Research Article

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# Everyone Has to Start Somewhere: Democratisation of Digital Documentation and Visualisation in 3D

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**Abstract:** Digital technologies have become a core component of archaeological and cultural heritage research and "born digital" data sets are now commonplace within the discipline. Yet, despite significant efforts within the digital community, there exists an increasing dichotomy between approaches that make information and data accessible to wide audience and user groups and those that require a significant depth of specialism to access. Broadly speaking, the latter fall into the data analysis and interpretation category, carrying a lag between innovation and wider adoption. Here, we discuss the value of "democratising" these processes. That is to say: how can we open complex digital approaches to as wide a user group as possible? Not in a way that undermines specialisms, but which increases the amount of digital data that can be analysed and interpreted in novel ways. Using the documentation and analysis of carved rock art as a case study, this article aims to stimulate a discussion about the value of democratisation within digital workflows. It defines key terminology and criteria that have an impact on the democratisation process and highlights the importance of self-reflection and "future proofing" in how we publish methods. Ultimately, this article argues that everyone benefits from a broadening approach to digital data capture, analysis, and dissemination and hopes to contribute to the ongoing discussions of "digital affect" and methodological curation within archaeological research.

**Keywords:** democratisation, digital documentation, rock art, visualisation, accessibility

## 1 Introduction

Digital technologies can be identified as a medium for accessibility[1] within history, cultural heritage studies, and archaeology. For the past 20 years, numerous projects have used digital technology to document, analyse, and communicate research outputs and knowledge in innovative and diverse ways. Digital tools are easily used by archaeologists from a range of backgrounds and specialisms to share data and their interpretations and, arguably, considerable attention has been paid to making them accessible and democratic.[2] Here, though,

**1** Here, implying that the technology used and the output from its use are easier to share, recreate, and work with.
**2** Here, implying that the methods are usable by the wider majority, with less restrictions based on location, funding status, or possibility to travel.

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we draw a distinction between passive (content consumption) and active (capture and analysis) engagement with digital technologies. This distinction is important because accessibility in digital technologies is focused on the passive, whereas there are significant advantages to improving access to the active. This is exemplified by projects including Citizan, Micro Pasts, Beacons of the Past, LoCATE, and the New Forest Tree graffiti project which have all demonstrated the benefit of such approaches where democratised elements of data capture and analysis have vastly broadened the potential scope of the projects (Bollwerk, 2015; Burnell & Woodhouse, 2022; Gill, 2019; Shaw, 2023; Smith, 2010, 2014; Smith & Waterton, 2012; Turnbull, 2022; Wintle & Morrison, 2019). More generally, aspects of digital data capture within the heritage sector have become increasingly accessible in areas such as field survey, 3D documentation, geochemistry, and aerial survey, albeit often developed within proprietary tools that are developed with specific project needs in mind. Conversely, analysis and interpretation of these data have become increasingly complex and less democratised, often relying on a detailed knowledge of coding, as well as financial resources to acquire increased computer power and highly specialised software. This is particularly true within the field of 3D documentation of rock art, where structure from motion (SfM)[3] has afforded a surge in digital recording.

This article assesses how developments in digital data processing and analysis can be used to "democratise" the use of digital data, unlocking significantly more potential than the traditional analogue outputs. An additional aim of this article is to stimulate wider discussion on the role democratisation can play in developing digital archaeology. Using the 3D documentation and visualisation of rock art as a case study, this article demonstrates the value of developing the skillset of amateur and professional practitioners who have access to the techniques necessary to capture data, as well as analysing and presenting it. An additional avenue of potential for the democratisation of digital data is its role in the conservation and management of vulnerable heritage assets. While this issue is beyond the scope of this article as its focus is primarily on the digital aspects of 3D documentation and visualisation, it is important to acknowledge and build upon this potential in future discussions. This discussion must also include how public and researcher rights regarding access and documentation of rock art are handled and disseminated.

## 2 What Is Democratisation/Open-Science/Findable, Accessible, Interoperable, and Reusable (FAIR)?

In this article, we see the move towards being a more democratic subject as a process that makes research more accountable, transparent, accessible, and repeatable. This, in turn, allows the adoption and critique of complex processes to be accessible to general professionals and interested amateurs, rather than only to specialists. Building from Huggett (1995), democratisation in archaeology is here defined as the move to make the collection, processing, publication, and dissemination of research and research material available to as wide an audience as possible, both for specialists and non-specialists alike (Huggett, 1995). Democratisation is inextricably linked to open science and the FAIR principles. Open science can be broadly defined as "efforts to make the output of publicly funded research more widely accessible in a digital format to the scientific community, the business sector, or society more generally" (OECD, 2015, p. 9). While there are a number of different outlooks on how open science should be achieved (Fecher & Friesike, 2014), it is primarily intended to improve collaboration through the openness of methods, data, and results (Aspöck, 2019). The FAIR principles primarily refer to data management and are a set of guidelines to ensure that scientific data are FAIR through the sharing of raw data and their associated metadata (FORCE11, 2016; Wilkinson et al., 2016). In the interests of maintaining readability, throughout this article, democratisation will be used as an umbrella

**3** Structure from motion is a photographic documentation technique that involves taking multiple overlapping photographs and using software to calculate a 3D mesh using common points extrapolated from the photographs. The output from this method can be a 3D mesh, a point cloud, a digital elevation model (a 2D black and white image where the grey value represents height), and an orthophotograph (for a more in-depth overview see Green (2018)).

term for democratisation, open science, and the FAIR principles. While none of these principles were specifically created with archaeology in mind, as a scientific subject, albeit one that incorporates aspects of the humanities, they should still be applied to all projects.

# 3 Terminology and Criteria

To place approaches to the study of rock art into a democratic context, it is useful to define some key terms that can be used as criteria for the assessment of digital approaches.

## 3.1 Accessibility

Accessibility is here referred to in the general sense of “making things accessible.” In the digital world, this can relate to the capture of data, as well as its presentation, and the analytical/processing methods used being presented in a meaningful and understandable way, which means that they are possible to use by both specialists and non-specialists. This means a preference for easy-to-use recognisable file formats that are readable in commonly used and easy to learn software (though not at the expense of innovation) (Angás et al., 2013, p. 3; Bozia et al., 2014, p. 427). Cost is a significant factor in how accessible a method is, since methodologies that require powerful computer hardware, expensive equipment, internet connections and other expensive consumables will determine how many researchers have access to them (Angás et al., 2013, p. 3).

## 3.2 Dissemination

Dissemination relates to the distribution of data and publication of materials (Huggett, 1995, p. 23). Open-access publishing refers to an agreement between authors and publishers (usually for a fee) to allow articles to be accessed freely by others. Open-access publishing is seen as a benchmark of open science as it allows for wider distribution of research, rather than it being behind a paywall or limited to research institutions that have an agreement with publishing houses (Aspöck, 2019, p. 540; Huggett, 2015, p. 90). This discussion has received a wider push with the emergence of Plan S in 2018 with which research funders attempt to mandate open-access publishing of scientific results for their grantees (Else, 2021).

In the last decade, dissemination has also seen a step change with regard to non-academic content creation. Web resources and popular publications have allowed non-specialists to engage with and benefit from the results of often publicly funded research or better appreciate their heritage which can otherwise be restricted through gatekeeping (Bonacchi, 2012, 2017). This recent trend is exemplified in Sweden by the description and enumeration of public presentations, site visits, and non-scientific publications in excavation reports (see for example, Kihlstedt et al., 2023).

For the purpose of this article, as well as publication of results, dissemination also covers the need for researchers to release their raw digital data and code, so that both can be reused or validated independently (Aspöck, 2019, p. 540; Marwick, 2017, p. 426; Marwick et al., 2017, p. 9). This will be discussed further below.

## 3.3 Reproducibility

Reproducibility is a consistency measurement in science guaranteeing a quality control of results of scientific projects, data capture techniques, analyses, and results. It means that other researchers should be able to follow any given methodology and be able to achieve the same results with the same data. This is strongly related to dissemination, as it provides the possibility for other researchers to understand the methodology and data that are presented (Marwick, 2017, p. 426), which is essential to reliably reproduce scientific outcomes.

An important aspect of this is open-methods, which is the principle that methodologies should be described and published in such a fashion that they are reusable by the majority of researchers and interested parties (Marwick & Wang, 2022). In addition to reuse and validation, open methods offer the possibility for specialists to re-purpose and develop methodologies in innovative ways (Aspöck, 2019, p. 541; Marwick et al., 2017, p. 10). Where a methodology requires bespoke software, it is advantageous to release the software as a packaged and executable black-box solution[4] because this increases its accessibility to researchers unfamiliar with coding. However, it is also beneficial to release the software script simultaneously so that it can be developed further by others (Marwick, 2017, p. 434).

### 3.4 Authenticity

Authenticity is an additional factor when considering 3D model representation (Cardozo & Papadopoulos, 2021; Eve, 2018; Jeffrey, 2015). While usually applied to objects that are documented for display, rather than for scientific analysis – it is typically defined as the qualities of the object that make it feel like a real object from the past (van Gerven et al., 2018) – the concept of authenticity is also relevant to the documentation of rock art (Gustafsson & Karlsson, 2008).

Here, authenticity is adapted to issues of using data that has been created by “digital surrogates”[5] and how certain one can be that the model is accurate and an authentic representation of the original (Amico et al., 2018; Mudge et al., 2007, p. 1; 2008, p. 3).

## 4 How Is Rock Art Documented and Visualised?

For this article, we focus on rock engravings in Scandinavia, specifically those located within the Bohuslän region. The discussion below, however, aims to be site agnostic and can be applied to any similar type of site regardless of location.

Mainly created during the Nordic Bronze Age (1700–500 BCE), the rock engravings were produced through percussive pecking of bedrock panels using a variety of tools creating a shallow negative relief in the surface. The panels feature a variety of motifs ranging from animals to boats, to anthropomorphs, to cup marks (Figure 1). The bedrock upon which the rock engravings were usually smoothed through the movement of ice masses during the Ice Ages giving the panels a very fine polish (Horn et al., 2022b).

The engravings have historically been documented using traditional methods including frottage and tracings but are increasingly recorded using digital methods like photogrammetry and laser scanning. Once the panels have been documented, they are typically processed further to make it easier to see, present, and publish the engravings on the surfaces (Figure 2): there are a number of techniques commonly used for this (Bertilsson, 2017; Carrero-Pazos et al., 2018; Díaz-Guardamino et al., 2015; Horn et al., 2018, 2019, 2023; Pires et al., 2014; Vergne et al., 2010). A comprehensive overview of the rock art can be found in, for example, Bertilsson (2017), Bradley (2006), Chacon et al. (2020), Goldhahn and Ling (2013), Horn et al. (2022b), Milstreu (2017), and Sognnes (2011).

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**4** Black-boxes here refer to software where the user inputs data and obtains an output without understanding how the software processes the input data. For a full definition and overview of black and glass boxes, see Huggett (2021).

**5** Digital surrogates are defined as digital representations of a real-world object that have been created by someone other than the researcher working with them (Mudge et al., 2007).

**Figure 1:** An example of a rock art from a site at Aspeberget in Bohuslän, Sweden.

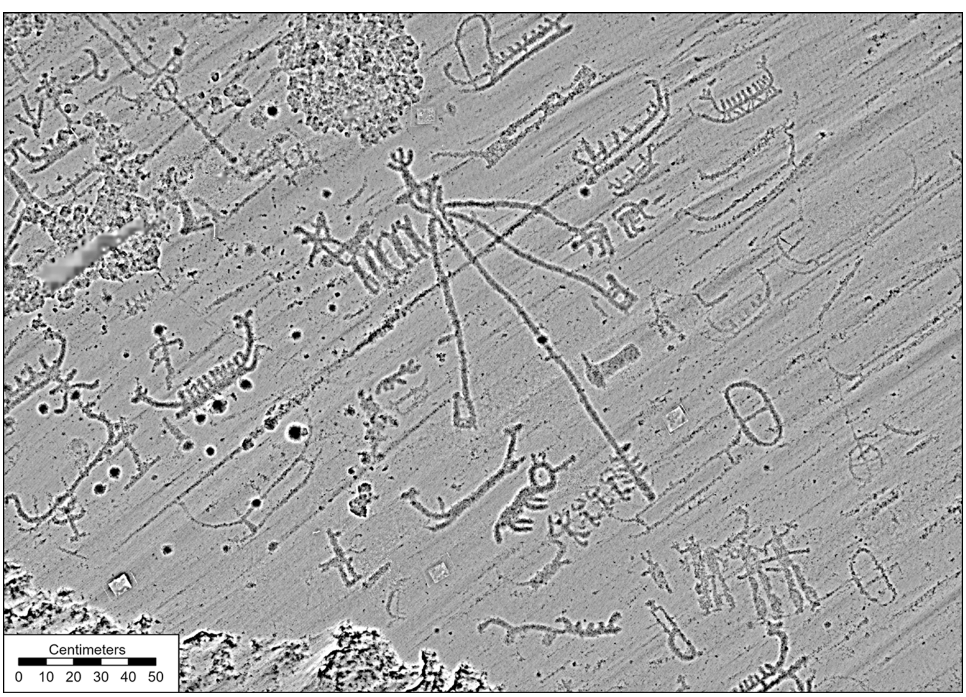


**Figure 2:** A rock art panel in Bohuslän (Tanum 311:1) with rock art highlighted using local relief modelling (Horn et al., 2019).

There are three digital documentation methods commonly used for recording of rock art panels: reflectance transformation imaging (RTI) (Mudge et al., 2006), SfM (Green, 2018), and laser scanning (Trinks et al., 2005). RTI produces 2.5D .ptm files[6] which can be viewed in a free open-source software called RTI Viewer; the raw data are

6 2D representations that appear to have characteristics of the 3D data that they represent. PTM = polynomial texture map.

photographs. SfM produces 3D models, point clouds, orthographic photomosaics, and digital elevation models (DEMs)[7] from photographs taken on site. Laser scanning produces point clouds and meshes (some of which can be textured depending on the equipment used). While RTI and SfM use equipment that most researchers and interested amateurs will have access to, i.e. cameras and tripods, laser scanning requires a significant initial investment. It is not feasible to use affordable laser scanners or phone-based LiDAR scanners for rock art research as the resultant mesh is too low resolution for scientific purposes (Horn et al., 2018), and while high-powered laser scanners are considered useful, they are beyond the budget of most documenters. Conversely, RTI was specifically designed to be an open, accessible, affordable, and democratic method. While it is still maintained by cultural heritage imaging (CHI), it has not been updated since 2012, and the ptm fitter[8] it requires is no longer officially hosted by Hewlett–Packard: both factors severely impede its future sustainability and ease of access as they can require extra effort to work around. Should the ptm fitter disappear, this means that RTI builder will no longer be usable. Recently, however, an open-source software[9] created by the Visual Computing Lab[10] has been released, which can be seen as a natural successor to CHI's RTI builder/viewer (especially as it is being created in collaboration with CHI). While this software offers many advantages to CHI software, including the possibility to view ptms directly on the web and a much more refined and intuitive creation process, the viewer does not offer as many options as CHI's RTI viewer. It is, however, still possible to use the RTI viewer to view the output from Relight. The RTI method has also become significantly more accessible with the development of wireless flashes and the ability to release the camera shutter with mobile devices, rather than requiring physical camera triggers. However, of all the methods described, SfM produces the most versatile and adaptable set of outputs from an analytical perspective – including the possibility to create virtual RTIs from meshes, and for this reason, the previous two methods will not be included in the following except as discussion points.

There are several SfM workflows that are suitable for rock art panels and other 3D surfaces, but all share the same basic approach to recording. As this has been explained in several places in a way that is both accessible and easy to understand (Agisoft, 2023; Green, 2018; Meijer, 2015), it will not be covered in detail below.

The outputs created when recording rock art with SfM (usually the 3D mesh and the DEM) often require processing in secondary software packages to produce visualisations that bring out more details in the surface of the rock. The purpose is to empower visual identification, improve publication opportunities, and enable further analysis (see below). Such visualisation methods either use the mesh itself or compare a high-resolution version to a smoothed lower-resolution version of the same mesh (for a full overview, see Potter et al., 2023). The results are usually then reduced from 3D to a 2D format ready for analysis and publication (Nobles & Roosevelt, 2021, p. 591). These can be simply uninterpreted visualisations of whatever was recorded, but more often they convey the author's interpretation via the angle at which the images are rendered and how they are lit (Valdez-Tullett & Figueiredo Persson, 2023, pp. 15–16). This inherently introduces bias, as the author is presenting the reader with their interpretation of the material, rather than a complete view of the material. It is possible for the author to manipulate the lighting or viewing angle to present images that suit their interpretation. This often also removes the complete context of what is being presented.

Visualisation techniques are necessary, in part due to the difficulty of presenting 3D surfaces in 2D formats, i.e. images in a journal (Horn et al., 2019; Nobles & Roosevelt, 2021, p. 591; Valdez-Tullett & Figueiredo Persson, 2023, pp. 15–16), because they obscure as much as they reveal depending of the light direction and reflection. Additionally, they help to enhance the carved detail that is not necessarily visible to the naked eye. As has been previously demonstrated, visualising rock art also helps to discover currently unknown details about the rock art, as well as completely new motifs (Horn & Potter, 2019; Potter et al., 2022). These visualisations are also useful in reducing the computing power required for the development of a semi-automated

7 A 2D representation of a topography that holds black and values for the lowest and highest points, with different shades of grey representing the height values in between.

8 An integral part of the software which was originally developed by Tom Malzebender at HP studios and is responsible for "stitching" the photos together.

9 https://vcg.isti.cnr.it/vcgtools/relight.

10 https://vcg.isti.cnr.it.

system of rock art identification and classification (Horn et al., 2022a; Jalandoni & Shuker, 2021; Melnik et al., 2022; Seidl, 2016).

# 5 Democratisation in Rock Art Studies

In the following, the terminology outlined above will be applied to examples of current practices, with suggestions of how we can add accessibility, authenticity, dissemination, and reproducibility to the existing workflow.

## 5.1 Accessibility in Rock Art

A benefit of creating digital data is that it can be shared much more easily (Scopigno et al., 2017, p. 8). Large datasets, i.e. full rock art panels and extended areas around the panels, can often be assessed relatively quickly by moving a 3D model. While limiting factors including computing power and internet speed must be considered here, it is usually quicker and cheaper than planning a trip to the site, or simply not being able to visit at all (Huggett, 1995, p. 23). One of the largest 3D model sharing platforms is Sketchfab (as will be discussed below), but this platform limits the size of models that can be uploaded. The Swedish rock art research archive (SHFA)[11] has recently released an updated platform for their database which makes use of 3DHop (Figure 3) and allows users to interactively view, rotate, zoom in on, and relight, high-resolution versions of their 3D data, without the need for large downloads (Bridge et al., 2024; Green & Horn, 2025). As well as Swedish rock art sites, this platform also includes rock art sites from Norway, Denmark, and Italy, which allows users to skip quickly between datasets in entirely different geographical areas, while traversing between the macro to micro level of detail.

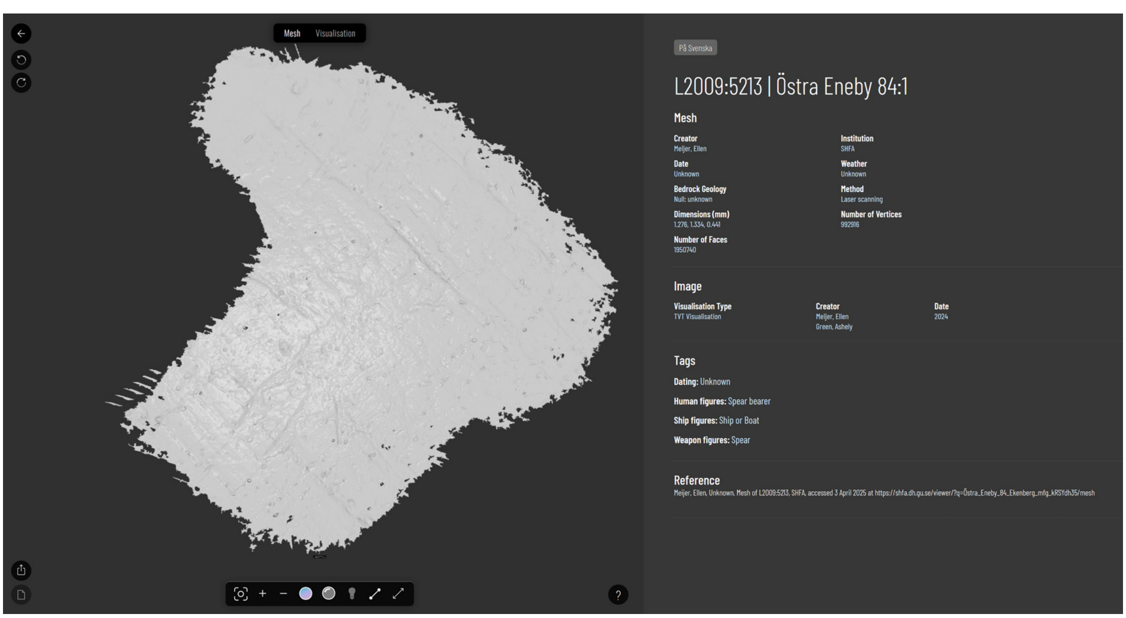


**Figure 3:** The SHFA platform showing the 3D mesh tools (https://shfa.dh.gu.se/viewer/?q=%C3%96stra_Eneby_84_Ekenberg_mfg_kRSYdh35/mesh).

11 https://shfa.dh.gu.se/.

The raw data and outputs should be made available in accessible formats, e.g. obj, stl, jpg, tif (Angás et al., 2013, p. 3; Bozia et al., 2014, p. 427), which can be created, opened, and edited in open source or free software including MeshLab, Blender, and GIMP. Using similar formats will also help to normalise data, increasing its interoperability. Data should also feature appropriate metadata (i.e. confidence maps, processing reports from SfM software) that can be used and understood by the majority of people (Angás et al., 2013, p. 3), or even disseminated in print form (e.g. the extensive 2D documentations of engravings published by Stiftelsen för dokumentation av Bohusläns hällristningar, a large number of which have also been made available online).[12] Whatever the method of access provided by researches, it is undeniable that advancements in technologies have meant that the results of rock art can be made more accessible than ever before.

## 5.2 Dissemination and Reproducibility in Rock Art

The internet has made the sharing of data significantly easier (Scopigno et al., 2017, p. 8), but there is still significant shortfall in the possibility of hosting large amounts of raw data with publications, and there are easily observable issues with projects running out of funding and their online presence subsequently disappearing: an issue which has long been considered (Koller et al., 2009). It should also be remembered that not everyone has equal access to the internet (Griebel et al., 2016, p. 295). While a file might be considered small to one group, it might take several hours to access in another region. At present, the internet is still often the best option for dissemination, but where it is not a possibility, either due to slow internet or large datasets, dissemination should be made available by means of portable storage medium (i.e. USB stick, DVD, portable hard drive) upon request (Trinks et al., 2005, p. 132). Sharing data, while also allowing researchers to recreate models and perform their own analysis and quality control, encourages the original researchers to take greater consideration of how their data are collected, as their results will be visible to others (Kansa & Kansa, 2014, p. 225). In turn, this also enables a better understanding of what works, and what does not, for non-specialists (ibid).

As opposed to the more traditional analogue methods of recording rock art sites, the SfM methodology makes it possible to share raw data files (i.e. photographs) so that other researchers can go through the processing stages and recreate and validate the results independently (Angás et al., 2013, p. 1). This not only removes the potential bias from the original researchers (which is already reduced through the use of digital techniques) but also makes it possible to oversee the quality of the raw data. While traditional methods remain a valuable asset, especially for validating 3D results (Potter et al., 2022), they frequently suffer from creator bias both in terms of the rubbings being more detailed where the creator was expecting engravings and also suffer from issues with dimensions due to rock surfaces not being flat which can lead to skewing. 3D documentation, while not entirely unproblematic, removes creator bias as the raw data can be disseminated and validated, meaning that other researchers can be confident reusing it. An additional benefit of this is that sites can be reinterpreted using completely different and potentially new methods from the published raw data, rather than only having access to one static output (Huggett, 1995, p. 23). This also opens up the possibility to use the raw data for entirely other processes than initially intended, for example, creating a vRTI from SfM material (Bryan, 2009, p. 8; Trinks et al., 2005, p. 132). Sharing datasets also reduces the risk of potential loss of data when projects end or run out of funding (Kansa & Kansa, 2014, p. 225).

An unfortunate reality is that when project funding disappears, this also tends to mean that the data archive that they have created disappear with it (Huggett, 1995, p. 24). A number of archives are already attempting to remedy this problem with long-term funding, e.g. ARIADNEplus and SHFA, but the question still remains as to what will happen to them should that funding run out. A commonly used tool for the display of rock art panels and cultural heritage objects is Sketchfab, which currently serves as an archive tool of sorts, even catering specifically for museum and cultural heritage institutes (García & Aláez, 2021, p. 85; Scopigno

**12** https://hallristning.se/, https://shfa.dh.gu.se/.

et al., 2017, p. 4). However, websites like this cannot be considered a permanent resource as they are owned by a commercial company. This has recently been demonstrated by Epic's[13] decision to change its website model and move assets to FAB, its new commercial store.[14] It is not clear what the long-term implications for Sketchfab are.

### 5.3 Authenticity in Rock Art

While it is useful to be able to disseminate the information following a site recording, the work on site must not be forgotten or undervalued (Meijer & Dodd, 2018, p. 294; Valdez-Tullett & Figueiredo Persson, 2023, p. 24), particularly the non-digital recording methods and physically experiencing the site for oneself (Meijer & Dodd, 2018, pp. 290–291; Potter et al., 2022). There are several ways in which the authenticity of the panels (as defined above) can be improved. Although for scientific analysis, the researcher's impression of the panel is not strictly necessary, it does help to have some sense of how the panel is placed within a wider context, particularly in relation to the landscape. We here suggest that to give the engravings context, efforts should be made to record the entire panels in one large model to see how the motifs are placed, both in terms of their proximity to other motifs, as well as their placement within the topography of the rock panel. Where two panels are joined together, i.e. two differently named sets of engravings on the same surface which are considered to be from different panels, the entire surface should likewise be recorded including the empty space between. In addition, contextual photographs that should be taken, which show the panel as a part of the wider landscape, either with a drone or terrestrially. Gaussian splatting and NeRF are also emerging technologies that offer the possibility of realising large areas quickly (Kerbl et al., 2023; Mildenhall et al., 2020). Where possible, high-resolution textures should be included with 3D models, so that details of the surface can be seen clearly and used in analysis. As with all raw data, metadata should be supplied for these contextual additions.

## 6 Moving Forward to Democratise 3D Data Capture and Analysis

### 6.1 Documentation and Visualisation of Rock Art

Documentation methods can be made inaccessible through high startup prices or running costs. Examples of this in the rock art domain are laser scanning, which gives highly accurate results but has a very high startup cost due to the necessary purchase of the scanner, laptop, batteries, and target points, which can easily amount to over 50,000 €. In comparison, other methods like SfM only require a camera and software. While SfM results depend on the quality of the photographs, and good dSLR cameras can incur considerable costs, it has been demonstrated that scientifically useful results can be obtained using cheaper equipment (Espinosa et al., 2021, p. 168; García & Aláez, 2021, p. 89). Continuously falling costs of the equipment required for these processes make it possible for smaller-scale, lower-budget projects and community groups to make use of these digital methods (Beale & Smith, 2018, p. 175). While the price of professional software for SfM can be quite expensive, especially for non-educational institutions, there are open-source alternatives available, like VisualSfM[15] or Meshroom[16] (Green et al., 2014, p. 173). However, these often require additional processing steps and may have less comprehensive instructions and support.

**13** Epic games is a large gaming company which created Unreal Engine and have recently purchased several 3D asset-based websites including Sketchfab.

**14** https://support.fab.com/s/article/Sketchfab-Fab-FAQ.

**15** https://gist.github.com/patriciogonzalezvivo/0cc2d0fb6e9af9040eff.

**16** https://alicevision.org/.

Results from laser scanners can be reproduced by using the same equipment, similar conditions, and the skillset of the documenter. The same can be said for SfM, which will reliably reproduce previous documentation results with the use of the same camera type, the same conditions, and a similarly skilled photographer. Laser scanners may be somewhat more forgiving in that recording is direct and offers immediate feedback, whereas photographs for SfM can easily be accidentally blurry, which, given the volume of photographs taken in a session, can potentially only be noticed when the model is being processed. However, in addition to affordability, SfM models are based on easily shareable raw data, i.e. photographs, which aids openness. Therefore, surfaces documented with laser scanners should additionally be documented using SfM since this makes independent reproduction more open. This requires visualisation methods to be democratised in the sense that they need to be interoperable using data from laser scanners and SfM meshes. It is typically also possible to record larger areas using SfM than laser scanners due to time constraints and file sizes (see Section 5.3).

Democratising the documentation of rock art makes it possible for community groups to participate in the documentation and visualisation of rock art. Opening up to working with communities of non-professional archaeologists can lead to an increased amount of data, as well as innovations and developments within existing methods that can be of benefit to both amateurs and professionals alike (Beale & Smith, 2018; Gabriel & Jensen, 2018; Harkema & Salt, 2018, p. 188; Opgenhaffen et al., 2018, p. 77; Politopoulos et al., 2019, p. 173). The potential for extra data collection in a shorter time period is not only because there are additional helpers but also because the majority of digital documentation skills can be taught quickly and subsequently passed on to others, as demonstrated by the "Re-reading the British Memorial project" (Beale & Smith, 2018). Another example is through the Scotland's Rock Art Project, whose openness with methodologies (Scotlands Rock Art Project [ScRAP], 2018a, b) and encouragement towards non-specialists to record and report rock art has led to the important discovery of a new sites (Barnett et al., 2021; Valdez-Tullett & Barnett, 2021; Valdez-Tullett et al., 2023). An additional benefit is that the inclusion of community groups in projects can help add to the authenticity of the recordings (Jeffrey, 2015).

## 6.2 Method Development, Coding, and the Problem with Current Practices

While methods of collecting data are well documented, especially in the field of rock art (Meijer, 2015; ScRAP, 2018a, b), quite often the descriptions of how post-processing methods are actually achieved fall short or use software and terminology that is not possible to understand as a non-programmer or IT professional. There has been a general trend amongst open science articles to suggest R as a good tool for the presentation and dissemination of methods (Marwick, 2017; Marwick & Wang, 2022). R is a programming language with a strong open-source environment frequently used for statistical and graphics computing that has also become popular in the humanities. However, the authors rarely take into account that not everyone is familiar with R or is able[17] to learn code (Stienen-Durand & George, 2014). Marwick states that it took him 3 years to become a confident R coder and suggests that R should be taught during the undertaking of an archaeology degree (Marwick, 2017, p. 441; Marwick & Wang, 2022, p. 212). While it is generally a good idea to offer archaeology and other students of cultural heritage-related fields the opportunity to learn transferable skills, the proposal fails to consider that many students opted to take archaeology as a degree, not computer science, and are therefore not necessarily interested in learning to code. In addition, there are many other transferable skills students may wish to learn, and the variety makes it impossible for everyone to learn everything to a high level. Furthermore, professionals, researchers, and interested amateurs rarely have adequate time allocations required to learn the coding associated with these methods. Since R is an interpretive language, it is difficult

**17** For example, those with dyslexia – of which a significant amount of working archaeologists in the United Kingdom – have (https://www.archaeologists.net/practices/equality/resources/disability/neurodiversity) struggle with learning coding (Stienen-Durand and George, 2014).

to compile in a way that would be possible for someone with no experience in coding to use, especially when dependencies[18] are required. While this is certainly streamlined in R-Studio,[19] it is by no means intuitive for those unfamiliar with it. There is of course potential for successful visualisation techniques using R, as demonstrated by Rolland et al. in their ambient occlusion article (Rolland et al., 2021), but these projects require some prior experience of R to get them to work which means that a very large portion of the public, researchers or otherwise, will be excluded from its use. It is also a concern that libraries can be removed from CRAN (the main pathway for installing dependencies through R-Studio), meaning that they essentially disappear for those not skilled in R, reducing the longevity and sustainability of methods developed in R and solely published in raw code.

Some visualisation techniques are made accessible by using software that is already common to archaeologists, such as GIS applications,[20] reducing the learning curve (Horn et al., 2019). Others make use of free or open source software like MeshLab or xShade with, in part, sustained development histories and a reasonable documentation (Carrero-Pazos et al., 2018; Cignoni et al., 2008; Pires et al., 2014). A third group uses code to produce their own open-source software and compiles it into standalone programs (Dubinsky et al., 2023; Horn et al., 2022a). By developing tools in software that the majority have or can gain access to, they become more accessible to a wider audience. The raw code or scripts should be stored in open-source repositories allowing those interested to engage with it, while others can simply use the applications and benefit from an intuitive GUI, thereby offering several layers of functionality to different levels of users. This enables the creative use of the software for the potential inclusion of new data, for example, the new cuneiform script found on the burial stones of a 3D model of the megalithic tomb in Züschen, Germany (Hansen et al., 2021). Releasing the script enables further method development, and while there is no question that this is beneficial, it is problematic to suggest that only releasing the script is the best way forward. Even the inclusion of considerable annotations and comments in the script will be impenetrable to some and will exclude researchers from reusing the method.

## 6.3 Benefits of the Black-Box

Black-box solutions are frequently held in contempt as they are perceived as taking away a fundamental understanding of how a process works (Huggett, 2021, pp. 425–426; Marwick, 2017, p. 434). However, we argue that this position contributes to digital gatekeeping, as the majority of those who will use it will not want or be able to develop the methods, nor will they have the desire to follow every step of the process due to a variety of constraints such as time, skill, and knowledge gaps.

A good example of a black-box can be found in the RTI builder/viewer. RTI was developed as a democratic and accessible software from the outset (Mudge et al., 2008, p. 5; Mudge et al., 2010, p. 113) and was developed as a black-box software. The user only needs to understand the principles of use and be able to validate the quality of the inputs and outputs. They do not need to understand the processes that created the outputs (Huggett, 2021, p. 425). To facilitate its use, RTI builder and viewer were published free of charge and open-source, and access has been maintained.[21] CHI also developed detailed instructions for the creation, processing, and evaluation of RTI documentation (Cultural Heritage Imaging, 2011, 2013a, b). In addition, for those

**18** External libraries of code that are required to make the main code run.

**19** https://posit.co/download/rstudio-desktop/.

**20** While we acknowledge that GIS programs are generally not the most user-friendly or intuitive software, which still have a learning curve, this is significantly less so than learning to code from scratch. GIS software is well documented with in-depth manuals, traceable error codes, free tutorials, and large online user bases and support desks. It is also possible to create and distribute toolboxes for users so that they can run processes without having to understand the finer details of the processes or remember the names of various tools.

**21** A philosophy which has been continued with the release of Relight.

interested, it is possible to delve into the algorithms through their detailed publications. This allows for several levels of access to different types of users, rather than limiting options for specialists and non-specialists alike.

It is simply neither important nor realistic that the user understands every single black-box process, but it is highly important that the user understands the inputs and outputs of the process (Huggett, 2021, pp. 424–426). Expecting every person engaged in research to understand the code of every software or the mathematics behind every algorithm they use is unrealistic. The majority of archaeological methodology is something that is learnt from the ground up by practice, and it is the same for digital methodologies. It is therefore the responsibility of those who develop the black-box software to offer detailed and ground-level instructions on what the expected input and outputs should be and why.

## 6.4 Conclusion: Democratisation Through Teaching

For the field of rock art studies, nearly all documentation and post-processing methods can easily be taught openly and accessibly through the medium of simple instruction texts or video tutorials that can be presented online (Scherjon et al., 2019). We have experienced this in our own teaching at the University of Gothenburg with large groups of students with no experience being able to quickly create their own 3D models. Online lectures, workshops, and videos proved extremely effective in helping the students to gain knowledge of SfM, post-processing visualisation, and analysis of the outputs.

There are obvious perceived downsides to democratisation of methodologies, in that non-specialists are likely to make mistakes when collecting data and do not have the experience to acquire data as well as those who have worked with the procedures for a long time (Dell'Unto & Landeschi, 2022, p. 16). However, there are ways in which this issue can be mitigated, primarily through the sharing of data and reprocessing of raw data. Specifically for SfM, there are several tools, for example, point confidence in Agisoft Metashape,[22] which gives a colour scale demonstrating how accurate the data is, which can be used to assess how well the data were collected. It is also usually clear how well the data were collected based on the quality of the mesh and textures/orthophotos, as well as by checking the initial photographs. A lingering issue, however, is that there is no possibility of controlling exactly how the data were collected, especially if metadata[23] is not available (Huggett, 1995, p. 24). While it is clear that those considering themselves to be experts probably have more expertise than non-specialists, it is more productive that specialists teach non-specialists how to collect and process data correctly, rather than preventing them from starting at all (Gabriel & Jensen, 2018).

### 6.4.1 Everyone Has to Start Somewhere

Developing and teaching the use of black-box tools means a greater number of engaged users and an increased amount of comparative data for projects. Being open with material and methodologies allows beginners to understand how they can improve their own data creation, and black-boxes give access without the necessity to understand the coding behind them. Simultaneously releasing code also empowers those that want to learn and develop methods to understand the principles of the tool. This widens the user base by including both groups and reducing reluctance to engage with digital methods perhaps perceived as being too complicated. This is not to suggest that we should "dumb down" our methods or processes to the lowest possible level, but that we should make them as open and accessible to as many as possible. It is not just the practitioners who are enriched by specialists sharing their skills, but the discipline as a whole.

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**22** A software used to process SfM datasets. https://www.agisoft.com/.

**23** Information that describes the data, for example, lens type, focal length, and ISO, for a photograph.

## Abbreviations

CHI cultural heritage imaging
DEM digital elevation model
FAIR findable, accessible, interoperable, and reusable
PTM polynomial texture map
RTI reflectance transformation imaging
SfM structure from motion
SHFA Svenskt Hällristnings Forsknings Arkiv (Swedish Rock Art Archives)

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