Introduction

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The expansion of computer technology within Archaeo–logical Science has contributed to the growth of a variety of new approaches in archaeological research. Specifically, the representation and analysis of archaeological sites and objects by means of virtual reconstruction. This is particularly noticeable within rock art studies, where 3D modelling has been used in the documentation, evaluation, dissemination, and historical analysis of rock art.

This monograph demonstrates, through different case studies, how digital approaches can benefit rock art research by providing new visualisations for rock art panels with different levels of preservation and, by using these, extracting historical and archaeological information. These case studies also demonstrate how cutting-edge methodologies are integrated within 3D modelling workflows and how the results can be managed and disseminated to the general public.

The 20th International Rock Art Congress, IFRAO 2018, Standing on the Shoulders of Giants, held in Darfo Boario Terme, Valcamonica, Italy, from the 29th August to the 2nd of September 2018, was one of the largest rock art conventions, with more than 800 people participating, 530 scientific papers presented, and over 36 sessions organised. Among these were three sessions concerned especially with digital technology and its usage within rock art research:

- *Challenges and changes for rock art research in the digital age*, a session centred around the possibilities and consequences of digital technologies applied to rock art concerning recording, dissemination and digital curatorship of rock art, and rock art heritage management.
- *Rupestrian archaeology, question & answers: tools, methods and purpose*, which focused on the relationships between methods, techniques of analysis and goals of the archaeological research applied to rock art studies.
- *Made for being visible. Developing 3D methodologies for the study of rock art carvings. Managing suitability in sites with Rock Art*. The purpose of this session was to present different case-studies centred on the application of 3D modelling and post processing techniques in relation to the study of rock art carvings.

Four years later, with a world pandemic having stopped our lives for over a year, we can now present the proceedings of these sessions, all of which focus on the application of digital methodologies within rock art research. This monograph is composed of 11 chapters from these sessions and offers a comprehensive insight into the application of digital technologies within rock art research.

I.1 Interdisciplinarity, archaeological data and methods

The need to find research tools beyond the traditional, coupled with the technological innovation of the last thirty years has expanded the development of new documentation methods and of archaeological data representation. In historical and archaeological studies this technological innovation is extensively used within an interdisciplinary framework that utilises traditional and new methods. A change that has broadened horizons. Among these new methods a large contribution has been made by computer sciences, both hardware and software, mathematics, optics, physics, mechanics and network communication. Thanks to this innovation, it has been possible to refine the traditional recording methods with these digital methodologies confirming the centrality of their role and taking advantage of the many opportunities offered by the continuous advance of technical and computer-based methods.

Four studies presented in this monograph highlight the application of this interdisciplinary approach and its results. Rocha and Morgado, in the municipality of Monforte (Portugal), studied the site of Penedo do Ferro, a prehistoric open-air sanctuary. This project showed the integration of photogrammetry techniques in order to help to obtain a better documentation of the engravings. The research team combined the documentation of the area with Georeferencing (GPS) and a photographic survey, to obtain both a photogrammetry and a three-dimensional view of each panel. The combined work of these techniques resulted in a good characterization of the rock art present, even where the surface was almost indecipherable. A similar approach has been used also by the team led by Paz-Camaño, who worked on Iron Age engravings in Western Galicia. This work documented the rock art panel by employing digital photography and photogrammetry, that was complemented by a geological analysis of the stone. The results offered important information and produced a wide variety of different imagery products that were used to enhance the visibility of the rock art. The article of Dickinson combines the integration of archaeological assessment with the benefit of digital imaging, including the comparison of the Upper Eskdale site and the engravings from other sites. He focused on the polissoir and the incorporation of digital image interpretation, 1:1 tracing and digital graphical

transcription of specific features. In the fourth study, we look at the Arara Vermelha Rock Shelter, Roraima, Brazil with the team of Cavallini, where the preservation of archaeological layers offered greater chances for rock art contextualization and dating. This project demonstrated how the use of AMS radiocarbon dating can lead to better understanding the graphic transformations and in the defining of a chrono-stylistic analysis of the rock art.

I.2 3D modelling, Photogrammetry, RTI

The documentation of rock art is one of the most important factors for a good interpretation of these manifestations. For years, researchers have used manual methods for the reproduction of rock art, which have a great impact on the panel in the moment of its documentation, for example, tracing on plastic sheets or the rubbing technique. Both methods have a negative impact on the conservation of the panel, yet are still being used frequently.

From the 21st century, there has been a major change in the methodology of the documentation of the rock art, and the manual documentation techniques had been replaced by digital techniques. Digital techniques allow 3D virtualisation of the engravings as well as a detailed and reliable study of rock art. The current digital methodology is the result of an improvement of digital techniques that were first experimented at Stonehenge in the late 1960s (Atkinson 1968).

The digital representation of rock art has also become a tool for dissemination. The acquisition of the data necessary for the creation of 3D models requires a good choice of methodology that depends on the variables that affect the documentation phase. The main methods of data acquisition today, which we will see in the articles of this book, are: Laser Scanning, Structure from Motion (SfM) photogrammetry and Reflectance Transformation Imaging (RTI). The main difference between them is the handling of the instruments according to the accessibility of the site and the derivation of the 3D point cloud. Laser Scanners provide range data that contains the 3D coordinates needed for the mesh generation phase, i.e., they extract the points from reality by themselves. Whereas Photogrammetry and RTI obtain data taken from 2D images that require further processing to transform them into 3D information.

The use of these techniques in rock art and the results obtained from them are explained in several of the articles in this book. Palonka and Zych show the benefits and disadvantages of these three techniques, highlighting not only the results obtained but also the ease and difficulty of each. Furiassi focuses on the use of the laser scanner and Martinotti and Marretta on the reproduction of a panel utilising SfM photogrammetry.

I.3 Digital analysis and enhancing techniques

3D modelling and Digital Imaging Techniques are currently a standard in data acquisition and analysis of archaeological carved remains, such as rock art, inscriptions, or emblems. In the last decades, there has been a wide expansion on the use and application of techniques such as SfM Photogrammetry and laser scanning (Robin 2015). Reflective Transformation Imaging is also being adopted in cultural heritage to highlight the readability of incised surfaces, such as rock art, wall graffiti (Valente 2020).

Following these developments, the use of digital image techniques to improve the visualisation of the engraved panels has become a particular field of research (see e.g., Mudge *et al.* 2006, 2012; Díaz-Guardamino, Wheatley 2013; Olsen, Bryant 2013; Duffy 2013; Domingo *et al.* 2013; Pires *et al*. 2014). In technical terms, these approaches use several filters and analyses over the created 3D models to highlight their morphological features, evolving to digital tracings of the rock art panels that try to surpass the traditional hand-drawn based techniques. One of the most used is Radiance Scaling (Vergne *et al.* 2010; Granier et al. 2012). Currently widespread through the MeshLab open-source software, its fast application allows the highlighting of the different views of a 3D model. Thus, it allows a more detailed view over rock art panels (Vázquez-Martínez *et al*. 2016). The list of techniques includes the management of mesh comparisons and manipulating shadows over the 3D models at different scales (e.g., exaggerated shading, Carrero-Pazos et al. 2018), and the application of traditional raster and LiDAR visualisation techniques (Lymer 2015; Horn 2019).

The present monograph highlights the application of digital filters to improve the visualisation of the 3D rock art models. Tanda and Manu take this opportunity to present new research over the famous Domus de Janas, by applying DStretch analytical imaging filters, thereby providing new insights into the paintings within the funeral hypogea. Bettineschi *et al*. present the results of the application of LiDAR-derived enhancing techniques over several engravings from the vertical walls of the Assa Valley, in Vicenza. The application of multiple digital methods allows them to discuss the motifs and techniques used. Finally, Papú demonstrates how digital techniques can be used to unravel long-term complex sequences of superimpositions at the Cerro de los Indios 1, in Santa Cruz (Argentina).

I.4 Display and interaction with data

A new way of presenting and looking at the output of 3D digitization processes has come into focus: "virtuality". A term that encompasses 3D computer graphics, Augmented Reality (AR) and Virtual Reality (VR)[1].

[1] The two terms are not always clearly distinguished from one another. Virtual Reality creates a completely virtual 3D world for the observer, in which the observer can "move" and interact with it. This is usually done with the help of VR equipment, such as glasses, gloves, etc. In Augmented Reality, the observer perceives the real world, but additional, virtual information is added to it, using simple devices such as e.g., a smartphone.

Virtual environments have the advantage of being able to combine spatial information with contextual annotations and give the observer an interactive three-dimensional insight into the real-world appearance of the object and its environment.

The use of virtual environments was first undertaken in the 1970s within the fields of engineering, aviation and the military, before it entered the realm of gaming and entertainment in the 1980s and 1990s. By the 1990s, this application also found its way into museums and cultural heritage institutions, where it was used to create a new medium for interacting with objects and the transfer of knowledge. At the end of the 1990s it began to be more widely used in archaeology,[2] where it has been used in knowledge transfer, making inaccessible sites virtually accessible, and to allow for the interactive appropriation of a reconstructed past with associated scientific questions. Moreover, it has been proposed to undertake virtual excavations as a learning aid (Reilly 1990). Unsurprisingly, the use of VR has also found its way into rock art research.[3]

However, the term "virtual" includes various degrees of integration of the senses, interactivity and detachment from the real world. While in the early applications the very existence of virtual solid models or 3D models has been understood as virtual (Reilly 1990: 1), Barceló *et al.* (2000: 1) state that "virtuality" must at least include a sensory experience. The technical basis for virtual environments, both in the acquisition of the data and in the presentation of it, has changed significantly since the first use of virtual environments. The limitations of the presentation of the data were first defined by computing capacity and the development of devices necessary for a full 3D experience. However, with the development of ever faster computers and virtual reality devices, such as headsets, it is now possible to have a higher degree of rendering and interactivity that allows annotations with information in addition to the "simple" 3D experience. Moreover, unlike the 1990s, we are now able to complete reconstruction of archaeological excavations utilising laser scanners and Structure from Motion (SfM) Photogrammetry.

An increasingly popular form of using virtual simulated environments are virtual tours. One of the first virtual tours started in 1994 with the virtualization of Dudley Castle[4] with a "walk-through" of a 3D reconstructed castle dated to 1550. From this starting point, virtual tours have evolved to modern game-based tours[5], which can convey scientific content to an audience. Urcia et al. (this volume) presents the setup of an interactive virtual reality tour of the rock art area in Nag el Hamdulab, Aswan, Egypt. They stress the necessity of not only recording the site in 3D, but also in reconstructing the perception between the viewer, the image and the landscape in which it is embedded. The advantages proposed by Urcia et al. are that virtual reality can bring specialist knowledge to an audience and be used as an innovative tool for research purposes.

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[2] For the implementation of virtuality in archaeology in the 1990s, see: Reilly, P. 'Towards a virtual archaeology." Computer Applications in Archaeology. Oxford: British Archaeological reports (Int. Series 565), 1990 and Gillings, M. "Engaging Place: A Framework for the Integration and Realisation of Virtual-Reality Approaches in Archaeology." In Archaeology in the age of the Internet. CAA 1997. Edited by L. Dingwall, S. Exon, V. Gaffney, S. Laflin, M. Van Leusen. Oxford: British Archaeological Reports (Int. Series, S750), 1999. For virtual projects in the 2000s, including archaeology, see: https://3dvisa.cch.kcl.ac.uk/index.html (Last accessed: 23.11.2021). For a summary of the state of research of VR in archaeology in the 2000s, see: Barceló, J. A., M. Forte and D. H. Sanders (ed.), Virtual Reality in Archaeology: Computer Applications and Quantitative Methods in Archaeology (BAR Publishing, Band 843). Oxford: BAR Publishing. 2000.

[3] There exists a range of projects, which apply virtuality as a means to explore rock art, e.g., 3D-Pitoti project: http://3d-pitoti.eu/index.php/project-details (Last accessed: 23.11.2021). British Museum rock art project: https://africanrockart.britishmuseum.org/vr/ (Last accessed: 23.11.2021) Virtual Museum Canada: https://images danslapierre.mcq.org/en/ (Last accessed: 23.11.2021).

[4] http://www.exrenda.com/dudley/index.htm (Last accessed: 23.11.2021).

[5] E.g.: Ubisoft Discovery Tours, https://www.ubisoft.com/de-de/game/assassins-creed/discovery-tour (Last accessed: 23.11.2021)

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Case studies in this book

1 - The Arara Vermelha Rock Shelter, Roraima, Brazil - Perspectives Concerning Amazonian Sheltered Petroglyphs
2 - Phantoms on granite: Evidence of Iron Age engravings in Western Galicia (NW Iberia)
3 - The prehistoric open-air sanctuary of Penedo do Ferro (Monforte, Portugal)
4 - Neolithic image, symmetry and context: challenges in montane stone from Cumbria, U.K.
5 - New technologies for the survey, documentation and representation of rock art remains
6 - Digital documentation of Ancestral Pueblo and Ute rock art in the Canyons of the Ancients National Monument, Colorado (USA)
7 - Close encounters of the third dimension: recording the three-dimensionality of the "topographic representations" in the prehistoric rock art of Valcamonica and Valtellina (Italy)
8 - New digital insights over the Domus the Janas with paintings: some case studies
9 - More than meets the eye. Structured light and 3D enhancing strategies: the case of the Assa Valley rock art (Vicenza, Italy)
10 - Rock art superimpositions in Cerro de los Indios 1 (Santa Cruz, Argentina). Unravelling the sequence using digital technologies
11 - The site of Nag el-Hamdulab in 360°. An alternative way to experience a story from the past