Computer Graphics and Cultural Heritage, Part 2

Continuing Inspiration for Future Tools

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Part 1 of this article examined the 50-year history of computer science and cultural heritage. It concentrated on challenges for technologies that document what exists—recording the evidence of our tangible cultural heritage.[1] From computing's early days, cultural heritage in its many guises has been inspiring computer scientists with computational challenges rooted in the evidence of past human experience.

Here, I examine the new types of analysis and new applications that the availability of large quantities of cultural-heritage data could enable. Currently, most of these applications are experimental. We can expect them to take many years of research before they mature and provide cultural-heritage professionals with novel research methods.

Visualization

"Visualization" has a slightly different meaning in archaeology than in computer graphics. In computer graphics, visualization is the set of tools and techniques that let us visualize a body of data. In archaeology, visualization is mainly the reconstruction of sites, based on the archaeological evidence, whereas the viewing of digital assets is assumed to be inevitable and a somewhat trivial adjunct.

Computer graphics also offers advanced understanding of light's behavior. This can increase our understanding of our ancestors' intentions in creating cultural artifacts. It also offers opportunities for communicating these virtual reconstructions with cultural-heritage professionals and the public.

Visualization in computer graphics often has a time dimension—a scene might be animated with people, as I discuss later, or a visualization might demonstrate how a piece of industrial machinery functions. There are also classes of object that are as yet only poorly documented and displayed digitally. Historical costume is an obvious class of object in which the best visualizations would show how the garments move. Modeling this accurately would require not only the physics of the simulated materials but also the engineering construction of the garment itself. This exercise would be challenging even without taking into account the degradation of materials over time.

Visualization as a way to present huge quantities of data in an understandable form, demonstrating patterns in the data, is only just emerging as these quantities increase.

Shape Grammars and Procedural Modeling in Reconstruction

In part 1, I considered applications that analyzed fragments of cultural artifacts and reconstructed past states by considering how the parts could be fitted together. Shape grammars use a set of production rules to describe the structural composition of a set of shapes in 2D or 3D within a class of object.[2] Procedural modeling also uses a set of rules to generate a parameterized class of object. Procedural modeling originated in the 1970s with the work of George Stiny and James Gips[3] and others in shape grammars, Christos Yessios in rule-based planning of architectural layouts on sites,[4] and others who experimented with the automated production of architectural forms.

The Rome Reborn project (http://romereborn.frischerconsulting.com) sets out to present the city as it might have looked at its height, around AD 320.[5] The project has evolved in a number of stages. The reconstruction initially included a digital terrain map and more than 7,000 buildings. Approximately 250 buildings were described

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Figure 1. A still from the procedurally generated crowd simulated in a reconstructed Pompeii.[7] To model the city's residential areas, researchers fitted procedural models for Roman vernacular architecture to the footprints of buildings found during archaeological excavations on the site. (Source: ETH Zurich; used with permission.)

in some detail; the rest were modeled from the Plastico di Roma Antica model at Rome's Museum of Roman Civilization. Later versions have added detail to these models using rule-based systems to simulate appropriate designs and have added detailed models of major sites in the city.

Researchers used the CityEngine procedural modeling system to reconstruct ancient Pompeii. They fitted procedural models for Roman vernacular architecture to the footprints of buildings found during archaeological excavations on the site.[6] They also procedurally generated a video simulating crowds of Romans on the site (Figure 1 shows a still).[7] As the characters circulate through the city, they undertake tasks, with a pattern of behaviors based on probabilities that any character will perform each task (for example, entering the bakery to buy bread).

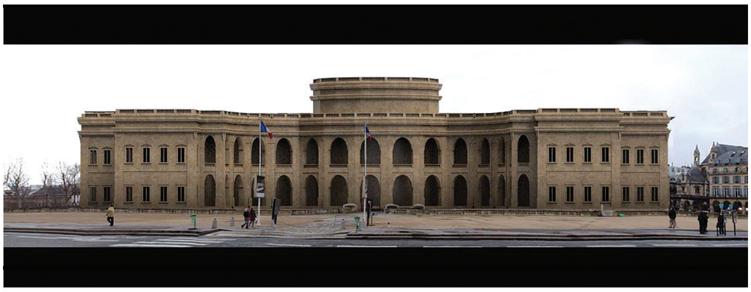
Procedural modeling systems for architecture worked initially with a set of rules that divided up building plans or facades. This paradigm originated from translating architectural plans into 3D. Constructive solid geometry (for example, Ian Braid's BUILD system[8]) is based on volumetric modeling ab initio. An intellectual descendent of that approach is Sven Havemann's Graphics Modeling Language (GML), a scripting language that has been used to apply volumetric modeling to cultural-heritage content.[9] Figure 2 shows the results of setting parameters within a procedural model of Gothic church windows to fit a template to an actual example.[10] This also generates a very compact description of a complex object.

Analyzing the mathematical relationships embodied in particular styles has a long history. Probably the most widely known studies are those of Vitruvius in the first century AD analyzing classical temples' layouts and proportions.[11] George Stiny and William Mitchell developed a parametric shape grammar representation of the ground plans of Palladio's villas as the essence of Palladian style.[12] They then used parameters with the grammar to generate the plan for Palladio's Villa Malcontenta.

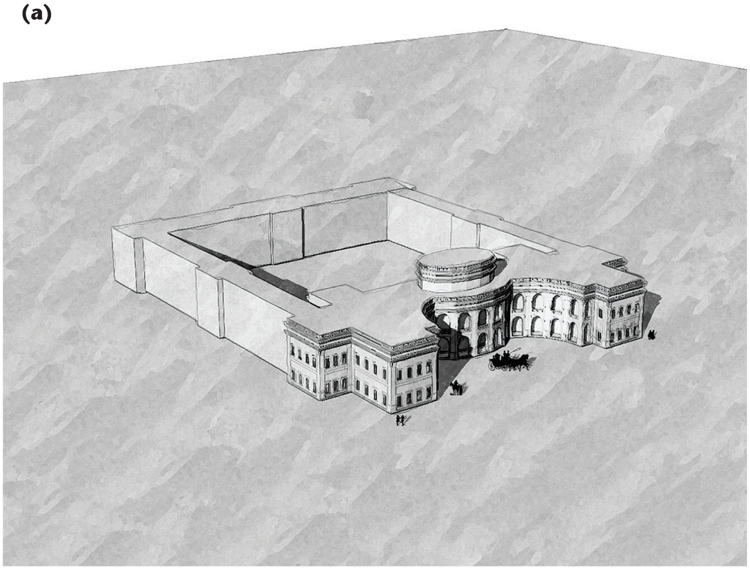
One current objective is to reverse-engineer this process using parameters derived from the partial remaining evidence of the past to hypothesize complete artifacts in a class. So, you could use the footprint of a building known to be from a particular period and in a particular construction style, along with production rules for buildings in that style, to hypothesize structures that could have occupied the site. In this case, you would derive parameters from the evidence and use them to tune a generic understanding of how items in a class are constructed. The more evidence that was available and used, the higher the probability the hypothesis would be meaningful.

(a) (b) (c)

Figure 2. Applying procedural modeling to architecture. (a) A Gothic-style ecclesiastic window. (b) A Graphics Modeling Language (GML) template of this class of object. (c) Fitting the GML template to the window. (Source: Sven Havemann, TU Graz; used with permission.)



(a)



(b)

Figure 3. Applying procedural modeling to a building that has never existed. (a) A model of the first design by Bernini for the Louvre Palace. (b) A nonphotorealistic rendering of the model of the first Bernini design. (Images © University of Brighton; used with permission.)

In fact, the principle can be applied even where the artifact has never actually existed. For example, researchers used CityEngine to visualize building designs proposed in an architectural competition in the 1660s to extend the Louvre Palace (now the Louvre Museum) to include a new east wing. Figure 3 shows a reconstruction of one of the competition entries using CityEngine.[13] The winning design has also been modeled using GML.[14]

Studies tend to focus on particular iconic architectural styles rather than less grandiose styles. Vernacular styles are typically shared by thousands of buildings and have been adapted by many architects for stylistic reasons or to fit different circumstances. The fact that humans can often identify individual buildings as typical of architectural periods shows that these buildings demonstrate specific characteristics. However, quantifying each style's essence is more challenging. This is partly because capturing the geometric complexity and set of interrelationships isn't easy (see, for example, Figure 4[15]). In addition, the factors that allow human recognition of specific styles include elements beyond the composition of shapes that digitization might not capture. These include material types and construction methods that time-of-flight scans of building facades don't normally capture.

The Science of Light

One of the most iconic combinations of computer graphics and cultural heritage is *The Parthenon*, a film directed by Paul Debevec[16] that built on several years of research.[17,18] It combines

Figure 4. An analysis of Brunswick Square in Brighton during the Regency period.[15] (a) The east elevation. (b) The west elevation. Quantifying a style's essence is challenging, partly because capturing the geometric complexity and set of interrelationships isn't easy. (Source: University of Brighton; used with permission.)

- documentation of the Parthenon's condition;
- relighting based on onsite observations; and
- reconstructions based on reincorporating statues no longer on the site, using plaster casts from the Basel Skulpturhalle's Parthenon sculpture collection.

The film combines many computer science innovations with stunning visuals and pioneering research to illustrate technologies' potential to reunite dispersed cultural assets—an objective that has been called *digital repatriation*. The approach provokes a range of reactions; for some individuals and communities this form of repatriation is unwelcome and an inadequate restitution for one culture's looting of another's heritage.

Other studies have examined how the light sources available in past societies influenced not only how people viewed artistic works but also how artists created them. For example, Alan Chalmers' film explores how flame-based light sources would have been used in prehistoric caves, to hypothesize how the flickering might have simulated animation in cave paintings.[19] Subsequent papers investigated the light spectra of different historical fuels and additives.[20,21] The results for illuminating different materials demonstrate how artists exploited material properties to create particular effects. Figures 5 and 6 show the calculated impact on the appearance of frescoes in Pompeii and a Byzantine painting, respectively.

Multispectral scanning is also undergoing rapid development. Researchers have used it to remove noise from low-quality ancient documents and to exploit chemical properties of inks and surfaces to reveal normally invisible aspects. For example, Martin Lettner and Robert Sablatnig demonstrated improvements in scanning ancient manuscripts.[22] Meg Twycross used similar techniques to see through water damage in medieval manuscripts of the York Mystery Plays.[23]

Visualizing Spatially Organized Datasets

By definition, cultural-heritage data is associated with geographically located cultures, whose influences move and spread as countries war, societies trade, and peoples migrate to create diasporas in other cultures. Computer graphics can aid the presentation of complex time series data to analyze, cross-correlate, and visualize these temporal and spatial movements.

For example, a recent study mapped the movement of UK design professionals over time (see Figure 7), on the basis of registered locations of designers with different specializations.[24] Similar studies in other disciplines have plotted the density of reported crime and the associated property values. Such spatial presentations offer the opportunity for different ways to explore and understand the data. Of course, this type of study can only operate with the available underlying data, and the data sources' quality and completeness dictate the quality of results. However, computer scientists have been known to overlook the lack of high-quality data as they seek to demonstrate the potential of research methodologies for the

(a) (b)

Figure 5. The appearance of frescoes in Pompeii with (a) modern lighting and (b) oil lamp lighting.[21] The results for illuminating different materials demonstrate how artists exploited material properties to create particular effects. (Source: Alan Chalmers; used with permission.)

(a) (b)

Figure 6. A Byzantine painting's appearance with (a) modern lighting and (b) candlelight. [21] Note how the candlelight emphasizes the halos. (Source: Alan Chalmers; used with permission.)

humanities at a time when routine digitization of sources is neither widespread nor systematic.

Recently, researchers have been using medical-imaging technologies to examine cultural-heritage artifacts internally. Figure 8 shows the results of using computed-tomography scanning technology on a corroded object.[25]

Cultural Heritage and the Big-Data Agenda

The concepts of big data and analytics are only slowly being formulated in the contexts of arts and humanities research, partly because of the limited volumes of available data. The earliest applications have dealt with processing text data, statistical methods for natural-language processing, and generating corpora of texts in different languages and from different authors.

For computer graphicists, the data will likely be multidimensional, and organized collections tend to be much smaller as the number of dimensions increase. Image libraries are common. However, searches are frequently based on searching tags and metadata, and the idea of implementing a content-based search over all the images on the Internet is in relative infancy. Nevertheless, image search, segmentation, and recognition remains a rapidly

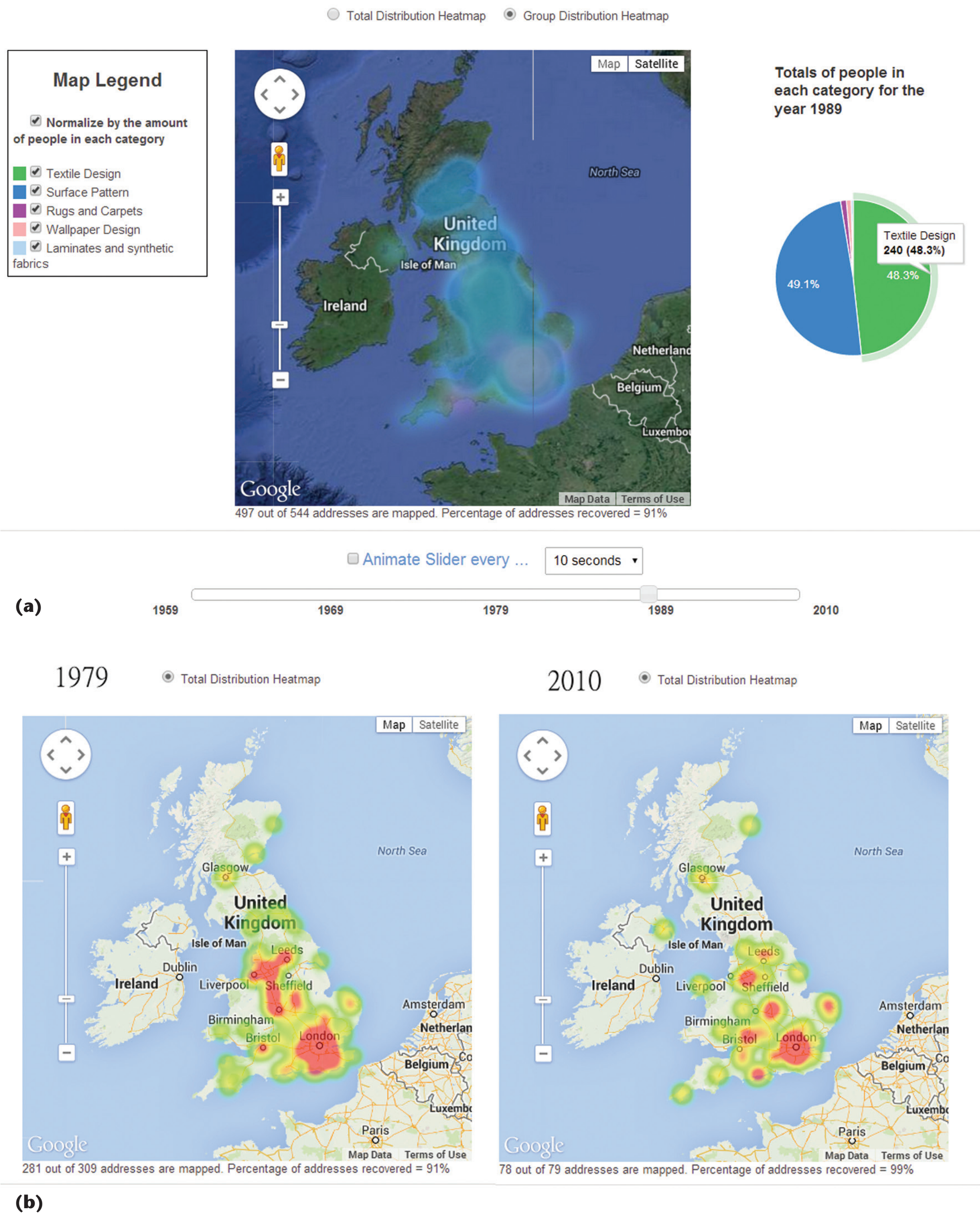


Figure 7. Mapping the movement of UK design professionals from 1959 to 2010.[24] (a) The distribution of different types of textile designers in 1989. (b) Heat maps showing the distribution of typographers in 1979 and 2010. Computer graphics can aid the presentation of complex time series data to analyze, cross-correlate, and visualize such distributions. (Source: University of Brighton; used with permission.)

growing domain.[26] The PASCAL project (Pattern Analysis, Statistical Modelling, and Computational Learning; http://pascallin.ecs.soton.ac.uk/challenges/VOC/voc2012/index.html) ran a series of open competitions on recognizing objects from a number of classes in realistic scenes. After that series finished in 2012, the mantle was picked up by the 3D Shape Retrieval Contest 2013 (SHREC 13; http://3dor2013.di.univr.it/SHREC13_Cfp.pdf). Undoubtedly, the methods developed to address such challenges will find cultural-heritage applications.

With 3D repositories, the number of artifacts currently digitized is even lower, and the lack of consistent representations of objects (for example, from CAD models to triangle meshes) hampers cross-collection search. This paucity of data means

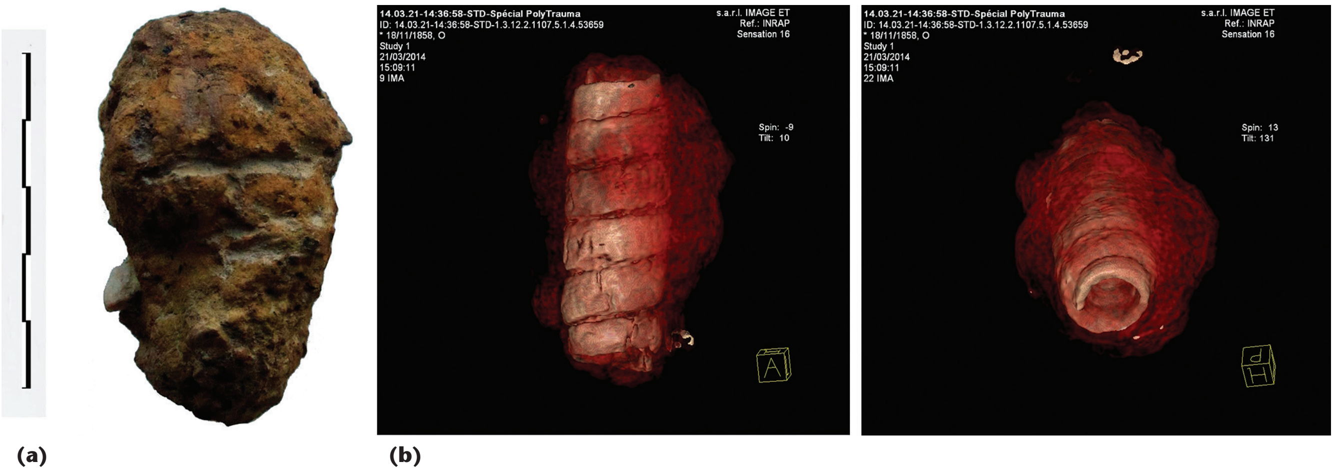


Figure 8. Using medical imaging to examine a cultural-heritage artifact internally. (a) A corroded Gallic manufactured object. (b) Two views of the internal structure. (© J.C. Durand—Inrap; used with permission.)

that we don't yet have a good test environment for experimenting with new big-data visual or shape analytics for cultural heritage. We also lack a consistent shape vocabulary and language to describe and analyze (for example) a triangle mesh's semantic elements. This means we have far to go before shape analysis of collections of 3D objects is routinely useful for heritage professionals. However, this avenue of research is computationally interesting and challenging. The ongoing series of Eurographics workshops (http://diglib.eg.org/EG/DL/WS/3DOR) provide considerable background in this area.

Large-scale datasets are beginning to be established and, by linking data from many diverse sources, are creating "big data" for the arts and humanities, but exploitation requires the appropriate analytic techniques. This involves developing methods that look for patterns to detect features of interest that would be too buried in other data to allow manual identification.

In part 1, I described how researchers used DNA to identify the remains of the last Czar's family. As the volume and complexity of cultural-heritage data online grow, researchers will seek out the patterns and characteristics uniquely associated with particular cultures and artistic styles, and so on. The research on using shape signatures in content-based shape search reported in part 1 is an early step in this direction. Similarly, the mathematical characterization of styles through parameterized shape grammars and procedural models might act as the cultural equivalents of DNA. These "signatures" should help empower the visual and big-data analytics and drive novel research methods.

In some cases, an alternative might be to enlist "the crowd," whether to solve jigsaw puzzles on a massive scale or correct optical-character-recognition failures in large-scale digitization projects. An effective combination of crowdsourcing and user-friendly open-access tools would allow large numbers of people to help solve massive challenges. The crowd's efforts would be followed by professional review of the results. Experiments in crowdsourcing heritage projects have already occurred—for example, to transcribe handwritten texts, such as in the Transcribe Bentham project (http://blogs.ucl.ac.uk/transcribe-bentham). However, few experiments have tried to capture 3D models of community-heritage features.[27]

Linked Open Data and Multimodal Knowledge Bases

Many objects include embedded semantics related to what they represent or how they're used (that is, their function, including symbolic functions). One challenge critical to the use of novel applications in cultural heritage is the ongoing development of the information base. This must support both mechanisms for annotating cultural objects with links to other information and query systems that can explore linked open data.

For example, Figure 9 shows a carved wall at Karnak that looks like a spreadsheet, apparently representing a calendar of offerings that a neighboring community was to make to the temple. The challenges include not only dealing with the stones and interpreting them through their damage but also establishing and maintaining their relationships to other knowledge systems. This example clearly illustrates the challenges of multimodal information systems interconnecting the language of hieroglyphics, carved shapes, spatial organization, 3D object representation, and other knowledge bases.

Physical Surrogates through 3D Printing

3D printing affords a different form of visualization, creating a physical representation of an artifact that users can handle and view from any angle. It's one of the fastest-growing areas of technology, with new devices rapidly going into production and broadening the range of material finishes, colors, and accuracy.

For example, the Kazafani boat is a unique 12th-century-BC grave artifact from Cyprus, unearthed in 1963 and on display at the Cyprus Archaeological Museum. The boat is too fragile to travel. So, when the Smithsonian Museum wanted to exhibit it, the Cyprus Institute and local curators collaborated to use rapid prototyping—3D printing—to produce a surrogate for the exhibit.[28] Size, shape, colors, surface markings, and even evidence of past damage and restoration were all recorded and recreated.

By the time organizers planned to display the replica at the 3D-COFORM exhibition in Brighton, even the copy that had been created by the 3D-COFORM project was deemed a cultural artifact in its own right and required more shipping documentation.[29] Time limitations meant this wasn't an option. So, the digital file was shipped electronically and reprinted in the University of Brighton's prototyping laboratory, and a fine-arts graduate painted the new copy. This version was half-size to accommodate the maximum print size available. The whole exercise became part of the exhibition's narrative, prompting debate on new opportunities and surrogacy in exhibitions (see Figure 10).

Figure 9. The remains of a carved wall from the Temple of Karnak, part of which resembles a spreadsheet, illustrate the challenge of semantics. This example combines physical objects, broken parts, surface carving, hieroglyphics, and semantic content. How do you record this? What's the significance? How do you link the representations and other knowledge sources?

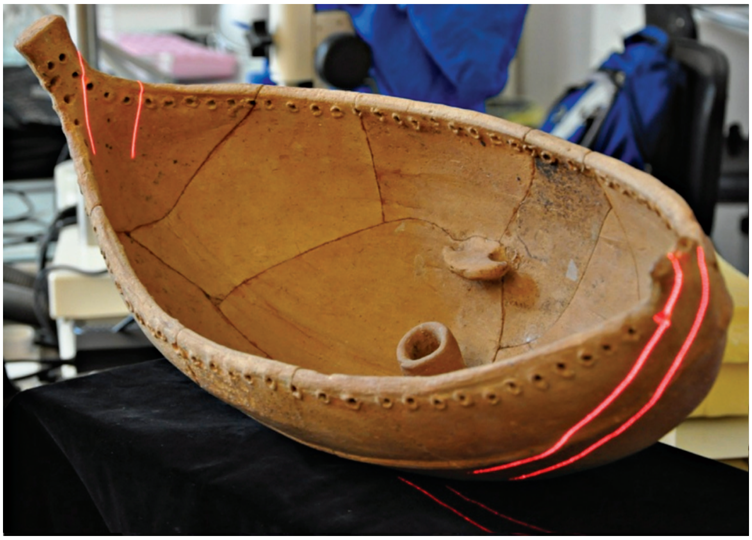


Figure 10. The Kazafani boat. The boat was first scanned. Then, a digital file of the boat was shipped electronically and 3D printed, and the copy was painted. (Source: Cyprus Institute / 3D-COFORM; used with permission.)

The 3D scanning also enabled conservators to analyze the boat in greater detail without risking any damage to the original. For example, they could use the digital model to evaluate the alignment of the fragments in the original restoration.

The experiment has shown how simple and cost effective this method of creating replicas can be—with obvious benefits for museum curators, education, and merchandise. Museum-based educationalists often use a small collection of pieces that can be allowed out of the museum and made available during schools' visits. This lets students handle objects that bring to life the topic being discussed. These objects are by definition suitable for handling by many people—they're placeholders for the objects that can't be circulated so freely. 3D printing allows a different form of surrogacy in which people can handle tangible representations of iconic museum items.

I know of no studies comparing 3D printed objects' educational effectiveness to that of substitute objects related to the same narrative. However, this approach is reminiscent of the use of plaster casts in art education in the 19th century. It also suggests a potential business model for touring exhibitions that avoids transportation challenges, the risk of damage to the original, and insurance costs.

Bringing the Past to Life

In almost all previous digital documentation and reconstruction of the past, human activity has been noticeably absent. The experiment with Pompeii is one exception, but authors must balance imagination with reality, and audience satisfaction with cultural sensitivities. Onsite experiences typically use live actors, but these face the similar challenges of addressing cultural interpretation. In addition, this approach's cost and effectiveness must be balanced with those of either recording or using virtual humans. Prerendered animations or films aren't intrinsically interactive and hence become merely a different form of passive consumption.

Whereas the example of *Lara Croft: Tomb Raider* (see part 1) clearly presents a fiction associated with the Ta Prohm temple, the more engaging and believable a narrative is, the greater the risk of distorting perceptions of the underlying cultural heritage. This is dangerous ground in which fictional narratives might create new perceptions of cultural heritage, blurring the boundaries between history and fantasy.

Plenty of opportunities exist for computer graphics to enrich the appreciation of tangible heritage. For example, the Chronicon Vulturnense is a 12th-century illuminated manuscript describing the history of the Benedictine Monastery of San Vincenzo, including its sacking by the Saracens on 10 October 881.[30,31] This narrative, coupled with the extant archaeological evidence of shattered windows, melted glass, burnt wood, and arrowheads, could form the natural basis for an intriguing serious game drawing players into the area's history and that period of history. Or, these artifacts could form the basis for a fictionalized account as an interactive experience in a visitor center. However, both these applications run the risk of interpreting the evidence beyond its known meaning and redefining the heritage's significance.

The sensitivities are similar to those surrounding the proposals to restore the Bamiyan Buddhas (see part 1). A concern for curators is that the underlying educational experience in serious games can easily be lost in the narrow divide between making the game engaging and delivering nothing more than heritage-based entertainment. The educational perspective that the experience adopts might also be seen as inappropriate. This opens up the potential for criticism of such experiences as culturally inappropriate or distorting truth in the interests of particular world views that discount some, possibly minority, opinions.

In part 1's conclusion, I outlined the challenges of making it routine practice in heritage organizations to use technologies that can already be effective. In this part, I examined less well-developed techniques that have yet to gain widespread acceptance in cultural-heritage organizations and among researchers and practitioners.

Clearly, this interdisciplinary community faces research challenges at all points in the digital workflow of capture, analysis, presentation, and preservation. The early stages have seen interdisciplinary communities of pioneers from both technological and cultural-heritage backgrounds build trust based on shared interdisciplinary research projects. This has been a long process of sharing aspirations and vocabulary and, gradually, producing new understanding. Computer science is beginning to provide a new generation of practical tools that offer opportunities for cultural-heritage professionals that couldn't be envisaged without the technologies.

Probably our greatest challenge is to ensure a supply of well-educated technologists and cultural-heritage professionals who span these interdisciplinary domains and collaborate across the divide to create tools and discover new understandings of cultural-heritage evidence. The result will be a shared enterprise with many opportunities for new ways of working, new research questions, and new methods still to be explored. The recently approved Centre for Doctoral Training in Science and Engineering in Arts, Heritage and Archaeology (http://seaha.org), principally funded by the UK's Engineering and Physical Sciences Research Council, should continue to provide doctoral graduates to help fill this gap for years to come.

As the debate on reconstructing Bamiyan, which has continued for well over 10 years, and the projections in *The New Renaissance*[32] (see part 1) demonstrate, the timescales seem longer than others in technology. So, this interdisciplinary field is less mature than others, and the journey is really only just beginning.

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References

1. D. Arnold, "Computer Graphics and Cultural Heritage: From One-Way Inspiration to Symbiosis,

Part 1," *IEEE Computer Graphics and Applications*, vol. 34, no. 3, pp. 76–86.
2. L. March, "Letter from the Guest Editor: Forty Years of Shape and Shape Grammars, 1971–2011," *Nexus Network J.*, vol. 13, no. 1, 2010, pp. 5–13.
3. G. Stiny and J. Gips, "Shape Grammars and the Generative Specification of Painting and Sculpture," *Proc. IFIP Congress '71*, 1971, pp. 1460–1465.
4. C.I. Yessios, "Formal Languages for Site Planning," *Spatial Synthesis for Computer-Aided Design*, C. Eastman, ed., Applied Science Publishers, 1975.
5. K. Dylla et al., "Rome Reborn 2.0: A Case Study of Virtual City Reconstruction Using Procedural Modeling Techniques," *Proc. 37th Ann. Conf. Computer Applications and Quantitative Methods in Archaeology* (CAA 09), 2009, pp. 62–66.
6. J. Maïm et al., "Populating Ancient Pompeii with Crowds of Virtual Romans," *Proc. 8th Int'l Symp. Virtual Reality, Archaeology, and Intelligent Cultural Heritage* (VAST 07), 2007, pp. 109–116.
7. J. Maim, *Populating Ancient Pompeii with Crowds of Virtual Romans*, 2007; www.youtube.com/watch?v=ZA3gzqG94JQ.
8. I.C. Braid, *Designing with Volumes*, Cantab Press, 1974.
9. S. Havemann, "Generative Mesh Modeling," PhD thesis, Inst. of Computer Graphics, Braunschweig Technical Univ., 2005.
10. S. Havemann and D.W. Fellner, "Generative Parametric Design of Gothic Window Tracery," *Proc. 5th Int'l Symp. Virtual Reality, Archaeology, and Intelligent Cultural Heritage* (VAST 04), 2004, pp. 193–201
11. V. Pollio, *Ten Books on Architecture*, Digireads.com, 2005.
12. G. Stiny and W.J. Mitchell, "The Palladian Grammar," *Environment and Planning B*, vol. 5, no. 1, 1978, pp. 5–18.
13. E. Calogero et al., "Using Procedural Modeling to Explore Alternative Designs for the Louvre," *J. Computing and Cultural Heritage*, vol. 6, no. 4, 2013, article 19.
14. R. Zmugg et al., "A New Approach for Interactive Procedural Modelling in Cultural Heritage," *Proc. 40th Conf. Computer Applications and Quantitative Methods in Archaeology*, 2012.
15. E. Calogero et al., "Using Procedural Modeling as a Framework for Representing Style: An Example from Regency Architecture," *31st Ann. Conf. European Assoc. for Computer Graphics (Eurographics 2010), Areas Program (Cultural Heritage)*, 2011, pp. 41–48.
16. P. Debevec, *The Parthenon*, 2004; http://gl.ict.usc.edu/Films/Parthenon.
17. J. Stumpfel et al., "Digital Reunification of the Parthenon and Its Sculptures," *Proc. 4th Int'l Symp. Virtual Reality, Archaeology, and Intelligent Cultural Heritage* (VAST 03), 2003, pp. 41–50.
18. C. Tchou et al., "Unlighting the Parthenon," *ACM Siggraph 2004 Sketches*, 2004, p. 80.
19. A. Chalmers, *Firelight: Graphics and Archaeology*, Siggraph Electronic Theater, 2000.
20. K. Devlin and A. Chalmers, "Realistic Visualization of the Pompeii Frescoes," *Proc. 1st Int'l Conf. Computer Graphics, Virtual Reality and Visualisation* (AFRIGRAPH 01), 2001, pp. 43–48.
21. J. Happa et al., "Illuminating the Past—State of the Art," *Virtual Reality*, vol. 14, no. 3, 2010, pp. 155–182.
22. M. Lettner and R. Sablatnig, "Multispectral Imaging for Analyzing Ancient Manuscripts," *Proc. 17th European Signal Processing Conf.* (EUSIPCO 09), 2009, pp. 1200–1204.
23. M. Twycross, "Virtual Restoration and Manuscript Archaeology: A Case Study," *The Virtual Representation of the Past*, M. Greengrass and L. Hughes, eds., Ashgate, 2008, pp. 23–48.
24. K. Rodriguez-Echavarria et al., "Using GIS Technologies to Explore the Disciplinary Reach and Geographic Spread of British Designers," *Proc. 2012 Digital Humanities Congress*, 2012.
25. T. Nicolas et al., "Revealing Hidden Tangible Artefacts to Understand Intangible Cultural Heritage," private communication, 2014.
26. L. Van Gool et al., "Mining from Large Image Sets," *Proc. 2009 ACM Int'l Conf. Image and Video Retrieval* (CIVR '09), 2009, article 10.
27. K. Rodriguez-Echavarria, D. Morris, and D. Arnold, "Enabling Users to Create and Document 3D Content for Heritage," *Proc. 1st Int'l Conf. Creative Content Technologies* (CONTENT 09), 2009.
28. S. Hermon and L. Kalisperis, "Between the Real and the Virtual: 3D Visualization in the Cultural Heritage Domain—Expectations and Prospects," *Virtual Archaeology Rev.*, vol. 2, no. 4, 2011, pp. 59–63.
29. *3D-COFORM Film*, Parsley Productions, 2012; www.youtube.com/watch?v=N6CQjzNYEpE.
30. R. Hodges, "A Postcard from San Vincenzo Al Volturno," *Current World Archeology*, no. 47, 2012, pp. 60–63; www.aur.edu/wp-content/uploads/2012/10/richard-hodges-san-vincenzo.pdf.
31. R. Hodges, S. Leppard, and J. Mitchell, "10 October 881 Reconsidered by Archaeology: Introduction," *Acta Archaeologica*, vol. 82, no. 1, 2011, p. 291.
32. E. Niggemann, J. De Decker, and M. Lévy, *The New Renaissance,* Comité des Sages, 2011; http://ec.europa.eu/information_society/activities/digital_libraries/doc/refgroup/final_report_cds.pdf.

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