USE OF PHOTOGRAMMETRY TO SURVEY IRON AGE ROCK ART MOTIFS IN THE CÔA VALLEY: THE VERMELHOSA ROCK 3 CASE STUDY (VILA NOVA DE FOZ CÔA, PORTUGAL)

USO DE LA FOTOGRAMETRÍA EN EL LEVANTAMIENTO DE LOS MOTIVOS DE ARTE RUPESTRE DE LA EDAD DEL HIERRO EN EL VALLE DEL CÔA: EL CASO DE ESTUDIO DE LA ROCA 3 EN VERMELHOSA (VILA NOVA DE FOZ CÔA, PORTUGAL)

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Highlights:

- The high-precision 3D model for the Côa Valley rock art enables the digital preservation of the rocks and motifs.

- The methodology presented for the vector drawing of rock art motifs uses ortho-images derived from the 3D models produced through photogrammetry.

- This study confirms using a photogrammetric survey is highly effective in facilitating the vector drawing of rock art motifs.
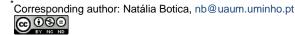
Abstract:

The Côa Valley, listed as a World Heritage site since 1998, presents over 1200 open-air engraved rock panels. The Archaeological Park of the Côa Valley has meticulously documented these rock art motifs, employing various techniques including direct tracing processes on the rocks, using both natural and artificial lighting. However, this intensive work is highly demanding, especially considering that many of the rocks are not easily accessible. In the context of the "Open Access Rock Art Repository" (RARAA) project, this paper presents a methodology for the three-dimensional (3D) survey of rocks with rock art motifs, as well as the subsequent production of orthophotos from the resulting 3D models, accomplished through photogrammetry. These orthophotos serve as the foundation for the vector drawing of the motifs. Remarkably, the level of detail captured in these records has shown that most of the motifs are visible and can be accurately represented through the orthophotos. This has significantly reduced the time required for field surveys. However, in certain cases where specific small areas of the panel are affected by challenging lighting conditions, further fieldwork is still necessary, analogous to the direct tracing process. Additionally, this study introduces an information system designed to integrate the vector graphics and the motifs characterisation data; this supports enhanced research in the area and promotes improved open access for potential reuse in new interpretations or integration into future projects. By creating highly detailed 3D models, the authors complement the two-dimensional drawings of the surfaces and ensure the digital preservation of both the rocks and the associated iconography. These records serve as highly detailed digital surrogates that facilitate the monitoring efforts of the rocks and motifs; they also guarantee the availability of valuable resources for future research and analysis, even if natural or deliberate changes occur.

Keywords: rock art; digital archaeology; digital photogrammetry; documentation; Iron Age

Resumen:

El Valle del Côa, inscrito en la Lista del Patrimonio Mundial desde 1998, presenta más de 1200 paneles rocosos grabados al aire libre. El Parque Arqueológico del Valle del Côa ha documentado meticulosamente estos motivos de arte rupestre, empleando diversas técnicas que incluyen procesos de trazado directo sobre las rocas, utilizando tanto iluminación natural como artificial. Sin embargo, este trabajo intensivo es muy exigente, sobre todo teniendo en cuenta que muchas de las rocas no son fácilmente accesibles. En el contexto del proyecto "Open Access Rock Art Repository" (RARAA), este artículo presenta una metodología para el estudio tridimensional (3D) de rocas con motivos de arte rupestre, así como la posterior producción de ortofotos a partir de los modelos 3D resultantes, realizada mediante fotogrametría. Estas ortofotos sirven de base para el dibujo vectorial de los motivos. Sorprendentemente, el nivel de detalle captado en estos registros ha demostrado que la mayoría de los motivos son visibles y pueden representarse con precisión a través de las ortofotos. Esto ha reducido significativamente el tiempo necesario a la hora de realizar las inspecciones sobre el terreno. Sin embargo, en algunos casos en los que pequeñas zonas específicas del panel se ven afectadas por condiciones de

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iluminación difíciles, sigue siendo necesario realizar más trabajo de campo, de forma análoga al proceso de trazado directo. Además, se introduce un sistema de información diseñado para integrar los gráficos vectoriales y los datos de caracterización de los motivos; ello es un apoyo a la investigación en el área y promueve un acceso abierto mejorado con el potencial de reutilización de las nuevas interpretaciones, o la integración en futuros proyectos. Mediante la creación de modelos 3D muy detallados, no sólo se complementa los dibujos bidimensionales de las superficies, sino que también se garantiza la conservación digital tanto de las rocas como de la iconografía asociada. Estos registros sirven como sustitutos digitales muy detallados que facilitan los esfuerzos de seguimiento de las rocas y los motivos, asegurando la disponibilidad de valiosos recursos en futuras investigaciones y análisis, incluso si se producen cambios naturales o deliberados.

Palabras clave: arte rupestre; arqueología digital; fotogrametría digital; documentación; Edad de Hierro

1. Introduction

The archaeological record has undergone a significant transformation with the introduction of photogrammetry techniques. In the past, archaeologists relied on manual measurements, sketches, and photographs to document and analyse artefacts, sites, and landscapes. However, these techniques document in two dimensions (2D) what are essentially three-dimensional (3D) surfaces and volumes, leading to results that could contain some inaccuracies (Simpson, Clogg, Díaz-Andreu, & Larkman, 2004). The emergence of photogrammetry has improved this process, since it empowers archaeologists to create accurate and highly detailed 3D digital representations of artefacts, architectural structures, and entire archaeological sites (Magnani, Douglass, Schroder, Reeves, & Braun, 2020; Marín-Buzón, Pérez-Romero, López-Castro, Ben Jerbania, & Manzano-Agugliaro, 2021).

Modern photogrammetric techniques bring numerous benefits to the field of archaeology in general, and they have particular significance in the study of rock art. One of the most appealing aspects of these technologies is that they utilize low-cost tools, whether conventional cameras or mobile devices, to produce high-quality results that can often reveal details that are difficult to see with the naked eye (Moro & Pavón, 2022). Through photogrammetry, it is possible to generate highly accurate 3D models and analyse objects and landscapes remotely. Additionally, the produced 3D models serve as precise and non-destructive documentation, ensuring their integrity and safeguarding (Roosevelt, Cobb, Moss, Olson, & Ünlüsoy, 2015; Morgan, & Wright, 2018). The integration of photogrammetry with other digital tools like Geographic Information Systems (GIS) and data analysis algorithms further enriches the interpretation and understanding of the archaeological record (Psarros, Stamatopoulos, & Anagnostopoulos, 2022). This integration opens up invaluable insights into the material culture of past civilizations, allowing researchers to delve deeper into our collective history.

The Côa Valley has been recognized as a World Heritage Site since 1998 and presents a collection of over 1200 open-air engraved rocks (Reis, 2015). Since 1993, various teams, including those from the Côa Archaeological Plan, the National Centre for Rock Art, the Côa Valley Archaeological Park, and the Côa Park Foundation, have meticulously documented the rock art motifs using different techniques. These techniques have involved direct decal processes on the rocks, with both natural and artificial lighting.

Photogrammetry in the realm of rock art research offers the aforementioned advantages. This is evident in the case study from Kakadu National Park (Australia) (Jalandoni & May, 2020) and the research regarding Gravettian rock art in the Aitzbitarte caves (northern Spain). The latter is particularly noteworthy as it recognises the significance of this technology, despite the challenges posed by artificial lighting conditions (Garate et al., 2020).

The RARAA project recognises the significant research question surrounding the influence of light conditions on the 3D restitution process using photogrammetry. Particularly in the case studies discussed herein, which involve open-air sites, there are significant challenges associated with the effect of natural light on the quality and precision of the resulting 3D models. Consequently, the usability of these models for conducting meticulous surveys of engravings is directly impacted.

In the forthcoming sections, we shall proceed to characterise one of the sites selected as a case study, namely *Vermelhosa Valley*, specifically focusing on Rock 3. Furthermore, we shall discuss the progressive evolution of the adopted recording methodologies over the years, taking into careful consideration the distinctive characteristics of the site. Additionally, a comprehensive account shall be provided concerning the careful execution of the photographic survey procedures, along with the process involved in getting the 3D model and orthorectified images of each notable panel that composes the Rock 3.

The subsequent sections of this study provide a detailed account of the process involved in linking the geometric and graphic elements to a Geographic Information System (GIS) implemented on QGIS. Furthermore, the motifs present on the rock are comprehensively characterised to enable a deeper understanding of their nature and significance.

We conclude this work by presenting our outcomes and perceptions regarding the application of this survey methodology in the context of open-air rock art. Additionally, we provide considerations and suggestions for future procedures, aiming to enhance and refine the methodology further. These conclusions serve to consolidate the knowledge gained from this research and contribute to the ongoing advancement of survey techniques in the field of open-air rock art.

2. The *Vermelhosa Valley* site

While the discussion on the dating of the Côa Valley Palaeolithic rock art and the fight for its preservation were underway, mainly led by archaeologists and prehistorians (Zilhão et al.,1997), local non-archaeologists were surveying the valleys surrounding Vila Nova de Foz Côa. The discovery of the Vermelhosa rock art site in June 1995 is attributed to José Constâncio ("Pilério"), a native of Vila Nova de Foz Côa (Abreu, Arcà, Jaffe, & Fossati, 2000). However, a small news item in the *Diário de Coimbra* newspaper on June 10, 1995 (p. 19) identifies Jorge Bregas, also a native of Vila Nova de Foz Côa, as

the discoverer. The description of the discovered representations ("a presumed bird-headed deity under which a fight is depicted, and to the side another scene where a human figure is perforated by a spear") identifies Rock 3 as the panel where this significant finding was made.

The Vermelhosa rock art site is situated in a narrow and rugged seasonal water valley. It descends from the surface of the Foz Côa plateau (~380 m) to the left margin of the Douro River (~110 m, before the construction of the Pocinho dam), following an East-West direction, with a slope ranging from 18 to 28º, indicating a significant slope in the terrain (see Fig.1).

Figure 1: Location of the Vermelhosa Valley and the rocks with Iron Age rock art.

The initial investigation of the Vermelhosa rock art site started during the summer of 1996. At that time, six panels, including Rocks 1 and 3 (referred to as number 4 in this particular project), were documented and studied. These panels were believed to be associated with the Iron Age. The findings of this research were initially presented in a preliminary version (Abreu, Arcà, Jaffe, & Fossati, 2000). Subsequently, in the following year, the number of recorded panels increased to eight. By the year 2000, the team from the *Centro Nacional de Arte Rupestre* (CNART) had documented a total of 10 engraved panels at the site. This number further expanded to 11 in 2002 and 12 in 2006. A systematic survey conducted in November 2011 led to the identification of an additional 12 panels, bringing the total count to 24 (Reis, 2013). However, it should be noted that the process of identifying engraved panels at the site was ongoing, as two more panels were later discovered.

The ongoing research has revealed that the Vermelhosa rock art site now consists of a total of 26 panels adorned with various motifs spanning from the Upper Palaeolithic to modern times. Among these panels, 15 of them exhibit motifs that have been attributed to the Iron Age, based on stylistic and technical characteristics. These Iron Age panels are concentrated in two distinct areas. The larger group comprises 13 panels (numbered 1, 3, 6-10, 15-17, 19, 24, and 26) situated on the left bank of the watercourse, ranging in elevation from 145 to 180 m. The remaining two panels (numbered 13 and 14), with one of them already located on the right bank of the stream, are positioned more than 200 m upstream, at elevations between 250 and 270 m.

All of the rock art representations were carefully engraved on the vertical surfaces of schist rocks belonging to the Desejosa Formation. These rocks are part of the larger Dúrico-Beirão Supergroup and have formed as a result of regional tectonic processes (Aubry, Luís, & Dimuccio, 2012). It is worth noting that all of these engraved panels face southeast, exhibiting a consistent orientation.

3. The evolution of rock art survey at the *Vermelhosa Valley* site

The first surveys of Iron Age art in the region between the Côa and the Douro rivers took place in Vale da Casa in 1982. These surveys used a new technique of direct decal on transparent polyvinyl plastic, which was considered effective for visualising fine traces. Latex moulding was also used alongside the decals (Baptista, 1983).

Thirteen years later, the "Engraved in Time" project conducted the first decal work on rocks in Vermelhosa, using two methods (Campos, 1996). The first method involved indirect registration using a grid defined by wires measuring 100 x 100 cm, further subdivided by a 10 x 10 cm grid. The drawings were done at a scale of 1:5 with the help of eye tracking. To address the challenge of representing the thin traces of the panels, a direct daylight decal on plastic was also employed, utilising shadows and mirrors for improved visualisation. The decals were later reduced to a 1:1 scale using photocopies.

During this period, drawings of Palaeolithic art in the Côa Valley were already being created, initially by Nelson Rebanda and later by António Martinho Baptista and Mário Varela Gomes. Fernando Barbosa, who had participated in the Vale da Casa surveys in the 1980s, served as the main designer for both teams. They employed the method of direct tracing on plastic with different-coloured pens. The use of the dichromatic method and latex moulding was abandoned due to preservation concerns. The practice of night decal was introduced, allowing control of light and shadow for identifying the finest lines, which were practically invisible during the day. The development of patina on the rock surface after engraving causes the engraved lines to blend with the rest of the rock, making them difficult to see. Artificial lights, positioned perpendicular to the direction of the engraved lines, were used in darkness to create shadows and visualise the finest lines. This was the common practice of the CNART and other institutions, and it was how the team managed to decal Stone 3 in Vermelhosa on February 18, 1999.

Interestingly, most of the surveys conducted by the CNART team on Iron Age rocks were done during the daytime. This is because the engraved traces from this period are mostly still white and visible during daylight.

After the direct decal, the plastic with the survey is digitised, and then all the lines are vectorised in a drawing program (Adobe Illustrator CS6) and grouped by motif (Baptista et al., 2013).

Within the scope of the RARAA project, we conducted experiments utilising photogrammetry for surveying purposes. Specifically, we tested various unmanned aerial vehicles (UAVs) and utilised different camera setups to capture the necessary data. As a result, we were able to generate accurately scaled and georeferenced 3D models and orthophotos, which served as the foundation for creating vector drawings of motifs. The registration methodology employed for these surveys will be further explored in the upcoming sections.

4. Photogrammetric survey of rocks and panels

Photogrammetry methods have increasingly been adopted for the recording and analysis of rock art, particularly those dating from the Upper Palaeolithic period (Rivero, Bécares, & Álvarez-Fernández, 2021; Garate, et al., 2020). Traditionally, recording rock art involved manual measurements, sketches, and photographs taken from various angles. However, the introduction of photogrammetry has revolutionised the field, allowing for more accurate and detailed documentation of this fragile and often inaccessible art. One of the main advantages of photogrammetry in rock art documentation is its non-invasive nature. Unlike other methods that might require physical contact with the artwork, photogrammetry allows researchers to capture data remotely, preserving the integrity of the rock art while still obtaining precise measurements and surface details.

Registration procedures in archaeological projects need to be tailored to address specific challenges and motivations (Forte, 2014). In our study, we adapted the recording methodology to accommodate the scale and material characteristics of the archaeological elements under investigation.

For the record of the focal rock formation, which occupied a medium-scale area, we employed a manoeuvrable and versatile UAV equipped with an integrated camera featuring a 1/2.3" CMOS sensor capable of capturing images with up to 12.35 million effective pixels. The UAV used in this study was a DJI Mavic Pro, offering a flight autonomy of approximately 25 minutes and equipped with dual satellite navigation systems (GPS/GLONASS). The UAV's lens features a 78.8º field of view, a focal length

equivalent to 26 mm in the 35 mm format, an aperture opening of f/2.2, minimal optical distortion (<1.5%), and a focus range spanning from 0.5 m to infinity. Additionally, we employed a digital camera (Canon EOS 6D Mark II) with a full-frame CMOS sensor boasting approximately 26.2 million effective pixels, equipped with a Sigma 35 mm 1:1.4 DG HSM Art lens. To capture detailed images of the rock art incisions, a macro lens (Canon EF 50 mm 1:2.5 Macro) was utilized. Georeferencing of control points for accurate orientation and scaling of the 3D surfaces derived from the captured images was facilitated by employing the GPS MobileMapper 120 in conjunction with an external precision antenna (L1/L2 GPS + GLONASS, Ashtech ASH-111661).

To conduct the 3D recording, we adhered to established photogrammetry procedures based on multiple images (McCarthy, J. (2014). M) widely employed in cultural heritage and archaeology (Magnani, Douglass, Schroder, Reeves, & Braun, 2020; Marín-Buzón, Pérez-Romero, López-Castro, Ben Jerbania, & Manzano-Agugliaro, 2021). This process (see Fig. 2) entailed capturing a series of overlapping photographs of the archaeological element of interest using the aforementioned equipment.

The photographic register at Vermelhosa Valley occurred in two distinct moments. During the first moment, the primary objective was to capture the entire rock as well as each panel individually. This initial visit started at 9 a.m. and encompassed not only the photographic register but also involved the careful placement of control points for georeferencing, scale, and orientation of the archaeological elements of interest.

For the global reconstruction of the rock, photographs were taken at distances ranging from 2 m to 15 m, ensuring comprehensive coverage. On the other hand,
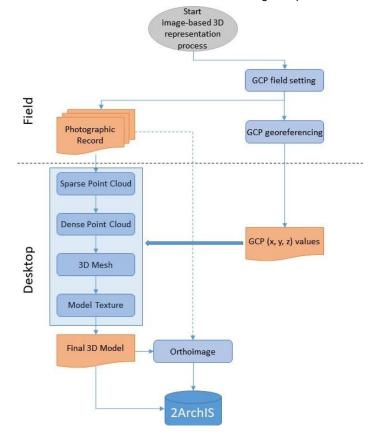

Figure 2: Simplified workflow of the 3D reconstruction process

when capturing the intricate details of the panels, photographs were recorded at substantially closer distances, varying between 1.5 m and 0.5 m. This approach allowed for higher resolution and greater visibility of the panel motifs.

In total, the photographic register procedure involved the capture of 1186 photographs, which was accomplished within approximately 90 minutes. It is important to note that out of these photographs, 318 were specifically utilised for the global restitution of Rock 3. The remaining photographs were dedicated to recording each individual panel, amounting to a total of four panels considered in the study. The images of each panel were initially intended to be recorded at a constant distance from the surface of interest to ensure a consistent Ground Sampling Distance (GSD). However, due to the challenging terrain, each panel ended up being captured at different distances from the surface.

During a subsequent visit at a later date, the second moment of the photographic register commenced around noon. This phase of the survey took a more targeted approach, focusing specifically on the lower part of the rock near the motifs. The objective was to capture detailed images that would further enrich the understanding of the archaeological elements.

In this selective survey, a total of 250 images were recorded, ensuring that no intricate detail was overlooked. The process was executed efficiently, taking approximately 20 minutes to complete. By dedicating specific attention to the lower section of the rock, the researchers aimed to gather precise data that would contribute to a more comprehensive analysis of the motifs and their associated features.

The initial phase of generating a comprehensive and coherent 3D model involved the meticulous restitution of the surface of the global rock model. This process encompassed the steps of Figure 2 that were executed, with a duration of 3 hours and 11 minutes.

Following the completion of the global rock model, the same approach was employed for each panel present on the rock. Each panel's restitution, involving a similar set of procedures, took approximately 1 hour and 30 minutes to accomplish. This meticulous effort aimed to capture the unique characteristics and attributes of each panel, contributing to a comprehensive understanding of the rock art composition as a whole.

The first step in the 3D reconstruction procedure entailed the identification of common points across the photographs, which served as the basis for triangulating the 3D coordinates of the archaeological element. This process is illustrated in Figure 3, providing a visual representation of the point triangulation technique employed.

Once the initial 3D model was generated, it underwent a comprehensive optimisation process to ensure accuracy and quality. This optimisation phase aimed to address any gaps or holes present in the 3D model, ensuring a complete and seamless representation of the archaeological element.

Texture mapping played an important role in enhancing the visual appearance and surface details of the 3D model. Through the application of texture mapping techniques, the researchers were able to overlay high-resolution textures onto the 3D model (see Fig. 4).

The culmination of the 3D modelling process involved utilising the final model to generate orthoimages, which is crucial for facilitating the archaeological illustration of rock art motifs. The orthoimage generation process involved projecting the detailed 3D model onto a 2D plane, effectively creating a flattened representation of the archaeological element. By carefully aligning and merging the individual images, it was possible to generate an orthoimage that accurately portrayed the entire archaeological element. This process ensured that the orthoimage captured all the relevant details and maintained the spatial accuracy of the original 3D model.
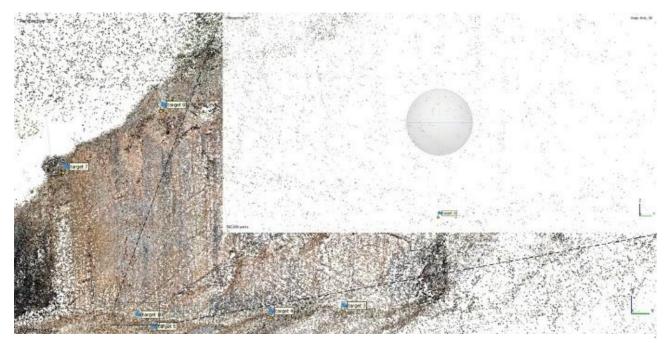

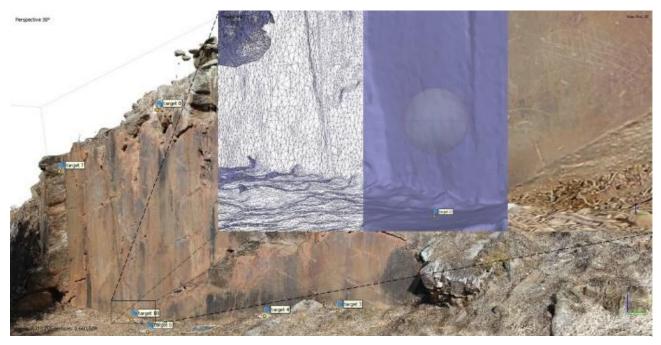**Figure 3**: Sparse Point cloud (Rock 3, Vermelhosa Valley).

Figure 4: Textured 3D mesh (Rock 3, Vermelhosa Valley).

Following the generation of the orthoimage, a rigorous evaluation was conducted to assess its accuracy and rectify any distortions. Special attention was given to aligning the images correctly and correcting any discrepancies that might have occurred during the stitching process. This procedure was necessary to ensure that the orthoimage faithfully represented the original archaeological element.

For the orthoimage generation, the authors took into consideration that the considered rock art is engraved on shale rocks, which exhibit planar surfaces that may not necessarily be vertical. To achieve an orthoimage with optimal accuracy, a customised projection plane was specifically designed, taking into account the tilt of each panel. To facilitate this process, three markers were designated on each panel, enabling the calculation of both horizontal and vertical axes. This meticulous approach guarantees the accurate projection of each panel onto a plane, resulting in a precise and high-quality orthoimage.

The resulting orthoimage, as depicted in Figure 5, served as a valuable resource for data analysis and interpretation of the archaeological elements, with precision and accuracy.

Figure 5: Details of motifs on a panel (Rock 3, Vermelhosa Valley).

5. Geographic information system (GIS) of rocks and motifs

The vector drawing of motifs engraved on the rock surface serves two purposes. The first is to identify, isolate, and highlight the engraved motifs, while the second is to integrate them with metadata that allows for the visualisation of all or selected motifs based on specific criteria (Sanches, 2012).

To facilitate data management and recording in a standardised manner, we created a web-based back-office application. This application includes validation routines and error prevention mechanisms, such as associating fields with predefined lists of values and chained lists that automatically update based on previous selections (Botica, Luís, & Silva, 2022).

In the RARAA project, we developed a module in the 2ArchIS information system (IS) of the University of Minho's Archaeology Unit (Botica, 2017) to describe rocks and rock art motifs. 2ArchIS was implemented as a modular structure using a MySQL database, where macro data related to the territory, cartography, bibliography, etc., are recorded. It also stores data about archaeological sites, whether obtained from archaeological surveys, excavations, or rock art data surveys (see Fig. 6).
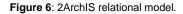
5.1. Rectified orthophotos as the base image of the vector drawing

The vector drawing of the motifs is performed on the orthophotos derived from the previously described photogrammetry method. These orthophotos are georeferenced and exported at their true scale, ensuring the highest possible resolution. In the case of large panels such as Rock 3 of Vermelhosa, the orthophotos are exported as mosaics, divided into smaller sections with dimensions of 80 cm^2, to facilitate visualisation and enable zooming in and out. This subdivision allows for the efficient examination of the rock art panel through a series of juxtaposed images.

5.2. Layer organisation and nomenclature and motif drawing

In QGIS, in addition to the layer created with the raster image, which is the basis for motif drawing, we created a vector layer, where all motifs were saved as they were drawn. In this vector layer, we created a field to record the motif's inventory number. Thus, when a set of lines configures a motif (figurative, geometric or alphanumeric), these lines were grouped and given an inventory number composed of the acronym of the site, followed by the rock number and a hyphen with the sequential number of the motif (e.g., VRM003-023).

Figure 6: 2ArchIS relational model.

In the context of rock art, which is inherently visual, the use of a GIS is crucial. This tool enables the visualisation of graphic information, the interconnections between motifs and the rock surface, combined with motif characterisation data, enriching vector data and facilitating the establishment of selection criteria for the interpretation and study of art. For implementing the GIS, we selected the QGIS v. 3.28.3-Firenze software, which integrates and visualises rock art drawings with both graphic and alphanumeric data stored in the 2ArchIS back-office application.

When we have motifs that overlap, they can be stored in different layers, so that they can stand out with different colours. In that case, the layer designation should be the motif inventory number (see Fig. 7).

Although rock art motifs can be drawn digitally using a mouse, this tool implies interruptions in the features, which were not drawn natively that way. Thus, to represent the motifs more faithfully, we used a digitizer table (Wacom - one 13.3" pen display) and the drawing of the motifs was made with a pen over the orthophoto, sometimes enlarged, to represent them as accurately and in as much detail as possible.
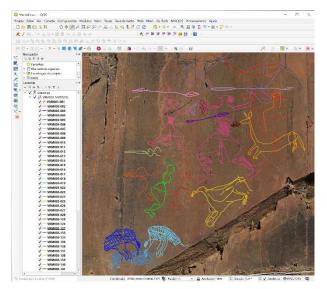
Figure 7: QGIS Layer Organisation.

The lines are created with the same thickness as the trace on the orthophoto. We found, in Vermelhosa Rock 3, distinct line thicknesses ranging from 0.1 mm to 2 mm.

5.3. Data and metadata recording in 2ArchIS

Once the motifs are drawn in vector format, they are obtained as scaled and georeferenced drawings. These motifs are then individually characterised in the 2ArchIS forms, specifically designed with descriptors and attributes for this purpose (Botica, Luís, & Silva, 2022). The vector drawings are associated with the generated images, creating a comprehensive record.

5.3.1. General characteristics of the motif

The registration of a motif's general characteristics is closely tied to the specific rock hosting the engraved panel. In the case of Rock 3, and similar to most rock art panels in the Côa Valley, it is composed of schist lithology, exhibiting a reddish-brown colour and a smooth vertical surface with varying height and width.

In the motif registration form, the motif is assigned an inventory number consisting of the site acronym, rock acronym, and a unique motif number. Additionally, a free-text description is provided, along with details on the style, technique, and maximum width and height measurements. Based on the motif's typology, it is associated with a group descriptor such as figurative, geometric, or alphanumeric, and further classification is determined by specifying its type and subtype within the chosen group. Additional data are included, such as whether the figure is complete or incomplete, whether it is an inverted figure, the orientation and perspective depicted, and whether it represents an animate figure (Botica, Luís, & Silva, 2022).

5.3.2. Parts represented in the motif

In addition to documenting the general characteristics of the motif, the 2ArchIS application form allows for the detailed description of one or more specific features depicted in the motif. For anthropomorphic and zoomorphic motifs, these may include details about the head, limbs, or other relevant body parts. In the case of weapons or similar motifs, the form provides sections to specify the different components (Botica, Luís, & Silva, 2022).

5.3.3. Scene Recording

The motifs are individually drawn and characterised. However, certain motifs form part of a figurative set or scene, such as a feeding scene or an anthropomorphic holding a vase on its head (see Fig. 8) (Luís, 2023).

In the back-office application, we can associate multiple motifs that constitute a scene or belong to a figurative set. Each scene is assigned an inventory number (site acronym, rocky outcrop acronym, and scene number) as well as a name and description. To establish the associations between motifs, we simply select the corresponding motif from the registered inventory numbers on the panel and define the type of connection, whether they are juxtaposed or overlapped (Botica, Luís, & Silva, 2022).
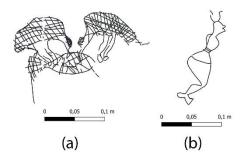

Figure 8: Motifs setting scenes. Feeding scene (a) and anthropomorph with a vase on head (b).

By initially recording motifs individually and subsequently establishing associations between motifs that collectively represent scenes or composed motifs, the database offers great versatility in searching and querying. This approach enables us to search for patterns that are often hidden, allowing us to selectively view individual motifs based on specific criteria or conduct queries related to scenes and the motifs comprising them.

5.3.4. Relative chronologies of motifs

The rock art motifs found on the engraved panels of the Côa Valley often exhibit overlapping features, indicating that they are not always isolated (see Fig. 9).

In the case of the Feeding Scene, the overlapping lines provide insight into the sequence of the drawings. For example, motifs VRM003-022 and VRM003-023, depicting birds, were drawn before motif VRM003-024, representing a fish (see Figure 10). The time gap between these motifs can vary, ranging from narrow intervals, as seen in the feeding scene, to wider gaps, as observed on the same Rock 3, where Iron Age motifs overlay striated representations of Azilian herbivores (~12000 BP).
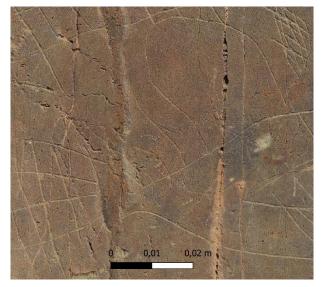
Figure 9: Detail of the feeding scene (Rock 3, Vermelhosa Valley).

Figure 10: Relative chronology recording form.

When it is recorded that motif A overlaps motif B, the back-office application automatically establishes the inverse relationship, indicating that motif B is overlapped by motif A (see Fig. 10). This information can be exported, for instance, to ArchEd, enabling the automatic creation of the Harris motif matrix (Harris, 1989).

5.4. Sharing Data in the Repository

The 2ArchIS serves as a comprehensive platform for managing various project data, including rock outcrops, rock art motifs, bibliography, images, and vector drawings. However, access to this system is limited and requires permission. To fulfil the goal of making the data openly accessible, the RARAA project has chosen to make use of *DatarepositóriUM*, an institutional repository provided by the University of Minho, which ensures the sustainability and long-term sharing of the data.

As data depositors, our aim is not only to transfer the project data to the repository for sharing and preservation but also to adhere to the FAIR principles, making the data findable and reusable (Hollander et al., 2019). To achieve this, we carefully establish descriptors and attributes when recording the rock art motifs (Botica, Luís, & Silva, 2022). We export datasets and images to the repository, along with metadata that clearly defines the data type, authors, dates, and origin.

By following this approach, any researcher in archaeology or related fields can access the 3D models of rock outcrops (Bernardes & Borges, 2023) and their surroundings. These models can be utilised for creating new motif drawings or interpretations, monitoring the condition of the rock panels, or developing visualisation and heritage dissemination applications such as tourist guides or augmented reality applications.

Additionally, the rock art motifs, which have been created based on orthophotos, are also available on *DatarepositóriUM*. Researchers can download CSV files containing all the recorded characteristics of the motifs from the back-office application, as well as files containing the vector drawings of the motifs (see Fig. 11).

6. Characteristics of the motif lines

The rock art panels in the Côa Valley, including the Vermelhosa site, offer unique conditions for drawing due to their historical use as canvases for various artists.

Figura 11: *DatarepositóriUM* rock art motif data (Rock 3, Vermelhosa Valley).

These panels display artistic representations from different periods and diverse iconography. The techniques and tools used for drawing have also evolved, resulting in overlapping engravings and marks on the panels. These specific characteristics, combined with natural properties and changes undergone by the panels, make the visualisation and drawing of motifs a complex and demanding task in terms of accuracy and detail.

The heritage inventory of rock art incorporates the geometric documentation that results from the vector drawing of the rock art motifs and constitutes a study base and assumes special importance as a base for the study of rock art. (Gil-Docampo, Peña-Villasenín, & Ortiz-Sanz, 2019).

The case study conducted at Rock 3 of the Vermelhosa site demonstrates the effectiveness of using orthophotos for drawing rock art motifs. This methodology proves valuable in expediting and simplifying fieldwork for researchers. By using orthophotos as a reference, designers can analyse motifs repeatedly, zoom in significantly (as orthophotos are captured at real scale), and easily share them with other researchers for clarification and discussion, enabling a comprehensive examination of the orthophotos.

However, similar to field drawing, this methodology may require on-site validation at times. Despite the level of detail captured in orthophotos, certain features, such as line depth, colour, overlaps, natural fractures on the surface, or changes resulting from natural processes, may necessitate field verification.

The Vermelhosa Rock 3 panel serves as an illustration of these challenging features encountered during vector drawing from orthophotos.

6.1. Colour

The surface of the rock art panel naturally exhibits an orange-brown colour. When the silicometallic layer of the engraved surface undergoes a scraping process, it creates a distinctive white trace that stands out due to its chromatic contrast (see Fig.12).

However, after the incision, a process of surface film reformation takes place, causing the whitish colour to gradually change over time and approach the colour of the rock surface. The speed at which these changes occur depends on various factors, including sun exposure, water accumulation, chemical elements, and plant colonization. In Figure 13, it can be observed that the same line exhibits different tonalities, ranging from whitish to darker shades, with a reddish colour present in some areas. These variations in tonality are closely associated with different surface regions, likely indicating the migration of rock elements to the surface.
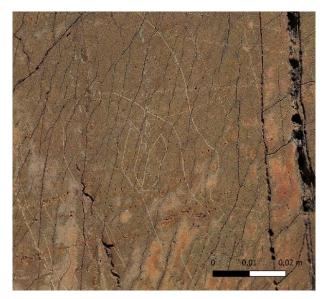
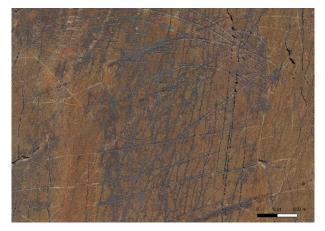**Figure 12:** Whitish trace after surface scraping, Rock 3.

Figure 13: Lines with different colour tones, Rock 3.

6.2. Line depth and thickness

The orthophotos reveal that the lines exhibiting greater visibility and ease of depiction are characterised by deep incisions and/or a whitish colouration. For instance, in the bird motif within the feeding scene (e.g., Fig. 14), the bird's body and head are depicted using a deep incision, facilitating line tracing on the orthophoto.

However, when examining bird motifs, it becomes apparent that different levels of depth exist within the same motif and across different motifs, despite employing similar techniques. This disparity in depth is likely influenced by the force applied during the engraving process and the tools utilised. An illustration of this phenomenon can be observed in Figure 14, where the birds' feet exhibit thinner and less pronounced lines, accompanied by a more faded whitish colouration, sometimes preventing the identification of their contours.

Figure 14: Detail of incised engraving on panel (Rock 3, Vermelhosa Valley).

A significant majority of the lines discovered on rock 3 at Vermelhosa are linear in nature. Nonetheless, the bird motif in the feeding scene exemplifies variations in line depth and thickness within the same motif, as well as across different motifs. These variations likely stem from differences in engraving force and tool selection (e.g., Fig. 15).

Figure 15: Details of motif depth and thickness, Rock 3.

6.3. Reinforced line

Most of the Rocha 3 motifs from the Vermelhosa Valley result from a simple linear line, but on some occasions, it can be seen that a repeated line was made to better define the shape of the motif. This is the case of the eye of the warrior where its outline resulted from the incision of more than one line (e.g., Fig. 16).

6.4. Interrupted or dashed lines

The lines which define the contour of the motifs are very often continuous lines, with more or less thickness and depth. However, some lines seem to have been interrupted in some parts of the outline and others even have the appearance of dashed or dotted lines (e.g. Fig. 17).

These characteristics of the lines, and the fact that they are often angular, may suggest the use of a metallic tool for their engraving. The interruptions of the trace or the greater depth of incision may be related to the pressure

applied on the tool and its flexibility, as well as the position of the hand more or less away from the extremity of the tool used for engraving (Luís, 2023).

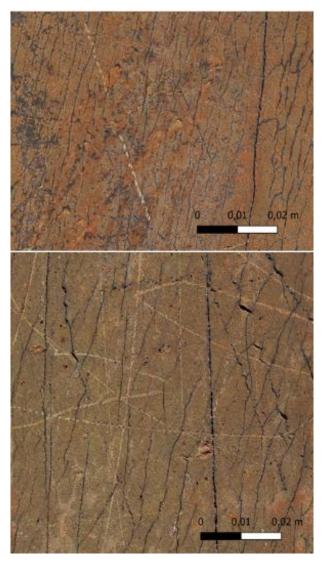**Figure 16:** Details of reiterated trace to draw warrior's eye, Rock 3.

Figure 17: Details of interrupted lines, Rock 3.

6.5. Natural surface fractures

As it is possible to observe from the images presented above, natural fractures frequently occur on the surfaces of the panels. This is a factor that can sometimes make it difficult to recognise part of the motifs since the fissures resulting from these fractures can look very similar in appearance to the lines made by the linear incision, and sometimes they are even overlapping.

7. Conclusion and final considerations

This work is part of the RARAA project, where a case study of drawing Iron Age rock art motifs was developed based on orthophotos. These were produced from the 3D models, obtained from the photogrammetric survey of rocks and panels. As an outcome of this work, the motifs from Vermelhosa Rock 3 were drawn vectorially, scaled and georeferenced in a GIS and described in the 2ArchIS.

By adopting a systematic approach to photography, the researchers ensured a comprehensive and detailed record of the archaeological site. The inclusion of control points for georeferencing, scale, and orientation further enhanced the accuracy and reliability of the collected data. These efforts provide a solid foundation for subsequent analyses and the creation of detailed 3D models and orthophotos.

The photographic register conducted at distinct moments exemplifies the necessary approach taken to document and study the rock art site, facilitating in-depth analysis and interpretation of the archaeological elements within the broader context of the region's cultural heritage.

The application of photogrammetry techniques at Vale da Vermelhosa has significantly enhanced the documentation and analysis of rock art. The use of UAVs, digital cameras, and GIS has provided precise measurements, detailed 3D models, and comprehensive visual representations. While challenges related to lighting conditions persist, the integration of photogrammetry with other digital tools continues to shape the field of archaeology, contributing to the ongoing advancement of survey techniques in open-air rock art research. However, according to the various works carried out in this area, there is no single method that can be recommended, and the available solutions must be chosen and evaluated according to the requirements of the stone type and motifs (Plisson & Zotkina, 2015).

The rock art panels in the Côa Valley, particularly the Vermelhosa site, present unique challenges for drawing due to their historical use as canvases for various artists, resulting in overlapping engravings and marks. The 3D models are a very accurate representation of the characteristics of the surfaces in three dimensions and that can be revisited repeatedly, allowing a continuous evaluation of the motifs, their characteristics and the interconnections between themselves and with the natural characteristics of the rock (Simpson, Clogg, Díaz-Andreu, & Larkman, 2011). The use of orthophotos as a reference for drawing rock art motifs has proven to be an effective methodology, expediting and simplifying fieldwork for researchers. Orthophotos enable detailed analysis, zooming capabilities, and easy sharing with other researchers.

Despite the benefits of using orthophotos, on-site validation is still necessary in certain cases. Factors such as line depth, colour, overlaps, natural fractures, and changes resulting from natural processes may require field verification. Natural surface fractures frequently occur on rock art panels, posing challenges in distinguishing them from engraved lines. These fractures can overlap with the motifs and resemble the lines created by linear incisions.

This methodology's most significant advantage is certainly the time saved in the field and the office. Traditional field surveys, besides the difficult conditions under which they are done, involve a meticulous and time-consuming process of drawing all the features, which are later redrawn in vector format in the office. With photogrammetric surveys, fieldwork is much faster than direct decals on panels, although they may also require one or more field validations and/or new partial photogrammetric surveys in areas where there are some uncertainties.

Acknowledgements

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