upper left corner) and 4.41 W, 39.2 N (lower right corner)



Fig. 3 Photographs of the megaliths mentioned in text. **A** Guadalperal in 2019 (flooded). **B** Azután during its excavation (not flooded). **C** View of the area of Guadalcencil 1 in 2012 (flooded). **D** General view of the dolmen of Navalcán during its excavation (flooded)

beyond this site to the west is the necropolis of Guadalquivil [44] also submerged. The close relationship between the megaliths and the course of the Tagus River or its direct tributaries points to the relationship between river streams and prehistoric settlement, being a factor that has furthered the flooding of these sites once the dams were built.

The discovery and excavation of Guadalperal between 1925 and 1927 was the work of Hugo Obermaier [45–49]. In 1936, Obermaier moved to Fribourg [46] during his fieldwork. The work concerning Guadalperal was published monographically years later after his death by Georg and Vera Leisner [33]. The site initially appeared as a large tumulus formed by quartzite from which some of the slabs forming the chamber appeared slightly. During the dig, the sediments and quartzite blocks that formed the mound were removed entirely and disposed around the chamber forming a circle, which left the structure of the dolmen free of its covering. The internal architecture was made up of a chamber, a corridor and atrium. The corridor, as far as can be gleaned from the photographs taken during the dig [33], was restored with concrete, although most of the slabs have now collapsed. Within the chamber, which may well have contained 12–14 slabs, from which only nine remain. The chamber was surrounded by a system

of buttresses made mostly of slabs of the same size and material as those in the chamber. The slabs closer to those in the chamber are larger, while those further away are smaller and use materials of different nature such as quartzite. The stela at the entrance of the chamber [50] would have been originally located at a place nearby from it was erected and consolidated during Obermaier's work. Figure 4 shows the location of these elements on a current aerial image of the site.

Through the 1960s the massive construction of reservoirs was perceived in Spain as an opportunity for technological modernization [51, 52]. Any assessment of the impact on cultural sites was reserved solely for those monuments that were regarded as masterpieces of Roman past [53]. On the other hand, innumerable sites of widely varying chronologies, such as megalithic monuments, were flooded without collecting any records of them. These decisions were taken considering a sparsely developed legislation dating back from 1933 [54] which failed to contemplate the impact of civil infrastructures on archaeological goods.

Guadalperal was flooded in 1969. It first re-emerged in 1992, when a graphic record was drawn up of the menhir-stela [43]. It did not reappear above the water again until the summer of 2019, which is when the site

Table 2 Specifications of the used hardware

Device	Purpose	Specifications
Faro Focus 3D X330 (TLS)	Recording of point clouds	Range: 0.6–330 m Ranging error (systematic measurement error at around 10 m and 25 m): ± 2 mm Measurement rate (pts/sec): 9,76,000
DJI Phantom 4 Pro (UAV)	Aerial photogrammetry	GPS-GLONASS positioning system (± 0.5 m vertical accuracy, ± 1.5 horizontal accuracy) Effective: pixels: 20 million Image sensor: one-inch CMOS sensor Image size: 5472 \times 3648 pixels File format: JPEG Focal length (fixed): 8.8 mm
GoSCAN 50 (short-range scanner)	Recording of point clouds	Range (recommended): 0.05–0.5 m Accuracy: 0.1 mm Resolution: 0.1 mm Measurement rate (pts/sec): 5,50,000 Scanning area: 143 \times 108 mm
Nikon D5300 (camera)	Close-range photogrammetry	Effective pixels: 24.2 million Image sensor: 23.5 \times 15.6 CMOS sensor Image size: 6000 \times 4000 pixels File format: NEF, 14 bit compressed Focal length (used): 18 mm

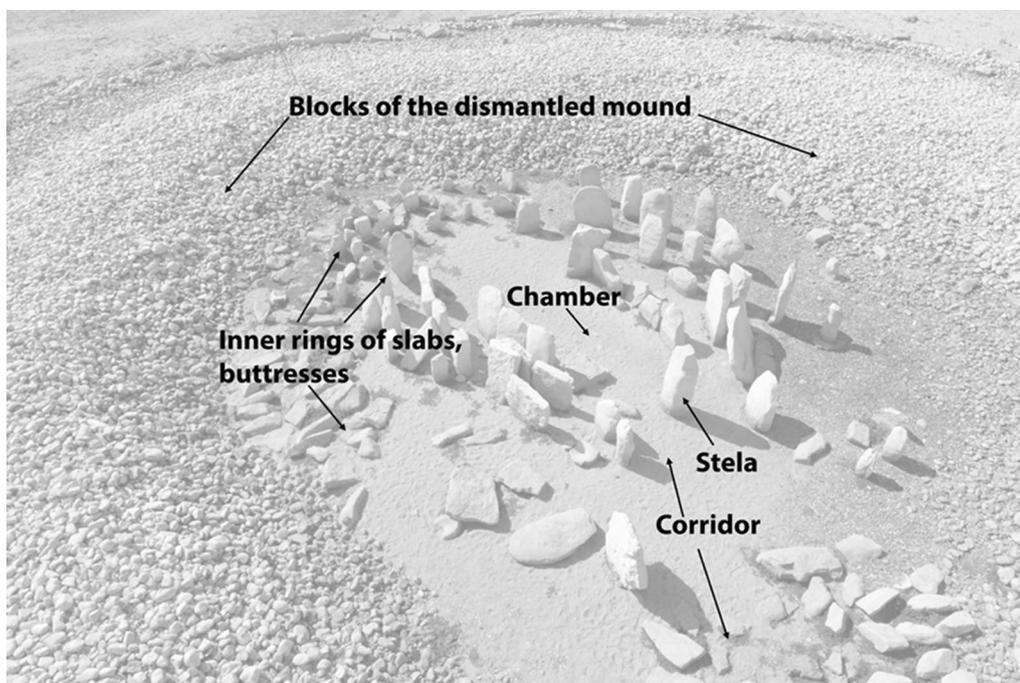


Fig. 4 The main architectural parts of the Guadalperal dolmen (Spain) described in the text on an aerial image of the year 2019

acquired its fame, and we were able to carry out the documentation presented here.

Methods

Digital documentation techniques can provide three-dimensional models of archaeological elements in detail, being ideal for the study of an archaeological site whose access is limited or intricate. These techniques include, but are not limited to, unmanned aerial vehicles (UAV), terrestrial laser scanning (TLS), photogrammetry and short-range scan. For this study we can consider three ranges of documentation: (a) ‘long-range’, which refers to the element in its surroundings such that a digital model of the ground and a high-resolution orthophotograph are obtained; (b) ‘medium-range’, referring to a digital model in the form of a point cloud with a minimum density of 2.5 mm of the entire element, and precision lower than to 5 mm; and (c) ‘short-range’, to obtain high-resolution digital models of singular elements within the structure (i.e., the stela located at the entrance of the chamber). The workflow is depicted in Fig. 5 Device specifications are given in Table 2.

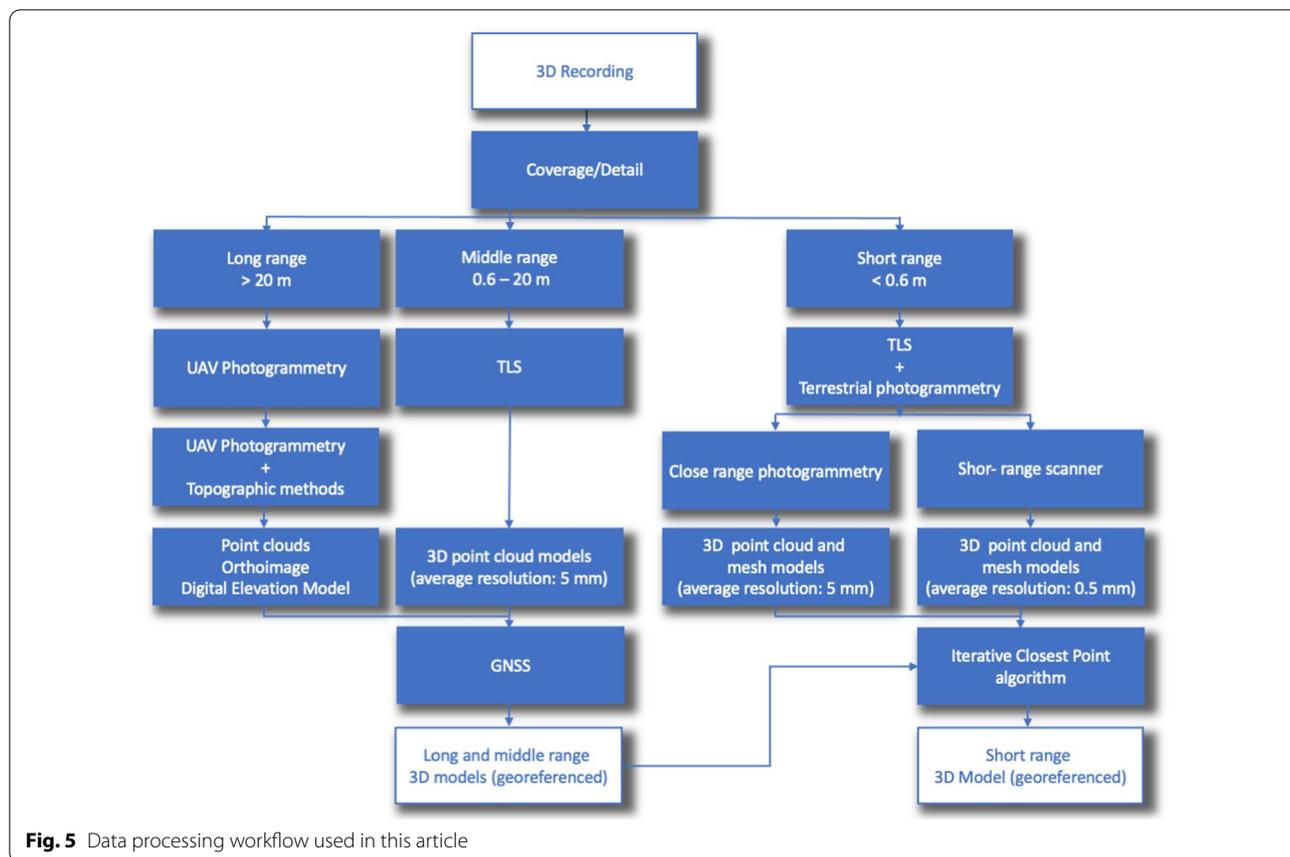
Terrestrial laser scanner (TLS)

Terrestrial laser scanner is an instrument that facilitates 3D models of point clouds of an object at a distance from the equipment of between 0.6 and 300 m. It

is a commonly used technique in the documentation of heritage goods, buildings or infrastructure for academic study, records, intervention or preservation [55–58]. For the documentation of the dolmen in Guadalperal, a medium-long range scanner was used, with a capacity of 1 million points per second at a maximum distance of 330 m (Faro Focus 3D X330) [59, 60]. The documentation of the element is obtained from the capture of 3D spherical images taken from different positions. Work is structured according to a flow implemented by the authors [58, 61] the different takes using the spheres as reference points, thus obtaining a 3D point cloud model. Noise is cleaned and filtered out, including the effect of the edge of the elements on the monument or the “mirror effect” produced as a result of the reflection on certain surfaces at the moment of the scan.

Photogrammetry using UAV

The photogrammetry workflows of images captured from unmanned aerial vehicles have increased in archaeological studies due to both the improvements in spatial resolution and the fall in costs [62–67]. A detailed description of the state-of-art can be found elsewhere [68–79]. For image collection a drone DJI Phantom 4 Pro [80] was used with a GPS-GLONASS positioning system, a maximum flight time of around 25 min, a triple-axis stabilizer, a frontal, lower and back vision system, a camera with a one-inch CMOS sensor, effectively 20 MP, image size



of up to 5472×3648 pixels and the objective at a fixed focal distance of 8.8 mm.

Two flights were planned: (a) aerial and zenithal photogrammetry surrounding the area of the dolmen at a mean altitude of 35 m ($GSD = 1$ cm), longitudinal coverage of 85% and transversal of 65%; (b) another with three circular orbits with a 15 m radius ($GSD = 0.4$ cm) at heights of 7, 16 and 23 m, at speeds of 1, 2 and 3 s to achieve coverage of 85% in the three orbits.

Photogrammetry and short-range scanner

The recording of the engraved supports is of particular interest as we knew of the existence of a stela located next to the entrance to the chamber of the dolmen [50, 71]. There are two possible ways of getting 3D models with optimal resolutions: digital photogrammetry and short-range scanner. Employing photogrammetry an individual survey was conducted on the most relevant supports, particularly the slabs that make up the chamber. The photogrammetry was performed using a conventional Nikon D5300 camera with a CMOS sensor of 24×16 mm, which produces images of 24 megapixels (6000×4000 pixels). To compare the previous results with a second source we used an additional technique on

the front face of the menhir at the entrance to the dolmen. To do so, we used a short-range scanner, GoSCAN 50 with a maximum resolution of 0.5 mm and a precision of 0.2 mm. This equipment is based on the technology of measurement using calibrated photogrammetric cameras and patterns of structured light beams [57]. This system is slow in comparison with photogrammetry, so its use was reserved for those surfaces where the engravings were evident. The result obtained is a mesh of triangles with the resolution required (maximum 0.5 mm) textured with the original colour.

Results

The three ranges of documentation (long–medium–short) were covered by the measurements taken. A digital model of the terrain and the dolmen from a zenithal plan were obtained using photogrammetry, as well as a high-resolution orthophoto. TLS provided a 3D point cloud model of the element from a viewpoint on the ground. By putting together the photogrammetry and the short-range scanner a high-resolution 3D model was generated of those parts of the structure requiring greater detail.

Terrestrial laser scanner

For the full documentation of the dolmen, 36 independent takes were needed. These were performed using two scanners simultaneously over 4 h. Regarding the estimation of errors in the joining of the point clouds, the RMSE was estimated at 4.76 mm, with an average error of 4.4 mm and considering a total of 107 points.

The point cloud obtained contains 363 million points. For cleaning and filtering, point cloud classification algorithms from the software RealWorks® were used. Through automatic and manual filtering unwanted points were eliminated. These made up 2% of the total of 355 million points that the cloud was made up of. Figure 6 shows the point cloud after the noise had been eliminated and classified as follows: dolmen structure, dolmen ground and terrain. The point cloud generated is

georeferenced in the ETRS89 UTM H30 system of coordinates with orthometric heights. The absolute accuracy was estimated using ground control points. The RMSE values after georeferencing the point cloud can be found in Table 3.

Photogrammetry with UAV

The necessary fieldwork was carried out to provide the photogrammetric block with enough spatial position points over the terrain, known as support points. A total of 15 such support points were distributed uniformly. At the same time as the photogrammetric support was marked, the coordinates were taken using a GPS LEICA 1200 by means of two bifrequency receptors using the static method. For the first zenithal flight five passes over

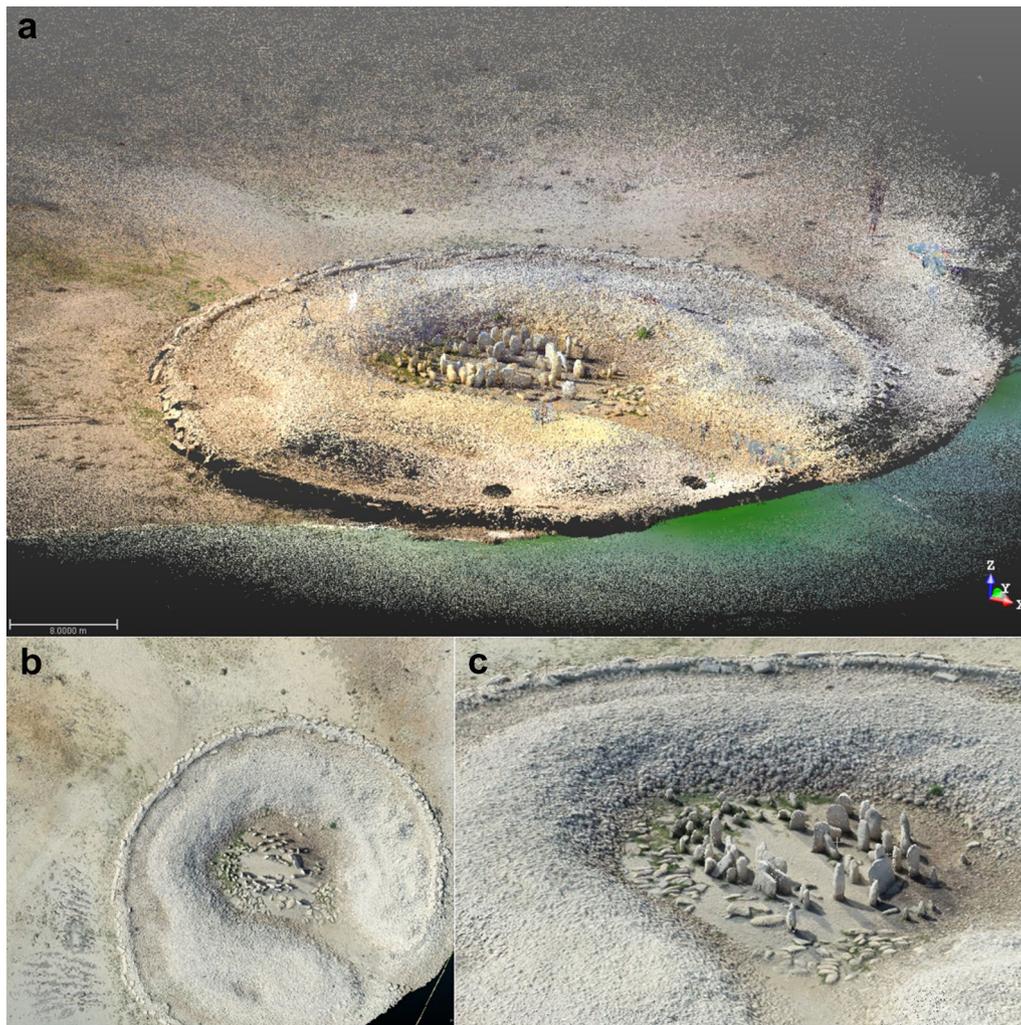


Fig. 6 Products obtained following the long-range procedure described in the documentation of the dolmen of Guadalperal. **A** Gross point cloud obtained using TLS. General views of the dense point cloud obtained by photogrammetry: plan (**B**) and perspective (**C**)

Table 3 RMSE of the TLS-generated point cloud and of the adjustment of the two photogrammetric blocks

Product	Number of points	RMSE _x (m)	RMSE _y (m)	RMSE _z (m)	RMSE _{xyz} (m)
TLS point cloud (after georeferencing)	11	0.007	0.004	0.008	0.004
Zenital flight (block adjustment)	9	0.012	0.024	0.024	0.036
Circular convergent flight (block adjustment)	8	0.009	0.019	0.015	0.025

the site were made and a total of 170 photographs taken, and for the convergent orbital flight 169 photographs were obtained, distributed in three different orbital planes.

The photogrammetry was processed using the software Agisoft Metashape, based on the acquisition of great densities of points from the correlation [73–75]. This software was developed using the techniques and procedures applied in the field of computational vision and graphics, such as SfM and MVS, with which a 3D model is automatically obtained from multiple convergent images [76–78]. In this research the basic steps of workflow in Metashape were followed as described in the publication [79], paying particular attention to the process of error reduction in the disperse point cloud [79]. The photogrammetric blocks were adjusted separately for each of the planned flights. The results of the absolute accuracy estimation can be found in Table 3.

Once the data from the flights had been fitted and optimized, they were joined together in a single block made up of 239 photographs and 11 ground control points. A total of 1,189,169 points of optimized links were used in this new model, model, resulting in a final fit of the block whose RMSE was 2.9 cm. Once the definitive block had been formed, the dense point cloud was generated (Fig. 6) from a total of 10,278,770 points. These were then filtered and classified to eliminate the noise from various sources. From the resulting point cloud, the triangulation, the digital elevation model and the final orthophoto were generated with a resolution of 2 cm.

Photogrammetry and short-range scanner

The number of images varied depending on the complexity, shape and size of the supports following the basic recommendations of the documentation through SfM. The data were processed using the software COLMAP [81, 82] in a cluster with 4 nodes equipped with GPUs. The software was configured to produce dense point clouds with the highest possible number of homologous points and with geometric filtering of information, a choice which reduces the number of possibly anomalous points. The result is a cloud of 35.9 million points with an average surface density of 12.86 points/mm² (standard deviation: 6.85).

The geometric documentation of the engravings on the menhir was also performed in a high-resolution survey using the short-range scanner (0.5 mm precision), which provided 4 million points on the front face. The estimated average surface density of the 3D point cloud is 3.73 points/mm² (standard deviation: 0.56). To homogenize the point cloud derived from the photogrammetry we sampled it so that it had a minimum distance between points of 0.5 cm. The result was a new point cloud with an average surface density of 2.93 points/mm² (standard deviation: 0.98), which can be better compared with the results of the short-range scanner. Additional file 1 includes a low-resolution version of this product.

The point clouds were scaled and georeferenced individually in the point clouds of the TLS such that each model of a slab had absolute coordinates (Fig. 7). This work was resolved using the Iterative Closest Point algorithm [83, 84] from the CloudCompare software. Iterative processes were set to reduce the RMS of the georeferencing below a threshold of the difference of 1e-06, being the difference the distance between each point of the cloud derived from photogrammetry and its nearest neighbour in the TLS reference cloud. This approach rendered in all cases an RMS of less than 1 cm (average 0.47), calculated from 50,000 points.

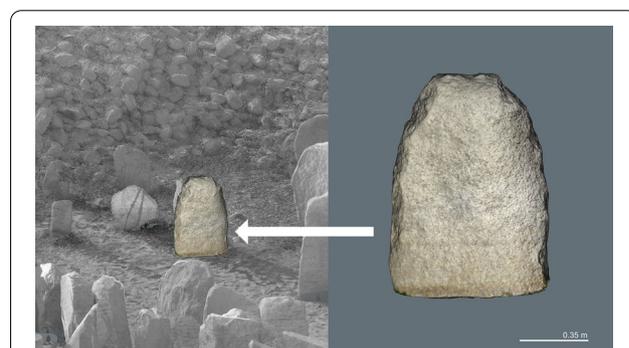


Fig. 7 Georeferencing of slabs point clouds generated by photogrammetry (right) on the overall point cloud obtained from TLS (left) using the Iterative Closest Point algorithm (RMS of the registration 0.34 cm)

Finally, to heighten the engravings, we applied the 3DMeshTracings methodology described in [27].

Discussion

By means of this detailed process, the 3D information of the documented element is available within the overall coordinates (ETRS89 UTM H30). The products obtained present the following advantages: (a) they supply data that make up for the lack of information on the archaeological site analysed to draw up fresh archaeological documentation, (b) they tackle the issue of the future monitoring of the site for any effects that changes in the reservoir may have on the structure of the dolmen, and (c) the model can be used for disseminating cultural contents. The first result is the availability of the documentation we provide, while the rest are perspectives which will need to be addressed in the future. Therefore, we centre our attention on the discussion regarding the progress made in the first point.

The structure of the monument and its preservation

The documentation generated effectively permits that the monument can be studied on a territorial level and compared with other monuments of the same nature. The photogrammetric and TLS data have served to create detailed cartography of the monument. The generation of sub-products has produced basic information, together with that described in “The archaeological and historiographic context of Guadalperal” Section, which is useful in the interpretation of the megalithic chamber (Fig. 8). The current location of the slabs and their comparison with the textual and graphical information facilitates the generation of thematic maps on the original position of

the slabs and their evolution over time, such that it is feasible to perform a virtual anastylosis of the monument. Thus, the identification of the slabs has been carried out after a thorough inspection of the known historic planimetry and photographs [18] and their comparison with the 3D models. This process allows us to visualise the various degrees of intervention and conservation in the tomb in 1925, 1935 and 1955. Figure 9 depicts different aspects of the dolmen both from the information collected by Obermaier and its current state.

This thematic planimetry Fig. 8 allows us to organize the information to plan conservation actions, but also the possible archaeological works that could be carried out in the future. The preliminary conclusions of this work allow us to state that the restoration of Obermaier was centred on a massive reconstruction of the corridor and the fixing of certain slabs both of the chamber and the circles around it. The chamber and its most immediate interior rings are those that present an optimum level of preservation, while the most exterior rings and the corridor, partly made-up during Obermaier’s restoration, are those that present the greatest structural damage.

Besides, this information serves to produce models simulating changes in conditions to which the supports of the monument have been subjected. Figure 10 shows the number of days that each part of the monument has been above water, information that can be obtained using historical data series of flooding and a precise survey. Using a Python script, we have associated the georeferenced height values of the point cloud with the historical data values of the reservoir water level in the period 1970–2019. These data allow us to visualise which specific areas of the monument are

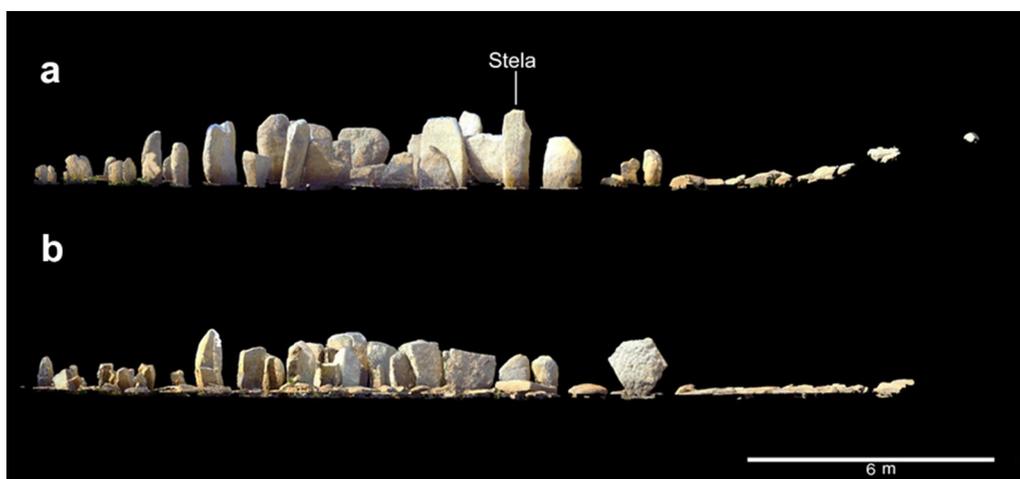


Fig. 8 Elevations of the construction of the Guadalperal dolmen generated from the point cloud. **A** North elevation showing the stela. **B** South elevation

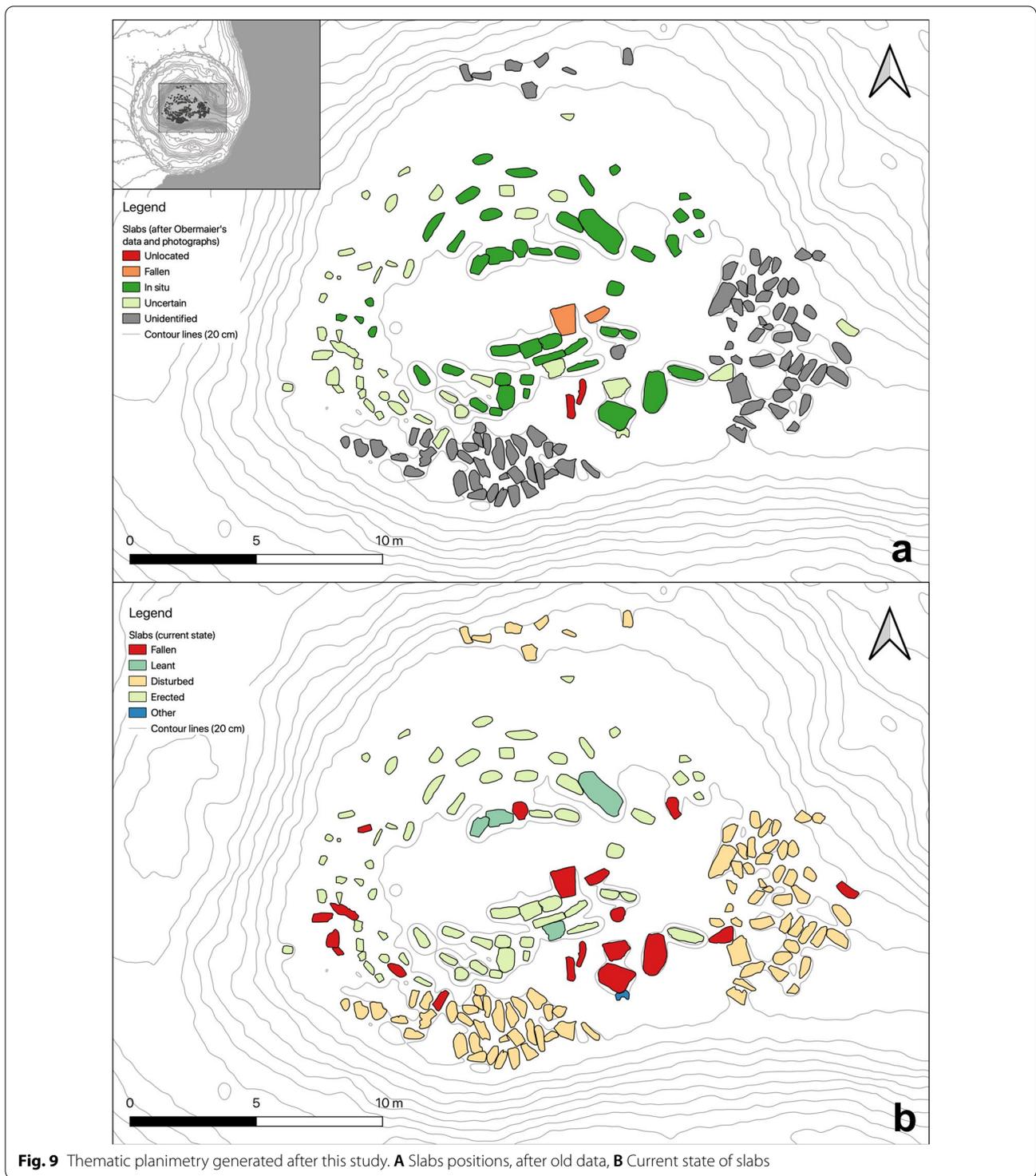


Fig. 9 Thematic planimetry generated after this study. **A** Slabs positions, after old data, **B** Current state of slabs

subject to the most drastic environmental changes, i.e., the variation from a dry environment to immersion in water. The data reveal a wide range of days (150–1500) in which the surfaces of the different slabs have been

exposed out of the water. This resource will be used to monitor any possible conditions the dolmen may suffer and for the simulation of the effects of the reservoir on the materials. The study of the evolution of surface erosion can be carried out by creating new geometric

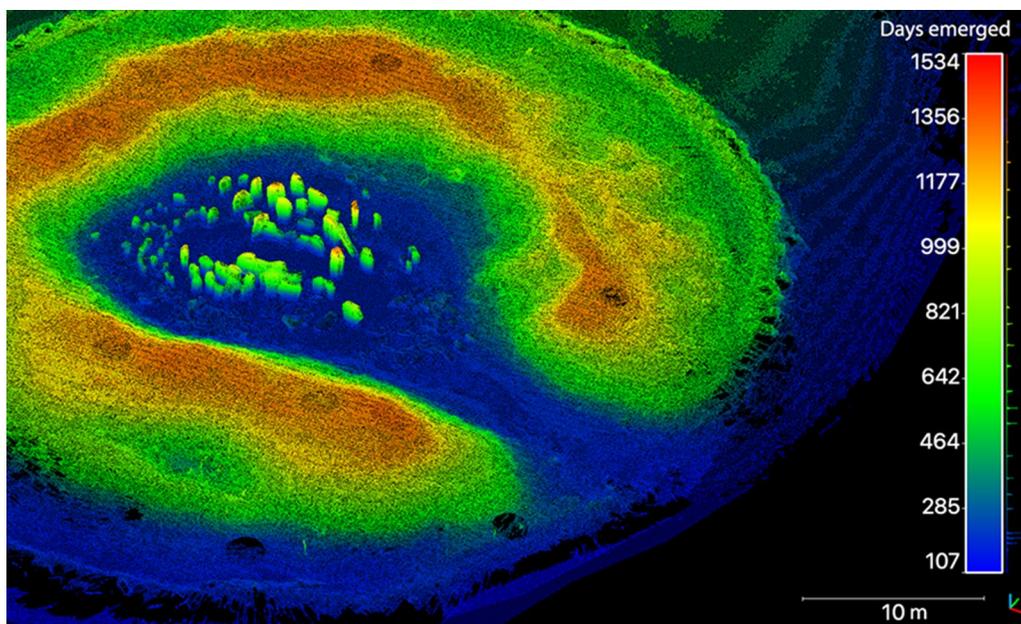


Fig. 10 Thematic point cloud of Guadalperal. The points have been classified by the number of days that its location have been emerged between 1970 and 2019. Historic data were provided by the Spanish Tagus River Hydrographic authority

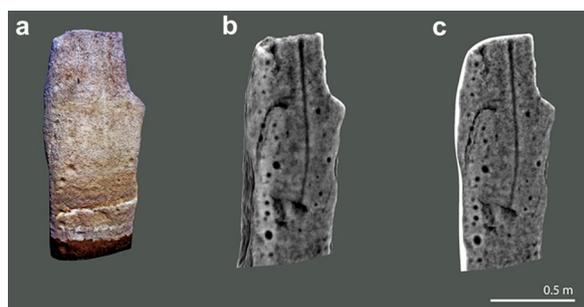


Fig. 11 Comparison between the photographic recording of the stela made in 1992 (a) and the 3D meshes produced in this work: b photogrammetry and c short-range scanner. b and c meshes have been obtained through the 3DMeshTracings procedure

models during future visits to the site, from which temporary erosion models can be derived.

The recording of the engravings on the stela

At short range, the products obtained allow the study of details of rock close to the limit of visual perception and the comparison of its degree of preservation and readability with the graphic supports obtained in 1992. The recording made at that time made it known that there was a stela-menhir at the entrance to the chamber. Its decoration could only be seen partially as the lower area was underwater. Its size was visible as well as the engravings accompanied by cupmarks on the northern face on

the western face. The work carried out on the stela-menhir using both short-range laser scanner and digital photogrammetry is mutually coherent (Fig. 11), highlighting the same type of information in the engraved surfaces. It should only be noted that the linear distribution of the scanner observations provides a sharper reading of the engravings, to the detriment of photogrammetry, which has a higher density of points, but a more irregular distribution. With this study case, and without the space necessary to make a full comparison between the two methods, we can confirm that the capture by photogrammetry is significantly faster and more versatile, which suggests that it should be the technique of choice when documenting free-standing, multi-sided volumes of a certain complexity, such as the ones in question. In summary, the geometric information newly obtained adds complexity and sharpness to the information deriving from the tracings of 1992, which will be the subject of future publications.

The digital preservation of the supports seems, in this case, a fundamental necessity for the assessment of the erosion they are undergoing. For the moment this information is quite unequal, as it is only based on the comparison between the visualization of the geometric information collected and the photographs taken in 1992. Even so, the images we present permit the speculation that the decoration on the engraved pieces has not undergone considerable erosion over the last three decades. It will only be possible to extend this monitoring to

the remaining supports in the future and base comparisons on the information we have generated in this study case.

Conclusions

Unfortunately, heritage management of reservoirs presents a fundamental inconvenience: the sheer number of archaeological sites in reservoirs is impossible to be quantified and it does not seem realistic to schedule a catch-all strategy of intervention on a set of goods with such different peculiarities, to which must be added any unexpected finds that might come to light in the coming years. These situations usually demand swift action, either because the sites are subject to a degree of degradation that cannot be estimated unless there exists a high-resolution recording of them, or because they cannot be visited except in short periods over many years. The latter is the case of the dolmen of Guadalperal. An effective solution is to adapt the documentation strategies to the particularities of each submerged archaeological site by means of an optimal three-dimensional recording.

Thanks to the application of the geometric documenting techniques used in Guadalperal we now can revisit the monument with the fidelity and quality that has not been possible until now. In this context, techniques for the digital documentation of heritage sites provide a diagnostic tool for alterations such sites have undergone, thus facilitating the decision-making process. More evidently, registering archaeological sites in high resolution permits the analysis of the information directly in the digital products, as is usual in European megalithic studies [24, 67–69]. The comparison of the documentation obtained with the dolmens in Fig. 1 seems the first activity to pursue.

Finally, such sites become a support that can easily be used in the social diffusion of contents that bring the good closer to the public who perceive it as something of its own [53, 85, 86]. Integrating all these perspectives in single documentation leads to the creation of support for the management of a scenario as complex as is that of submerged heritage.

Abbreviations

UAV: Unmanned aerial vehicles; TLS: Terrestrial laser scanning; CMOS: Complementary metal-oxide-semiconductor; SfM: Structure from motion; MVS: Multi-view stereo; RMSE: Root mean squared error; GCP: Ground control points.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40494-021-00590-5>.

Additional file 1. Point cloud of the Guadalperal dolmen. The density of points has been reduced to provide a better diffusion.

Acknowledgements

We also to thank Alicia Prada, Antonio González Cordero and Manuel Herrero for their collaboration during this work. We would like to acknowledge the two anonymous reviewers for their advice, which has enriched the final version of this paper.

Authors' contributions

Conceptualization, investigation, formal analysis, writing, fieldwork: ECC, JJSB, PBR, JAPA, RBB and MSF. Data processing: ECC, JJSB, JAPA and MSF. All authors read and approved the final manuscript.

Funding

This work has been Funded by the General Directorate of Fine Arts from the Ministry of Culture and Sports, through the General Subdirectorate of the Institute of Cultural Heritage of Spain through the project "Documentation and archaeological intervention in the Dolmen of Guadalperal and the basin of the Valdecañas Reservoir (Cáceres)" (2020–2021). We wish to thank the support of the Council for Culture and Sports from Extremadura regional government. Part of the photogrammetric works were supported by the computing facilities of Extremadura Research Centre for Advanced Technologies (CETA-CIEMAT), funded by the European Regional Development Fund. Also, thanks are extended to the Consejería de Economía e Infraestructuras (Junta de Extremadura) and European Regional Development Fund for funding through aid references GR18053 to the NEXUS Research Group (University of Extremadura).

Availability of data and materials

A low-resolution point cloud of the original data has been included as supplementary material.

Declarations

Competing interests

The authors declare that they have no competing interests.

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Received: 15 May 2021 Accepted: 3 September 2021

Published online: 17 September 2021

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