Quantitative Methods in the Humanities and Social Sciences

Matthew L. Vincent
Víctor Manuel López-Menchero Bendicho
Marinos Ioannides
Thomas E. Levy *Editors*

Heritage and Archaeology in the Digital Age

Acquisition, Curation, and Dissemination of Spatial Cultural Heritage Data

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Introduction

In recent years, cultural heritage and new digital technologies have grown increasingly closer together. Cultural heritage has gained much through the applications of these new technologies, with the ability to capture, visualize, and disseminate data in ways not previously possible through these methods. The continued advances mean that it is an exciting and opportune time to be part of the heritage field and witness this transformation from traditional analogue techniques to new digital techniques that empower us to engage in new lines of research. This volume represents an important contribution to digital cultural heritage and, more specifically, cyber-archaeology. Previous works (such as Ch'ng et al. 2013; Forte et al. 2012; Hermon 2007; Howland et al. 2015; Ioannides et al. 2014; Koutsoudis et al. 2015; Lercari et al. 2016; Levy 2013; Parry 2013; Pavlidis et al. 2007; Stylianidis and Remondino 2016) have highlighted many of advances in digital cultural heritage; however this book brings together some of the latest methodologies in a cohesive whole, specifically adopting a broad approach without a specific theme but rather adopting a holistic approach to digital cultural heritage. This volume has brought together the work we feel exemplifies the latest advances in terms of analytical methods as well as the best practices for archaeology and cultural heritage today.

We have broadly organized this volume into three sections: acquisition, curation, and dissemination, sections which broadly follow the cyber-archaeology model proposed by Levy (2013). Each section includes chapters that deal with some of the state of the art of the field, as well as case studies that show how some are engaging with heritage and new technologies. With the speed of development and change in digital technology and heritage today, no single volume can begin to encompass all that is being done or available in the field now. However, we hope that the volume can serve as a guide, as a blueprint, for the application of digital technology in cultural heritage. This is an increasingly important topic as digital applications to cultural heritage require a complete understanding as to the intentions, abilities, and purpose of these new applications. As cultural heritage and archaeological practitioners cannot be experts in both their field and spatiality as well as the emerging digital technology sectors, this book can help guide them in how they too can apply digital technology to their areas, as well as models for transdisciplinary research practices that can help enable them to continue to push their own research farther by bringing together varied disciplines.

Finally, we would also like to emphasize that while digital technology is exciting and the applications to cultural heritage promise great advances in the field today, it is necessary that we do not sacrifice cultural heritage and archaeological research for advances in digital technology. We insist that technology be at the service of cultural heritage and archaeological research in this instance, and not the other way around. Thus, it is the archaeological and cultural heritage research questions that drive innovations in the application of information technology in the digital humanities and digital social sciences.

Acquisition

One of the biggest impacts that new digital technology has had on cultural heritage has been 3D digitization of cultural heritage assets. The variety of applications is clear (Chane et al. 2013; Doneus et al. 2014; Fassi et al. 2013; Nocerino et al. 2014; Sansoni et al. 2009; Stanco et al. 2011; Yastikli 2007); it might be the digitization of an entire archaeological site or monument, all the way down to small finds or museum collections. It wasn't that long ago that digital elevation models (DEMs) had to be produced with painstakingly time-consuming methods such as total stations or GPS units. Creating a DEM for an archaeological site might take weeks if done quickly, and even then, have a low point density. Real Time Kinematic Global Positioning Systems (RTK GPS) have sped the work up considerably by removing the need to have two people working simultaneously. Sites could now be digitized in days rather than weeks. While the point density went up considerably, the accuracy was dependent on the operator holding the unit at the same height; otherwise the elevations could change considerably. Now with drones and photogrammetry, the data necessary to create a high-precision DEM of a site can take hours or even just minutes, and the processing time not adding too much more to the overall workload. 3D acquisition is opening new realms for cultural heritage by enabling practitioners to quickly and precisely represent aspects of heritage digitally that they could not previously have done with the same speed or accuracy as they can now.

The availability of terrestrial laser scanners (TLS) for cultural heritage documentation certainly helped to push forward high-accuracy 3D documentation of heritage assets. However, accessibility of these high-cost machines has prevented their wide-scale adoption as they are simply outside of many projects' budgets. The real change has come with the availability of photogrammetric techniques and software that have given researchers the power to digitally document heritage in 3D using just a digital camera (Howland et al. 2014; Levy et al. 2014; Stylianidis and Remondino 2016). These techniques produce highly accurate point clouds, ultimately allowing us to then create meshed and textured 3D models, DEMs, orthophotographs, or other photogrammetric outputs. Undoubtedly, photogrammetry has had an enormous impact on cultural heritage documentation and will continue to do so for many years to come.

In the chapter "Data Acquisition for 3D Geometric Recording: State of the Art and Recent Innovations," by Andreas Georgopoulos and Elisavet Konstantina Stathopoulou, the authors present a comprehensive review of the state of the art and advances in 3D documentation for cultural heritage. They review different 2D, 3D, and 4D (time) acquisition techniques related to cultural heritage. Georgopoulos and Stathopoulou give an in-depth look at each of these techniques, such as laser scanning, reflectance transformation imaging, and photogrammetry. This chapter should serve as an up-to-date guide on the best applications of these technologies, how to plan for the acquisitions, and how to choose which one you might want to use for a specific case.

In the chapter "Holistic Approaches to the Comprehensive Management of Rock Art in the Digital Age" by Víctor Manuel López-Menchero Bendicho, Mariano Flores Gutiérrez, and Jorge Onrubia Pintado, the authors present different digital documentations techniques, including digital photography and post-processing methodologies, photogrammetry, laser scanning, reflectance transformation imaging (RTI) photography, and even some rapid field acquisitions techniques. The authors emphasize the fragility of rock art and therefore, the urgency to document it using the techniques available to us today. In terms of global archaeology, the fragility and wide distribution of rock around the world make the application of new digital documentation methods of the twenty-first century especially relevant (Chippindale and Taçon 1998; Conkey 1987; David 2002; Ling 2014). Lopez-Menchero et al. acknowledge the rapid change in technology and documentation methodologies and that these will only continue to change and develop over the years. However, they conclude that in the field of rock art, it is necessary to continue to look towards these advances and employ the most appropriate and sustainable technologies available.

In the chapter "Materials Characterization for Cultural Heritage: XRF Case Studies in Art and Archaeology," by Brady Liss and Samantha Stout, the authors deal with one of the often-overlooked aspects of digital documentation: materials characterization. In the age of digital documentation, often the focus is primarily on geometry, particularly with the increased accessibility of photogrammetric digitization techniques. This has generated a buzz in the public mind that sees 3D documentation as preservation, even though it only records one aspect of cultural heritage. This chapter helps to raise awareness of the importance of materials characterization and uses X-ray fluorescence (XRF) to demonstrate the accessibility of tools available to heritage practitioners today. In some ways, this chapter complements the chapter by Zvalasky et al. concerning "Survey Analysis via Visual Exploration," which sets the stage for an online repository and research tool to examine the petrography of ceramic sherds. The chapter by Liss and Stout presents different applications of XRF, as well as discussing different tools being developed at UC San Diego: the WAVEcam and ARtifact for acquiring and visualizing these data respectively. The authors make a compelling case for the inclusion of materials characterization as a key tool in the digital archaeology toolkit. The case studies provided, as well as the tools discussed, are invaluable to anyone looking to document not only geometry but also some of the unseen aspects of cultural heritage.

Curation

After researchers acquire digital data, it is imperative to carefully manage these data, semantically enriching it and providing the necessary metadata to ensure the ability to reuse those data at a later point. This section of the volume presents two case studies involving crowdsourcing, a hot topic in cultural heritage which could easily fall into any of the three broad categories. The ability to harness the power of large numbers of participants to help manage, analyze, and process our heritage data is perhaps one of the most important advancements in digital heritage today. Furthermore, this crosses over into both acquisition (as often the "crowd" is providing us with original data) and dissemination, particularly in the case where the crowd's participation results in greater awareness of heritage among the public. The final part of this section deals with the fundamental aspect of data curation, that of semantics and ontologies. These concepts are key in managing our data and ensuring their future usefulness.

In the chapter "TerraWatchers, Crowd-Sourcing, and At-Risk World Heritage in the Middle East," by Stephen H. Savage, Andrew Johnson, and Thomas E. Levy, the authors present a crowdsourcing platform for the identification of looting, damage, and illegal excavation for at-risk heritage sites in the Middle East. This web-based platform employs a geographic information system (GIS), allowing users to document visible changes to heritage sites. Through crowdsourcing efforts, TerraWatchers is able to document changes at in-danger heritage sites, making it an invaluable resource for preservation planning efforts, as well as documenting the cost of conflict to cultural heritage. In the case of TerraWatchers, the authors have teamed up with the ASOR (American Schools of Oriental Research) Cultural Heritage Initiatives (http://www.asor-syrianheritage.org/) to help monitor at-risk cultural heritage in the war zones of Syria in particular, and the neighboring Middle East in general. In the case of TerraWatchers, the project is not open to the general public because of the specialized knowledge necessary to interpret satellite imagery. Accordingly, TerraWatchers is part of the larger University of California Office of the President (UCOP) Catalyst grant entitled "At-Risk World Heritage and the Digital Humanities" in which undergraduate students from UC San Diego, UC Merced, UCLA, and UC Berkeley are trained in how to determine a wide range of photographic signatures of damage to archaeological sites by military activities and natural formation processes such as erosion (https://www.universityofcalifornia.edu/news/cyber-archaeology-big-data-and-race-save-threatened-cultural-heritage-sites).

"Crowdsourced Data for Cultural Heritage," author Matthew L. Vincent further examines the applications of crowdsourcing in cultural heritage, some of the benefits and some of the difficulties of using such methods. As a case study, he presents his own project, Rekrei (formerly Project Mosul), the first platform for crowdsourcing the visualization of lost heritage. The impetus for Rekrei was the destruction of the Mosul Museum in Iraq by the Islamic State terrorist group and the need to find some way of reconstructing what had been proudly displayed in the museum before the advent of the conflict in Iraq.

The Rekrei platform allows the public to take an active role in preserving the memory of lost heritage by contributing photographs and time (in the form of organization and data processing). The platform has successfully recreated a virtual museum experience of the Mosul Cultural Museum, thanks to a partnership with the Economist Media Lab. The author examines some of the debate surrounding lost cultural heritage and reproductions, as well as the importance of documenting the process for the public to understand how these 3D digital representations of lost heritage are made.

In the study "Cultural Heritage Data Management: The Role of Formal Ontology and CIDOC CRM," by George Bruseker, Nicola Carboni, and Anaïs Guillem, the authors tackle one of the more complex issues of digital documentation and curation in cultural heritage: ontologies. Perhaps one of the most important issues yet to be resolved in cultural heritage is that of data interoperability and reuse. At the moment, the only international standard for cultural heritage data is CIDOC-CRM (ISO 21127:2014). The authors give a detailed overview of the importance of data harmonization, organization, and aggregation. They then present knowledge representation and engineering, before a comprehensive overview of CIDOC-CRM and its implementation in the cultural heritage domain. This chapter should give the reader an understanding of both the importance of the inclusion of ontologies in cultural heritage and how one might implement the CIDOC-CRM into their own data systems. The project reviews some of the existing CRM implementations, which might further guide the reader towards resources that they can implement in their own work and therefore contribute their data to a growing cloud of harmonized cultural heritage data.

Dissemination

The final section of this volume deals with dissemination of our cultural heritage data. Here, two case studies are presented demonstrating some of the state-of-the-art ways of sharing and disseminating cultural heritage data using digital technology. With the increasing integration of digital technology into cultural heritage fields, we are seeing these technologies used not only for internal purposes but also for sharing these data and results with other researchers and the greater public. New visualization platforms allow us to share 3D acquisition online with the entire globe, often with just a single click. Our data can be made to share interchangeably with other researchers, giving us the ability to work well beyond the confines of our own field or geographical area of focus. Virtual and augmented reality allow us to transport ourselves and others to worlds recreated to represent the hypothetical past, or to place heritage back into its original context. These are thanks to the integration of new digital technologies into the area of cultural heritage.

"A New Approach to Online Visual Analysis and Sharing of Archaeological Surveys and Image Collections," by Ilya Zaslavsky, Margie Burton, and Thomas E. Levy, the authors present a novel system sharing digital archaeological data online through a web-based interface. This tool, called Survey Analysis via Visual Exploration (SuAVE), allows researchers to visualize large datasets quickly and easily. Here, survey is used not in the idea of questionnaire, but rather in digesting a large sample of data from a specific area, such as a pottery, archaeological surveys, or archaeological site excavations. This platform gives users the ability to not only ingest these data but also perform statistical analyses using R, an open-source analytics environment. The authors demonstrate the capabilities of SuAVE in archaeology, and the chapter gives an example of legacy data from excavations at Shiqmim, Israel, and how they can be visually represented using this platform. This includes representations of burials, ceramics, as well as spatial distributions. The paper concludes that, while this is a general purpose survey tool, it has very positive implications for archaeological datasets and being able to publish and disseminate them using this platform. The potential of using SuAVE to visualize archaeometry data is also suggested.

In the chapter "Delphi4Delphi: Data Acquisition and Dissemination of Spatial Cultural Heritage Data: First Results of the Cyber-Archaeology Initiative for Ancient Delphi, Greece," by Ioannis Liritzis, George Pavlidis, Spyros Vosynakis, Anestis Koutsoudis, Pantelis Volonakis, Matthew D. Howland, Brady Liss, and Thomas E. Levy, the authors present a holistic framework for digital documentation in archaeology today. The project proposes a digital documentation project aiming to capture immersive visual imagery through both photogrammetric and 360 stereographic acquisitions. These data can then be used for researchers and public alike to provide educational and study materials. The chapter goals and acquisition techniques, emphasize the ability for these to be used outside of research frameworks and in the public sphere. The 3D models and immersive 360 panoramic imagery can be distributed to a variety of platforms, allowing Delphi to be visited and studied from anywhere in the world. These data will be incorporated into further research, such as archaeo-astronomical research, demonstrating the further importance and applicability of these sorts of acquisitions for wider archaeological applications. The chapter summarizes the methodology that is beginning to characterize many digital cultural heritage documentation projects through the "Digital Enterprise for Learning Practice of Heritage Initiative for Delphi" (Liritzis et al. 2016). It describes ongoing work that highlights the first large-scale interdisciplinary cyber-archaeology project to make use of structure from motion (SfM) and CAVEcam measurements of heritage monuments and artifacts in Greece on any significant scale (Levy 2015). Delphi was the most prestigious and authoritative oracle in the ancient Late Bronze Age and Classical world. Its reputation centered on the political decisions taken after consultation of the Oracle, especially during the period of colonization of the Archaic period (c. eighth to sixth centuries BC), when Greek cities sought her consent and guidance. The DELPHI4DELPHI presents a new innovative way to bring the cultural significance of this ancient Oracle site to the public and researchers.

Summary

Cyber-Archaeology represents the marriage of archaeology with computer science, engineering, and the natural sciences. In *Acquisition, Curation, and Dissemination of Spatial Cultural Heritage Data* researchers from the United States and Europe have come together to demonstrate many of the advances in Cyber-Archaeology since it began to crystalize as an important component of digital cultural heritage more than a decade ago (c.f. Forte 2010; Levy 2013). When cyber-archaeology emerged as a methodological and intellectual workflow for cultural heritage, two especially useful tools were not in the practitioner's tool box. We are referring to SfM photography for creating 3D photogrammetric models and crowdsourcing. In this volume, many of the authors have highlighted the usefulness of SfM work for cultural heritage documentation; others the utility and excitement of crowdsourcing as a "citizen scientist" tool to engage not only trained students and researchers but also the public in the cyber-archaeology endeavor. Both innovative tools facilitate the curation of digital cultural heritage and its dissemination. Together with all the chapters in this volume, the authors will help archaeologists, researchers interested in the digital humanities, and scholars who focus on digital cultural heritage to assess where the field is and where it is going.

The organization of the book reflects the essence of new technologies applied to cultural heritage and archaeology. Each of these stages brings their own challenges and considerations that need to be dealt with. The authors in each section present case studies and overviews of how each of these aspects might be dealt with. While technology is rapidly changing, the principles laid out in these chapters should serve as a guide for many years to come. The influence of the digital world on archaeology and cultural heritage will continue to shape these disciplines as advances in these technologies facilitate new lines of research.

Acquisition is certainly one of the fundamental challenges for practitioners in heritage and archaeology. Capturing data today that can be valid and useful tomorrow is one of the great unknowns. As experts, we often find ourselves looking back on past data and wishing our colleagues had recorded just one more element of metadata, or had taken one more photograph from a different angle. Experts today should strive to provide valid and useful data for generations to come, yet often this becomes a guessing game. The chapters included in this section should provide a template for future work, a template that highlights the principles for present and future work that will provide sustainable models for digital documentation.

Following acquisition, the expert must also pay attention to curation. Equally important, the future of digital documentation depends on how it is curated. Everyone has heard stories of modern-day excavations of digital data that have lost their usefulness due to lack of curation. Preservation of digital data requires preservation that can guarantee a future for generations to come.

Finally, dissemination puts these data into the hands of other researchers and the public. Dissemination is what pushes the data beyond the shelves of storage and allows the public to experience the past through these new technologies, but also opens new lines of investigation by giving access to these data to researchers around the globe. Digital technology promises significant changes in how we approach social sciences, cultural heritage, and archaeology. However, researchers must consider not only the acquisition and curation but also the dissemination of these data to their colleagues and the public.

The editors hope that the reader of this volume will find it to be instructive and useful, a volume that offers suggestions of how they might take on their own work and add their findings to a global perspective offered by these new technologies.

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Data Acquisition for 3D Geometric Recording: State of the Art and Recent Innovations

Andreas Georgopoulos
and Elisavet Konstantina Stathopoulou

Introduction

Monuments are irreplaceable evidence of world history and contribute to preserving historic memory. Their thorough study is an obligation of our era to mankind's past and future. During the nineteenth century, archaeological excavations became common practice, while they later matured in the twentieth century. Over the recent decades, international bodies and agencies have passed resolutions concerning the obligation for protection, conservation, and restoration of monuments. Nowadays, most countries of the civilized world are putting their scientific and technological efforts towards protecting and conserving the monuments, within or even outside their borders, assisting other countries for that particular purpose. These general tasks include geometric recording, risk assessment, monitoring, restoring, reconstructing, and managing Cultural Heritage.

It was in the Venice Charter[1] (1964) that the absolute necessity of the geometric recording of monuments before any future intervention was firstly agreed upon. This task, also referenced as geometric documentation of a monument, should be considered as an integral part of a greater plan, the Integrated Documentation of Cultural Heritage, and may be defined as the action of acquiring, recording, processing, and presenting the necessary data for the determination of the position and the actual existing form, shape, and size of a Cultural Heritage asset in the three-dimensional space at a particular given moment in time. The complete geometric documentation of a Cultural Heritage asset includes a series of necessary activities, from which visual metrics outcomes such as vector drawings, orthoimages, and 3D models may be produced.

3D geometric recording refers to the collection of such kind of data that will enable metric products in three dimensions (X, Y, Z) as well as in 2D. As we live and act in a three-dimensional world the 3D recording and subsequent reconstruction of objects, especially Cultural Heritage ones, adds significantly to realism, and hence enables a better understanding and studying of these objects. Thus, conservation, preservation, and protection of Cultural Heritage, in general, are directly benefitting from 3D recording. Furthermore 3D models find additional uses in education, dissemination, tourism, and, recently, in edutainment with the advancement of Serious Games (Anderson et al. 2010; Mortara et al. 2014; Laamarti et al. 2014; Kontogianni and Georgopoulos 2015).

[1] https://www.icomos.org/charters/venice_e.pdf

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Nowadays, experts that are traditionally concerned with Cultural Heritage, i.e. archaeologists, architects, engineers, conservators, art historians, librarians, etc., demand the production and usage of such geometric documentation products using modern techniques. Therefore, they are considered *the end-users* of the technology, while experts able to apply these techniques are considered *the providers* (Letellier and Gray 2002). Between these two groups a gap of communication exists, which is gradually being bridged, provided both parties communicate closely and show mutual understanding. CIPA,[2] the International Scientific Committee (ISC) of ICOMOS and ISPRS for Heritage Documentation plays a key role in this effort.

Traditionally, Cultural Heritage specialists wished to have such measurements in the form of vector plans, sections, or even as outlines plotted on hard copy, which enabled their direct use on site. The development of new methods, algorithms, and digital techniques in the field of 3D data acquisition along with robust computational systems and affordable costs of the respective devices have enabled the efficient usage and dissemination both of imagery products and 3D data, usually in the form of 3D models. In addition, these advancements have enabled automation, higher speeds, and increased accuracy. However, their most important contribution is the possibility of producing alternative digital documentation products, like the ones referred to above.

In the following sections these contemporary acquisition methods will be presented and examined, including an inevitable reference to the accompanying processing methodologies, which have been developed to manage the huge amount of data collected and produce these contemporary digital geometric documentation products.

Acquisition Methods for Cultural Heritage

As already mentioned, recent technological advances have enabled the acquisition of suitable and rich data for 3D object reconstruction. However, traditional or classic methods of data recording should by no means be considered obsolete, as they might provide valuable information, which, when combined with contemporary acquisition techniques contribute to the completeness and reliability of the final result. The range of object sizes vary in size from a few millimeters and may reach up to a couple of 1000 m, while the number of acquired points should practically have no limit. Innovation in data acquisition technologies along with the continuous increase of computational power has made low-cost 3D reconstruction of objects possible and efficient.

The geometric recording of an object or site can be realized by several measurement techniques, ranging from the conventional basic topometric methods (for partially or totally uncontrolled surveys), to the elaborated contemporary surveying and image-based ones depending on the survey requirements and specifications. Between all the available sensors, platforms and techniques, the most suitable ones should be chosen each time, considering their accuracy, flexibility, cost-effectiveness, computational speed, etc. (Remondino and Rizzi 2010).

Böhler and Heinz (1999) first attempted to classify the then available geometric data acquisition methods with respect to their implementation range. Today their diagram may be adapted to include the newly developed techniques (Fig. 1). In this diagram the implementation range of each method is represented in terms both by the number of acquired points (y-axis) and by the object size (x-axis). In this diagram, all available methods for acquiring metric data are displayed in such a way that their implementation range is roughly denoted. The lower row, colored with yellow, involves methods which (a) do not involve images and (b) finalize the selection of the acquired points in the field, thus leaving no opportunity to further exploit the data collected. On the other hand, the methods in the upper row, in blue color, involve taking images of the object of interest, which may be later revised in order to repeat or add metric information.

The traditional and simple tactile and topometric techniques could be applied as such only when the complexity of the object to be recorded allows it or as auxiliary solutions together with

[2] cipa.icomos.org