White Paper Report

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White Paper on

New Digital Tools For Polychromy of Digital Models of Sculpture

(NEH grant # HD 51022)

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Summary. The aims of this grant were two-fold: (1) to create a digital tool to make it easier for humanists to add color to 3D meshes of sculpture; (2) to use as a test bed the statue known as the Augustus of Prima Porta (Vatican Museums) to show how color can be added to a 3D mesh of an ancient statue. These two goals were achieved. The results can be seen on the project webpages.[1] Moreover, we also made unanticipated progress in solving a problem that long has plagued creators of 3D content: we cooperated with a start-up company to help create a new WebGL solution allowing web designers to incorporate interactive 3D models (including colorized models) as an element of a webpage in much the same way as they can display text or 2D images. We developed new relationships with three leaders in the field of 3D digital technology: Autodesk, FARO, and Pixologic.

Activities. The project goals were achieved despite two unexpected challenges that we encountered. First, the University of Virginia was unable to sign the Vatican Museums' standard agreement for third parties proposing to undertake work such as photography or 3D data capture on the premises of the museum.[2] So, with the approval of the NEH, the principal investigator obtained the permission of the Antikensammlung of the University of Erlangen (Germany) to scan an excellent first-generation cast of the statue (for the permission letter,

[1] At: www.digitalsculpture.org/tools.html; www.digitalsculpture.org/augustus/index.html.

[2] A number of unresolvable legal issues prevented the parties from reaching an agreement, despite a good-faith effort on both sides.

please see Appendix II).[3] The actual scanning and 3D modeling was done by Breuckmann GmbH. The grant application called for creating two versions of the digital model: one showing the current state (see Appendix I [a] and [c]); the other showing the statue with all the traces of color digitally restored (see Appendix I [b] and [d]). The restoration model was created by Matthew Brennan of The Virtual World Heritage Laboratory. Both models were posted on the project webpage.[4]

Secondly, the person tapped to be co-principal investigator at the time of the grant application had left the employ of the principal investigator's laboratory by the time the grant was received. The co-p.i. would have brought to the project the use of his software known as Scanview.[5] This is a stand-alone program, created in the late 1990s, that makes it practicable for end-users to run 3D models of complex objects such as statues of organic forms. It also uses a system of "secure remote rendering" to protect the intellectual property of the full scan model. Experience has shown that cultural heritage institutions throughout the world do not typically allow end users to download the full scan model without signing a contract to do so. Moreover, end users typically do not need the full model; instead, they require as quick a visualization of the full model as their bandwidth permits. Scanview addresses this problem by downloading to the end user only a dramatically simplified 3D model while keeping the full scan model secure on a server. The simplified and full models communicate with each other such that when the end user stops moving the mouse over the simplified model on his computer, the server generates the exact same view of the full model and sends it to the end user as a PNG image.

The original idea behind the present grant application was to build a colorizing tool into Scanview so that the software could be used both to view and to paint 3D meshes of sculpture.

The co-p.i.'s departure necessitated that a different approach be taken. There were two aspects of Scanview that needed to be replaced: (1) as a

[3] Research completed by the principal investigator and sponsored by the Samuel H. Kress Foundation had already shown that because plaster is more receptive to laser light than is marble, there are advantages to scanning a good, first-generation plaster cast.

[4] http://www.digitalsculpture.org/augustus/.

[5] http://graphics.stanford.edu/software/scanview/,

real-time interactive browser of 3D meshes (something Scanview could already do when we applied for the grant); (2) as a platform into which a colorizing tool could be embedded (the new feature we proposed to add to Scanview through the grant).

The opportunity to solve the first problem arose when the principal investigator made the acquaintance of the owner of a start-up company that was developing an alternative and, in the principal investigator's view, superior solution to the problem of interactive browsing of 3D models addressed by Scanview. The new solution made it possible to run interactive 3D models in standard HTML browsers such as Firefox and Chrome. The principal investigator offered the company use for noncommercial, developmental purposes several of his lab's large 3D models of sculpture. In return, the company granted the University of Virginia a four-year free license to use its software. The resulting partnership was mutually beneficial and without cost to the parties.

There are several advantages to the new browser-based solution as compared to Scanview. First of all, unlike Scanview, it is not a stand-alone program. To achieve this, the new program runs on standard HTML browsers that have adopted a new standard called WebGL.[6] It is expected that the standard will shortly be implemented in other browsers such as Safari and Opera. Microsoft has indicated that Internet Explorer will not support WebGL. So the WebGL community has developed several solutions to enable IE users to benefit from WebGL applications.[7] Unlike Scanview, which supports only gray scale, the new solution supports color. Finally, and most important of all, the new solution makes it possible for web designers to incorporate interactive 3D models onto web pages with the same ease and control that they have long enjoyed for text and 2D images. Meanwhile, Scanview remains a stand-alone program that does not run in an HTML browser.

For all its strengths, the new solution does have several shortcomings. One pertinent to this grant is that it is not readily able to accommodate the painting of 3D meshes. So for this, the principal investigator

[6] See http://en.wikipedia.org/wiki/WebGL.
[7] The three solutions available as of the date of this report are: Google Chrome Frame; IEWebGL, and CWebGL.

partnered with the ISTI-CNR lab in Pisa, the developer of Meshlab, a software package for editing 3D meshes.[8] The strength of Meshlab is that it is free, open source software. The weakness of the software is that it is an assemblage of dozens of different, completely undocumented functions. Included among these is a useful tool for painting 3D meshes. The principal investigator persuaded ISTI-CNR that it made sense to create, at project expense, a special edition of Meshlab that contains only the paint and strictly related functions. This has been posted on the project's webpage where it has been freely available since September 2011.[9] Our experience shows that end-users find Meshlab Paint Edition easy to learn to use. Its particular strength is that it quickly enables students and scholars with little technical training in the editing of 3D meshes to paint a 3D model. This makes it superior to another excellent, but much harder to use piece of freeware: Pixologic's Sculptris.[10] The latter may, however, be the right solution for "power users" of digital technology who cannot afford a license of Mudbox or Zbrush.

Thanks to the grant, the principal investigator was able to hire Mr. Matthew Brennan, a technician who brought with him knowledge of Zbrush,[11] which, along with Autodesk's Mudbox,[12] is one of the two software packages typically used to paint 3D meshes in computer graphics companies, digital film studios, etc. Through the collaboration of Brennan, the principal investigator, and the project's consultant for polychromy—Prof. Paolo Liverani—it became clear that Meshlab Paint Edition does not obviate the need for use of software such as Zbrush, which was used for the final version of the Augustus of Prima Porta. An additional benefit of Zbrush is that it has a built-in function for outputting as video the results of editing the 3D mesh. The Virtual World Heritage Laboratory now routinely publishes movies along with interactive, WebGL-based 3D models on its digital sculpture web pages. It will not be surprising to find that professional tools are required for obtaining the best professional results. This should not be taken to diminish the value of Meshlab Paint Edition, which remains useful when a student, conservator, or scholar wants to mark up a 3D mesh

[8] See http://en.wikipedia.org/wiki/MeshLab.
[9] See "Meshlab Paint Edition" on http://www.digitalsculpture.org/tools.html.
[10] http://www.pixologic.com/sculptris/.
[11] http://www.pixologic.com/home.php.
[12] The other package is Autodesk's Mudbox (http://usa.autodesk.com/adsk/servlet/pc/index?id=13565063&siteID=123112).

with his color solution before handing it over to a technician to implement in a program like Zbrush or Mudbox.

One unexpected and welcome result of this grant is that Pixologic, the publisher of Zbrush, has become a sponsor of the principal investigator's laboratory to which it has donated a number of seats of Zbrush.

Audiences. This project is aimed at students and scholars of Greek and Roman art. The start-up grant is one of a series of initial research projects undertaken by The Virtual World Heritage Laboratory to lay the foundation for creating something lacking at the present time: a free library of scientifically accurate 3D digital models of ancient sculpture. At the present time, study of sculpture is limited to 2D photographic views. But sculpture is three dimensional and cannot be properly appreciated and analyzed without the information that only an interactive 3D viewing can provide. Tens of thousands of students study ancient art in US colleges and universities each year, whether superficially in general education courses or in depth in more advanced courses. Web statistics show that our project website (www.digitalsculpture.org) has been receiving over 100 visits per days since it was revamped in October, 2011. Here are the average number of visits:

Month	**Average number of visits/day**
October, 2011	156
November, 2011	136
December, 2011	134

Evaluation. We evaluated the project internally in terms of our meeting of project goals. As reported above, the goals were successfully met. For external evaluation, we conducted an e-mail survey of scholars active in the field of ancient Greek and Roman sculpture, asking them to view the project webpage and to send comments. We received many appreciative remarks about the new WebGL solution. Scholars who have seen the website have been highly receptive to participating in follow-up projects, including the projected implementation grant. The only criticism received concerned the restricted compatibility of the new solution: for example, it cannot run Internet Explorer, nor can it run under Windows XP even when the end user is using a browser that

supports WebGL. In the future, we plan to address these issues and make a new, improved WebGL solution available across all operating systems and browsers.

The project was accepted for presentation at one international peer-reviewed conference—Computer Applications to Archaeology 2011 (Beijing, April, 2011)—and at four by-invitation meetings: Motion in Place Platform (University of Sussex, July 10, 2011); Autodesk CTO summit (San Francisco, September 8, 2011); Getty Museum and University Malaga Conference on Digital Art History (Malaga, Spain, September 20-22, 2011); and FARO 3D Documentation Conference (Feb. 22, 3012 in Orlando, FL). At the Beijing conference, the principal investigator was also invited to give the closing conference keynote address on the digitization of sculpture. Response to these conference presentations has been uniformly positive.

Continuation of the Project. The larger project to create a free library of scientifically accurate 3D models of important works of sculpture from all periods and cultures continues apace. We plan to apply for a NEH Implementation Grant to add up to 50 new statues to our existing collection.

Institutional commitment. The Virtual World Heritage Laboratory of the University of Virginia reiterates its commitment to provide web hosting for the project results for at least the next three years.

Cooperative relationships. The sponsorship of Pixologic, publisher of Zbrush, has already been mentioned, as has the possible collaboration with ArtStor to ensure that our 3D models reach as large an audience as possible. We have received the cooperation of Faro, one of the world's major scanning companies, to provide free services for sculpture in Europe through their German branch. We have been invited by The Dresden State Museums to work with Faro in 2012 to scan statues in its collections and use our WebGL solution to publish the results as interactive 3D models on the museum's website. We have developed a close collaboration with Project Photofly of Autodesk, which is developing a free 3D data capture service called 123D. This software has the potential to dramatically lower the cost of 3D data capture, which now typically costs ca. $10,000 per statue.

Long-term Impact. Three-dimensional sculpture of complex organic forms has long posed a challenge to digital technology. This explains why there are almost no 3D digital models of the world's great statues available online today. Accurately capturing and digitally representing such data are much more complex tasks than digitizing a text, 2D image or 3D object with relatively simple geometry such as a work of architecture. Digital models of statues can consist of over 100 million polygons resulting in file size far too large for speedy transmission over the Internet. The Digital Sculpture Project is addressing these and related problems that have stood as impediments to bringing the Digital Revolution to the study of the world's great sculpture. The present project has resulted in several enormous steps forward including the ability to display color for the first time; the ability to add color to 3D meshes at no cost and with little, if any, training; and, most important of all, the ability to use interactive 3D models of objects such as statues as normal design elements of web pages. The impact on the study of sculpture should be enormous: in effect, in no small part thanks to the present grant, the digitization of sculpture has just now reached the point where texts and images were when Tim Berners Lee invented the World Wide Web in 1989-90.

Impact on public perception. As evidenced by industry sponsorships and invitations to give presentations and keynotes at scholarly conferences, the Digital Sculpture Project has made the Virtual World Heritage Laboratory well-known all over the world as the only research group focusing primarily on solving the many technical challenges standing in the way of the creation of scientifically-authenticated, highly accurate, and high-resolution 3D digital models of complex objects such as sculpture.

Grant Products:

- Meshlab Paint Edition (downloadable at no cost from: http://www.digitalsculpture.org/tools.html
- Augustus of Prima Porta: 3D digital model showing the current state of the statue (viewable at no cost at: http://www.digitalsculpture.org/augustus/index.html

- Augustus of Prima Porta: 3D digital model showing restoration of all traces of the ancient polychromy (viewable at no cost at: http://www.digitalsculpture.org/augustus/index_video.html

Conclusion and Lessons Learned. The two main goals defined in the grant application were reached. We created a free, easy-to-use tool for colorizing 3D meshes (Meshlab Paint Edition);[13] and we scanned, modeled, and restored the polychromy of the Augustus of Prima Porta (cf. Appendix I).[14] Since October, 2011 the results of the project have been posted on the relevant pages of The Digital Sculpture Project website of The Virtual World Heritage Laboratory at the University of Virginia. There were also some unanticipated positive results of the project including development of a new WebGL solution for running 3D models interactively on standard HTML web pages; and new lab relationships with leading 3D companies (Autodesk, FARO, and Pixologic).

The main lessons learned were that:

- Traditionally, restoration of the damaged and lost features of sculpture (including color, or polychromy) was done via plaster or (more recently) resin casts. Today, such restoration may also be done using 3D digital technology.
- If the purpose of restoring the statue is to publish hypotheses of reconstruction for students, scholars, and the general public, digital technology offers a far more efficient and effective publication method than does the physical cast.
- If the purpose of restoring the statue is to experiment with alternative hypotheses in a conservation laboratory prior to making physical repairs or intervention on the original work of art, then the digital model offers a quicker and much more flexible approach than does the physical cast.
- In creating the digital model of a statue of marble or metal, it is acceptable (and sometimes even preferable) to use not the original but a first-generation plaster or resin cast. This is because of the cast's greater receptivity to the scanning process, which in the cases of marble and metal can often result in noise distortion.

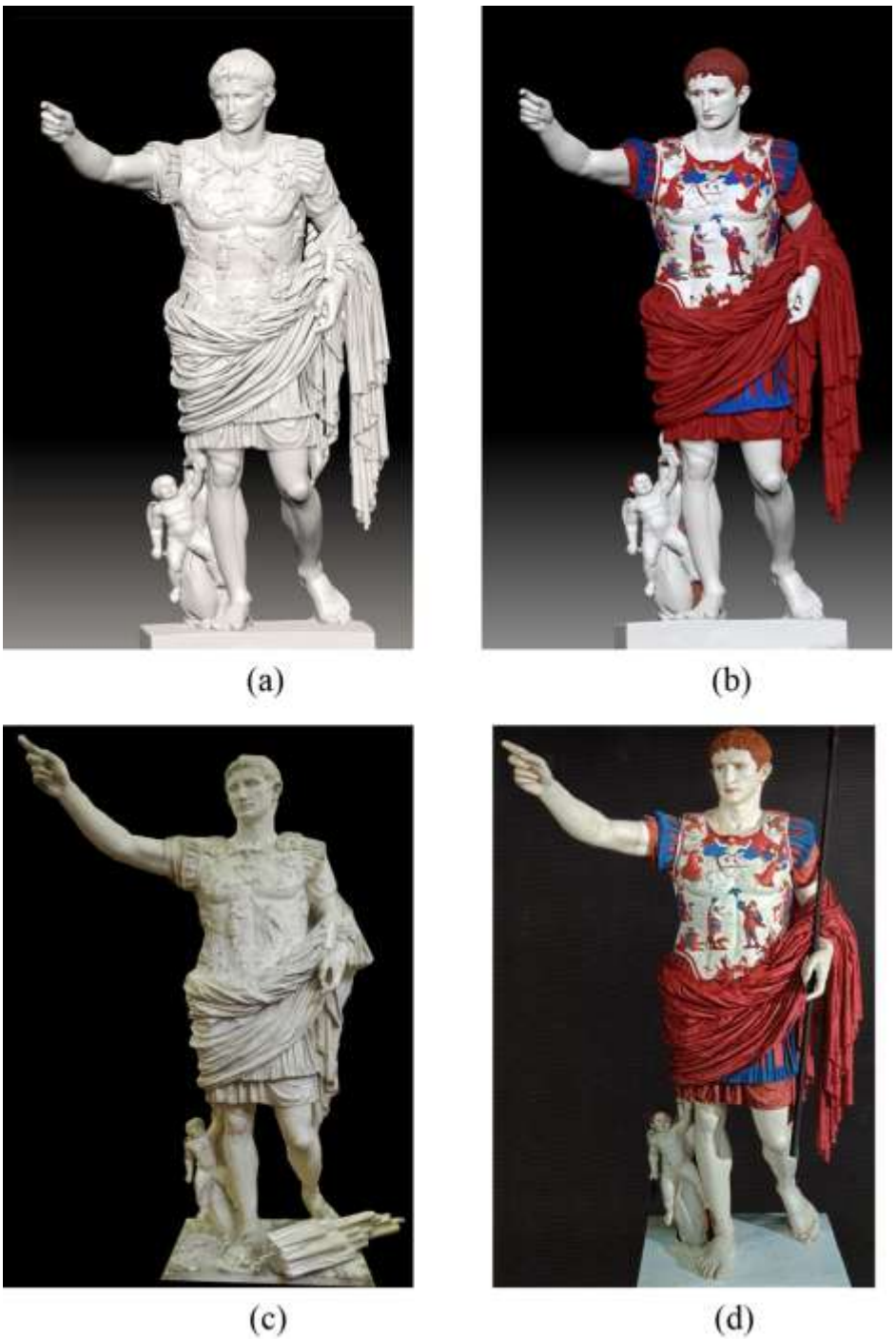
[13] Downloadable at no cost from: http://www.digitalsculpture.org/tools.html.
[14] These models can be viewed at no cost at: http://www.digitalsculpture.org/augustus/index.html.

- In any digital restoration of lost polychromy, it is essential that qualified relevant experts on sculpture and historical painting techniques be consulted.
- Such experts may find it efficient to express their ideas about how the polychromy should be restored both verbally in writing and visually by means of a free, easy-to-use mesh painting tool such as Meshlab Paint Edition. "Power users" of digital technology may also wish to consider the use of Sculptris, another piece of freeware.
- Best results for painting 3D digital meshes of complex objects such as sculpture of organic forms are obtained from professional products such as Audodesk's Mudbox and Pixologic's Zbrush. The main barrier to use of these products is not cost (in fact, academic licenses are not prohibitively expensive) but training: they are complex tools with a steep learning curve even for professional digital technicians.
- If the experts on sculpture and painting use Meshlab Paint Edition, the resulting model(s) should be used by a professional digital technician to prepare the final version using Mudbox or Zbrush.
- Digital publication of the restoration 3D digital model should be done in two formats: (1) as a short movie showing a rotation of the model of the statue; (2) as an interactive 3D model. For the former, the built-in animation tools can be used, or (if greater flexibility in setting up the shots is required) the models can be exported to software such as 3D Studio Max. For the latter, WebGL should be used to display the model on a standard web page.
- As in any project of 3D digital restoration that strives toward scientific results, the recommendations of The London Charter for the Computer-based Visualization of Cultural Heritage should be observed.[15]

Finally, we take this opportunity to thank the National Endowment of the Humanities for its generous support of this project and record that we have given public acknowledgement of this support on the Credits page of The Digital Sculpture website.[16]

[15] http://www.londoncharter.org/,
[16] See: http://www.digitalsculpture.org/credits_augustus.html.

Appendix I:
Images of the Augustus of Prima Porta



(a) Digital model of the current state of the statue; (b) digital restoration showing all traces of color found on the statue; (c) the cast in Erlangen; (d) the colorized cast in the Vatican Museums.

Appendix II:
Permission Letter from the University of Erlangen

Friedrich-Alexander-Universität
Erlangen-Nürnberg

Institut für Klassische Archäologie
Antikensammlung
Dr. Martin Boss

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An

Erlangen, den 6. Februar 2011

Betreff:

Dear Prof. Frischer:

I hereby grant you a perpetual license to publish online on your non-profit academic website the 3D scan data you will collect of the following cast in the collection of the Antikensammlung of the University Erlangen: Augustus of Prima Porta (inventory I 134). We ask that in any web publication of the 3D digital model of our cast that you acknowledge that the cast is the property of the Antikensammlung of the University Erlangen.

Yours,
Dr. Martin Boss, Curator

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