

An Overview of Digitally Documenting Surface and Subterranean Sites at the U.S. Army's Pōhakuloa Training Area, Hawai'i

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Abstract

Recent archaeological survey work at the U.S. Army's Pōhakuloa Training (TA) Area 22, Hawai'i, used low-cost, highly portable, three-dimensional (3D) modeling techniques to document surface and subterranean sites. Project crews created 65 photo models of previously undocumented cairns, rock shelters, and cave entrances. They used consumer-grade point-and-shoot and DSLR cameras and commercial photogrammetric software. There are also over a dozen new models of underground lava tubes, using Microsoft Kinects as sensors. Over the last decade, 3D modeling of archaeological resources has become commonplace. Limitations associated with the cost, difficulty of use, and limited mobility of LiDAR technology have discouraged digitizing widely-scattered archaeological resources in difficult terrain. The digital recording work at PTA provides scaled representations of sites that are as or more accurate than those obtained from traditional field recording techniques.

Introduction

Archaeologists are continually challenged to record as much information as they can while in the field. This is especially true when working in remote areas or difficult terrain. The following paper highlights how 3D technologies supported a federally-contracted archaeological pedestrian survey of the U.S. Army's Training Area 22 (TA 22) in the U.S. Army's Pōhakuloa Training Area (PTA) on the Island of Hawai'i. The survey objective was to locate and record archaeological features and sites in TA 22, both above and below the surface. This contributes to the Army's responsibility under federal law and regulation to identify archaeological sites on the land it controls. The work was conducted during two seasons: survey of a 162 ha (400 acres) section in January and May 2015, and an additional 230 hectares (570 acres) in December 2015 and January 2016. TA 22 lies on the broad saddle between Mauna Loa and Mauna Kea shield volcanoes at approximately 1500 m (5,000 ft) elevation. (Figure 1).

This was a physically challenging survey because much of TA 22 is not accessible by vehicle, so all of

the recording and survey gear has to be hand-carried or back-packed into the field. Additionally, the survey area is covered by 'a'ā and pāhoehoe lava flows with uneven surfaces and loose stones. Invasive grasses obscure pits, depressions, and sharp rocks required vigilance when walking. High winds, humidity fluctuations, and large temperature variations are daily occurrences in the PTA, so survey and documentation gear had to be rugged, in addition to being compact, and light-weight.

The surface sites in TA 22 include rock cairns, pedestrian trails, shelters, and shallow pits. Subterranean sites are mainly lava tube cave complexes, although some rock shelter features extend underground. The 3D digital recording technologies relied on photography and infrared (IR) capture, each of which had advantages and limitations. Photographic modeling of subterranean sites was limited by a lack of light, and IR modeling of surface sites is impossible in bright tropical sunlight. The solution was to use different mobile 3D mapping methods in each context. Using 3D technologies saved valuable time in the field compared to older recording methods, while producing models with good dimensional accuracy.

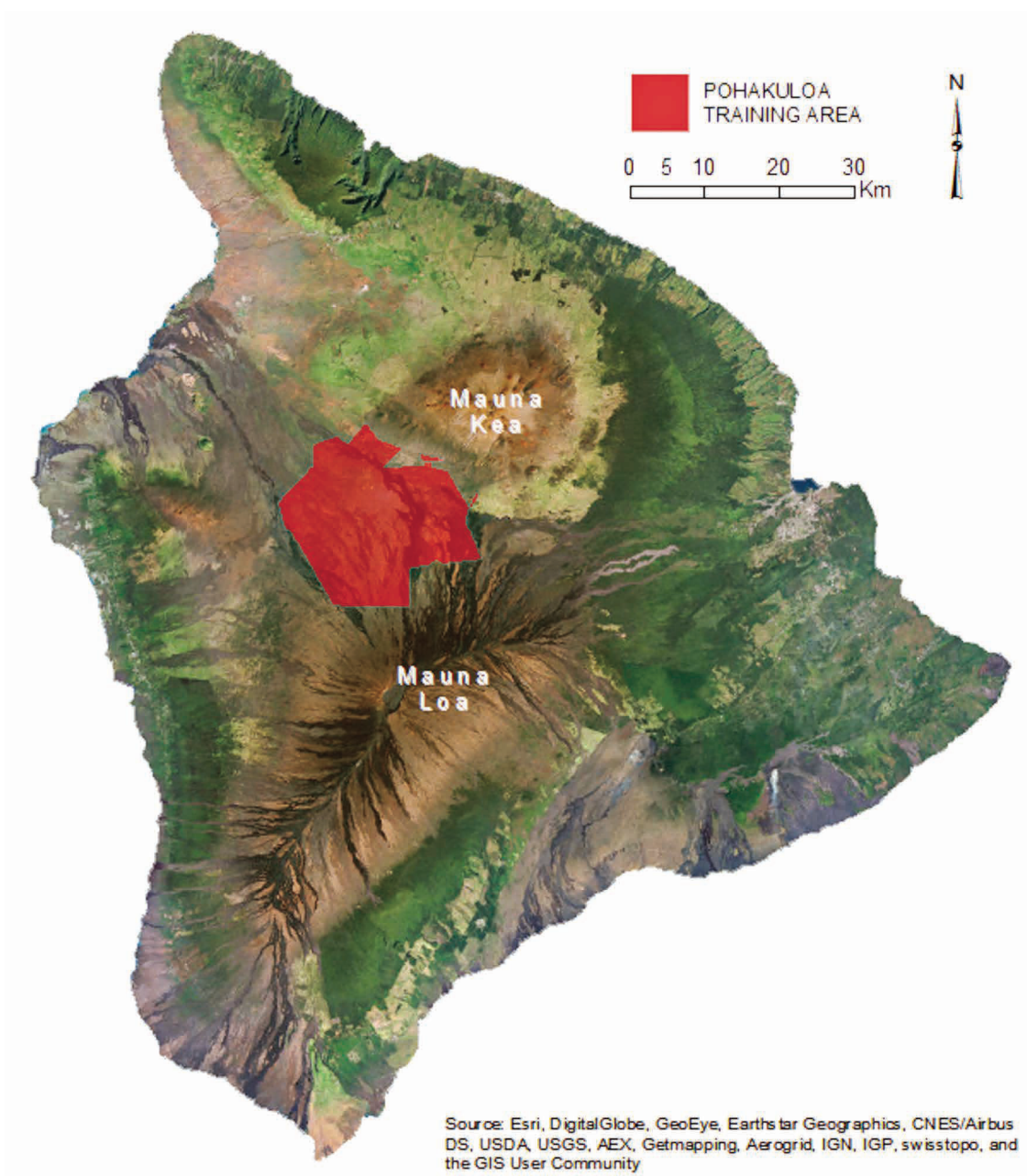


Figure 1. Ortho mosaic map of the Island of Hawai'i. The Pōhakuloa Training Area is shown in red. Mauna Kea shield volcano is to the north, and Mauna Loa to the south of the PTA. Map created by Margan Grover.

Materials and Methods

The photography-based 3D technology used cameras and Agisoft PhotoScan Professional software to record surface sites. PhotoScan uses Structure from Motion and MultiView Stereo (SfM/MVS) algorithms to combine 2D digital photographs into a 3D model (Agisoft 2016). PhotoScan Professional is available for Macintosh, Windows, and Linux operating

systems. The cameras used varied: in the first season, the survey crew used a consumer-grade digital single lens reflex (DSLR) camera with an APS-C sensor (Canon Rebel T5). Both zoom and fixed focal length (“prime”) lenses were used. For the second season, survey crews primarily used compact point-and-shoot Panasonic DMC-TS6 cameras. These cameras were designed to be water, dust, and shock-resistant. One Canon Rebel T6i APS-C DSLR camera, fitted with



Figure 2. The Microsoft Kinect sensor for Xbox 360, or V1. The leftmost circular window is the IR emitter, the middle window is the RGB camera, and the rightmost window is the IR camera.

a prime lens, supplemented the point-and-shoots. Final PhotoScan models were produced on a lab-based desktop computer, running 64-bit Windows 7. This computer has 32 GB of RAM, an Intel i7 central processing unit (CPU), and an Nvidia GeForce 700-series graphics processing unit, or GPU.

The scanning crew used a Microsoft Kinect for Xbox 360 game controller during both seasons to record subterranean sites. The 3D community knows this device as the V1 (Figure 2). The V1 operates in concert with Occipital's Skanect software (Macintosh or Windows). Microsoft sold millions of V1s during its production run. Used V1s in good condition cost less than \$30.

The V1 has a normal (RGB) camera, an infrared (IR) emitter, and an IR camera. The IR components function to measure depth, even in the absence of visible light. The IR light source internal to the V1 is a laser, but the beam is attenuated through an optical grating system to create a projected pattern of dots (Khoshelham and Elberink 2012). Therefore the V1's invisible IR emissions are eye-safe, and it is not, strictly speaking, a laser scanner.

Surface Sites and Features

In addition to field book note and sketch documentation, the crew took digital photographs while walking in circular paths around each surface site, taking care to include calibrated scales in some

photographs (Figure 3). Most of the crew on the PTA project used the Panasonic cameras, which were smaller, lighter, easier to operate, and less expensive than a DSLR camera. Aside from keeping costs down and improving mobility in the field, use of the smaller cameras enhanced the overall picture quality over using a DSLR alone. Despite the smaller sensor size (6.08 mm x 4.56 mm vs. 22.3 mm x 14.9 mm) and slightly lower megapixel count of the compact cameras (16 vs. 18 megapixels), the Panasonics proved quick to adjust exposure settings to varying lighting conditions and were easy to stabilize and aim, returning crisp images with little motion-blurring. Ease of use in the field is important, as survey crews had many sites to record per day: the survey located over 65 previously undocumented sites.

Prior studies evaluating PhotoScan model outputs demonstrate precision and accuracy close to that of terrestrial laser scanning (TLS), given good-quality input photographs (Andrews *et al.* 2013; Fassi *et al.* 2013). Other than being highly overlapping (~66% overlap), the modeling software requires photographs that are in focus and not motion blurred. Blue sky and moving objects that persist in a scene, like plants swaying in the wind, do not model well. However, unlike early implementations of SfM/MVS, PhotoScan ignores transient objects like people (and their shadows) moving through a scene during a photography session. After problem portions of individual photos are manually masked, the operator initiates the "Align Photos" process. A by-product of



Figure 3. Agisoft PhotoScan image of a lava tube opening (at the bottom of the photograph) demonstrating the ability of the software to locate calibrated photogrammetric scale bars (with 12-bit coded targets) designed by personnel at the Bureau of Land Management’s National Operations Center for Photogrammetry, and sold by Cultural Heritage Imaging (CHI). Photographed by Paul White, UAA.

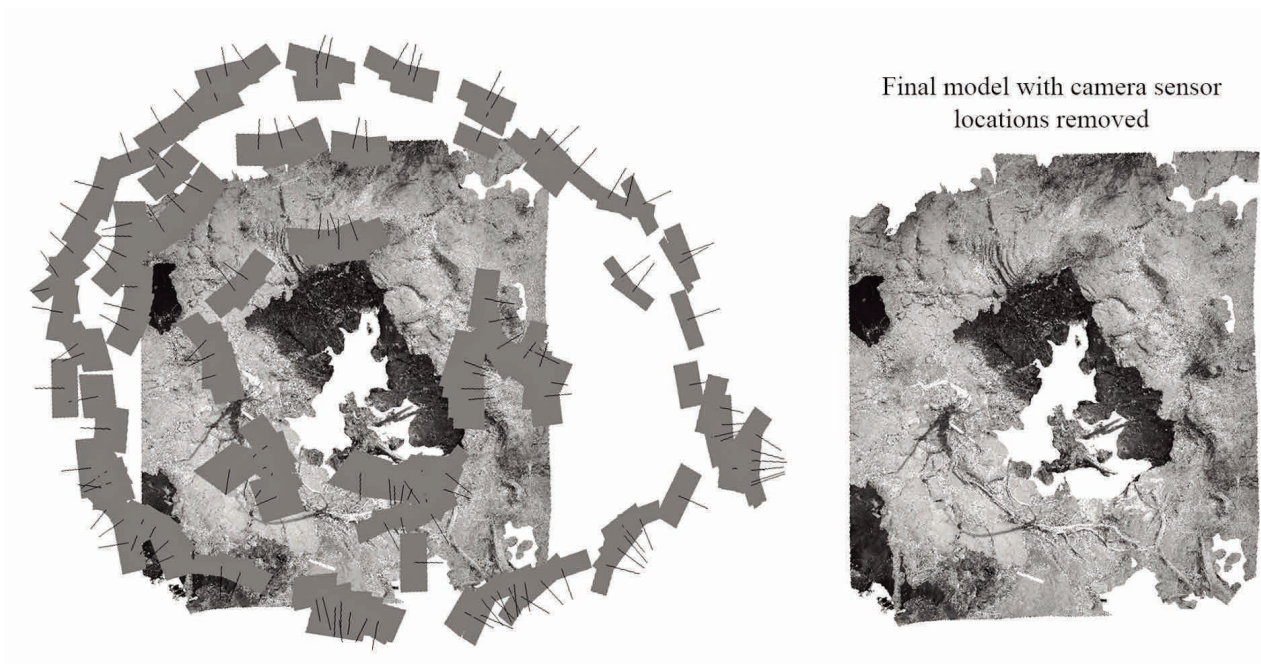


Figure 4. Screen capture of a textured PhotoScan 3D model of a rock shelter incorporating 148 photographs. The blue rectangles show where the camera’s sensor was located in 3D space when each photograph was taken.

aligning photographs is the creation of a sparse cloud of points. Subsequent workflow steps include building a dense point cloud, building a mesh, and then adding texture to the model (see below). The software runs in a semi-automatic manner, pausing for user input after each major processing stage. Alternatively, batch processing can be used for greater automation. Figure 3 demonstrates PhotoScan's ability to automatically locate coded digital markers, which helps produce a model that has good dimensional accuracy.

Figure 4 shows a screen capture of a finished PhotoScan 3D model of a rock shelter incorporating 148 photographs. In the last processing stage, PhotoScan restores color pixel-by-pixel to texturize the model. In addition to the standard PhotoScan workflow, an optimization process taught by Cultural Heritage

Imaging (CHI 2016) helped eliminate lower quality data points. Figure 4 demonstrates how the point-of-view is flexible in 3D models. The camera was never located at this nadir location, but by rotating the model on-screen, the observer can "virtually" be there.

Figure 5 shows screen captures of a rock cairn model (constructed from 197 photos) at each major stage of processing, and a 3D PDF output image. This model has over 23 million points in the dense cloud, and 4.6 million faces in its "mesh." A mesh is a representation of a 3D object consisting of points (vertices) connected together into a network of many small triangles. In 3D modeling terminology, the mesh (the purple-blue portion of the lower left image in Figure 5) is the first phase that is a true "model": it represents a solid surface, unlike the prior stages.

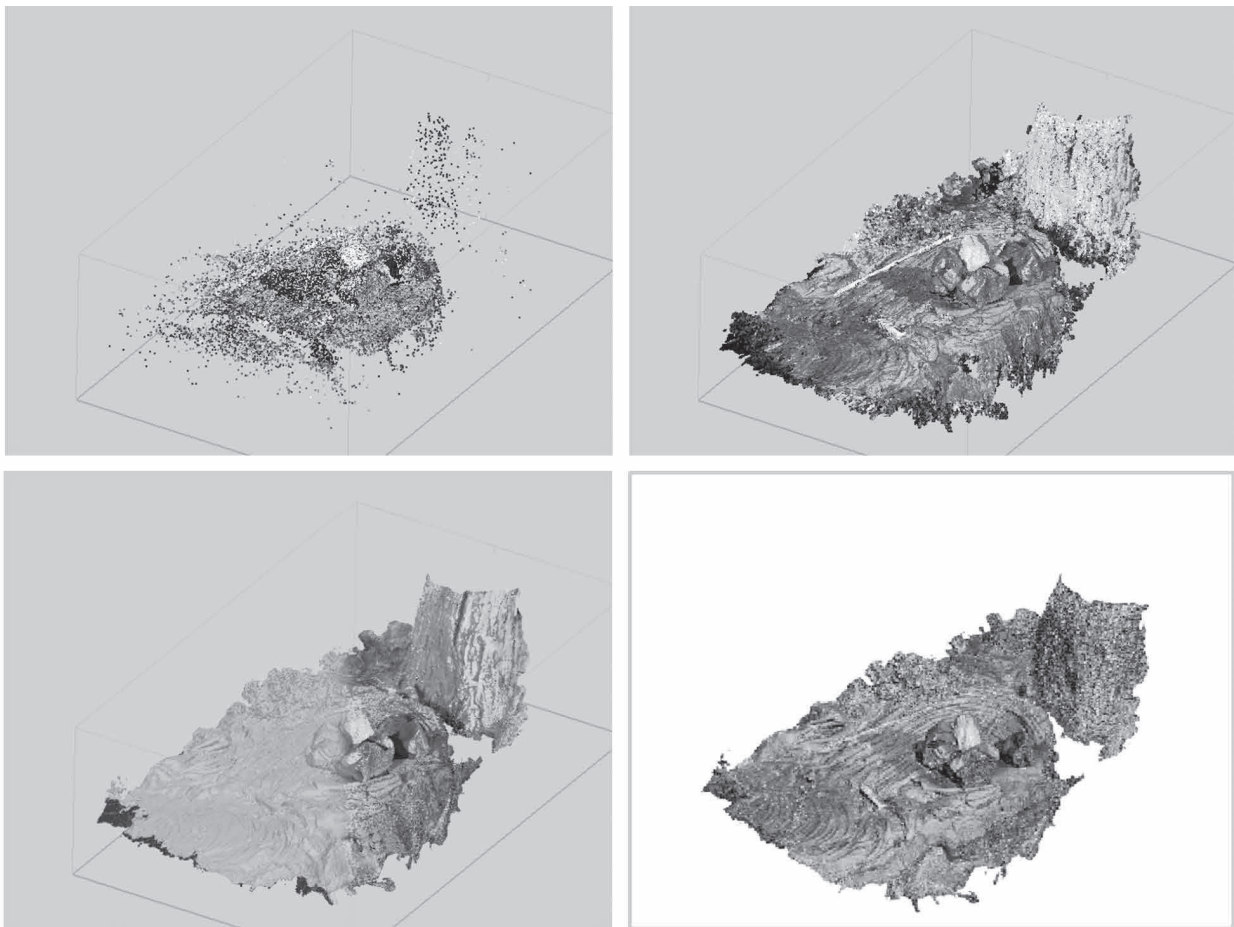


Figure 5. Screen captures of a rock cairn model (constructed from 197 photos) at each major stage of processing and a 3D PDF output image. Upper left: sparse point cloud (89,000 points), output by the first stage of processing. Upper right: dense point cloud (23 million points). Lower left: the purple portion is the mesh (4.6 million triangular faces). The normally colored part is the textured version, produced by the last stage of the normal PhotoScan workflow. The large grey object behind and to the right of the rock cairn is the trunk of a tree. Lower right: a screen shot of the 3D PDF output, directly exported from PhotoScan. Photographed by Jay Rapoza, UAA.

Notice that the resolution of the 3D PDF in Figure 5 is reduced over that of the textured output. This is a compromise between sharpness and file portability. Although this 3D PDF is a large file (155 MB), it is considerably smaller than the higher-resolution files exported in other 3D formats (up to 520 MB).

PhotoScan is noteworthy among 3D modeling programs in that it can create 3D PDF files. Current Macintosh and Windows versions of the free Adobe Acrobat Reader or commercial Adobe Acrobat software can open 3D PDFs. Once opened, they can be rotated, virtually relighted, viewed as simple line drawings, and directly measured. 3D PDFs can be “stand alone” or they can be inserted into electronic documents, including online versions of scholarly articles. See Porter *et al.* (2016) and Danz and Katsaros (2011) for examples of published 3D PDFs, and Newe (2016) and Lautenschlager (2014) for how-to instructions. For the PTA project, 3D PDFs and orthomosaics (reduced-distortion 2D images) were submitted to project illustrators for conversion to line-drawings for printed final reports (Hanson *et al.* 2015; Grover *et al.* 2016).

Photo modeling requires little time and minimal equipment in the field, but is computationally demanding (Chow *et al.* 2012). Agisoft recommends 12 to 36 GB of RAM to build a high-quality model from the number of photos our crews took. Computers with advanced multi-core central processors like the Intel i7 running at 3 GHz or faster, and OpenCL-compatible graphics cards significantly speed up PhotoScan processing. Even with higher-end hardware, photo modeling can take a while. While hard to predict with certainty, factors that influence processing time include number of photos, size of photos (number of pixels), and desired model accuracy. A typical rock cairn model using 60 photographs took an hour to complete on the project computer (32 GB RAM, i7 CPU, GT 720 GPU). A more complex model of a sinkhole including two lava tube entrances incorporated 138 photographs, and took 5.5 hours to process. Both of these models were run at a “High Accuracy” setting, with 18-megapixel photographs. Test runs using computers with less advanced graphics processors took much longer with the same photo set and accuracy settings. Ultrahigh accuracy models are beyond the practical capabilities of our current hardware, as they can take several days to complete.

PhotoScan has another significant advantage beyond creation of 3D PDFs over other available photo modeling systems: all processing is “local.”

Processing entirely off-line solves several potential problems, including data security and ownership of intellectual property rights. Microsoft’s free cloud-based Photosynth is an example of remotely computed SfM processing service. Users of Photosynth must grant Microsoft the right to use their models, including in promotional material (Microsoft 2015). Security concerns, lack of control over output quality, and the inability to run test models in off-grid locales are all reasons to avoid cloud-based services. Our crew used laptop computers in a remote field camp for daily quality control, building reduced-accuracy quick trial models. If a site’s photo set proved inadequate for modeling, the survey crew could return the next day to take more pictures.

Subsurface Sites and Features

Subsurface sites and features in TA 22 presented different challenges. Lighting varied from partial to total darkness, and remoteness and rugged terrain ruled out the use of TLS. We used the V1 sensor to document lava tube caves and rock shelters because it is compact (29 x 6 x 4 cm) and lightweight. However, one limitation is that the V1 requires 100-240 V AC line current to operate. The solution was to use a 12 V DC non-spillable lead-acid battery (12 Amp-hour) and a small AC to DC inverter to provide 115 AC power in the field (Figure 6). The battery was compact (15 cm x 10 cm x 9 cm) and reasonably light-weight (about 4 kg). A laptop computer ran the Skanect software.

The V1 sensor’s infrared camera captures images of the transmitted dot pattern, and Skanect software notes the shift in apparent position of each dot. By triangulation, the system determines distance, building a depth map on the fly (Khoshelham and Elberink 2012). The IR emitter and camera combination thus reconstruct depth (the “D” in RGB-D). Figure 7 shows a scene illuminated by the V1 in the IR band and a conventional RGB camera image for comparison.

Skanect automatically creates a 3D model, overlaying RGB and IR data. When operating in dark conditions, IR is alone sufficient to document and model internal lava tube cave morphology. Our scanning crew found the Skanect software easy to use: after specifying capture parameters, including the dimensions of the region to be recorded, tapping the space bar starts the capture process. Visual feedback cues show scan completeness. Post-capture Skanect editing options include simplifying, filling

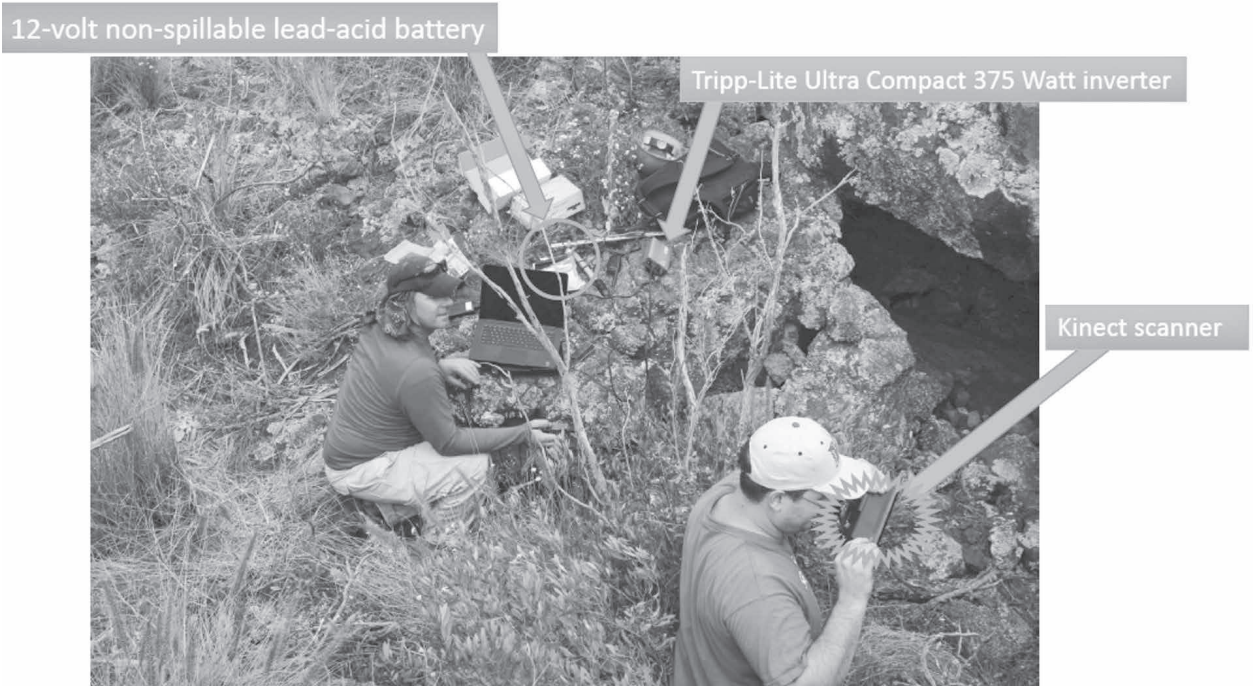


Figure 6. Kinect V1 in the field. Note the 12 volt battery and inverter, as well as the laptop computer running Skanect software (John Hemmeter (UAA) on the left, Ryan Harrod (UAA) on the right). Photographed by Jay Rapoza, UAA.

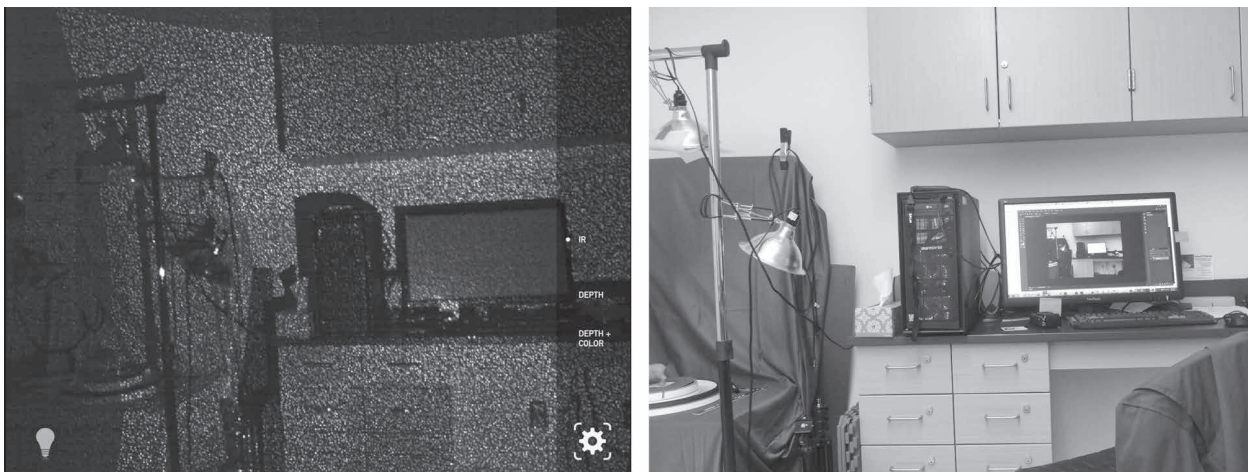


Figure 7. Left image: An IR camera's view of a lab scene illuminated by the Kinect V1's IR emitter. Note the "speckle" pattern of dots. Right image: photograph of the same scene taken with a conventional RGB camera.



Figure 8. A workflow that allows the creation of 3D PDFs from virtually any 3D modeling program. Workflow and chart adapted from Porter (2015), and used with permission.

holes, cropping, restoration of color, and the ability to create a “watertight” model (required for 3D printing). The Skanect model can be saved in several standard 3D file exchange formats, but not as a 3D PDF. It does export in the Wavefront Object (OBJ) file format, and OBJ files can be opened in Meshlab. Meshlab is a free 3D viewing, conversion, and editing program (Meshlab 2016). We used a variation of the workflow developed by Porter (2015), which permits the creation of 3D PDFs from virtually any 3D modeling or rendering program (Figure 8). Daz Studio software (free; Macintosh or Windows) then converts Meshlab-refined OBJ files to Universal 3D (U3D) files that Adobe Acrobat can in turn open and convert to 3D PDFs (Daz 3D 2016).

Figure 9 shows two screen captures: an unprocessed Kinect/Skanect 3D model of rock shelter site T-011415-02, and a slightly different view of the same site with color restored and opened in Meshlab. This is the same PTA site modeled using PhotoScan in Figure 4. Both photo modeling (PhotoScan) and Kinect scanning capture only a façade, that is, only surface details visible to the camera or sensor. The dark surfaces in Figure 9 indicate the reverse, or back side, of the cave walls and ceiling. Again, viewpoint

can be anywhere in relation to a digital model in 3D space. The scan that produced the model shown in Figure 9 was taken inside this spherical rock shelter, while the vantage points in Figure 9 are from the outside. Skanect was able to capture color inside this rock shelter because natural daylight enters through the roof opening. Enough light entered to support a plant community on the shelter floor.

The Skanect model of T-011415-02 has 143,000 faces. Although perfectly adequate for documenting the site, this is fewer than the number of faces that a photo model of the same site would have. The reduced number of faces reflects a less-detailed model, due to some inherent limitations of the V1.

The Kinect V1 was not designed as a scanner. The Kinect’s RGB sensor is very small; Smisek *et al.* (2013) charitably characterize the RGB camera’s images as medium quality. The V1’s IR system is low-powered and subject to ranging errors. These errors become noticeable beyond 4 to 5 m for individual measurements (Smisek *et al.* 2013; Chow *et al.* 2012), but this is partially compensated for by Skanect. The Skanect/V1 software-hardware combination is analogous to a video camera. Rather than capture single images as in photo modeling, it acquires scenes



Figure 9. Two screen captures: on the left an unprocessed Kinect/Skanect 3D model of rock shelter site T-011415-02, and on the right a slightly different view of the same site with color restored, and exported into Meshlab. Scanned by Ryan Harrod (UAA), John Hemmeter (UAA), Jay Rapoza (UAA), and Paul White (UAA).

up to 30 IR and RGB frames per second. Because the Kinect is an “active” sensor that both transmits and receives energy, distances are continuously calculated. Skanect merges the data stream to produce more accurate computed distances. Unfortunately, the V1 will not function in bright sunlight, being overpowered by the sun’s powerful emissions of IR-spectrum light. Our other projects and tests confirm that the V1 *will* work normally during daylight under heavy cloud-cover, or under a forest canopy.

The limitations of the V1 did not seriously impact its usefulness in this project. The scanned lava tube caves and rock shelters were generally less than 4 m in maximum dimension, and reasonably dark. Larger subterranean sites were scanned in sections, and aligned with one another in Meshlab. Despite diffuse sunlight entering the roof entrance of rock shelter site T-011415-02, the V1/Skanect output was good. Chow *et al.* (2012) performed rigorous calibration trials on the V1, and said that, “for the cost and portability it is delivering fairly high geometric

accuracy at close-range” (179). Computer hardware recommendations for the V1-Skanect combination are more modest than those for PhotoScan: a 64-bit Intel i7 processor running Windows 7 or Macintosh OS, 4 GB RAM, and an Nvidia GTX 560 or later graphics card. While not capable of producing models with as much detail as photo models, processing V1 data is not as computationally intense. The V1/Skanect combination required more equipment in the field than photo modeling, however, including a computer and an external battery. V1/Skanect output for the project illustrators consisted of 3D PDFs (see below), and selected screen shots of the model opened in Meshlab.

Model Use

Imagery from the PhotoScan models expedited the work of project digital artists who created the final overhead and elevation drawings of surface features and sites (primarily rock cairns). Individual rocks

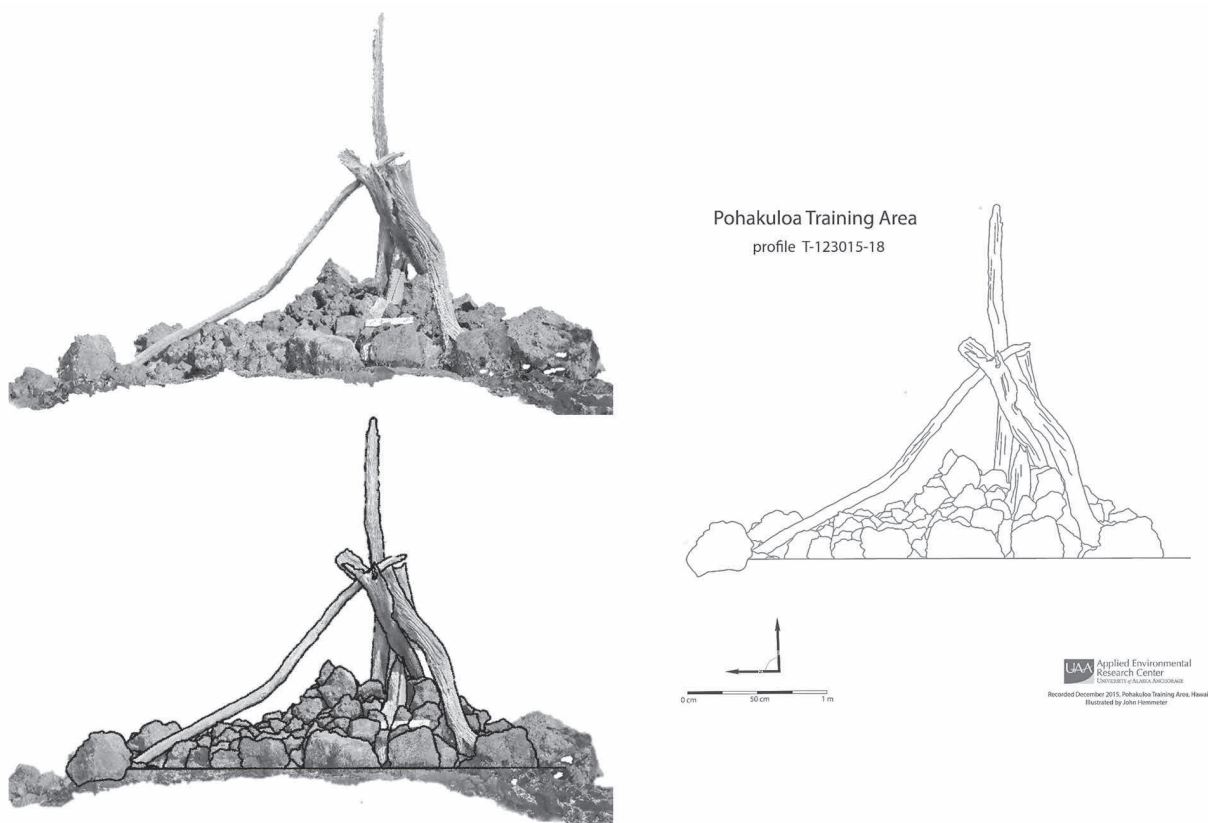


Figure 10. Rock cairn (site T-123015-14) Top image: an elevation orthomosaic exported from PhotoScan. Photographed by John Hemmeter (UAA). Middle: screen capture showing how the artist traces relevant outlines from the orthophoto in Adobe Illustrator. Bottom: the finished line drawing. Note: line weights increased and colors changed for this illustration to highlight details. Illustrated by John Hemmeter (UAA).

were distinguishable and were traced in Adobe Illustrator (Figure 10). Scale could be read directly in the 3D PDF format, or indirectly by referring to the calibrated scales in individual photos.

Project artists likewise used output from V1 models to create accurate two-dimensional drawings of rock shelter floors, including artifact locations, in Adobe Illustrator. See Figure 11 for a summary

of the steps involved in doing this. Rapid in-field capture of 3D data, good dimensional accuracy, and ease of conversion to line-drawings validated the use of the both photo modeling and the Kinect V1. Short of using bulky and expensive TLS systems, the alternative is to create on-site sketches with measuring tape, compass, pencil, and paper, a time-consuming and less accurate process.

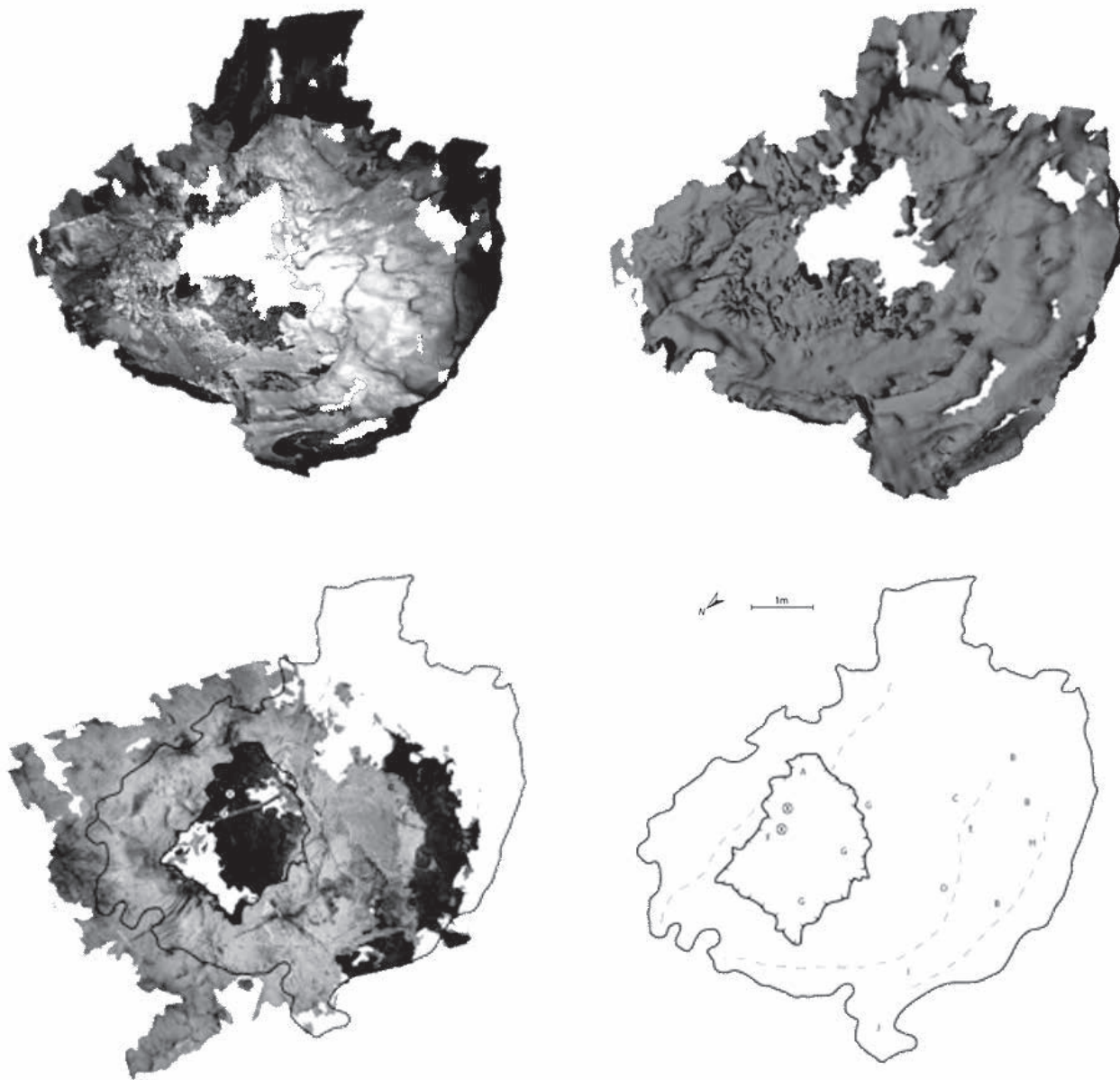


Figure 11. Sequence of steps in creating a plan view of the floor of rock shelter T-011415-02. Note: an operator first digitally edited the 3D models to remove the rock shelter roof structure in Meshlab. Upper left: color image as viewed in Meshlab (the red and blue patches are bits of crewmembers' clothing and gear). Upper right: greyscale 3D PDF. Removing color makes it easier for the artist to see fine details. Lower left: orthoimage of the shelter entrance superimposed on a traced line drawing of the cave floor. Lower right: the finished report drawing, with overhead shelter entrance, with artifact locations and cave features noted. Illustrated by Margan Grover (UAA).

Future Upgrades and Improvements

Survey crews used artificial lighting during the second field season to photograph the interiors of some lava tubes. Processing of that imagery is ongoing. Preliminary results indicate photo modeling of underground features is practical when artificial illumination is available. The light sources employed are lightweight, rechargeable-battery-powered, LED panels.

Survey crews also introduced the use of the newer Kinect for Xbox One (or V2) game controller as a scanner. Like the V1, the V2 has RGB and IR depth-sensing components. The V2's operating principle is different, falling in the class of "time of flight" scanners. Improvements in the V2 include a wider field of view, greater maximum range, and better ranging precision. Unlike the V1, the V2 requires Windows 8 or 10 (Microsoft 2016). Unfortunately, the otherwise-versatile Skanect software does not work with the V2, nor is there yet a user-friendly Skanect replacement.

The crew tested several software packages during the pre-field phase of the project. Trials included scanning in a simulated cave constructed in a campus storage room, and V1 vs. V2 head-to-head scans of field sites. So far using the V2 as a scanner in field conditions is problematic due to software limitations. We hope this situation will improve, and that we may more widely employ the V2 in the future.

There are many uses of 3D models beyond including 3D PDFs in on-line academic publications (Porter *et al.* 2016; Danz and Katsaros 2011). Models can be integrated into public outreach campaigns. This can include posting on Web sites (3DHOP 2015) and use in information kiosk displays. Free Meshlab iOS and Android viewers can display 3D files on smart phones and tablet computers (Meshlab 2016).

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REFERENCES CITED

- 3DHOP, 2015. 3DHOP: 3D Heritage Online Presenter. Electronic document, <http://3dhop.net/>, accessed May 6, 2016.
- Agisoft LLC, 2016. Agisoft PhotoScan User Manual: Professional Edition, Version 1.2. Electronic document, http://www.agisoft.com/pdf/PhotoScan-pro_1_2_en.pdf, accessed May 1, 2016.
- Andrews, D.P., J. Bedford, J. and P.G. Bryan, 2013. A Comparison of Laser Scanning and Structure from Motion as Applied to the Great Barn at Harmondsworth, UK. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 1 (2): 31–36.
- Chow, J, K Ang, D Lichti and W Teskey, 2012. Performance Analysis of a Low-cost Triangulation-based 3D Camera: Microsoft Kinect System. *Proceedings of the International Society for Photogrammetry and Remote Sensing Congress (ISPRS)* 39: 175–180.
- Cultural Heritage Imaging (CHI), 2016. Cultural Heritage Imaging. Electronic document, <http://culturalheritageimaging.org/>, accessed May 6, 2016.
- Danz, J.C., and C. Katsaros, 2011. Three-dimensional Portable Document Format: A Simple Way to Present 3-dimensional Data in an Electronic Publication. *American Journal of Orthodontics and Dentofacial Orthopedics* 140 (2): 274–276.
- Daz 3D, 2016. Daz Studio. Electronic document, http://www.daz3d.com/daz_studio, accessed April 29, 2016.
- Fassi, F., L. Fregonese, S. Ackermann and V. De Troia, 2013. Comparison Between Laser Scanning and Automated 3D Modeling Techniques to Reconstruct Complex and Extensive Cultural Heritage Areas. *ISPRS 3DArch, Trento, Italy* 5: 73–80.
- Grover, M.A., T. Parsons, and D.K. Hanson, 2016. *Draft: Archaeological Survey of Training Area 22, Pōhakuloa Training Area, Island of Hawai‘i, Hawai‘i*. Submitted to the Cultural Resources Section, Environmental Division, Directorate of Public Works, US Army Garrison, Pōhakuloa Training Area, Hilo, Hawai‘i. Cooperative Agreement W911KB-14-2-0001, Task Order 0002. Copies available from the Cultural Resources Section, US Army Garrison, Pōhakuloa Training Area, Hilo, Hawai‘i.

- Hanson, D.K., M.A. Grover, and T. Parsons, 2015. *Final: Archaeological Survey of Training Area 22, Pōhakuloa Training Area, Island of Hawai‘i, Hawai‘i*. Submitted to the Cultural Resources Section, Environmental Division, Directorate of Public Works, US Army Garrison, Pōhakuloa Training Area, Hilo, Hawai‘i. Cooperative Agreement W911KB-14-2-0001, Task Order 0002. Copies available from the Cultural Resources Section, US Army Garrison, Pōhakuloa Training Area, Hilo, Hawai‘i.
- Khoshelham, K. and S.O. Elberink, 2012. Accuracy and Resolution of Kinect Depth Data for Indoor Mapping Applications. *Sensors* 12: 1437–1454.
- Lautenschlager, S., 2014. Palaeontology in the Third Dimension: A Comprehensive Guide for the Integration of Three-Dimensional Content in Publication. *Paläontologische Zeitschrift*, 1 (88): 111–121.
- Meshlab, 2016 Meshlab. Electronic document, <http://meshlab.sourceforge.net/>, accessed May 6, 2016.
- Microsoft Corporation, 2015. Microsoft Services Agreement. Electronic document, <https://www.microsoft.com/en-us/servicesagreement/>, accessed May 5, 2016.
- 2016 Kinect Hardware Requirements and Sensor Setup. Electronic document, <https://developer.microsoft.com/en-us/windows/kinect/hardware-setup>, accessed May 1, 2016.
- Newe, A., 2016. Enriching Scientific Publications with Interactive 3D PDF Figures: A Complete Toolbox. *PeerJ PrePrints* 4:e1594v2.
- Porter, S., 2015 Creating 3D PDFs: Part 1. Electronic document, <https://youtu.be/8RowlRrrKkc?list=PLZzVwXTSDAJ06zVj8d0jEEAB3wF2GnNBO>, accessed April 28, 2016.
- Porter, S.T., M. Roussel, and; M. Soressi, 2016. A Simple Photogrammetry Rig for the Reliable Creation of 3D Artifact Models in the Field: Lithic Examples from the Early Upper Paleolithic Sequence of Les Cottés (France). *Advances in Archaeological Practice* 4 (1): 71–86.
- Smisek, J., M. Jancosek, and T. Pajdla, 2013. Consumer Depth Cameras for Computer Vision. In *Consumer Depth Cameras for Computer Vision: Research Topics and Applications*, edited by Andrea Fossati, Juergen Gall, Helmut Grabner, Xiaofeng Ren, and Kurt Konolige, pp. 3–25. Springer, London.

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