KEYWORDS: *3D recording – DStretch – Holocene rock art – Visualisation – Photogrammetry*

3D DOCUMENTATION AND USE OF DSTRETCH FOR TWO NEW SITES WITH POST-PALAEOLITHIC ROCK ART IN SIERRA MORENA, SPAIN

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Abstract. In the last ten years rock art documentation technique has undergone a significant development thanks to advances and use of new auxiliary techniques. Computing and its applications in conjunction with digital photography have an indispensable tool in the analysis of archaeological remains of artistic nature. The elaboration of 3D models, these being almost exact reproductions of the originals, may be the best way to obtain a copy of an archaeological item avoiding its damage. Finally, scientific dissemination and popular outreach can also benefit from these tools. 3D visualisation of rock art is a communication tool that allows us to explain complex processes with easily understandable graphic elements. As an example of the versatility and suitability of this methodology of communication we show the photogrammetric results of two new sites with post-Palaeolithic rock art documented in Sierra Morena (Ciudad Real), the shelter of Arroyo del Castañarejo and the shelter of Cueva del Arco.

1. Introduction

Up until a few years ago the techniques used to obtain documentation of rock art were very rudimentary, given that they had almost not evolved since the first widely reported discoveries of this kind of archaeological remains at the beginning of the 20th century. Thanks to the preserved graphic material we know that nearly all the drawings were freehand drawings made through direct observation of the figures. It is needless to say that the researcher had to have a certain level of expertise in drawing and great artistic abilities or, failing those, count on the help of an artist who would assist him in obtaining the tracings. Also, and whenever it was possible, he relied on the emerging technology of photography, bearing in mind that the general public was not very familiar with it at its inception and that the weight and volume of the equipment hindered its use due to the intricate orography of the sierras where these art forms were located: crags, shelters and caves with very little or no accessibility to human beings.

As an example and amongst the different archaeologists who were also excellent draughtsmen, we will mention the Abbé Henri Breuil (1877–1961), one of the pioneers of the study of peninsular pre-Historic rock art, an indefatigable researcher and gifted draughtsman (Figs 1 and 2). In the second place, we take as an example the painter and draughtsman Francisco Benitez Mellado (1883–1962) who worked together with Breuil as well as with Juan Cabre (1882–1947), Hugo Obermaier (1877–1946) or Eduardo Hernandez Pacheco (1872–1965) and whose work, mainly kept

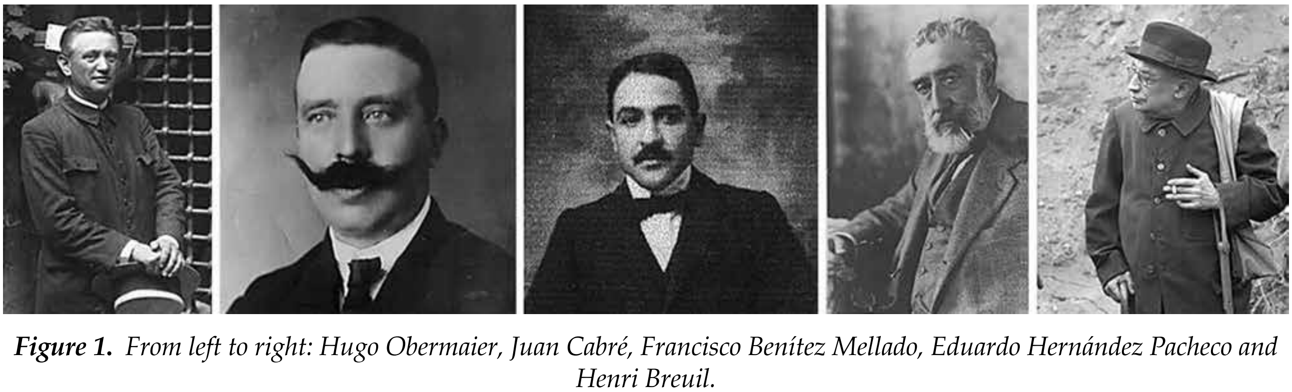


Figure 1. *From left to right: Hugo Obermaier, Juan Cabré, Francisco Benítez Mellado, Eduardo Hernández Pacheco and Henri Breuil.*

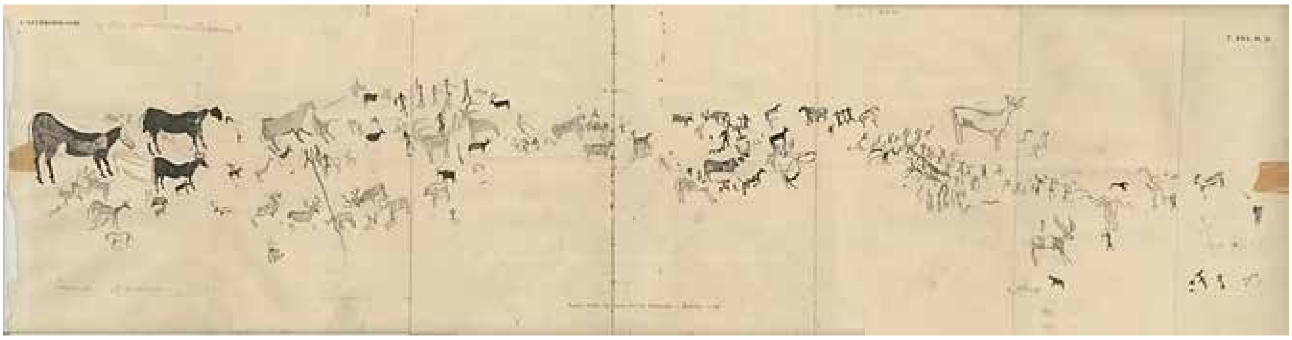


Figure 2. *Tracing carried out by Henri Breuil of the Abrigo de Minateda (Hellín, Albacete, Spain) (Breuil 1920).*

at the Natural Science Museum in Madrid, has been immortalised in the tracings of the panels of such relevant sites as La Cueva de La Vieja in Alpera or the Abrigo Grande de Minateda in Hellin, both of them in the province of Albacete, Castilla La-Mancha, Spain (Moneva 1993).

In the last third of the 20th century great improvement was made both in the field of analogic photography, which allowed the use of cameras with many interchangeable lenses, smaller in size, more manageable and more accessible to everybody, as well as in the revolutionary use of film and colour developing.

A whole standardisation of the in-field data collection method and in its interpretative ideographic representation responded to requirements that would be common for a universal comprehension. Thus, in tracings and drawings made with flat inks, the artistic concepts are minimised for the sake of the canons of technical and objective drawing, incorporating measurements, topographic coordinates, planimetries, sections and elevations of the shelters and caves. All these elements became fully accepted.

Likewise, the development and diversification of plastics and acetates as well as of permanent markers enabled us to speed up the making of tracings directly from the figures in the rock art enclave.

In the early 1980s methods not as aggressive as direct tracings started to be used, enabling a better understanding and realisation of the drawings. Thanks to the developing in slides and their adjustable projection, which allowed us to scale the images on a wall or screen, it became possible to make indirect tracings in the office. Thereby, we could also save time in 'in situ' documentation and were able to develop other field work activities. The use of slides and projectors contributed to facilitate and improve the composition and editing of pictorial panels (Fig. 3).

But it has really been only in the last ten years that the documentation of rock art has experienced a major development due to the use of new auxiliary techniques. Computing and its applications on the whole as well as digital photography have become mandatory methodological tools for an accurate documentation and subsequent analysis of archaeological remains. It goes without saying that this set of tools is now indispensable for the visualisation, description and subsequent interpretation of rock art expressions. Equally, its use will complete the ultimate purpose of every research: the preservation, dissemination and value of these places, many of them inaccessible to the general public.

In the two cases that we present, the shelter of Arroyo del Castañarejo and the cave of Los Arcos (Viso del Marqués, Ciudad Real, Spain), we have selected the photogrammetry for its 3D documentation. In the same way, we have obtained amazing results through the use of the image processing DStretch software created by Jon Harman, to visualise and define different pictorial motifs as well as to carry out indirect digital tracings on orthophotos subjected to different treatments of

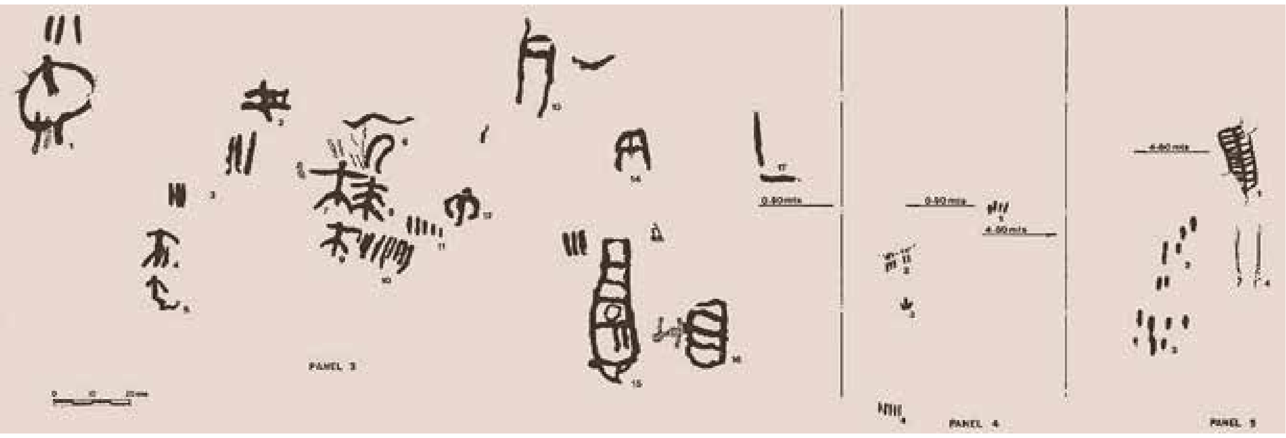


Figure 3. *Tracings with measurements of panels 3, 4 and 5. 'Puerto de Vistalegre', Virgen del Castillo (Chillón, Ciudad Real, Spain) (Caballero 1983).*

colorimetric decorrelation. We will describe these in the following lines as a methodological example for the documentation, research, dissemination and valuation of rock art.

2. Methodology for the 3D documentation of rock art

2.1. Why carry out a 3D documentation?

The first question we need to ask ourselves in each one of the chapters of a scientific project is if the time and effort spent on carrying out the work is really worthwhile. In this case, the question of the elaboration of 3D documentation had a positive answer. The main reasons for this could be these three:

- It allows us to boost and complete the archaeological documentation.
- It facilitates the dissemination and broadcast of scientific results.
- It serves as a tool for preservation and valorisation.

We will now attempt to develop these contents, bearing in mind that in broad terms, 3D documentation could be defined as a means of communication that provides a visual explanation of complex processes through easily understandable graphic elements. It bears out the old saying that a picture is worth a thousand words. Nevertheless, it should be noted that, in the field of scientific research, this should only be a means of researching and not an end in itself. Accordingly, the purpose of these lines is to highlight the use of virtual recording as a tool that can improve archaeological research as well as its necessary divulgation and dissemination.

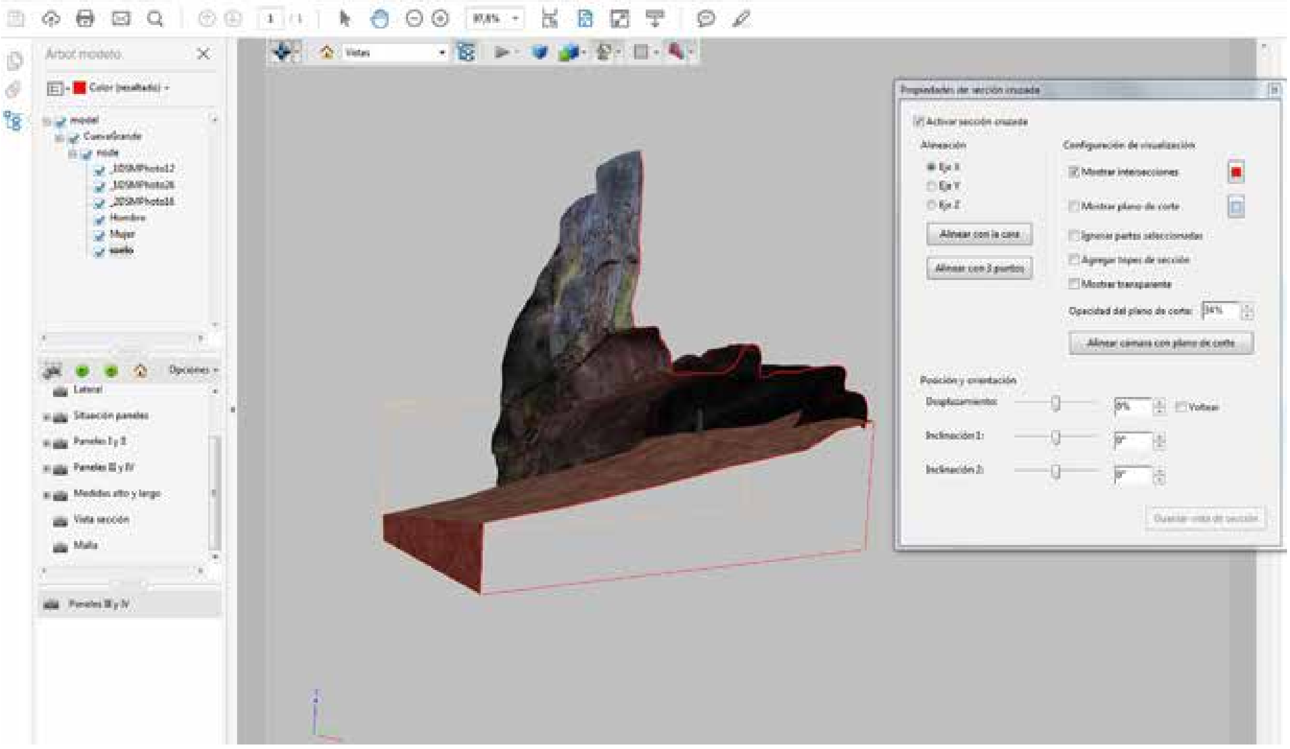
2.1.1. Dynamisation of archaeological documentation

One of the essential aspects of archaeology is the documentation of archaeological remains, in our case, of rock art. This, always being as complete as possible, is the fundamental pillar of scientific research. The execution of diaries, sheets, planimetries, photographs etc. is basic for the development of archaeological interpretation, and recording in 3D could serve as a support of theoretical work.

As a first premise, it is appropriate to stress that this type of recording enables us to complete the documentation. The elaboration of traditional planimetric recording in two dimensions is enhanced by adding new optimal elements for analysis.

Being able to add new information about the third dimension enables us to establish readings from any point, label information, add different images (photographs, tracings), suggest sections and dimensional calculations or create a dynamic interaction to analyse events. There are an endless number of tools that could be applied to specific problems. In addition, it allows us to contrast different artistic elements in scale, at the same time joining them in a single virtual sphere.

3D models must serve as vehicles of information applied to the needs of archaeologists. 3D documentation surpasses by far all the usual systems of graphic data collection. Photographs, videos, plans, elevations etc. are still necessary but they do not reach the level of documentary potential that 3D models offer. These combine all such information and in addition, they let us interact by choosing the information that is required



☑ Activar sección cruzada

● Eje X
○ Eje Y
○ Eje Z

☑ Mostrar intersecciones
☐ Mostrar plano de corte
☐ Ignorar partes seleccionadas
☐ Agregar tapas de sección
☐ Mostrar transparente

Opacidad del plano de corte: 34%

Desplazamiento: 0% ☐ Voltear
Inclinación 1: 0°
Inclinación 2: 0°

Figure 4. Work area where the section of the Cueva de los Arcos (Viso del Marqués, Ciudad Real-Spain) is being configured from its photogrammetry.

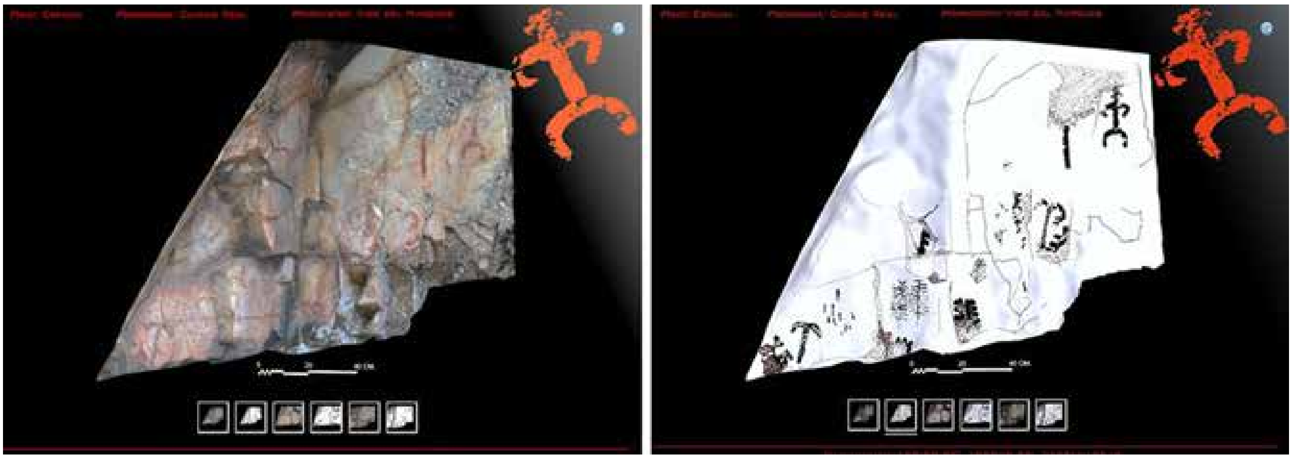


Figure 5. *With just one click we can simultaneously carry out, for example, the visualisation of the orthophoto of the central panel together with the three-dimensional tracing of the figures, this way, making its reading and interpretation easier for the user (Abrigo del Castañarejo, Viso del Marqués, Ciudad Real-Spain).*

in a particular moment.

2.1.2. It facilitates the dissemination of scientific results

We must not forget the most obvious aspect of digital recording: its communicative function. Visual language is a much faster vehicle for the transmission of information than textual language. A single image may depict the same argument as many text lines will. Archaeology has employed and will continue employing technical drawing to carry out this function; however, reproduction of 3D images could complement this tool because of its greater plasticity and adaptability. Digital reconstruction enables us to obtain endless views and corrections of the same item.

In this sense, scientific dissemination in books and magazines has been infused in the era of digitalisation. Although publishing in paper still exists, it is losing power in favour of digital copies that are distributed through the Internet. The expansion of digital formats has led to new ways of dissemination. In fact, traditional text documents and images can be enriched with different files, video or interactive 3D images.

Specialised scientific magazines such as archaeological ones are adapting to the new possibilities. In our opinion, disciplines related to rock art have been favoured by being able to exchange information about a discipline as plastic and visual as art is. Scientific publications more frequently incorporate all kinds of files whose distribution was very difficult just a few years ago.

In this scenario we think that the virtues of 3D recording are enough so as to be incorporated in the field of scientific digital dissemination. Researchers can interchange information on the registered documentation and its scientific results. This can be done not only through traditional-magazine print runs but also through thematic forums where each researcher can upload all the articles and books he has written throughout his or her career.

On the other hand, the dissemination of scientific results is an imperative of our contract with society. The privilege of working at archaeological sites entails the obligation to report back the results in a language that can be understood by the general public. The economic costs and the amount of time required to do this turns it into a difficult task often neglected by researchers.

We have insisted on the communicative power of digital information. Video and, to a lesser extent 3D formats, have established themselves as major engines of communication. Visual language has taken over all spheres of society through mobile or static digital devices. We think that archaeology should take advantage of these languages of communication to try to bring all that we value closer to as many people as possible. Thus, we could take part in the creation of a society more involved and respectful with our heritage. For these reasons we believe that 3D recording can help us to disseminate the results and raise awareness in our society.

2.1.3. Tool for preservation

3D recording of patrimonial elements contributes with new solutions to the preservation problems which affect our rich archaeological heritage. In fact, this richness involves disadvantages: it is not possible to take action at every site. The protection of our heritage is still an unresolved issue for our society and its progress is still slower than we wish. The fact is that there are thousands of unprotected rock art sites, shelters and caves are affected by climate, deterioration or by vandalism.

3D documentation enables us to create a database of all the artistic elements we have studied. Its main advantage is that, if for any reason, the originals suffer partial or total damage, at least we still have the digital model which faithfully reflects the ruined element. Therefore this could be one more tool to use when restoring heritage sites.

Furthermore, it could also be an instrument to enhance sites with difficult access or to which accessibility should be restricted for preservation reasons. Current technologies even allow us to reconstruct a life-size version of any object or place. Complete replicas can be created by means of construction techniques using both 3D models as base or 3D printers.

Equally, this methodology gives the user the chance to learn, see and enjoy all the information about archaeological sites thanks to the interchange in open networks, as direct linkers and fulfilling the European policies of cultural and heritage globalisation.

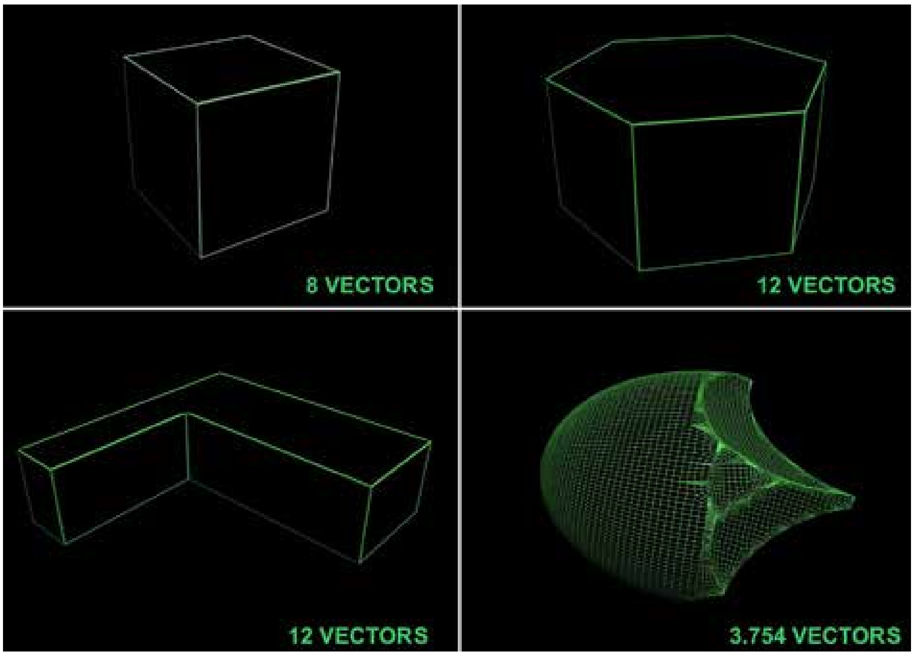


Figure 6. *These are examples of object characteristics based on various numbers of vector points.*

At present, and according to the communication of the Commission to the European Parliament, to the European Council, to the European Economic and Social Committee and to the Committee of the Regions under the heading 'Towards an integrated approach to the European cultural heritage' (22.7.2014 COM (2014) 477 end), preservation is mainly focused on preserving and enhancing a complete cultural landscape rather than a single isolated location, as it focuses more and more on everyday people. If in the past the intention was to protect the heritage by isolating it from daily life, the new approaches mean to fully integrate it in the local community life. Digitalisation and online accessibility offer unprecedented possibilities of commitment and generate new sources of revenue. The electronic learning tools facilitate a broader access to cultural contents at home, school or university and enable people to generate, reuse and add value to those contents, increasing the value of the cultural collections. As heritage sites turn into public spaces that generate social and environmental capitals, the cities and regions become engines of economic activity, knowledge centres, poles of both creativity and culture and spaces for communal interaction and social integration: in short, they generate innovation and contribute to a smart, sustainable and inclusive growth in line with the aims of the European 2020 Strategy.

Horizon 2020, the new EU Research and Innovation Program, is framed within this new European Strategy. With a funding of nearly eighty billion euros over seven years (2014–2020) it will help to strengthen the EU position regarding the preservation, restoration and value of cultural heritage, supporting cooperation between researchers in relation to a wide range of areas. The EU will support the use of cutting-edge scientific tools for protection of heritage, the development of more inclusive interpretations of the past and new ways of disseminating and exchanging knowledge. This is the European roadmap for research infrastructures that prioritises the creation of a new European Digital Research Infrastructure for the Arts and Humanities (DARIAH). (*https:// ec.europa.eu/research/infrastructures/pdf/esfri-strategy_report_and_roadmap.pdf*)

2.2. Methodology

In this section we will note the basics on the functioning of 3D information and the recording systems existing for its elaboration.

The real world is very complex. We are surrounded by millions of objects of different nature, which makes it very difficult to provide a faithful virtual representation of reality. However, it is possible to obtain highly valuable information via virtual documenting without necessarily achieving a perfect depiction of reality. The aim of 3D recording is not so much to achieve accuracy but to create a way to represent reality able to convey information to the recipient.

Flat areas are easy to represent in 3D; however, complex areas exponentially multiply the vectorisation data. Reality is represented by points that delimit the areas or 'mesh'. Each point contains information about its own location in the three dimensions in the real world using XYZ coordinates. Obviously, the more complex the object we need to portray is, the more information the 3D model will require. Thus, a cardboard box could be represented by eight vector-based points, while, for instance, a rock will need thousands of vectors to get close to reality (Fig. 6).

It is clear that a cloud only representing points will not be very useful. A three-dimensional model should represent reality and this has area and colour. While it may be possible to give colour to each point, the resulting density should be such that counting them

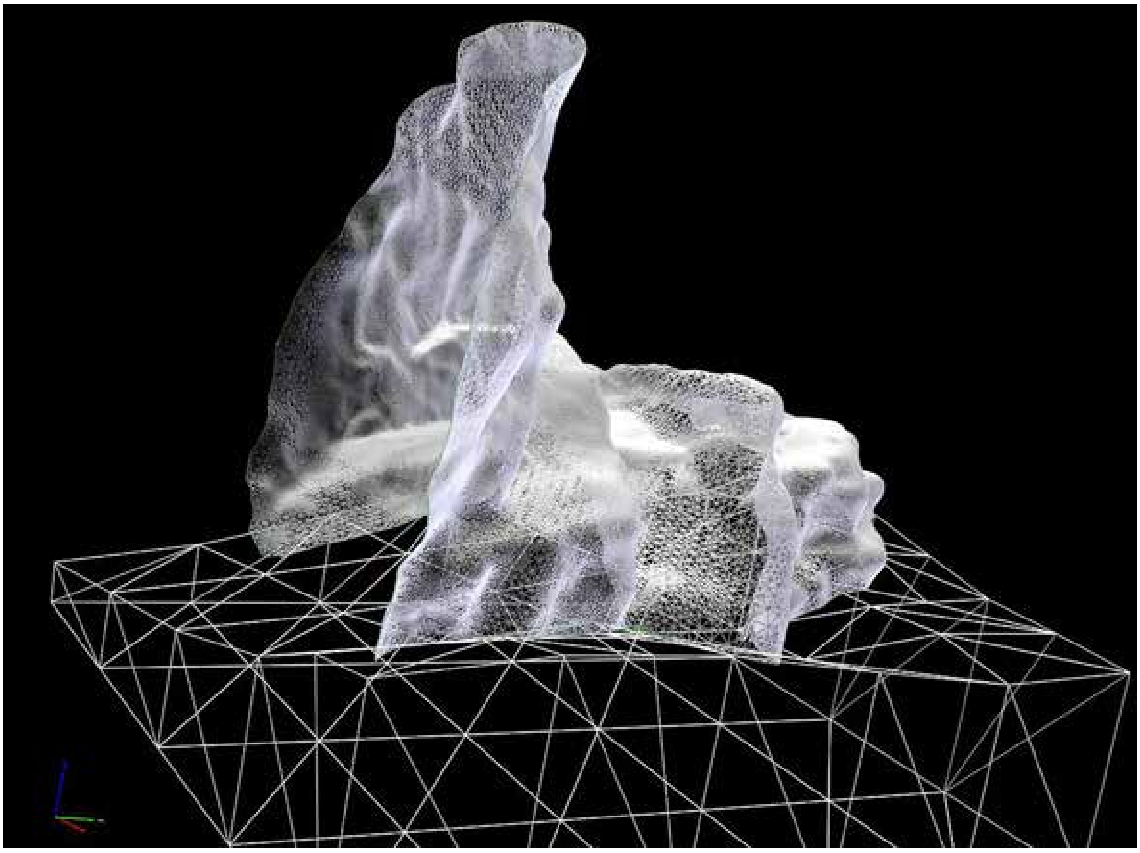


Figure 7. *Mesh of points generated using photogrammetry at the Cueva de los Arcos (Viso del Marqués, Ciudad Real, Spain).*

in real time would be very difficult. For this reason it is possible to generate a very complex documentation with photo quality from areas drawn from 3D points. A consecutive series of orthophoto images could be adapted to the point cloud creating a triangular mesh that acts as a 'skin' faithfully depicting reality. Each orthophoto connects to the 3D points without any lenticular distortion. The best-known models are those from videogames where there are vehicles, buildings etc., that recreate virtual sets.

The representation of rock art is directly related to the physical support where it was created. A painting is limited by the natural features of the canvas it is painted on, which is usually flat and rectangular. A sculpture will obviously be much more complex. The 3D recording of rock art will also be defined by its own features, that is to say, by the natural contours of the rock itself which is usually very complex.

To establish a full record of this support and the motif on it we need sophisticated documenting systems able to record thousands or millions of points with enough accuracy. The two systems most commonly used for this are digital photogrammetry and laser scanning. These are two very different systems, but their aim is the same: to recreate a digital model of an object or item. Although there is a duality of opinions regarding the use of these two methods by researchers, we believe that one is not better than the other and that they can even complement each other sometimes.

Laser scanning is the controlled steering of laser beams followed by a distance measurement at every pointing direction to obtain point clouds. It measures the distance when the beams hit the object we are studying. The quality and density of the cloud is proportional to the number of beams screened per second. The accuracy of this kind of equipment is very high with error values below one millimetre. Some models let us insert a digital picture in the same scan. The processing time is almost instantaneous although it will be processed again later to obtain a simpler and lighter mesh. The downside of laser scanning is its high cost and the difficulty to transport the equipment, although the new scanners are becoming increasingly cheaper and lighter.

Digital photogrammetry obtains three-dimensional models by means of processing digital pictures. The point clouds will depend on the quality of the pictures and the capacity of the software we have used. Its precision could also be highly accurate with values nearing one millimetre for medium-sized objects. The minimum equipment required consists of a digital camera and the photogrammetry software. This is why this is a very versatile and low-cost system. Nonetheless, the production time is higher and the learning curve sharper.

Just as there are no two identical sites, there are no identical ways to conduct a recording in 3D either. The choice of the methodological system to use is marked by the contextual circumstances of the equipment and the site itself. That is why, in our case, we have decided to use digital photogrammetry. Bearing in mind the weight of digital photography in our project (digital treatment, colorimetric decorrelation of pigments with DStretch, digital tracings), we valued the suitability of using photographic equipment for all these studies and also for the 3D recording. The difficulty to access shelters hindered our ability to carry heavier equipment.

We will go into more detail about photogrammetry and its principles when defining the techniques applied in the elaboration of 3D models.

2.2.1. Digital photogrammetry notions

Photogrammetry was born in the middle of the 19th century with Aime Laussedat, the first person who was able to obtain precise measurements through the processing of photographs. It soon started to spread through different European countries as a stand-alone practice. Its evolution continued throughout the 20th century, thanks to both the progress made by the first restitutors (beginning of the 20th century), and by the appearance of electronic calculation (middle of the 20th century) as well as, lastly, because it received a great boost since the 1980s thanks to the birth of the digital era and photogrammetry.

Digital photogrammetry can be divided into three broad areas of work as branches that follow different directions and diversities. They are classified according to a fundamental difference depending on the distance from which the pictures are taken. This makes an important difference, considering that depending on the distance, important nuances arise regarding geometry and different calculation errors occur that should be taken into account. The solutions diverge from various areas creating different issues, theories and practical applications. The following are the three key areas:

Terrestrial photogrammetry: photographs are taken from distances smaller than 300 m, so no errors of sphericity or refraction are taken into account.

Aerial photogrammetry: obviously, the pictures are taken from different aerial vehicles depending on the distance to the space to be modelled and the quality of the image detail. It is mainly used to produce Digital Terrain Models (DTMs) and orthophotos.

Satellite photogrammetry: it uses the same fundamental principles as aerial photogrammetry benefiting from the developments in the resolution of satellite photography.

Terrestrial photogrammetry is the most widely used in archaeology, except when the areas of land to study are too large. There are several works on the analysis of the territory in relation to human settlements and its exploitation. In such cases, the use of terrain models based on orthophotos is very helpful because of the existing barriers and other geographic constraints (for example the analysis of the gathering of materials) that can be seen. However, we should highlight the documentary value of terrestrial photogrammetry focussed on archaeological levels and structures. As an example, the modelling of a stratigraphic column or a rock art painting representing its volumetric shape is very useful.

We employ terrestrial photogrammetry using digital cameras in the different shelters. For the processing of the digital pictures we have used commercial software able to restore the common points of photos and turn them into three-dimensional XYZ coordinates.

It is important to point out that this is a direct data source obtained from digital cameras. We obtain these data using CCDs (charge couple devices) that shift the photons reaching its surface into electrons that are again turned into digital information. This complex system is embedded in all the digital cameras on the market, including low-cost ones. On the other hand, we can also obtain data indirectly, scanning analogic pictures and their subsequent complex processing.

Furthermore, any digital camera can be used as a photogrammetric station. The only essential condition is that the camera may be used to take photos using at least a specific focal lens, that is to say, that the zoom can be set in a specific focal lens (28 mm, 35 mm, 80 mm etc.). This is absolutely necessary since we need to calibrate the circular errors produced by the lens and this calibration only works with sets of pictures taken with the same focal lens.

However, there are cameras whose features improve the processing time and the results of the photogrammetry. An important factor is the storage capacity of the camera. The ability to view details is proportional to the amount of megapixels in the picture. It is advisable to record pictures with at least 5 megapixels and improve that capacity until we use new cameras that multiply this figure by five (and this will continue increasing). On the other hand, likewise, we should highlight the importance of the optic lens and CCD that the camera has, because the quality of the picture will benefit from it in the process.

With regard to the software, there is a wide variety on the market able to support photogrammetric processes of correction and restitution, there being over fifty brands, including commercial and free ones (*https://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software*).

Learning to use this kind of software is difficult since it uses mathematical systems for processing and a language of its own which we need to know at least in a basic way. It is necessary that we understand what we are doing to know if the result is good or poor. For this, there are users' guides that aim for independent learning, although maybe a much better option would be to take professional training sessions. Nonetheless, with a basic training, any researcher can do the photogrammetry of a rock art object if it is not very large and if its typology is not very complex.

Once all the pictures have been taken, the computer work starts. The pictures are downloaded and named, to facilitate their identification in our sketch. The processing with the photogrammetry software is done photo by photo, identifying the visible control points and their indexing. Once a basic amount of points has been indexed, the program does the necessary mathematical calculations to assign each point a precise coordinate. The mathematical process simply consists of the resolution of trigonometric issues. The software solves the problems raised according to the position of the camera for each picture, the lenticular error of the camera and the focal lens we have used.

The photographs, whether digital or analogical, recreate reality in a distorted way. The so-called lenticular error lies in the unavoidable use of crystal lenses. The picture contains a circular error that increases in direct proportion to the focal lens. The lower the focal length is, the more space of reality is recreated, but the distortion and the lenticular error are also higher. For example, using a 20 mm lens (also called 'fish eye') involves a much higher error than a 300 mm one. On the other hand, prior to the process, we should calibrate the focal lens we are going to use to carry out the photogrammetric process. This way, the program averages the lenticular errors in each photo and calculates the distance of all the indexed points. The result is the creation of a point cloud with absolute coordinates. The X, Y and Z of all the points are defined with a relative accuracy, the error of which does not exceed 2 mm in relation to its real relative position.

2.2.2. Interactive 3D formats

To finish the section on methodology, we believe it is important to analyse something as crucial as the final format of the recording. One of the main issues of the dissemination and broadcasting of archaeological information is to provide simple and universal access to the information. It often happens that highly comprehensive studies of all kinds have a very limited outreach due to the difficulty of accessing them or visualising the contents. To illustrate this, in the field of 3D recording, there are countless projects that are not very well known because the 3D models are very difficult to handle due to their density, or because only experts are able to visualise their formats.

The quality of the model, as we have already explained, is characterised by the number of three-dimensional points that define it as well as by the detail of the photographic image. An equation is then generated: the higher the accuracy is, the heavier and less versatile the files are. For this reason, it is necessary to specify the aims of the project. If the aim is, for example, to exchange documentation amongst specialists, detail will come first, leading to heavy file models that will have to be processed by very powerful computers. On the other hand, if what we want is to have samples intended for the general public, we will have to generate lighter 3D documentation that could be displayed even on a smartphone.

The most widespread visualisation standards (WRLM, COLLADA, X3D, O3D ...) require the installation of specific software for their recognition. This is a problem for people who are not used to this kind of content, in fact for most part of the population.

As a solution to this issue, we decided to use the Adobe standard for PDF files. This, despite having been developed by a commercial entity, is the most common transfer file in the world. The most widespread text editors have a PDF converter easy to access. In addition, practically all the platforms and operative systems, either static or mobile, have standard viewers for this format.

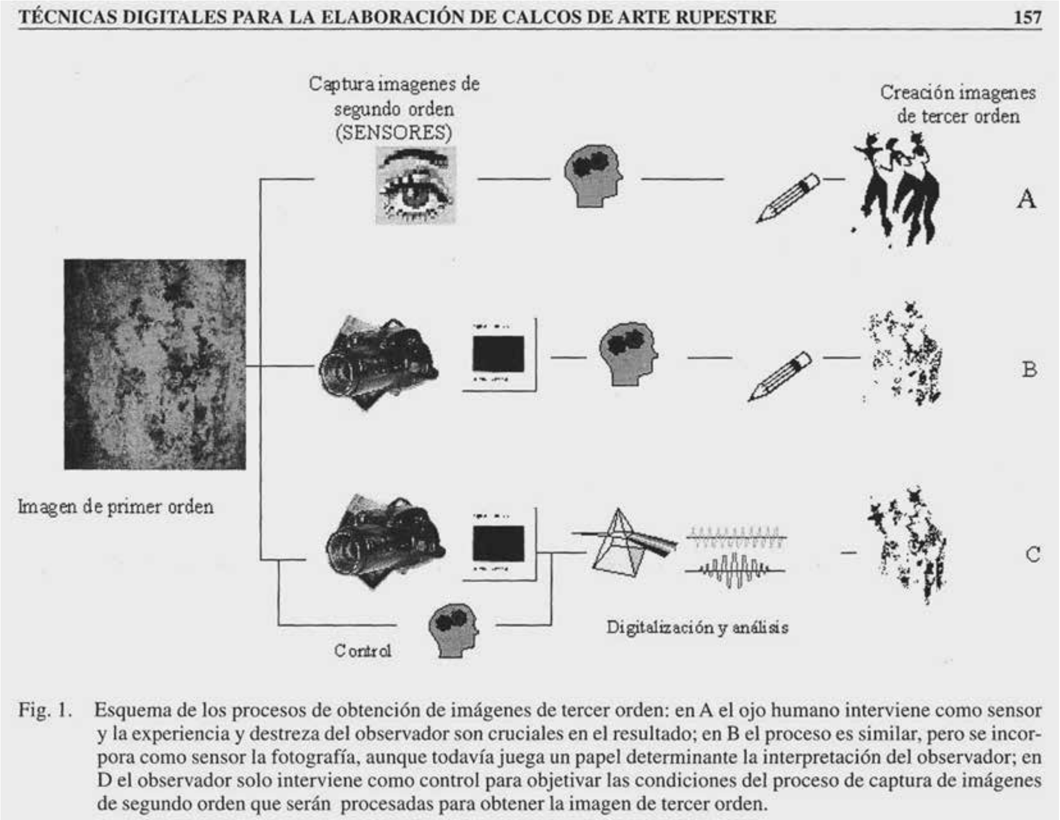
Since the edition of Adobe Reader 8 (free software) quite some time ago, a powerful render engine in real time has been included (PDF3D format). This way, any 3D model can be inserted in the files as if it were one more page. If you access the page with the 3D content, a series of powerful tools to interact with the three-dimensional model is displayed. The most noteworthy utilities are: browsing, interactive measurements, view definition or view layer.

3. 2D digital documentation: photographs and tracings

The correct documentation of rock art has been a constant concern for researchers as we have seen throughout this exposition. Also, framed within the development of new direct and indirect recording techniques, photography has been acquiring a greater role. Digital imaging and its processing with different treatments will allow for new opportunities to observe the depicted figures and, therefore, will give us a reading through indirect tracings which will have a reliability as high or even higher than that of the one done through direct observation. This will also avoid the damages that direct tracings cause. Likewise, these techniques that include colorimetric decorrelation based on mathematical algorithms foster exact reproduction at any time and on any device for any user who wants to verify the documented object and the information generated through the interpretative works. Thus, we can think about discussing tracings with objective information where free interpretations by the draughtsman are excluded and overridden by mathematics-based formulae.

Following Montero et al. (1998) we consider that the tracings or interpretative drawings of rock art belong to the 'third order' (Fig. 8). The first order would be the original graphics or rock paintings on their original support. The second order addresses the capture of these images — this could be done by means of direct observation from the eye or by capturing a photographic image — as both ways cause the captured image to reach our brain and cause our hand to draw. Obviously, objectivity here is very relative.

Another method is capturing the first order image, which then becomes a second order image by taking a digital picture that is processed by image treatment and colorimetric decorrelation software. It establishes standardised colorimetric parameters that generate a



TÉCNICAS DIGITALES PARA LA ELABORACIÓN DE CALCOS DE ARTE RUPESTRE 157

Fig. 1. Esquema de los procesos de obtención de imágenes de tercer orden: en A el ojo humano interviene como sensor y la experiencia y destreza del observador son cruciales en el resultado; en B el proceso es similar, pero se incorpora como sensor la fotografía, aunque todavía juega un papel determinante la interpretación del observador; en D el observador solo interviene como control para objetivar las condiciones del proceso de captura de imágenes de segundo orden que serán procesadas para obtener la imagen de tercer orden.

Figure 8. *Sketch of the imaging processes proposed by Montero et al. (1998: 157).*

third order image or digital tracing or drawing of the pictorial motif.

In fact, taking digital pictures under controlled conditions allows for their use not as mere visual analogues of a real image, but as spatially ordered quantitative data matrices that gather the variability of certain key physical properties of the surface subject to observation (for example, the distribution and variability of the pigments). It also allows us to make this variability accessible to quantitative analysis methods. In other words, the combination of strictly controlled photographic techniques and techniques of digital image processing lets us turn photography into an observation and measurement technique in the strictest sense of these terms in the general methodological vocabulary (Montero et al. 1998).

3.1. Photographic documentation: first methodological step

The documentary procedure of photography of the sites responds to and includes a framework of systematic application of a rigorous method where all the variables that participate in photographing (light, climate etc.) are annotated.

As far as the reflex photographic equipment is concerned, we use different brands to gather the same information. The brands used by us are Nikon, Canon and Sony. Having obtained information with different brands we can affirm that, for our purpose and taking the results into account, we do not notice any difference that would make us prefer any particular brand. The differences that a priori we can see stem from the original factory standards of the automatic programs that cause them to have different parameters (some of them have more or less overexposure, colour correction etc.). Since we do not use this automatic program but the manual one, with controlled parameters suitable for each shot, depending on the variable characteristics that take part in the taking of the picture (light, film speed, use of flash or any other artificial lighting system, climate etc.), we insist that for us there is no difference between brands. Ana M. Gomar Barea et al. (2011) reaches the same conclusion.

In relation to quality, we never work below 12 megapixels, so that the details are well defined and it is possible to capture any minimal trace of pigment. The shooting format is always RAW because it provides an understanding of the data without losing any information and without using any kind of enhancement filter. That is to say, it is an unalterable format that reproduces the motif as we can see it. The following treatments that are later applied to the digital image are carried out in JPG, as the RAW format can be changed into files that we can process.

The recordings of each panel and of each isolated figure are done either using a focus dial or not using it. Similarly, we also take macro and micro-photos to obtain a comprehensive gathering of all the details in the motifs.

3.2. Second step: digital treatment of photographs

The definition of digital image as per J. M. Vincent

(1994) is the definition of a data matrix that addresses the physical properties of the surface of the object of observation and that is susceptible to a quantitative analysis.

The digital images obtained in the field will be processed in the laboratory using any software of graphic design and image treatment. There are many of these software programs on the market, some of them are licence-free and others are not. We will handle constant numeric algorithms to establish and facilitate the reading of the outlines and interiors of the motifs, working with the parameters in a systematic way and controlling temperature, brightness, contrast etc. This will help discriminate the pixels depending on the layout of the different mathematical codes that characterise the 'colour' we perceive in each material exposed in the image capture, such as oxides, pigments, carbonates, lichens, cracks, flaking etc.

This way we prepare the image to carry out the tracing by decomposing the matrix information and reducing the variables that have been translated into colours to highlight those we are really interested in: pigment codes as against support codes (Gomar Barea et al. 2011). These tools to correct and modify the parameters of the digital image (that any image-processing software has) sharpen our visual ability to differentiate the pigment from the support, especially when the former is faded and its intensity is faint because of factors such as its own composition, accumulated dirt and pollution or gradual erosion. These treatments will enable us to recover shapes and outlines hardly noticeable to the naked eye. The former are also very useful to differentiate and delimit the strokes.

We must add that high-definition digital images enable us to view the figures in detail using the tool called 'zoom', which increases visualisation to higher levels and allows us to see aspects of the motif that were hardly noticeable in situ (unless by using a magnifying glass or microscope to examine them in the panel itself, which is often impossible because of poor accessibility).

This macro-observation and the possibility of devoting to it an unlimited amount of time at the laboratory are some of the most interesting contributions to the analysis of the technical aspects of the making of the figure: the application of the pigment, types of strokes, design techniques, order of execution in complex sequences of superimposition etc. (Lopez-Montalvo 2010).

3.2.1. DStretch application of the ImageJ software: a revolution in image processing of rock art

DStretch is a tool designed by Jon Harman in 2005 as a plugin for the ImageJ analysis software (*https://www.dstretch.com/*). DStretch was created for the study of rock art with the purpose of revealing possible shapes apparently hidden to the human naked eye (due to superimposition, loss of pigment, dirt and pollution etc.) in this kind of sites.

DStretch is inspired by what we know as 'decorrelation stretching' techniques. It is a very common resource in remote sensing so as to synthetically enhance the colour of a picture. It often creates what we know as a 'false colour image'. It basically responds to the decomposition in RGB bands of the original image and to the application of a series of statistical mathematical operations (decorrelation algorithm) on the quantitative information that the image contains. It results in obtaining a second false colour image to enable the visualisation of motifs that were previously very hard to notice by the human eye, as well as the distinction between different superimpositions and

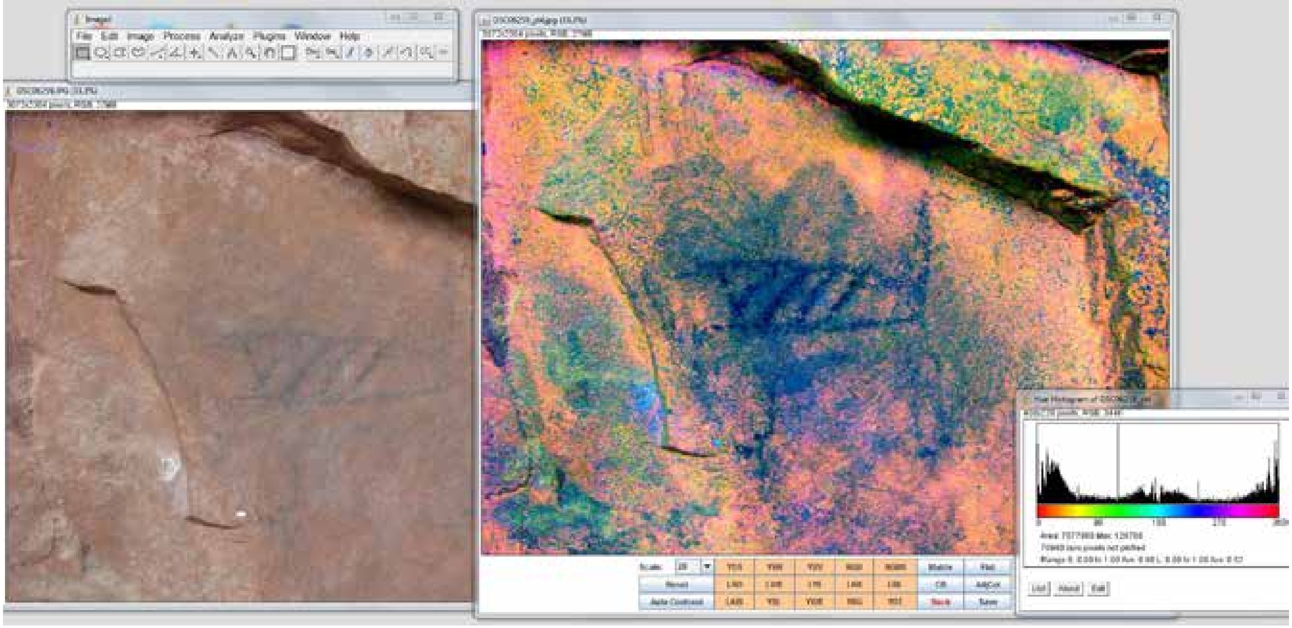


Figure 9. *DStretch work area with superimpositions of motifs in the Cueva de los Arcos (Viso del Marqués, Ciudad Real, Spain).*

types of pigments used in the panels (Quesada 2008–2010; Pereira 2012).

DStretch is able to apply this procedure in the form of a typical transformation matrix, like the one used in some colour profiles, to all the colours of the image. We can select the colourspace we want to view the image with, since the application has several buttons with different colourspaces; some well-known (RGB or LAB) and other synthetic colours are created by the author (YDS, YBR, YBK, LDS, LRE) based on the YUV or LAB spaces. Depending on the chosen buttons or parameters we will get a better view of the different colours, for example, YDS or LDS function better with yellow colours, YBR and LRE enhance reds while YBK enhances blacks, blues and yellows. The users can design their own colourspaces by using the YXX and LXX buttons.

The distribution of the colours, the selected colourspace and the option to activate or not the standardisation of correlated colours will modify the original image. This standardisation is a reverse operation used in mapping the colours back to the approximate original values. These transformations can be saved in a text file for their subsequent application to other images and to later create a standardised workflow.

The decomposition of the image in bands of the RGB (red-green-blue) visible spectrum, together with digital treatments carried out by means of the application of filters, the manipulation of specific variables, and the control of other parameters such as contrast, hue or saturation, offers a wide range of possibilities to visualise rock art motifs that are out of the field of vision of the human eye (Quesada 2008–2010; Vicent et al. 1996; Torres, J. 2010). In this regard, the ImageJ DStretch application is a versatile tool for the digital treatment of paintings, easy to use for rock art researchers, and that saves time during the manual processing of complex mathematical calculations offering standard parameters that contain all the information that can be extrapolated to any format and reproduced by any user anytime.

3.3. Third step: execution of the tracing

Progress and the great variety of tools offered by the different image processing softwares will allow the execution of digital tracings based on the digitalised photographic documentation. These softwares are widely used and they favour not only the completion of detailed interpretative documentation of pictorial motifs, but also allow for great versatility in their processing and ulterior scientific or informative use.

Once the images have been treated with the colorimetric de-correlator, we proceed to carry out the tracings. We have previously mentioned the usefulness of the zoom tool to amplify details for a better visualisation of the strokes and outlines of the figures. Another very important tool, whose functioning is often based on mathematical formulae of similarity and which will greatly facilitate our work, is the so called 'magic wand'. This is a one-click tool used to select pixels of a similar colour, allowing us to manually stipulate the tolerance parameters amongst those pixels, being '0' the only parameter that does not admit any

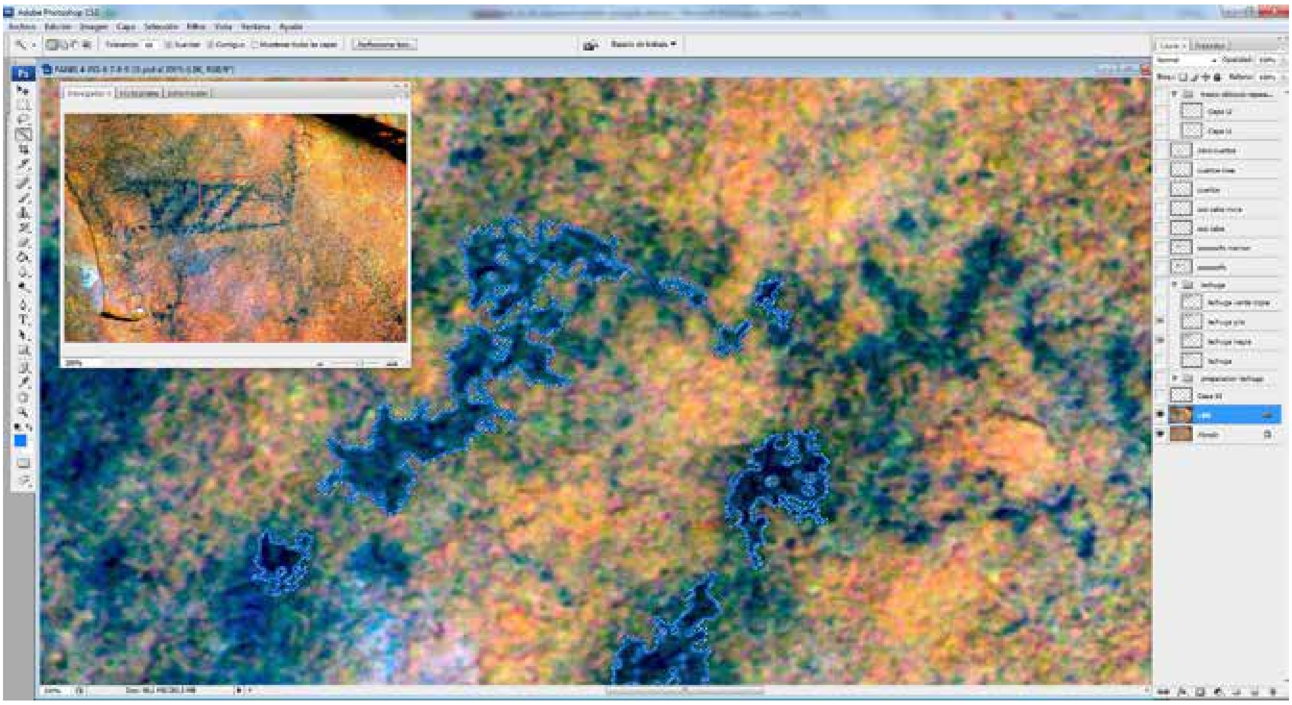


Figure 10. *Photoshop work area where the life-size image browser can be seen in the top left corner, versus the central one zoomed to 200%. The red box of the real image displays the enlarged detail box. The bluish silhouette in the enlarged picture marks the outlines of the strokes selected using the 'magic wand' with a tolerance of 60. The selected bluish areas can be filled with flat black ink. This filler option can be used with different colours, rasters etc., or even with the selection of the pigmentation of the figure itself depending on the finishing that we want for the tracing.*

tolerance.

The Photoshop software (Fig. 10) offers the possibility to create several work areas that can be superimposed and even controlled, as for example transparency (the so-called 'layers') and facilitates the task delimitating and identifying of the different figures that form the panel as well as of the superimposed figures that could possibly be found. Working through layers makes the individualised treatment of each figure easier and allows us to modify not only the transparency parameters but also others such as the tolerance degrees in the selection of colour, intensity, brightness, saturation etc. of the pigment we are working with. This improves the visualisation of the pigment when stipulating the lines and outlines at the time of drawing. These layers can in turn be grouped according to further processing criteria. At the same time, these digital supports for drawing enable us to correct the generated tracing as many times as necessary. They also offer a great variety of possibilities to present and publish the resulting graphic documentation.

4. 2D documentation vs 3D documentation

This reflection is neither new nor unjustified and it is framed within the scientific method itself. It is precisely these issues of critical comparison that advances the methodology and enriches it. Many of us obviously wonder about this issues and one of the answers that corroborates our own experience and which approaches reasoning we fully share is to be found in 'Thoughts about digital recording techniques of rock art: bi-dimensional restitution (2D) vs three-dimensional records (3D)' (Domingo et al. 2013).

2D and 3D digital recording techniques (photography and tracings) are complementary techniques, which combined increase the possible readings of the same document and therefore offer more comprehensive and in-depth readings. While 3D models provide more detailed information about the shape and dimensions of the site or about the location of the motifs and their relation to the support (given that they portray the three-dimensional nature of the sets), 2D tracings are necessary to facilitate the interpretation of the motifs, the compositions and the scenes, especially when there are superimpositions or the figures are very damaged or faded.

Ideally, we should use both 2D and 3D, but on many occasions this theoretical reality cannot be put into practice. Every scientific research depends on the real availability of resources, which are not unlimited but, in most cases are so restrictive that they demand a very objective analysis of the characteristics of the project to be executed. As well as the aims and availability of resources, at the same time as they imply making a full assessment of what is most profitable in scientific terms according to the goals we want to reach. Circumstances often force us to establish different research, preservation and dissemination stages that will be implemented at different periods of time, depending on the existence or absence of new resources for successive campaigns. Unfortunately, it is precisely the last stage, the dissemination, especially when

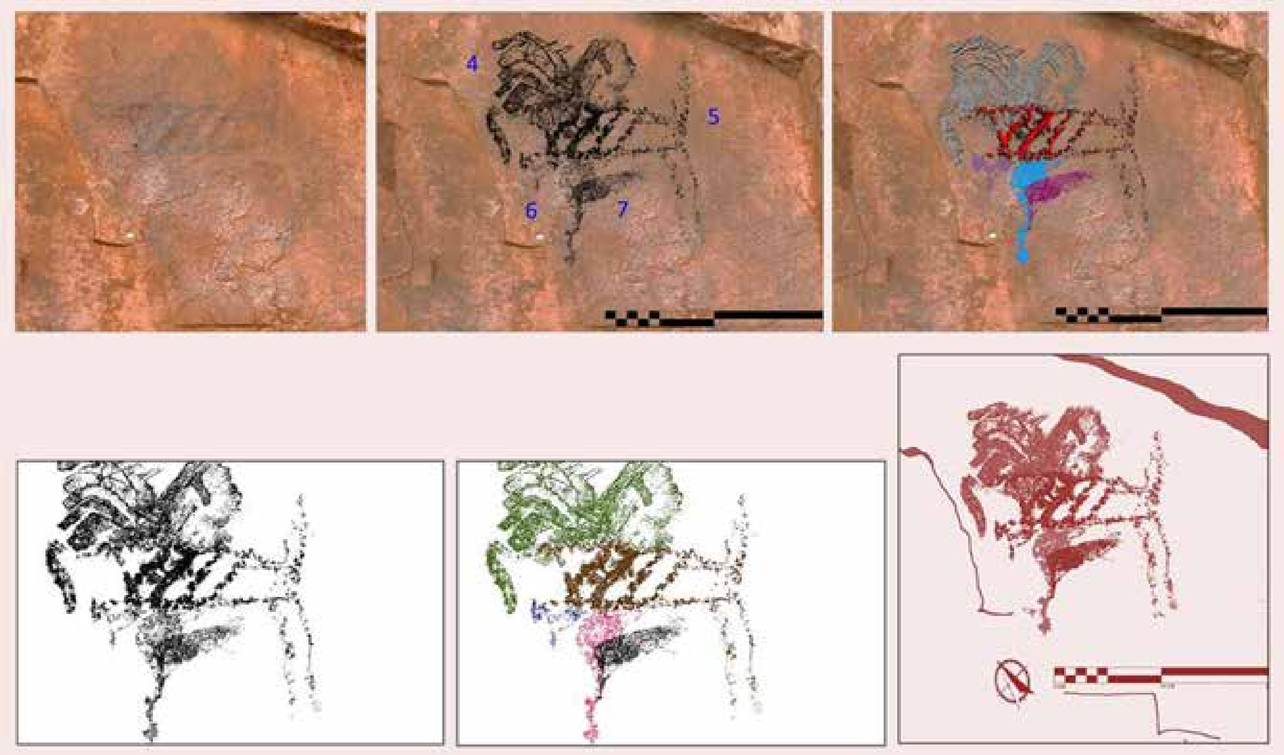


__Figure 11.__ The scientific as well as the informative possibilities of presentation offered by image processing softwares for the elaboration of tracings can be endless (figures 4–7 of panel IV of the Cueva de los Arcos, Viso del Marqués-Ciudad Real, Spain).

related to the general public, which is most affected by the lack of resources, not enabling us to reach the mentioned goals.

But, similarly, it is also true that scientific development advances at such a rapid pace that many of the tools we would never have thought of utilising years ago have both a common and in many cases domestic use. For example, as it has already been mentioned, 3D formats were very heavy and hard to move by traditional computers, hindering their use for dissemination purposes because of their high-cost, and did not reach those who did not have very powerful computers or very specific and uncommon software programs. However, nowadays, thanks to the new software developers, new applications for mass market operating systems are being created, allowing us to adapt these 3D models to PDF formats that can even be displayed in smartphones as we have previously presented with examples.

5. Brief description of two new sites documented in Sierra Morena

5.1. The shelter of Arroyo del Castañarejo (Viso del Marqués, Ciudad Real, Spain)

This is a small quartzite rockshelter facing towards the southeast and located about fifty metres from the stream after which it is named. It is morphologically formed by a central cavity whose depth was lower than four metres and had a width of approximately two metres at the dripline.

This entrance shows the remains of a dry-laid wall of quartzite rocks whose purpose could have been for human shelter against harsh weather conditions or perhaps to keep hurt or weak domestic animals. The inside of the cave is completely covered by soot due to its anthropogenic use and we have not located any rock art there. The site's images are located outside the cave, on the left side of the entrance placed on small flat areas of cracked surface. The high density of the surrounding vegetation typical of the Mediterranean forest (rockrose, holm oak, gall oak, arbutus etc.) makes the visibility of this site very poor and for this reason, it has only been discovered by pure chance.

We have documented 15 motifs, distributed over two panels which form an angle of 90 degrees. We must note that some of the figures that make up the panels are formed by tiny strokes of paint residue that, at present, prevent their description (Caballero et al. 2014).

5.2. The Cueva de Los Arcos (Viso del Marqués. Ciudad Real, Spain)

The Cueva de Los Arcos is on a great anticline that runs east to west and on branches running north to south, formed by he Armorican quartzites that are very abundant in the Sierra Morena area (Sierra de Mestanza and Alcudia valley).The dimensions of the

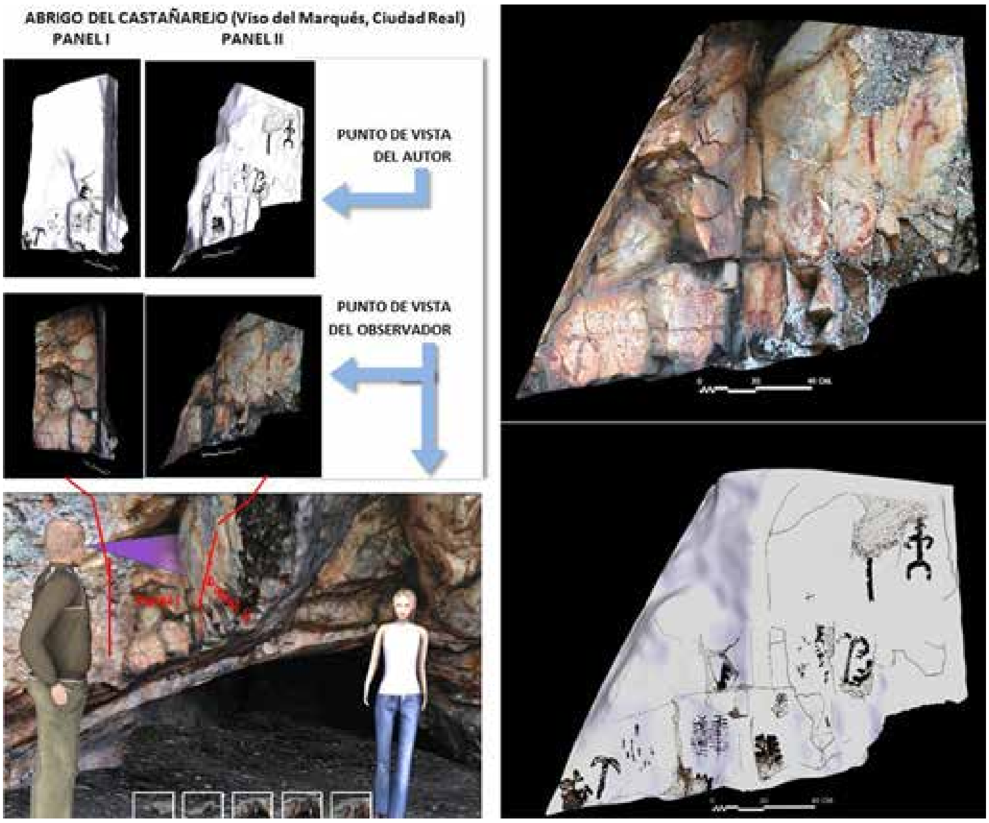


Figure 12. *3D model of the shelter of Arroyo del Castañarejo, with photographic texture, in which the individual tracings of each panel have been incorporated. In comparison with 2D, 3D multiplies the perspectives reproducing the observer's point of view, and facilitating the understanding of the motifs in relation to both the space and the support in which these are found. This enriches the point of view of the author or researcher who carries out the technical interpretative reading. An integral reproduction of rock art is achieved through the combination of both 2D and 3D documenting techniques.*

mouth of the shelter are about 25 m wide by 10 m high and it reaches a depth of 8 m in some parts, making it the largest shelter with rock paintings on the north face of Sierra Morena.

The pictorial representations appear on both sides of the back wall, at medium height and on small flat surfaces. To study them we have grouped them into four panels, two on the left side and two on the right side. We emphasise the poor state of preservation of the majority of the figures, mainly because of the soil and dust adhering to the quartzite. The size of the shelter turns it into a perfect space for sheltering and rest for the local wild fauna (mainly deer and wild boar) and its ground, although made of rock, contains a large amount of moved soil that has through time been adhering to the walls, making it very difficult to see the paintings. Indeed, the figures in panels III and IV were identified in the laboratory during the analysis of the photographic record and its processing by using the DStretch application (Caballero et al. 2015).

On panel III we originally sensed that there was some kind of motif under a graffito, but we must confess that in the pictures we took there was no evidence of the spectacular and enigmatic figure hidden under it and under the dirt on the panel. It was while working with the DStretch application in the lab that this panel emerged.

At a distance of 2.5 m from this panel, we found panel IV, this being no less enigmatic or significant. We could only notice with the naked eye what later became motifs 5 and 9 but, as happened with the previous panel, during lab work we realised that reality was a lot more complex. While analysing motif 5 with DStretch, motif 4 emerged underneath. This motif had not been noticed in situ at any time, as it had not been seen during the first visualisation of the photographic material. It was only after analysing it with the above-mentioned program that we became aware of its existence. Figure 9 is superimposed and it partially conceals another pictorial motif (motif 8). It is made up of a rectangular coloured area from the left side of which some oblique and parallel lines seem to stem.

6. Conclusions

3D documentation, whether by photogrammetry or laser scanning, is a step

Figure 13. *Location map of the two new sites reported here.*

Figure 14. *Images of the shelter of Arroyo del Castañarejo (Viso del Marqués, Ciudad Real-Spain).*

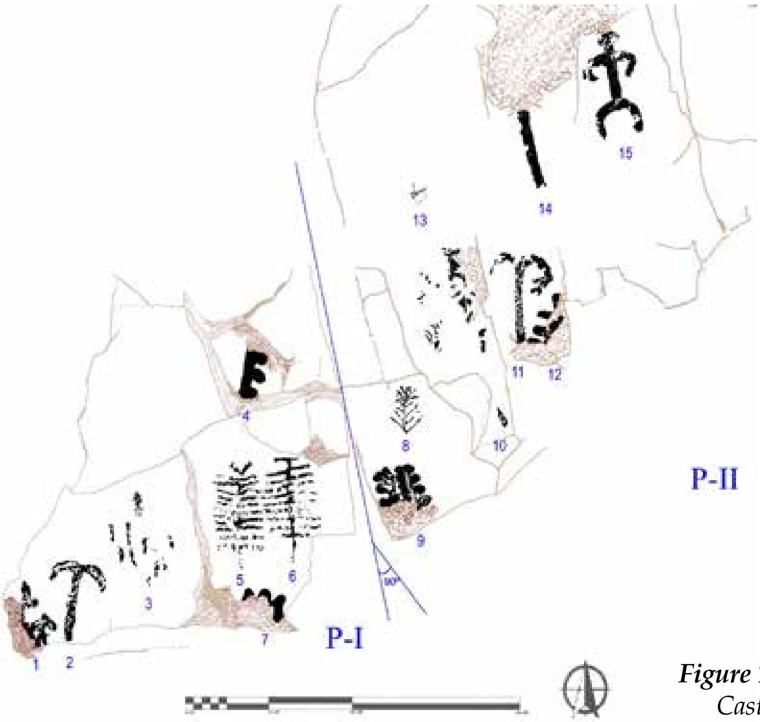


Figure 15. *2D tracing of the shelter of Arroyo del Castañarejo (Caballero et al. 2014).*

Figure 16. *The Cueva de los Arcos (Viso del Marqués, Ciudad Real-Spain). (A) General view of the shelter; (B) view from the site; (C) images of panel III: detailed picture of figure 1 and four pictures processed using different parameters of the DStretch application; (D) photographic detail of figures 8 and 9 of panel IV and the same picture processed with DStretch.*

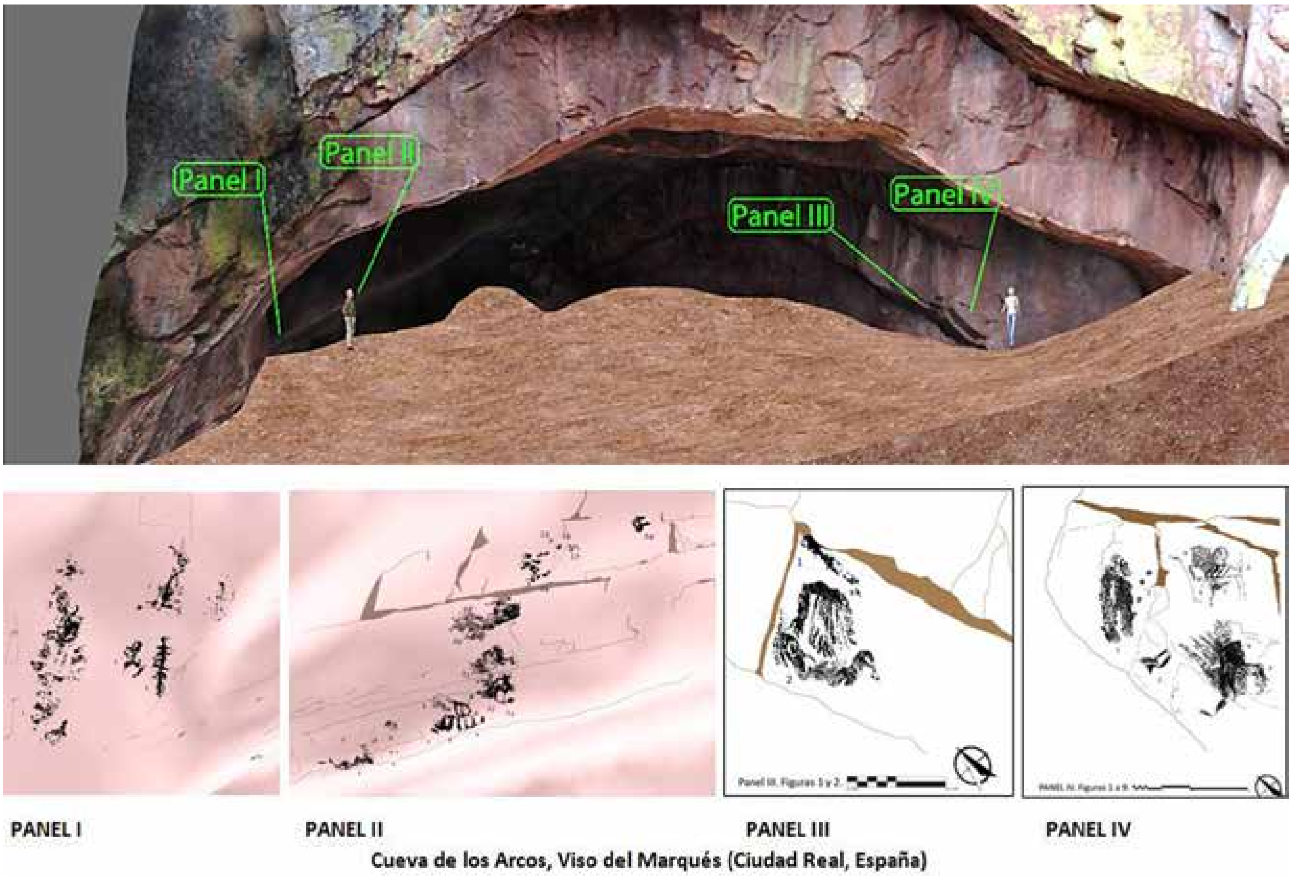


Figure 17. *Photogrammetic map of the location of the panels. Tracing on photogrammetry in 3D of panels I and II. Tracing on orthophoto in 2D of panels III and IV.*

forward for rock art recording. The representation of the supports in three dimensions, portable or non-portable, offers a more reliable visualisation of the studied motif. This being digital visual information, we can include all kinds of filters or add additional knowledge for its enrichment and understanding. The continuous improvements in the field of digital photography also have an impact on the quality of the three-dimensional models. In addition, the recording of rock art motifs can be extended by including their immediate surroundings.

Furthermore, preservation is one main issue of the rock art. The elaboration of 3D models, being almost exact replicas of reality, could be the best means of obtaining a copy of an archaeological item facing its possible damage or loss. New technologies related to 3D printing can substantially help in preservation and didactical issues, as well as in museology.

Finally, scientific dissemination and divulgation to the general public can also benefit from these tools. The 3D visualisation of rock art is a communication tool that allows us to explain complex processes using easily understandable graphic elements.

On the other hand, the use of computer tools such as the DStretch plugin of the ImageJ software, created by Jon Harman for the colorimetric decorrelation of rock art photographic images, is another example of the progress in rock art recording. It helps to study any pictorial trace in detail, especially when it is hardly noticeable to the human eye.

As an example of the suitability and versatility of this type of documentation and image processing methods, we have shown the photogrammetric results from two new sites of post-Palaeolithic rock art documented in Sierra Morena (Ciudad Real): the shelters of Arroyo del Castañarejo and Cueva de Los Arcos, both of them located in the municipality of Viso del Marqués, Spain.

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