

How 3D models (photogrammetry) of rock art can improve recording veracity: a case study from Kakadu National Park, Australia

Abstract

Creating an inventory of a rock art site in the field can be time-consuming and expensive, but Structure-from-Motion (SfM) photogrammetry has the potential to alleviate these issues. Using SfM, rock art sites can be recorded rapidly, with a 3D model created to allow a digital inventory to be compiled. However, the veracity of a digital inventory can be questioned. At the Blue Paintings site in Kakadu National Park, Australia, we tested two field inventories against a digitally-derived inventory and ground-truthed the results. The results demonstrated that the digitally-derived inventory was slightly less comprehensive than the field recordings, but only unidentified lines and blotches were lacking; this would not adversely influence interpretation. Furthermore, the field inventories conducted by different people also had variations, demonstrating that whether the inventory is done on a 3D model or in the field, an inventory is still a human interpretation.

Keywords

Rock art, photogrammetry, Structure-from-Motion, Kakadu, 3D, Dstretch

Introduction

Creating a detailed rock art inventory at individual sites opens up an array of research opportunities and has the potential to assist with the ongoing management of important places in the landscape. Indeed, an inventory is one of the key methods used to understand the archaeological context of rock art. Inventories of figures in rock art sites provide the data for analyses that can answer an array of archaeological questions about rock art. This includes intrasite studies of rock art change over time (e.g. Gunn et al. 2017), landscape analyses pinpointing distribution and shifts in style across large areas (e.g. Armstrong et al. 2018; Travers and Ross 2016), rock art as evidence of inter-regional interaction (e.g. Brady 2008), and more.

The conventional method used to create a rock art inventory is a detailed recording of the site while in the field. This has usually involved each identified figure being individually numbered and ‘catalogued’, with details such as colour/s, description, interpretation (where possible), and general condition recorded, plus photography with and without a scale. This information is either written into a field notebook or directly entered into a program on a handheld device before being transferred into a spreadsheet for analysis. The process can take hours or weeks depending on the size of the site. Australia is estimated to have over 100,000 art sites, and Kakadu National Park (KNP) alone is estimated to have over 15,000 (May and Taçon 2014:3235). Obtaining the necessary resources to accomplish detailed site recording using conventional methods, in terms of time, money, and trained archaeologists, is unfeasible. In this paper, we present the results of a trial whereby 3D computer models were used to create a quick, but detailed, inventory for a site.

Digital inventories can be expedited by the use of Structure-from-Motion (SfM) photogrammetry and there are numerous examples of the use of such data capture in rock art research (e.g. Burton et al. 2017; Fritz et al. 2016; Jalandoni and Kottermair 2018; Jalandoni and Taçon 2018; Wang et al. 2019). SfM photogrammetry has brought about a 3D modelling revolution in rock art (Jalandoni 2019; Willis et al. 2016). The method is cost-effective, fast, and can be performed by non-specialists (Jalandoni et al. 2018; Micheletti et al. 2015). Jalandoni et al. (2018) have demonstrated that SfM 3D models, even those created using

consumer-grade cameras, can be used successfully for tracing and measuring rock art motifs. The purpose of this paper is to explore whether 3D models of an entire site are accurate enough to perform detailed recordings and replace field-based recordings.

An experiment was designed to compare the process, benefits, and results of detailed recordings conducted in the field with those derived from a SfM 3D model. Specifically, we questioned whether detailed recordings from SfM 3D models resulted in more, less, or the same number of motifs able to be identified in the field. If detailed recordings can be undertaken reliably using a SfM 3D model, there is great potential for the reduction of project costs. An important aspect of this experiment was to demonstrate whether archaeologists with no experience with SfM 3D modelling can collect the necessary raw data and compile a rock art inventory from a 3D model. A discussion of what can be done to improve data collection in the field by integrating SfM 3D modelling with conventional field recording is also included.

Study Area

The site selected for this study is known as ‘Blue Paintings’ and is located in Kakadu National Park, Northern Territory, Australia (Figure 1). This and the surrounding area are the subject of an ongoing research programme entitled ‘Pathways: people, landscape and rock art’; a collaboration with Senior Traditional Owner Jeffrey Lee and Parks Australia (e.g. see May et al. 2020). The Blue Paintings site is located on the western side of a major outlier known as Nawulandja. Nawulandja is a sloped sandstone plateau near the Anbangbang Billabong – a major source of food and freshwater in the area. On the ‘Blue Paintings’ side of Nawulandja there are a series of creeks that connect clan groups across the region and are important camping places for people seeking to capitalise on local resources (e.g. Chaloupka 1982:27).

[FIGURE ONE HERE]

The Blue Paintings site itself is a low rock shelter measuring 6.85 m long and 2.6 m high. While it is not our intention in this paper to examine the cultural significance of the site or the history of research previously undertaken, it is important to note that Blue Paintings is a well-known rock shelter and was at one stage open to tourists visiting Kakadu National Park (see Chaloupka 1982, 1993; Edwards 1979; Haskovec and Sullivan 1986; Taçon 1989; Welch 2015).

Methods

Photogrammetry developed around 1860 (Guery et al. 2018). It has been used to document rock art since at least the 1970s (Clouten 1974; Dann and Jones 1984; Rivett 1983). Sabry et al. (2004), Chandler et al. (2007), and Chandler and Fryer (2005) demonstrated early on that digital photogrammetry and stereopaired low-cost cameras are capable of accurately recording rock art sites in Australia. Structure-from-Motion (SfM) photogrammetry is becoming mainstream for rock art recording (e.g. Alexander et al. 2015; Berquist et al. 2018; Bryan and Chandler 2008; Guedes et al. 2019; Jalandoni 2019; Lerma et al. 2010; Willis et al. 2016). Recently in the Wellington Range, Northern Territory, Australia, SfM models of rock art produced from low-cost cameras were shown to be visually and metrically accurate for rock art research (Jalandoni et al. 2018).

As mentioned earlier, the research reported in this paper was undertaken in collaboration with Senior Traditional Owner Jeffrey Lee and other rangers in Kakadu National Park. We were also able to visit the Blue Paintings site with elder Josie Maralngurra and Christine Nabobbob

to record oral history (May et al. 2019, 2020). For this study, three researchers with comparable experience and acumen in rock art recording collected four inventories of the rock art at the Blue Paintings site using different data capture methods. All three researchers had previously collaborated on fieldwork and continue to collaborate as part of the *Pathways: people, place and rock art* project. The methods used to conduct detailed recording practised by these three researchers are similar, since the researchers developed these methods together. To maintain an objective stance, we did not designate any of the four measurement methods as the benchmark for accuracy. Rather our overall aim was to compare different inventories created by three experienced rock art researchers - two created in the field (Datasets A and B), one created using a SfM 3D model (Dataset C), and one created after the completion of the SfM 3D model inventory to ground-truth the results of Dataset C (Dataset D).

We were not able to standardise all the parameters of the experiment because the recordings were done by different researchers. One way to normalise the results would have been to have the same person who made the inventory in the field (Dataset A) also make the inventory from the 3D model (Dataset C). We decided against this, however, because we were concerned this may cause a biased result. If the field-based inventory were conducted before the SfM 3D model inventory, we would not be able to tell if the researcher was really seeing the rock art or remembering it from the field exercise; this would create the possibility of correlated datasets. However, we did have the same person who recorded the inventory from the SfM 3D model (Dataset C) return to the site to create a ground-truthing inventory (Dataset D).

Results

Dataset A: field recording

Field recording consisted of first spending time becoming familiar with the site and the rock art. The art panels were sketched and each identified motif was numbered. Generally, motifs that touch each other, and deemed to be part of the same scene, were recorded as one motif. The site was recorded from left to right across the shelter, with each motif described individually. Descriptions included colour, interpretation, superimposition and any key or unusual features. The information was entered into a Samsung tablet via the Fulcrum program and then automatically transferred to a dedicated data management system. Each motif was then photographed with and without a scale. No measurements were taken. While measurements used to be part of the field detailed recording protocol, this task was left to be done using the 3D model. This process is usually conducted in teams of three to four people. In the case of recording Blue Paintings, the team comprised four people.

Dataset B: field recording

A second detailed recording was taken from a PhD thesis (Marshall, under review). The methodology followed the same process as that used by the aforementioned Dataset A team, however, information relating to conservation issues was also recorded. In this case, motifs were numbered within scenes as individual motifs, rather than grouping them together.

Dataset C: 3D modelling

Before the third researcher could create an inventory from the digital model, the raw data for a SfM 3D model were collected in the field. The data collection for SfM photogrammetry was conducted by two PhD students who were adept at photography but had little or no experience with any sort of photogrammetry. The students were given a few verbal instructions. They produced disparate datasets: one contained 42 photographic images and the other had 22 images. A Canon 6D camera with a 35 mm lens mounted on a tripod was used for all

photography following the procedures detailed in Jalandoni et al. (2018). The camera settings were fixed at F/22 and ISO100 with variable shutter speed.

The SfM 3D models were created using Agisoft Metashape v.1.5.1. Both students' datasets produced adequate models. However, a superior, additional model was created using all 64 JPEG images generated by the student recordings – i.e. a combination of both datasets. The quality of the combined model was determined to be superior by comparing all three models visually, paying special attention to the alignment of images, number of holes, and overall resolution. Decorrelation stretch (Dstretch) was applied using DStretch software with the preset colourspace CRG3, LRD, RGB0, and YRD to create four versions of the SfM 3D model (Figure 2). DStretch is a common tool used by rock art researchers for enhancing images of painted rock art. Usually it is applied to single images, but in this study we applied it to the whole model as discussed in Jalandoni (2019). The CRG3, LRD, RGB0, and YRD versions were loaded into Cloud Compare v.2.10.1 to facilitate switching between models when different colours needed enhancing.

[FIGURE 2 HERE]

The SfM 3D model inventory was compiled over two sessions. The first session was for the recorder to become acquainted with a 3D model, to identify the rock art motifs, and generate descriptions. One of the authors (SM) was instructed not to look at the detailed field recording notes to prevent an unfair advantage for her generation of detailed recording from a 3D model. A 5-minute tutorial was given on navigating the 3D models and toggling between versions because she had no previous experience working with 3D models. The other author (AJ) recorded her notes by labelling the motif numbers on a printed out 2D copy of the 3D model, filling out an excel spreadsheet on a separate computer, and time-keeping.

The second session was for measuring the motifs from a 3D model. Every motif was measured in the manner the researcher would have used in the field. A rectangle was drawn over the motif to include every aspect of the art image, then the edges of the rectangle were measured to provide minimum vertical (X) and horizontal (Y) measurements.

Dataset D: ground truthing

After the inventory of motifs had been compiled using the SfM model, the site was revisited by the authors to verify the results. Dataset D is a compilation of the motifs identified by the author (SM) in the field.

Discussion

Time

As illustrated in Table 1, recording Dataset A took 165 minutes based on first and last photograph times and deducting any break time determined by a long gap between images. No specific time measurements were taken. There were four people on the team for a total time of 660 person minutes. Each of the four team members was engaged in the recording process. It should be noted that this time calculation does not include the time initially taken to become familiar with the site and the rock art. There are no time data available for Dataset B.

Dataset C, the recording from a SfM 3D model, took a total of 33 minutes in the field based on first and last photograph times for the purpose of collecting the raw data for the SfM 3D model. Creating the SfM 3D model and applying Dstretch took 60 minutes. The inventory

took 140 minutes to identify and describe, and 70 minutes to measure. Therefore, Dataset C took one person 33 minutes in the field, 60 minutes to create the model, and two people to compile the digital inventory over 270 minutes for a total of 633 person minutes. In the future, not only will the inventory be compiled faster as familiarity with 3D model navigation increases, but it can be done by just one person. Therefore, the estimated time for completing an inventory of similar size in the future should drop to 363 person minutes.

Dataset D was the field-based ground-truth inventory (minus motif description). It was undertaken by the same researcher who identified the rock art from the SfM 3D model in Dataset C. This was undertaken in order to verify Dataset C. This recording took 20 minutes.

[TABLE 1 HERE]

Identifying and describing motifs

As illustrated in Table 2, Dataset A had 38 motifs and Dataset B had 41 motifs, Dataset C had 34 motifs, and Dataset D had 45 motifs. Figure 3 shows all the 34 motifs identified in Dataset C and Figure 4 shows the motifs, identified in Datasets A and D, but that are absent from Dataset C. While Dataset C may seem incomplete compared to the other datasets, the majority of the rock art absent from Dataset C consists of motifs classified as unidentified because they were either stray lines or blotches of pigment (Figure 4).

[TABLE 2 HERE]

[FIGURE 3 AND 4 HERE]

Other discrepancies between the datasets are mostly attributed to differences in interpretation by the researchers. The researchers classified motifs differently, but it is apparent from descriptions and images that they are, in fact, each describing the same motifs. For example, two Nayombolmi motifs are the most prominent features of the site and are considered one motif in Dataset A but two motifs in Datasets B, C, and D (Figure 5). Thus this ‘discrepancy’ is actually dependent on how imagery is classified by the viewer/recorder; if the recorder is classifying ‘anthropomorphs’, in this case two motifs would be identified, while if the aim is to classify ‘paired anthropomorphs’, only a single motif would be identified in the recording of this site.

Superimposition further complicates the recording process. The two Nayombolmi anthropomorphic motifs are recorded as two motifs in Dataset A, two motifs of different configuration in Dataset C, and three motifs in Dataset D. Clearly the discrepancy is in the nature of classification being employed by the researchers, and determining what superimposed rock art was part of which motif. Likewise, there were significant differences in the colours recorded for each motif. The researcher of Dataset C noted the colour pink on several of the fish, while the other two researchers made no such notation. The colour yellow was identified in Dataset A but not recorded in either Dataset B or Dataset C. However, yellow was corroborated in Dataset D.

[FIGURE 5 HERE]

Since photographs were only available for Dataset A, these were compared with Dataset C and the ground-truthed Dataset D. There were eight motifs identified in Dataset A that are not found in Dataset C. However, when compared with the ground-truthed Dataset D, five of those eight motifs were still not identified (Figure 4). Furthermore, there are at least eight

motifs recorded in Dataset D that are not found in Dataset A. In Figure 6, the inconsistency between Datasets A and D, both collected in the field but by different researchers, highlights the differences in rock art identification. Therefore, the majority of discrepancies between Datasets A, B and D, which were collected in the field, can be attributed to: differences in the amount of time spent at the site; lighting conditions; and interpretation of the marks found. This is a clear impediment to comparative analyses such as occurs in this study.

[FIGURE 6 HERE]

Discussion

A testament to the simplicity of the SfM 3D method is that neophytes of photogrammetry were able to collect data for 3D modelling and to create an inventory of the site from a 3D model with minimal instruction. In fact, the site was recorded twice in thirty minutes producing the raw data for adequate models.

The person recording the inventory from the SfM 3D model (SM) had no prior experience navigating 3D models, therefore, the resulting time is biased against Dataset C because it included learning time. Towards the end of both sessions, when familiarity with the 3D model had increased, the time needed to identify, and measure motifs reduced. It is fair to assume that the time needed for creating an inventory from a SfM 3D model of a rock art site would be greatly diminished with increased fluency in navigating 3D models. Also of note, the DStretch images of the art were barely consulted. Perhaps the extra rock art identified in the field would have been seen from a thorough investigation of the DStretch versions of the 3D models.

Blue Paintings is a relatively simple site on which to perform a detailed recording, both in the field and on a 3D model. There are fewer than 50 motifs and few superimpositions. It will be important to test detailed recording using a 3D model of a much more complex site to truly test the advantages of rock art recording using SfM 3D models and other 3D models generally. For example, Nanguluwurr, a large public site in Kakadu National Park, has been estimated to take four weeks for a field based detailed recording; the data capture using SfM 3D models took approximately seven days of fieldwork. Due to the orientation of the site, it can only be worked on for five to six hours in the morning before the sun affects both photography and accuracy. Furthermore, it is impractical and almost impossible to undertake detailed field recording of the rock art on the inaccessible ceiling in a safe manner because the art is approximately 7 m above ground level. Structure-from-Motion 3D models are particularly effective for such inaccessible rock art (Jalandoni et al. 2018). For this site, the in-field detailed recording inventory will be incomplete because of this problematic access to inaccessible rock art. Some might argue that recording might be achieved by using a telephoto lens or binoculars, however, accurate measurements cannot be obtained this way.

After evaluating the methods of detailed recording in-field and from SfM 3D models, we conclude that 3D recording provides a very useful additional form of record for rock art research - both to cross-check field-based records and to enable post-field data measurement and assessment. While our analyses tentatively suggest rock art inventories created from SfM 3D recordings can be as accurate as field recordings, it is the time-saving factor of 3D model recording that stands out in these findings. In-field detailed recording is time consuming and often limited to those parts of sites that can be safely accessed. Nevertheless, trying to create an inventory of all the rock art of a site solely from the 3D model risks being incomplete. While Dataset C included all the main motifs, it did lack a few stray lines and pigment

blotches. However, it should be noted that Datasets A, B, and D were all done in the field and yet due to different recorders had different inventories. Clearly, there are also problems of accuracy and comparability in field based datasets.

Our findings suggest that when documenting rock art, the whole site should be recorded using standard photogrammetry, and then sharper (closer) photographs of every rock art motif should be collected that can then align with the main dataset. Alternatively, teams could create unique high-resolution SfM 3D models of every rock art motif identified that could then be merged with the main model. Therefore, identification of all the rock art should still be done in the field with individual motifs numbered for later reference. Description and interpretation of individual figures can be done in the office, based on the SfM 3D model. While this would take a bit longer than basic photogrammetry of a site, it would facilitate detailed recording from the 3D model and increase accuracy. It should still greatly reduce the amount of time required to produce a detailed inventory of the rock art of a site.

Ground-truthing is also an essential step in the process. It is difficult to claim any inventory is complete, whether created in the field or from a 3D model, because revisiting sites often leads to new rock art being seen. This can result from different light at a site or the experience of the person recording. For this reason, it would also be prejudicial to look at a SfM 3D model of a rock art site once and expect all the rock art to be visible. The added benefit of a 3D model is that it can be revisited at any time.

The difference in colour interpretations could be reduced by using a standardised colour chart. As an example, the PERAHU (Place, Evolution, Rock Art Heritage Unit) card was designed for rock art research and includes a chart of the colours most commonly observed in rock art, particularly Australian rock art (Figure 7). The PERAHU card is meant to be used like a Munsell Color Chart, in an attempt to standardise colour descriptions. If the PERAHU card is held up to the rock art, the closest colour could be used to describe the pigment. The back of the scale is also useful for SfM 3D modelling by providing automatically detectable scaled points.

[FIGURE 7 HERE]

Conclusion

Inventories of rock art sites are invaluable to archaeological research. However, performing detailed recordings in the field are time consuming and, at times, dangerous when inaccessible art needs to be recorded. While doing detailed recording from SfM 3D models is not perfect, if combined with the right methods for data capture in the field, it can greatly increase efficiency in the field. Aside from processing the models, the data collection and creation of an inventory from the 3D models are able to be done by archaeologists with no prior experience. Applying the methods presented here will facilitate the detailed recording of more sites, allowing for an improved understanding of the rock art of a region as well as at individual sites because of the improved accuracy of motif identification. Undoubtedly, SfM 3D modelling is changing the way we conduct rock art research. However, this emerging technology needs to be tested every step of the way before we can readily accept the product to answer archaeological questions.

Funding details

This work was funded by the Australian Research Council through the Discovery project (DP160101832) associated with the ARC Laureate Fellowship granted to Prof. Paul Taçon

(FL160100123).

Acknowledgments

This research was undertaken as part of the *Pathways: people, landscape and rock art* project and was funded by the Australian Research Council grant 'Australian rock art: history, conservation and Indigenous well-being', part of Paul Taçon's ARC Laureate Project (FL160100123). As partners in this research, Jeffrey Lee and Parks Australia have provided much support, and we thank them for their collaboration. We are grateful to all the rangers who joined the fieldwork in 2018 and/or 2019, including Kadeem May, Gabrielle O'Loughlin, Jennifer Wellings, Jasmine Nabobob, Duane Councillor, Joe Markham, Jacqueline Cahill, Cindy Cooper and Louise Harrison. We would also like to thank John Hayward, Janet Davill, Phil Davill, Samuel Dix, Cindy Cooper, Kadeem May, Irina Ponomareva, and Emily Miller for helping to document the Blue Paintings site and allowing us to analyse their work in this paper. We are particularly grateful to Melissa Marshall for allowing us to refer to her unpublished PhD research and providing us with further information on her documentation of Blue Paintings. We would also like to thank Sama Low-Choy for statistical advice. Finally, thanks to Paul Taçon, PERAHU and the Griffith Centre for Social and Cultural Research for supporting this research.

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Figure Captions

Figure 1: The general location of the Blue Painting site within Kakadu National Park.

Figure 2: Screenshots of decorrelated stretched 3D models.

Figure 3: Screenshot Blue Painting site point cloud with recorded figures marked.

Figure 4: Orthomosaic of Blue Painting site with the figures found in Datasets A (red) and D (blue) that are absent from Dataset C.

Figure 5: Orthomosaic of Nayombolmi figures, Blue Painting site.

Figure 6: Orthomosaic created for Dataset C (upper) and photograph taken as part of Dataset A (lower). Examples of unidentified figures recorded in Dataset A that were not recorded in Datasets C and D but are visible on the 3D model, therefore the discrepancy is human interpretation.

Figure 7: PERAHU scale card.