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Using Photogrammetry to Document, Analyze, and Reverse-Engineer Grave Markers

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ABSTRACT

There are a wide range of applications for three-dimensional (3D) data in archaeology, and a diverse array of methods for collecting and analyzing those data. In this article, free 3D photogrammetry software (Autodesk 123D Catch) is used to document a series of grave markers. The data are subsequently exported to Geomagic Design X to demonstrate and briefly discuss the various potential analyses that might be used to illustrate the effects of preservation treatments and marker degradation through time. Further, one marker is reverse-engineered, illustrating the capacity of 3D modeling to expedite the process of design, should elements warrant replacement. Additional benefits of documenting the markers in 3D includes public outreach and public interaction through social media. Autodesk's 123D Catch allows users to render videos of each model and export them to YouTube, where they can be shared with a global audience. The capacity of these tools to expand the scope of our efforts to document and analyze grave markers is substantial.

Introduction

Using free photogrammetry software (Autodesk 2015a; Kramer 2013) grave markers at Oak Grove Cemetery in Nacogdoches, Texas, were documented in 3D by collecting 70 images of each, then submitting those to Autodesk's 123D Catch using the downloaded interface. The download process is well documented in how-to videos on the Autodesk website (Autodesk 2015a) and will not be discussed here. The resultant 3D meshes (Figure 1) have a variety of uses and can be integrated into a wide range of documentation and preservation programs for professionals (De Reu et al. 2013; Spring 2014; Martínez et al. 2015; Sanger 2015), and can also augment cemetery and preservation-based education efforts. There are various approaches to 3D documentation and analysis, however, and the options should be considered whenever exploring the

tenets of a new project (Koutsoudis et al. 2013; Magnani 2014). Grave markers represent a source of primary archaeological data and are also a heritage resource: as such, their importance in constructing or reconstructing dialogues concerning the past is crucial to our understanding of local histories, as well as how and where those histories fit within regional and national discourse.
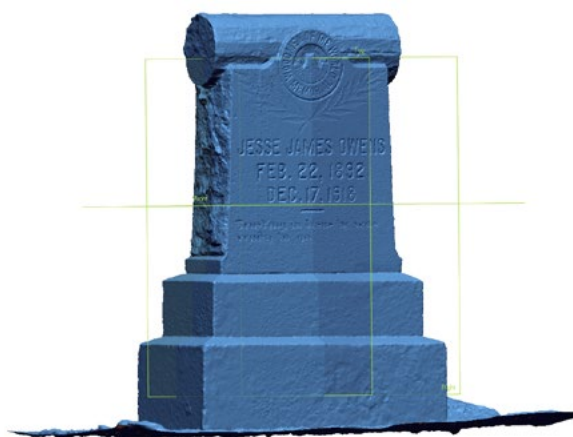

Figure 1. Textured (color) (ASCII.ply) and nontextured (ASCII.stl) 3-D meshes of the Woodmen of the World grave marker for Mr. Jesse James Owens at Oak Grove Cemetery in Nacogdoches, Texas (Selden 2015a).

Once the data are collected the 3D mesh can easily be exported to other software packages, where it can be animated (Figure 2) and used as the basis for surface and modeling. In the case of the Oak Grove Cemetery grave markers, the .obj files were downloaded from the project website (Autodesk 2015b) and imported into Geomagic Design X (reverse-engineering software) where they were modeled. Reverse-engineering, or creating a model from which duplicates can be generated, has significant potential in the fields of historical archaeology and historic preservation. The models produced using this process can be the basis of fabrication in various mediums.

Methods

Autodesk 123D Catch can render 3D meshes using apps available for Apple and Android phones, or from photographs taken with a digital camera (Autodesk 2015a). The camera used for this application was a Nikon Coolpix AW100. Guidance for planning a first shoot is provided by Autodesk (2011a), along with guidance for mesh cleanup (Autodesk 2011b) and creating an animation (Autodesk 2011c). For the Oak Grove Cemetery project, the time that it took to capture the images was minimal (approximately 10–15 minutes), but processing time was

Figure 2. Animated 3-D mesh of a marker from the Oak Grove Cemetery in Nacogdoches, Texas. (Graphic by author, 2015.)

substantially longer (approximately 1 hour or more per mesh). The free version of the 123D Catch software reduces each of the images to 3 megapixels (Chandler and Fryer 2013; Green et al. 2014), making it unnecessary to use high-end equipment for data collection. Additionally, 123D Catch meshes are cloud-processed, reducing the need for expensive computers and processing software (Spring and Peters 2014). Once processed, it is possible to view the contribution of each of the images to the 3D mesh (Figure 3).

For the Oak Grove Cemetery project, photographs were collected at varying times of day, and time of day was not found to be a factor in creating the meshes. The strategy for capturing the images necessary to create each mesh was to begin by taking 12–20 images around the marker, being sure to include two or three feet both above and below the marker (ground surface) in each image. The second pass included another 10–20 images (again, moving around the marker) of the top of the marker at an oblique angle, where the side of the marker and the ground surface were also included—a practice that may require a ladder. The third pass focused upon the base, and the final pass upon detail shots (at varying focal lengths) for complex geometry (e.g., undercuts).

In numerous instances, it was necessary to manually stitch the photos (Autodesk 2011d), which consists of placing four points at the same location on three images. These points are placed virtually within the 123D Catch software—physical contact was never made with any of the markers. This process is necessary when the program is unable to automatically stitch the photographs together, which often creates minor distortions and holes in the mesh. While this process is neither difficult nor tedious, it increases the time necessary to create the final render.
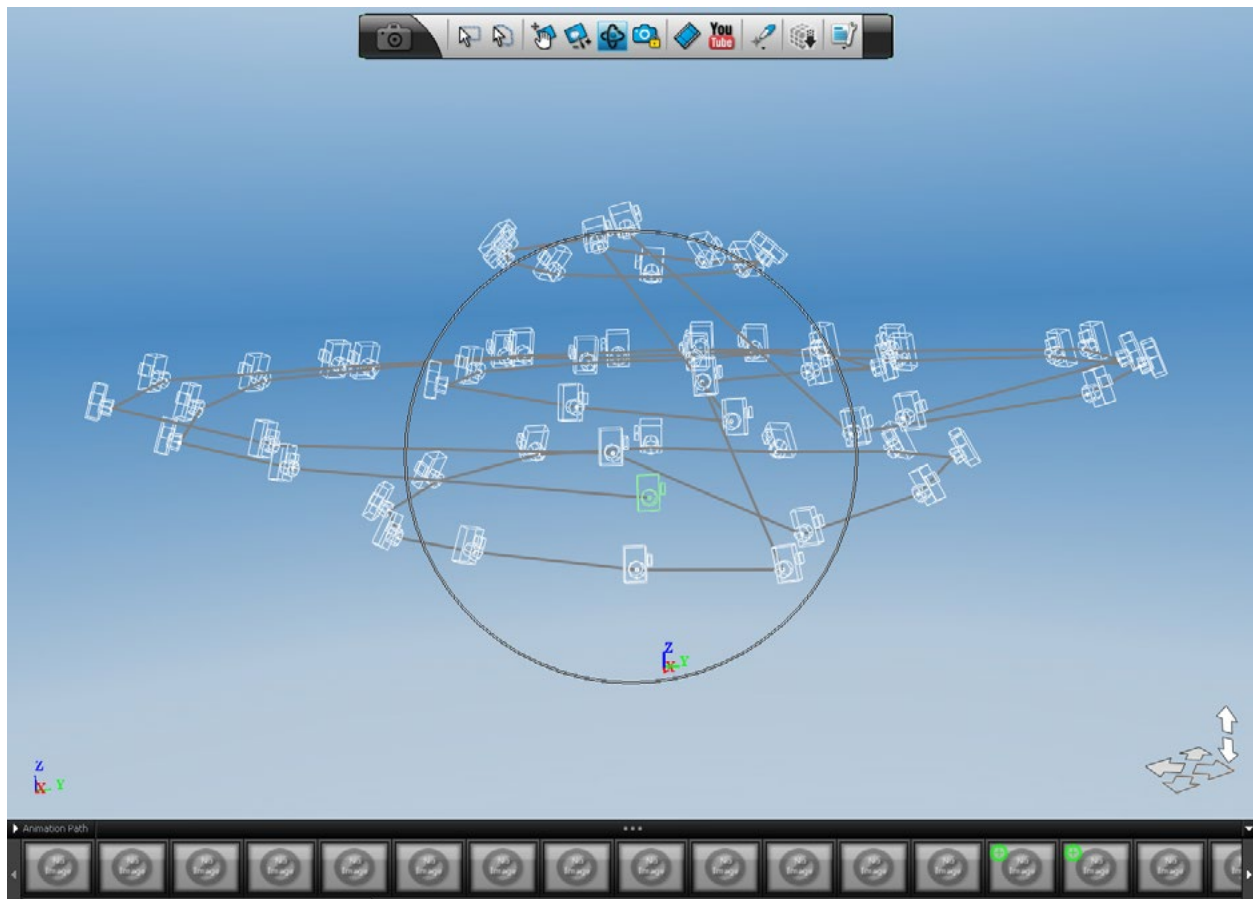

Figure 3. Autodesk 123D Catch interface illustrating the various camera positions used to create one of the 3-D meshes. (Graphic by author, 2015.)

Once created, each of the 3D meshes was scaled according to measurements taken at various points on each of the physical markers (Autodesk 2011e). This process rescales the entirety of the mesh; in this instance we used a measurement taken of the base at the front of each marker (measuring from left to right). The measurement is then inserted into the 3D scene, and the remainder of the mesh is rescaled based upon that measurement. After the grave marker data were processed and properly scaled using the steps outlined above, the meshes were published, then downloaded for the modeling process.

3D Modeling Grave Markers

In addition to the more traditional documentation efforts, markers can be reverse-engineered using one of two methods; by creating a 3D surface or a solid model. Both methods yield a model that can be exported to CAD/CAM-based software. One method is to render a nonuniform rational b-spline (NURBS) surface based upon the 3D mesh (Figure 4a), and another is to construct a solid model around the 3D mesh (Figure 4b). Both the surface and solid models can be exported as .step and .iges files for use in a variety of CAD-based software packages.

The creation of a NURBS surface is an automated process in Design X, and can be used to create a surface (freeform) model of the 3D mesh that can immediately be exported to CAD/CAM software prior to fabrication. The benefits of this approach are numerous, and it can be used to create an accurate model of the marker in its current form. Should the marker have been damaged or have degraded through time however, solid modeling may be the better option. While more time is required to create a solid model, all elements can be modeled using a pre-specified deviation ($\pm\,0.03$ mm in the grave marker case) around the 3D mesh, and any damaged or degraded areas can be corrected. This process is composed of creating 2-D sketches for various mesh profiles based on a point, vector, or planar surface that are subsequently extruded, revolved, lofted, or swept. Surface primitives (circles, cones, toruses, etc.) can also be used to insert basic shapes into the model as warranted. After the basic form is created, the various fillets and chamfers can be added. The benefit of a solid model is that it can be constructed in a manner consistent with the original intent of the de-signer, whereas elements of degradation and damage will be included in the NURBS surfaces. It is also possible to enlist a hybrid, where the NURBS surface is added to the solid model. This could be particularly useful in areas of complex geometry, cutting down on the time needed to create the final model.

Marker Monitoring

Since it is possible to calculate the deviation between multiple 3D meshes, the Oak Grove Cemetery project team will create numerous meshes of the same markers at various times throughout the next five years. The data can then be used to calculate various measures of deviation between the current and previous meshes in Geomagic Verify, allowing the growth of organics to be monitored and any movement of the markers that are currently sloping toward the ground to be recorded. On those markers where damaging practices have been used (e.g., cleaning with bleach), the impacts of those practices might better be documented and quantified.

While it would be ideal to have a mesh of the marker prior to the application of a destructive technique, it may be just as useful to document the progression of the damage through time, perhaps by creating an annual mesh (as well as a control, where available), through which degradation and erosion can be cataloged and illustrated. Simple photography is also useful for documenting this process, but the 3D meshes can be compared against one another in Geomagic Verify (or other similar program) and deviations between them can be calculated. This manner of documentation and analysis could provide cemetery managers with tools to better demonstrate—quantitatively—which markers might warrant additional preservation or stabilization treatments. These data may also help with the pursuit of grant funding to cover costs associated with maintaining historic cemeteries.

Public Outreach

While the interests of the project team primarily lie within the realm of documentation and analysis, 3D models of headstones do provide yet another method through which historic cemetery managers might engage in public outreach (McCarthy 2014). For this project, each marker was
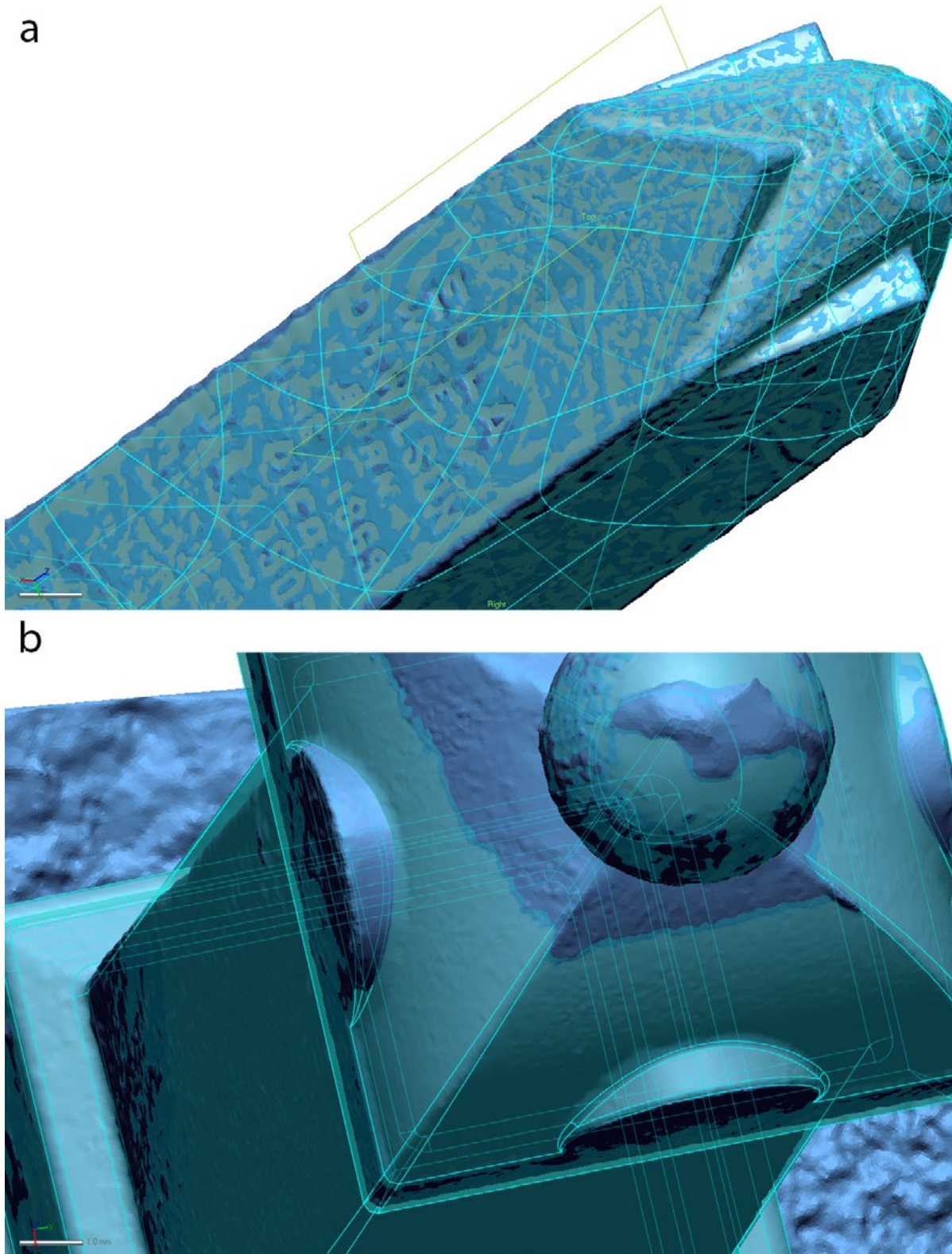
Figure 4. Two methods used in reverse-engineering: (*a*) nonuniform rational b-spline (NURBS) surface, and (*b*) 3-D solid model atop 3-D mesh of marker from Oak Grove Cemetery in Nacogdoches, Texas. (Graphic by author, 2015)

shared through social media (Twitter, Facebook, LinkedIn, Google+, and a research blog [Selden 2015b, 2015c, 2015d]), where users could view the animated meshes. Additionally, the project team will be uploading the models to CRHR:ARCHIVE (Selden 2015a), where they may be further explored, manipulated, and downloaded for use in future projects. Metadata fields for each marker include the marker name (name of the person buried), marker date (date range of birth to death), marker eulogy, marker cemetery (name of cemetery), marker city, marker county, and marker state. Downloadable files include an ASCII. stl (3D print ready), ASCII.ply (color model), and a 2-D screenshot of each marker.

Due to the relative ease with which the models can be created, incorporating this manner of documentation effort into existing curricula can help to extend humanities-based research methods into those areas traditionally reserved for STEM-based learning. This could potentially help to expand funding opportunities and assist with the recruitment of more technologically savvy students into humanities-based learning experiences. While beyond the purview of this article, the incorporation of these data in virtual museums (Selden et al. 2014) could help to further extend the reach of efforts focused upon 3D documentation and analyses.

While exploring potential educational applications for the 3D models, the project team found that it is also possible to create 3D cardboard (or wood) puzzles (Figure 5) of the markers that can easily be cut out and assembled (see Appendix A). These cardboard models have the added benefit of providing a tangible component to what is otherwise a purely virtual experience. The cardboard puzzle included here as Appendix A is in a .pdf format and can therefore be imported for use with a laser cutter. Potential applications of 3D cardboard puzzles include fundraising and public education. They might also be used to demonstrate the progression of tilt in a particular marker to policy makers and funding agencies by providing a tangible model of this progression, as well as a model of what the marker would look like if reset.
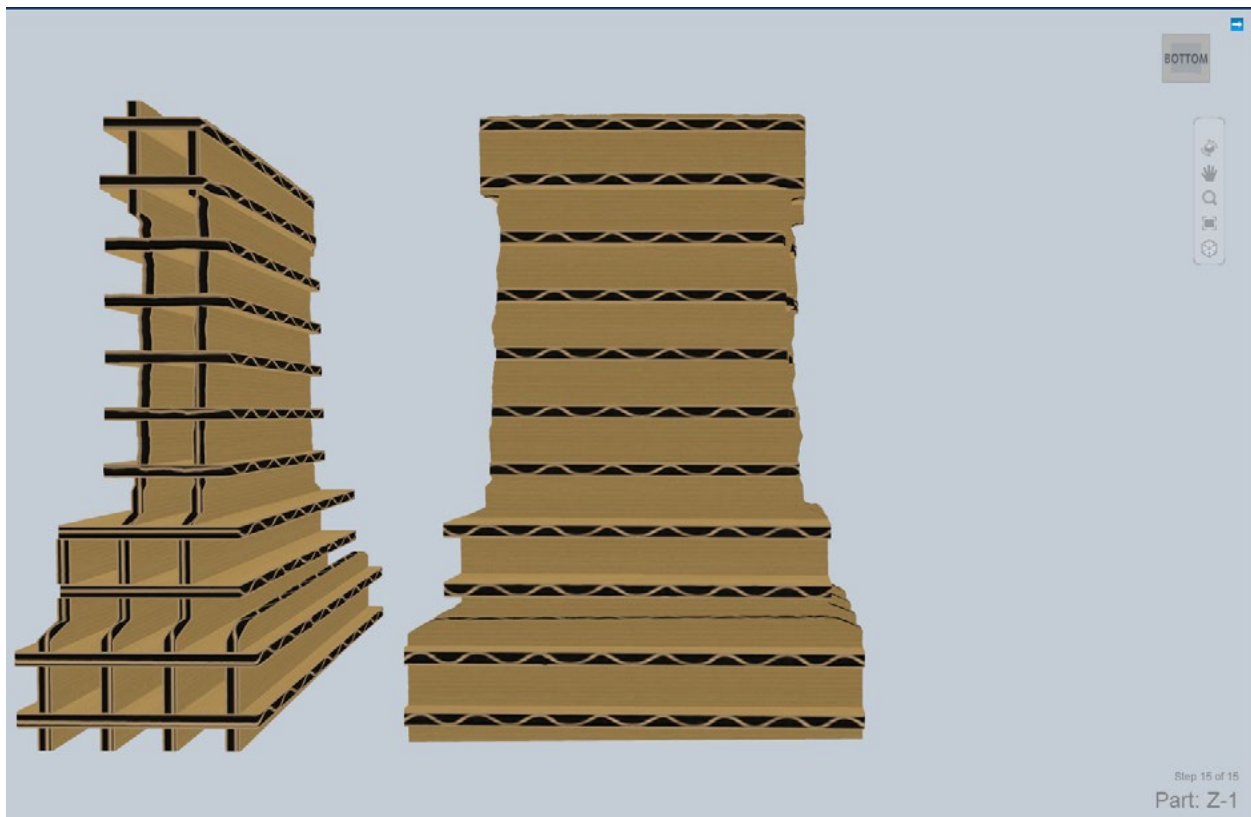

Figure 5. Three-dimensional cardboard model of the marker that appears in Figures 1 and 2. The plans for this model are included as an appendix. (Graphic by author, 2015)

Summary and Conclusions

The contribution of photogrammetry to historic cemetery management could be substantial as an analytical and educational tool. From monitoring growths upon, and movements of, the markers to reverse-engineering damaged elements that warrant refurbishing or refabricating, the addition of photogrammetry to historic cemetery management carries potential for meaningful advances in the care of these historic resources. While the time commitment is not small, once generated the 3D meshes can augment public outreach and education programs, extending access to cemetery resources through social media, digital archives, and other online venues.

References

Autodesk
2011a   123D Catch, Create Your Own Planning, Getting Started Series. Electronic resource, <https://www.youtube.com/watch?v=7TfXXJxDsXw&list=PL2F8EF70230430FC2&index=1>. Accessed 30 March 2015.

2011b   123D Catch, Mesh Details, Getting Started Series. Electronic resource, <https://www.youtube.com/watch?v=WZB7RUFS2fo>. Accessed 30 March 2015.

2011c   123D Catch, Animation, Getting Started Series. Electronic resource, <https://www.youtube.com/watch?v=YHbcqBFHf1w&index=2&list=PL2F8EF70230430FC2>. Accessed 30 March 2015.

2011d   123D Catch, Manual Stitching, Getting Started Series. Electronic resource, <https://www.youtube.com/watch?v=5yPt66D1S2E>. Accessed 30 March 2015.

2011e   123D Catch, Custom Scene Scale, Modeling Series. Electronic resource, <https://www.youtube.com/watch?v=kbd3ITVHAjA>. Accessed 30 March 2015.

2015a   123D Catch. Electronic resource, <http://www.123dapp.com/catch>. Accessed 30 March 2015.

2015b   Oak Grove Cemetery – Markers. Electronic resource, <http://www.123dapp.com/Project/Oak-Grove-Cemetery-Markers/3597667>. Accessed 30 March 2015.

Chandler, J., and J. Fryer
2013   Autodesk 123D Catch: How Accurate Is It? *Geomatics World* 2(21):28–30.

De Reu, Jeroen, Gertjan Plets, Geert Verhoeven, Philippe De Smedt, Machteld Bats, Bart Cherretté, Wouter De Maeyer, Jasper Deconynck, Davy Herremans, Pieter Laloo, Marc Van Meirvenne, and Wim De Clercq
2013   Towards a Three-Dimensional Cost-Effective Registration of the Archaeological Heritage. *Journal of Archaeological Science* 40:1108–1121. <http://dx.doi.org/10.1016/j.jas.2012.08.040>.

Green, Susie, Andrew Bevan, and Michael Shapland
2014   A Comparative Assessment of Structure from Motion Methods for Archaeological Research. *Journal of Archaeological Science* 46:173–181. <http://dx.doi.org/10.1016/j.jas.2014.02.030>.

Kramer, Miriam
2013   Autodesk 123D Catch. *Popular Science* 282(4):74.

Koutsoudis, Anestis, Blaž Vidmar, and Fotis Arnaoutoglou
2013   Performance Evaluation of a Multi-Image 3D Reconstruction Software on a Low-Feature Artefact. *Journal of Archaeological Science* 40:4450–4456. <http://dx.doi.org/10.1016/j.jas.2013.07.007>.

Magnani, Matthew
2014   Three-Dimensional Alternatives to Lithic Illustration. *Advances in Archaeological Practice* 2(4)285–297. <http://dx.doi.org/10.7183/2326-3768.2.4.285>.

Martínez, Santiago, Juan Ortiz, and MªLuz Gil
2015   Geometric Documentation of Historical Pavements using Automated Digital Photogrammetry and High-Density Reconstruction Algorithms. *Journal of Archaeological Science* 53:1–11. <http://dx.doi.org/10.1016/j.jas.2014.10.003>.

McCarthy, John
2014   Multi-image Photogrammetry as a Practical Tool for Cultural Heritage Survey and Community Engagement. *Journal of Archaeological Science* 43:175–185. <http://dx.doi.org/10.1016/j.jas.2014.01.010>.

Sanger, Matthew C.
2015   Determining Depositional Events with Shell Deposits using Computer Vision and Photogrammetry. *Journal of Archaeological Science* 53:482–491. <http://dx.doi.org/10.1016/j.jas.2014.10.026>.

Selden, Robert Z., Jr.
2015a   WoW_Owens_OakGrove. Electronic resource, <http://crhr-archive.sfasu.edu/handle/759656957/1462?mode=full> Accessed 30 March 2015.

2015b   3D Woodmen of the World Headstones from Oak Grove Cemetery in Nacogdoches, Texas. Electronic resource, <http://wp.me/p41HMA-cm7>. Accessed 30 March 2015.

2015c   Using Photogrammetry to Reverse-Engineer a Headstone. Electronic resource, <http://wp.me/p41HMA-d6E>. Accessed 30 March 2015.

2015d   3D Headstones from Oak Grove Cemetery in Nacogdoches, Texas. Electronic resource, <http://wp.me/p41HMA-hJd>. Accessed 30 March 2015.

Selden, Robert Z., Jr., Timothy K. Perttula, and Michael J. O'Brien
2014   Advances in Documentation, Digital Curation, Virtual Exhibition, and a Test of 3D Geometric Morphometrics: A Case Study of the Vanderpool Vessels from the Ancestral Caddo Territory. *Advances in Archaeological Practice* 2:64–79. <http://dx.doi.org/10.7183/2326-3768.2.2.64>.

Spring, Adam P., and Caradoc Peters
2014   Developing a Low Cost 3D Imaging Solution for Inscribed Stone Surface Analysis. *Journal of Archaeological Science* 52:97–107. <http://dx.doi.org/10.1016/j.jas.2014.08.017>.

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APPENDIX A

Plans for the cardboard model shown in Figure 5. The plans can simply be printed, glued to cardboard, and cut out. As a .pdf, this document can also be imported for use with a laser cutter. Click on the image below to open the printable .pdf in a new window.