

10-12-2016

2.3 Beyond the Basemap: Multiscalar Survey through Aerial Photogrammetry in the Andes

Steven A. Wernke

Vanderbilt University, s.wernke@vanderbilt.edu

Gabriela Oré

Vanderbilt University

Carla Hernández

Vanderbilt University

Aurelio Rodríguez

Abel Traslaviña

Universidad Nacional Mayor de San Marcos (Peru)

See next page for additional authors

Follow this and additional works at: https://dc.uwm.edu/artist_mobilizingthepast



Part of the [Classical Archaeology and Art History Commons](#)

Recommended Citation

Wernke Steven A., Carla Hernández, Giancarlo Marcone, Gabriela Oré, Aurelio Rodriguez, and Abel Traslaviña. "Beyond the Basemap: Multiscalar Survey through Aerial Photogrammetry in the Andes." In *Mobilizing the Past for a Digital Future: The Potential of Digital Archaeology*, edited by Erin Walcek Averett, Jody Michael Gordon, and Derek B. Counts, 251-278. Grand Forks, ND: The Digital Press at the University of North Dakota, 2016.

This Book is brought to you for free and open access by UWM Digital Commons. It has been accepted for inclusion in Mobilizing the Past by an authorized administrator of UWM Digital Commons. For more information, please contact open-access@uwm.edu.

Authors

Steven A. Wernke, Gabriela Oré, Carla Hernández, Aurelio Rodríguez, Abel Traslavina, and Giancarlo Marcone

MOBILIZING *the* PAST *for a* DIGITAL FUTURE

The Potential of
Digital Archaeology



Edited by
Erin Walcek Averett
Jody Michael Gordon
Derek B. Counts

MOBILIZING THE PAST
FOR A
DIGITAL FUTURE

MOBILIZING
the **PAST**
for a **DIGITAL**
FUTURE

The Potential of
Digital Archaeology

Edited by

Erin Walcek Averett
Jody Michael Gordon
Derek B. Counts



The Digital Press ©
The University of North Dakota
Grand Forks

Creative Commons License
This work is licensed under a
Creative Commons
By Attribution
4.0 International License.



2016 The Digital Press @ The University of North Dakota

This offprint is from:

Erin Walcek Averett, Jody Michael Gordon, and Derek B. Counts,
*Mobilizing the Past for a Digital Future: The Potential of Digital
Archaeology*. Grand Forks, ND: The Digital Press at the University of
North Dakota, 2016.

This is the information for the book:

Library of Congress Control Number: 2016917316

The Digital Press at the University of North Dakota, Grand Forks, North
Dakota

ISBN-13: 978-062790137

ISBN-10: 062790137

Table of Contents

Preface & Acknowledgments	v
How to Use This Book	xi
Abbreviations	xiii
Introduction	
Mobile Computing in Archaeology: Exploring and Interpreting Current Practices <i>Jody Michael Gordon, Erin Walcek Averett, and Derek B. Counts</i>	1
Part 1: From Trowel to Tablet	
1.1. Why Paperless: Technology and Changes in Archaeological Practice, 1996–2016 <i>John Wallrodt</i>	33
1.2. Are We Ready for New (Digital) Ways to Record Archaeological Fieldwork? A Case Study from Pompeii <i>Steven J.R. Ellis</i>	51
1.3. Sangro Valley and the Five (Paperless) Seasons: Lessons on Building Effective Digital Recording Workflows for Archaeological Fieldwork <i>Christopher F. Motz</i>	77
1.4. DIY Digital Workflows on the Athienou Archaeological Project, Cyprus <i>Jody Michael Gordon, Erin Walcek Averett, Derek B. Counts, Kyosung Koo, and Michael K. Toumazou</i>	111
1.5. Enhancing Archaeological Data Collection and Student Learning with a Mobile Relational Database <i>Rebecca Bria and Kathryn E. DeTore</i>	143

1.6. Digital Archaeology in the Rural Andes:
Problems and Prospects 183
Matthew Sayre

1.7. Digital Pompeii: Dissolving the Fieldwork-Library
Research Divide 201
Eric E. Poehler

Part 2: From Dirt to Drones

2.1. Reflections on Custom Mobile App Development for
Archaeological Data Collection 221
Samuel B. Fee

2.2. The Things We Can Do With Pictures:
Image-Based Modeling and Archaeology 237
Brandon R. Olson

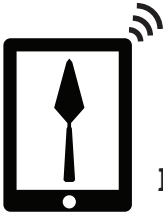
2.3. Beyond the Basemap: Multiscalar Survey through
Aerial Photogrammetry in the Andes 251
*Steven A. Wernke, Carla Hernández, Giancarlo Marcone,
Gabriela Oré, Aurelio Rodríguez, and Abel Traslaviña*

2.4. An ASV (Autonomous Surface Vehicle) for Archaeology:
The Pladypos at Caesarea Maritima, Israel 279
*Bridget Buxton, Jacob Sharvit, Dror Planer,
Nikola Mišković, and John Hale*

Part 3: From Stratigraphy to Systems

3.1. Cástulo in the 21st Century: A Test Site for a
New Digital Information System 319
*Marcelo Castro López, Francisco Arias de Haro,
Libertad Serrano Lara, Ana L. Martínez Carrillo,
Manuel Serrano Araque, and Justin St. P. Walsh*

3.2. Measure Twice, Cut Once: Cooperative Deployment of a Generalized, Archaeology-Specific Field Data Collection System <i>Adela Sobotkova, Shawn A. Ross, Brian Ballsun-Stanton, Andrew Fairbairn, Jessica Thompson, and Parker VanValkenburgh</i>	337
3.3. CSS For Success? Some Thoughts on Adapting the Browser-Based Archaeological Recording Kit (ARK) for Mobile Recording <i>J. Andrew Dufton</i>	373
3.4. The Development of the <i>PaleoWay</i> : Digital Workflows in the Context of Archaeological Consulting <i>Matthew Spigelman, Ted Roberts, and Shawn Fehrenbach</i>	399
Part 4: From a Paper-based Past to a Paperless Future?	
4.1. Slow Archaeology: Technology, Efficiency, and Archaeological Work <i>William Caraher</i>	421
4.2. Click Here to Save the Past <i>Eric C. Kansa</i>	443
Part 5: From Critique to Manifesto	
5.1. Response: Living a Semi-digital Kinda Life <i>Morag M. Kersel</i>	475
5.2. Response: Mobilizing (Ourselves) for a Critical Digital Archaeology <i>Adam Rabinowitz</i>	493
Author Biographies	521



Preface & Acknowledgments

This volume stems from the workshop, “Mobilizing the Past for a Digital Future: the Future of Digital Archaeology,” funded by a National Endowment for the Humanities Digital Humanities Start-Up grant (#HD-51851-14), which took place 27-28 February 2015 at Wentworth Institute of Technology in Boston (<http://uwm.edu/mobilizing-the-past/>). The workshop, organized by this volume’s editors, was largely spurred by our own attempts with developing a digital archaeological workflow using mobile tablet computers on the Athienou Archaeological Project (<http://aap.toumazou.org>; Gordon *et al.*, Ch. 1.4) and our concern for what the future of a mobile and digital archaeology might be. Our initial experiments were exciting, challenging, and rewarding; yet, we were also frustrated by the lack of intra-disciplinary discourse between projects utilizing digital approaches to facilitate archaeological data recording and processing.

Based on our experiences, we decided to initiate a dialogue that could inform our own work and be of use to other projects struggling with similar challenges. Hence, the “Mobilizing the Past” workshop concept was born and a range of digital archaeologists, working in private and academic settings in both Old World and New World archaeology, were invited to participate. In addition, a livestream of the workshop allowed the active participation on Twitter from over 21 countries, including 31 US states (@MobileArc15, #MobileArc).¹

¹ For commentary produced by the social media followers for this event, see: <https://twitter.com/electricarchaeo/status/571866193667047424>, <http://shawngraham.github.io/exercise/mobilearcday1wordcloud.html>, <https://twitter.com/electricarchaeo/status/571867092091338752>, <http://www.diachronicdesign.com/blog/2015/02/28/15-mobilizing-the-past-for-the-digital-future-conference-day-1-roundup/>.

Although the workshop was initially aimed at processes of archaeological data recording in the field, it soon became clear that these practices were entangled with larger digital archaeological systems and even socio-economic and ethical concerns. Thus, the final workshop's discursive purview expanded beyond the use of mobile devices in the field to embrace a range of issues currently affecting digital archaeology, which we define as the use of computerized, and especially internet-compatible and portable, tools and systems aimed at facilitating the documentation and interpretation of material culture as well as its publication and dissemination. In total, the workshop included 21 presentations organized into five sessions (see program, <http://mobilizingthepast.mukurtu.net/digital-heritage/mobilizing-past-conference-program>), including a keynote lecture by John Wallrodt on the state of the field, "Why paperless?: Digital Technology and Archaeology," and a plenary lecture by Bernard Frischer, "The Ara Pacis and Montecitorio Obelisk of Augustus: A Simpirical Investigation," which explored how digital data can be transformed into virtual archaeological landscapes.

The session themes were specifically devised to explore how archaeological data was digitally collected, processed, and analyzed as it moved from the trench to the lab to the digital repository. The first session, "App/Database Development and Use for Mobile Computing in Archaeology," included papers primarily focused on software for field recording and spatial visualization. The second session, "Mobile Computing in the Field," assembled a range of presenters whose projects had actively utilized mobile computing devices (such as Apple iPads) for archaeological data recording and was concerned with shedding light on their utility within a range of fieldwork situations. The third session, "Systems for Archaeological Data Management," offered presentations on several types of archaeological workflows that marshal born-digital data from the field to publication, including fully bespoke paperless systems, do-it-yourself ("DIY") paperless systems, and hybrid digital-paper systems. The fourth and final session, "Pedagogy, Data Curation, and Reflection," mainly dealt with teaching digital methodologies and the use of digital repositories and linked open data to enhance field research. This session's final paper, William Caraher's "Toward a Slow Archaeology," however, noted digital archaeology's successes in terms of

time and money saved and the collection of more data, but also called for a more measured consideration of the significant changes that these technologies are having on how archaeologists engage with and interpret archaeological materials.

The workshop's overarching goal was to bring together leading practitioners of digital archaeology in order to discuss the use, creation, and implementation of mobile and digital, or so-called "paperless," archaeological data recording systems. Originally, we hoped to come up with a range of best practices for mobile computing in the field – a manual of sorts – that could be used by newer projects interested in experimenting with digital methods, or even by established projects hoping to revise their digital workflows in order to increase their efficiency or, alternatively, reflect on their utility and ethical implications. Yet, what the workshop ultimately proved is that there are many ways to "do" digital archaeology, and that archaeology as a discipline is engaged in a process of discovering what digital archaeology should (and, perhaps, should not) be as we progress towards a future where all archaeologists, whether they like it or not, must engage with what Steven Ellis has called the "digital filter."

So, (un)fortunately, this volume is not a "how-to" manual. In the end, there seems to be no uniform way to "mobilize the past." Instead, this volume reprises the workshop's presentations—now revised and enriched based on the meeting's debates as well as the editorial and peer review processes—in order to provide archaeologists with an extremely rich, diverse, and reflexive overview of the process of defining what digital archaeology is and what it can and should perhaps be. It also provides two erudite response papers that together form a didactic manifesto aimed at outlining a possible future for digital archaeology that is critical, diverse, data-rich, efficient, open, and most importantly, ethical. If this volume, which we offer both expeditiously and freely, helps make this ethos a reality, we foresee a bright future for mobilizing the past.

* * *

No multifaceted academic endeavor like *Mobilizing the Past* can be realized without the support of a range of institutions and individ-

uals who believe in the organizers' plans and goals. Thus, we would like to thank the following institutions and individuals for their logistical, financial, and academic support in making both the workshop and this volume a reality. First and foremost, we extend our gratitude toward The National Endowment for the Humanities (NEH) for providing us with a Digital Humanities Start-Up Grant (#HD-51851-14), and especially to Jennifer Serventi and Perry Collins for their invaluable assistance through the application process and beyond. Without the financial support from this grant the workshop and this publication would not have been possible. We would also like to thank Susan Alcock (Special Counsel for Institutional Outreach and Engagement, University of Michigan) for supporting our grant application and workshop.

The workshop was graciously hosted by Wentworth Institute of Technology (Boston, MA). For help with hosting we would like to thank in particular Zorica Pantić (President), Russell Pinizzotto (Provost), Charlene Roy (Director of Business Services), Patrick Hafford (Dean, College of Arts and Sciences), Ronald Bernier (Chair, Humanities and Social Sciences), Charles Wiseman (Chair, Computer Science and Networking), Tristan Cary (Manager of User Services, Media Services), and Claudio Santiago (Utility Coordinator, Physical Plant).

Invaluable financial and logistical support was also generously provided by the Department of Fine and Performing Arts and Sponsored Programs Administration at Creighton University (Omaha, NE). In particular, we are grateful to Fred Hanna (Chair, Fine and Performing Arts) and J. Buresh (Program Manager, Fine and Performing Arts), and to Beth Herr (Director, Sponsored Programs Administration) and Barbara Bittner (Senior Communications Management, Sponsored Programs Administration) for assistance managing the NEH grant and more. Additional support was provided by The University of Wisconsin-Milwaukee; in particular, David Clark (Associate Dean, College of Letters and Science), and Kate Negri (Academic Department Assistant, Department of Art History). Further support was provided by Davidson College and, most importantly, we express our gratitude to Michael K. Toumazou (Director, Athienou Archaeological Project) for believing in and supporting our

research and for allowing us to integrate mobile devices and digital workflows in the field.

The workshop itself benefitted from the help of Kathryn Grossman (Massachusetts Institute of Technology) and Tate Paulette (Brown University) for on-site registration and much more. Special thanks goes to Daniel Coslett (University of Washington) for graphic design work for both the workshop materials and this volume. We would also like to thank Scott Moore (Indiana University of Pennsylvania) for managing our workshop social media presence and his support throughout this project from workshop to publication.

This publication was a pleasure to edit, thanks in no small part to Bill Caraher (Director and Publisher, The Digital Press at the University of North Dakota), who provided us with an outstanding collaborative publishing experience. We would also like to thank Jennifer Sacher (Managing Editor, INSTAP Academic Press) for her conscientious copyediting and Brandon Olson for his careful reading of the final proofs. Moreover, we sincerely appreciate the efforts of this volume's anonymous reviewers, who provided detailed, thought-provoking, and timely feedback on the papers; their insights greatly improved this publication. We are also grateful to Michael Ashley and his team at the Center for Digital Archaeology for their help setting up the accompanying Mobilizing the Past Mukurtu site and Kristin M. Woodward of the University of Wisconsin-Milwaukee Libraries for assistance with publishing and archiving this project through UWM Digital Commons. In addition, we are grateful to the volume's two respondents, Morag Kersel (DePaul University) and Adam Rabinowitz (University of Texas at Austin), who generated erudite responses to the chapters in the volume. Last but not least, we owe our gratitude to all of the presenters who attended the workshop in Boston, our audience from the Boston area, and our colleagues on Twitter (and most notably, Shawn Graham of Carlton University for his word clouds) who keenly "tuned in" via the workshop's livestream. Finally, we extend our warmest thanks to the contributors of this volume for their excellent and timely chapters. This volume, of course, would not have been possible without such excellent papers.

As this list of collaborators demonstrates, the discipline of archaeology and its digital future remains a vital area of interest for people who value the past's ability to inform the present, and who

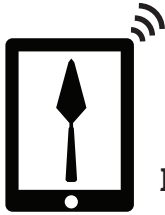
recognize our ethical responsibility to consider technology's role in contemporary society. For our part, we hope that the experiences and issues presented in this volume help to shape new intra-disciplinary and critical ways of mobilizing the past so that human knowledge can continue to develop ethically at the intersection of archaeology and technology.

Erin Walcek Averett (Department of Fine and Performing Arts and Classical and Near Eastern Studies, Creighton University)

Jody Michael Gordon (Department of Humanities and Social Sciences, Wentworth Institute of Technology)

Derek B. Counts (Department of Art History, University of Wisconsin-Milwaukee)

October 1, 2016



How To Use This Book

The Digital Press at the University of North Dakota is a collaborative press and *Mobilizing the Past for a Digital Future* is an open, collaborative project. The synergistic nature of this project manifests itself in the two links that appear in a box at the end of every chapter.

The first link directs the reader to a site dedicated to the book, which is powered and hosted by the Center for Digital Archaeology's (CoDA) Mukurtu.net. The Mukurtu application was designed to help indigenous communities share and manage their cultural heritage, but we have adapted it to share the digital heritage produced at the "Mobilizing the Past" workshop and during the course of making this book. Michael Ashley, the Director of Technology at CoDA, participated in the "Mobilizing the Past" workshop and facilitated our collaboration. The Mukurtu.net site (<https://mobilizingthepast.mukurtu.net>) has space dedicated to every chapter that includes a PDF of the chapter, a video of the paper presented at the workshop, and any supplemental material supplied by the authors. The QR code in the box directs readers to the same space and is designed to streamline the digital integration of the paper book.

The second link in the box provides open access to the individual chapter archived within University of Wisconsin-Milwaukee's installation of Digital Commons, where the entire volume can also be downloaded. Kristin M. Woodward (UWM Libraries) facilitated the creation of these pages and ensured that the book and individual chapters included proper metadata.

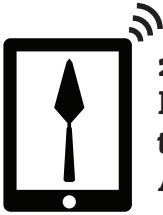
Our hope is that these collaborations, in addition to the open license under which this book is published, expose the book to a wider audience and provide a platform that ensures the continued availability of the digital complements and supplements to the text. Partnerships with CoDA and the University of Wisconsin-Milwaukee reflect the collaborative spirit of The Digital Press, this project, and digital archaeology in general.

Abbreviations

AAI	Alexandria Archive Institute
AAP	Athienou Archaeological Project
ABS	acrylonitrile butadiene styrene (plastic)
ADS	Archaeological Data Service
Alt-Acs	Alternative Academics
API	application programming interface
ARA	archaeological resource assessment
ARC	Australian Research Council
ARIS	adaptive resolution imaging sonar
ASV	autonomous surface vehicle
BLM	Bureau of Land Management
BLOB	Binary Large Object
BOR	Bureau of Reclamation
BYOD	bring your own device
CAD	computer-aided design
CDL	California Digital Library
CHDK	Canon Hack Development Kit
cm	centimeter/s
CMOS	complementary metal-oxide semiconductor
CoDA	Center for Digital Archaeology
COLLADA	COLLABorative Design Activity
CRM	cultural resource management
CSS	Cascading Style Sheet
CSV	comma separated values
DBMS	desktop database management system
DEM	digital elevation model
DINAA	Digital Index of North American Archaeology
DIY	do-it-yourself
DoD	Department of Defense
DVL	doppler velocity log
EAV	entity-attribute-value
EDM	electronic distance measurement
EU	excavation unit/s
FAIMS	Federated Archaeological Information Management System
fMRI	functional magnetic resonance imaging
GIS	geographical information system
GCP	ground control point
GNSS	global navigation satellite system
GPR	ground-penetrating radar

GUI	graphic user interface
ha	hectare/s
hr	hour/s
Hz	Hertz
HDSM	high-density survey and measurement
ICE	Image Composite Editor (Microsoft)
iOS	iPhone operating system
INS	inertial motion sensor
IPinCH	Intellectual Property in Cultural Heritage
IT	information technology
KAP	Kaymakçı Archaeological Project
KARS	Keos Archaeological Regional Survey
km	kilometer/s
LABUST	Laboratory for Underwater Systems and Technologies (University of Zagreb)
LAN	local area network
LIEF	Linkage Infrastructure Equipment and Facilities
LOD	linked open data
LTE	Long-Term Evolution
m	meter/s
masl	meters above sea level
MEMSAP	Malawi Earlier-Middle Stone Age Project
MOA	memoranda of agreement
MOOC	Massive Online Open Course
NGWSP	Navajo-Gallup Water Supply Project
NeCTAR	National eResearch Collaboration Tools and Resources
NEH	National Endowment for the Humanities
NHPA	National Historic Preservation Act
NPS	National Park Service
NRHP	National Register of Historic Places
NSF	National Science Foundation
OCR	optical character reader
OS	operating system
PA	programmatic agreement
PAP	pole aerial photography
PARP:PS	Pompeii Archaeological Research Project: Porta Stabia
PATA	Proyecto Arqueológico Tuti Antiguo
PBMP	Pompeii Bibliography and Mapping Project
PDA	personal digital assistant

PIARA	Proyecto de Investigación Arqueológico Regional Ancash
PKAP	Pyla-Koutsopetra Archaeological Project
Pladypos	PLatform for DYnamic POSitioning
PLoS	Public Library of Science
PQP	Pompeii Quadriporticus Project
PZAC	Proyecto Arqueológico Zaña Colonial
QA	quality assurance
QC	quality control
QR	quick response
REVEAL	Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy
ROS	robot operating system
ROV	remotely operated vehicle
RRN	Reciprocal Research Network
RSS	Rich Site Summary
RTK	real-time kinetic global navigation satellite system
SfM	structure from motion
SHPO	State Historic Preservation Office
SKAP	Say Kah Archaeological Project
SLAM	simultaneous localization and mapping
SMU	square meter unit/s
SU	stratigraphic unit/s
SVP	Sangro Valley Project
TCP	traditional cultural properties
tDAR	the Digital Archaeological Record
UAV	unmanned aerial vehicle
UNASAM	National University of Ancash, Santiago Antúnez de Mayolo
UQ	University of Queensland
USACE	U.S. Army Corp of Engineers
USBL	ultra-short baseline
USFS	U.S. Forest Service
USV	unmanned surface vehicle
UTM	universal transverse mercator
XML	Extensible Markup Language



2.3.

Beyond the Basemap: Multiscalar Survey through Aerial Photogrammetry in the Andes

Steven A. Wernke, Carla Hernández, Giancarlo Marcone, Gabriela Ore, Aurelio Rodríguez, and Abel Traslaviña

Unmanned aerial vehicles (UAVs, popularly known as “drones”) have revolutionized archaeological mapping. More broadly, computational photography has transformed our capabilities to capture high-resolution spatial representations of archaeological phenomena in the field, from the scale of small features within excavations (Opitz 2015; Poehler 2015; Roosevelt *et al.* 2015) to large sites and encompassing landscapes (Chiabrando *et al.* 2011; Mozas-Calvache *et al.* 2012; Fallavollita *et al.* 2013; Olson *et al.* 2013; Wernke *et al.* 2014). A quiver of generally inexpensive and efficient photogrammetric field tools are now within the reach of most practitioners across these scales (FIG. 1). High-resolution and high-fidelity orthomosaics, digital elevation models, and textured 3D models can now be captured using consumer-grade digital cameras through photogrammetric software. In just the last few years, technical and cost barriers have lowered and the use of these technologies has spread from innovators to early adopters to what is now the early majority of the bell curve of the archaeological research and conservation communities. The benefits are readily evident: richer and more granular datasets through fast, simple, and inexpensive techniques (see also Olson, Ch. 2.2). In addition to these developments, digital 3D and 3D-printed distribution also have greatly broadened the accessibility and impact of the results to researchers, educators, descendent communities, and global publics.

Here we present a multiscalar perspective on the progress and prospects of digital aerial photogrammetry in archaeology: at the scale of

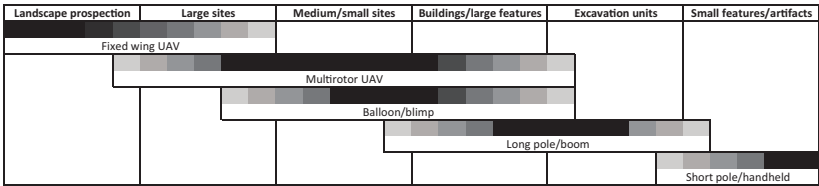


Figure 1: Schematic of photogrammetric tools for different scales of subject matter.

landscape prospection using a fixed wing UAV, at the scale of large site survey using a meteorological balloon, and at the scale of individual domestic architectural complexes using pole aerial photography. We illustrate how these aerial photo systems equipped with inexpensive digital cameras can be used to rapidly acquire mass imagery for processing into a variety of 2D and 3D digital images and models. We contend that the efficiency, fidelity, and cost-effectiveness of these methods are of such a qualitatively different character compared to traditional methods that they are transformative for the practice of both research-oriented field archaeology and cultural heritage management. That is, rather than acting as an add-on to traditional survey or excavation projects, these methods enable new kinds of field methodologies, in large part because conventional compromises between scale and granularity of spatial representation are greatly mitigated. This emerging field of “spatial archaeometry” (Casana 2014) promises to more fully and quickly capture the complexity of ancient settlements and landscapes (Wernke *et al.* 2014).

These advances are of equal importance for cultural heritage management. With the alarming loss of archaeological heritage around the world—including the recent specific targeting of monumental archaeological sites for violent destruction (Danti 2015; Harmansah 2015)—the importance of capturing whole-site “digital surrogates” (*sensu* Rabinowitz 2015) through aerial photogrammetry transcends academic interests (see, e.g., Ioannides *et al.* 2012; Hesse 2013). Archaeological patrimony in general is inexorably degrading and disappearing. It is a one-way, entropic process mitigated only by expensive conservation projects, usually at monumental sites. Given the expense and technical barriers to 3D scanning technologies, scanning efforts have also been largely limited to projects at monumental sites by specialized consultancy firms such as CyArk (see <http://www.cyark.org/about/>). Aerial photogrammetry has now dramatically lowered those barriers to enable the production of whole-site digital surrogates of the many “lesser” (i.e., the great majority) threatened sites and landscapes.

With these concerns in mind, this chapter addresses both heritage management and research-oriented problems. The first part presents a case study in rapid aerial photogrammetry documentation of sites and landscapes along the road network of the Inka Empire in Peru. This project was a collaborative effort between Giancarlo Marcone,

director of the Proyecto Qhapaq Ñan (Inka Royal Highway Project), and Steven Wernke (Vanderbilt University). Together with the other co-authors of this paper, we set out to document sections of the Qhapaq Ñan associated with major Inka imperial installations from locations near sea level to 3,900 m found along one of the main transverse highways that connects the primary imperial highway along the Pacific coast to its counterpart in the highlands.

While the Qhapaq Ñan case study illustrates the speed and utility of UAV-based photogrammetry for heritage management, the second part of the paper explores its richness and potential for integration with tablet-based architectural survey using high-resolution (sub-decimeter to centimeter) balloon- and pole-based aerial orthomosaics and 3D models. This research project, the Proyecto Arqueológico Tuti Antiguo (PATA, Ancient Tuti Archaeological Project) was designed from the ground up to use high-resolution aerial photogrammetry as central spatial reference data for mobile GIS-based mapping (see Wernke and Siveroni Salinas 2013; Wernke *et al.* 2014; Wernke 2015). While PATA is directed by Wernke, Gabriela Oré, Carla Hernández, and Abel Traslaviña all played instrumental roles in the execution of its methodology. The project investigates the transition from late prehispanic to Spanish colonial times, focusing on an Inka administrative center that was converted into a planned colonial town in the high Andes (4,100 m) and built as part of the *Reducción General de Indios* (General Resettlement of Indians), a mass resettlement program executed throughout the Viceroyalty of Peru in the 1570s. This large town—originally named Santa Cruz de Tuti—encompasses nearly 40 ha at an elevation of 4,100 m, with about 500 remarkably well-preserved buildings in a gridded street plan. With its excellent architectural preservation, Santa Cruz de Tuti provides an ideal context to investigate little-understood aspects of the General Resettlement, but it also poses significant challenges given its scale, complexity, and remoteness. Traditional mapping techniques would require major outlays in time and labor, and would result in a relatively impoverished cartographical representations. We present a methodological approach for mapping extensive and complex architectural remains using orthomosaics as base imagery for tablet-based, in-field digitization, with a much richer attribute data registry than possible through traditional mapping methods.

DIGITAL HERITAGE MANAGEMENT:
THE INKA ROYAL HIGHWAY PROJECT

The Proyecto Qhapaq Ñan (Inka Royal Highway Project), a special project of the Ministry of Culture, Peru, faces the monumental challenge of documenting and conserving the many thousands of kilometers of ancient roads of the Inka Empire in Peru (see <http://www.cultura.gob.pe/en/tags/proyecto-qhapaq-nan>). From a heritage management perspective, the Proyecto Qhapaq Ñan faces major challenges of scale and representation as it encompasses much of the territory of the modern republic of Peru, with over 3,000 km of the ancient road system documented in the field and many hundreds of associated Inka sites (FIG. 2). Mapping the entirety of the ancient road network in detail would be impractical, and non-commercial satellite imagery is not of sufficient resolution to detect important elements of the road system or preserved architecture in archaeological settlements. Thus, UAV-based mapping is especially attractive for the Proyecto Qhapaq Ñan due to its speed and low cost, its ability to render a variety of vector- and raster-based 2D and 3D formats, and the possibility of recording sites and landscapes many times, which enables seasonal or inter-annual, and long-term monitoring (longitudinal or time series analysis). Our collaboration is part of a broader effort by the Peruvian Ministry of Culture to seek methods for using UAV photogrammetry to document its thousands of archaeological sites (see, e.g., Neuman and Blumenthal 2014).

The Proyecto Qhapaq Ñan is also developing a new approach to managing this vast cultural patrimony, moving away from a previous site-based framework toward one centering on cultural landscapes and corridors around the Inka roads. This is more appropriate to the ancient practices associated with the Inka imperial road network itself, and in terms of patrimonial stewardship. Inka aesthetics and engineering worked at the scale of entire landscapes rather than settlements, neighborhoods, or buildings (Protzen 1993; Niles 1999; Kosiba and Bauer 2012; Nair 2015). From a stewardship perspective, the scale of the Qhapaq Ñan far exceeds the resources of the state and descendent communities are often literally dislocated from their cultural patrimony through the declaration of sites as “intangible zones.” Through a cultural landscape concept, the Proyecto Qhapaq Ñan seeks the participation of local stakeholders, placing sites within a living,



Figure 2: Overview of the sections of the Inka road system documented in the field by the Proyecto Qhapaq Ñan.

working contemporary landscape. As part of this new approach, the Proyecto Qhapaq Ñan is organized by *tramos* (tracts) between major Inka imperial centers. Our collaborative project focused on one of the major transverse Inka highways connecting the coast and highlands: the tramo between the monumental center of Tambo Colorado, located in the upper reaches of the coastal Pisco valley, and Vilcashuamán in the highlands of the department of Ayacucho.

The collaboration also enabled performance testing of a fixed-wing UAV at different elevations. Compared to multicopter designs, fixed-wing UAVs fly faster, with longer flight times, and a broader altitudinal range of operation, making them optimal for this kind of large site and landscape prospection. The UAV used for the project was based on the TechPod (<http://hobbyuav.com/>), a large fixed-wing airframe. This design was chosen for its large wingspan (2.67 m) and wing area (3903 cm²), facilitating large payload (1 kg of battery/payload), long flight times (capable of flights in excess of 1 hour), and slow cruising speed (59 km/hr). The large wingspan and wing surface are also crucial for achieving adequate lift for takeoff and stable flight in high elevation contexts. The TechPod is an open-source and low-cost UAV. For imagery capture, we equipped the TechPod with a small consumer point-and-shoot camera (Canon w/Canon Elph 300 HS camera, along with a 12.1 megapixel CMOS (complementary metal-oxide semiconductor) sensor) with CHDK (Canon Hack Development Kit) installed to enable the use of an intervalometer script and capture of images in raw format (uncompressed values from the CMOS sensor). Photos were taken every four seconds—an interval chosen based on the relatively high flight paths we planned for large-scale landscape aerial survey (a short video of a flight at Tambo Colorado can be downloaded at http://www.vanderbilt.edu/sarl/Images2/Tambo_Colorado_flight03.mp4).

Case Study: Tambo Colorado

Tambo Colorado is an elaborate Inka imperial center of painted adobe palaces, plazas, and ceremonial structures located in the Pisco valley. It is sited on the main Inka highway that connects to the highland imperial center of Vilcashuamán and eventually leads onward to the imperial capital of Cuzco. Just to the northwest of Tambo Colorado, the

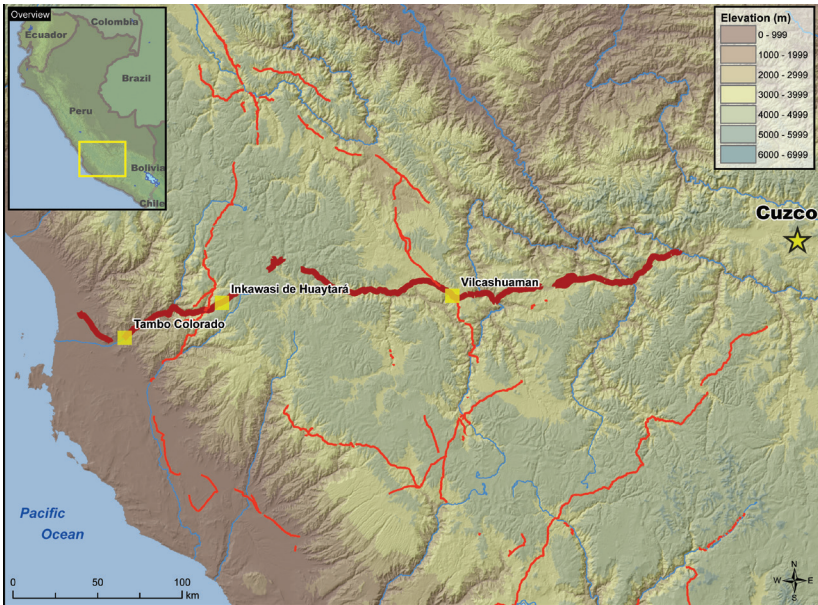


Figure 3: Overview of the Pisco-Vilcashuamán tramo (thick, dark red).

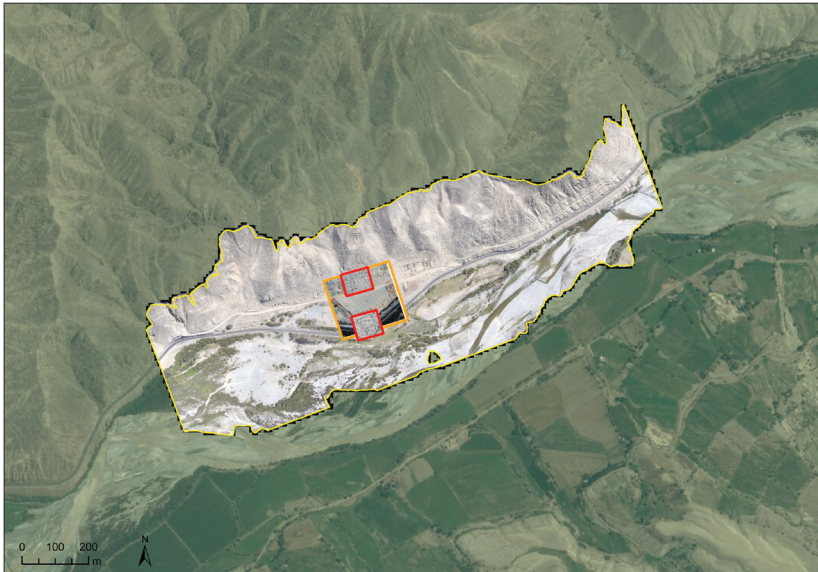


Figure 4: Tambo Colorado: overview of the area mapped by UAV, showing areas of prior mapping efforts.

Qhapaq Ñan turns northwest toward the Chincha valley and joins the main coastal highway (FIG. 3).

With its spectacular layout and architectural preservation, Tambo Colorado has a long history of research and archaeological mapping. German archaeologist Max Uhle mapped and excavated there in 1901. His remarkably accurate maps remain a vital reference for researchers. Later, in 2001, Jean Pierre Protzen and Craig Morris began a long-term investigation of the site. This project included extensive 3D laser scanning by CyArk during four field seasons (2001, 2003, 2004, 2005) in several areas of the site core, providing unprecedented renderings of palace complexes and many features, including details such as the many trapezoidal niches, windows, and doorways (see <http://www.cyark.org/projects/tambo-colorado/overview>). The logistical complexities of terrestrial laser scanning, however, ultimately limited the coverage of these operations. Our objective was to complement these previous efforts by contextualizing the site of Tambo Colorado in its broader landscape—mapping at mid-scale—while also providing adequate resolution to discern architectural detail.

Our fieldwork at Tambo Colorado took only two days: one day to set ground control points (GCPs) using a RTK GNSS (real-time kinetic global navigation satellite system (Topcon GR5)) with sub-centimeter accuracy (0.5 cm horizontal, 0.9 cm vertical), and one day to obtain the UAV-based imagery (GCPs were recorded in UTM coordinates (zone 18S), WGS 1984 datum, using Geoid EGM Peru 2008 for elevations). Two flights—one approximately 10 minutes, the other approximately 20 minutes—were flown over the site and surrounding landscape, following the course of the Qhapaq Ñan into and out of the site.

From the flight imagery, 467 images were selected for photogrammetric processing in Agisoft PhotoScan (v.1.1.5), performed in the Spatial Analysis Research Laboratory at Vanderbilt University (<http://www.vanderbilt.edu/sarl>). Of these, 465 images were automatically aligned in about two hours of processing time on an advanced workstation (workstation specifications include Intel Xeon E5-1650 v3 CPU, 128 GB RAM, and dual NVIDIA K4200 GPUs). In-field processing on a laptop would also be possible by dividing processing into two or three “chunks” (groups of photos covering contiguous areas). The resulting orthomosaic encompasses an area of 70 ha at a pixel resolution of 6.8 cm (FIGS. 4, 5). The DEM (digital elevation model) resolved to a 13.6 cm raster grid cell size (FIG. 6). The shape of the area prioritizes



Figure 5: Tambo Colorado: UAV orthoimage detail: north palace.

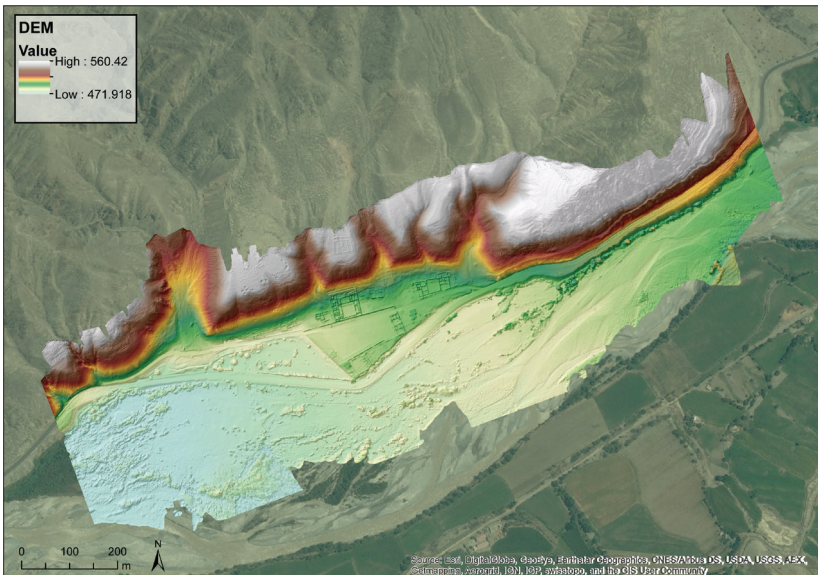


Figure 6: Tambo Colorado: DEM generated from UAV imagery.

documentation of the ancient road in relation to the site, which runs roughly parallel to the river and modern highway.

Compared to previous mapping efforts at the site, our UAV-based orthoimagery, DEM, and 3D model document a much larger area, placing Tambo Colorado in its fuller landscape context, while still at sufficient resolution to observe most architectural details. It thus complements the work of Uhle, Protzen, and Morris, which focused on the monumental core. The scale and resolution of this project enable new observations and heritage management capabilities. For instance, the orthoimagery and 3D models enable the project to evaluate risks not only to the monumental core but also to the sections of the Inka road that run through the site. In the core of the site, the primary threats are tourist foot traffic and damage from alluvial and colluvial flows. The photographic source data for the orthomosaics facilitates monitoring of foot traffic, since patterns of movement through the site can be inferred from the imagery itself. To the east of the site core, a remarkable section of the ancient road is preserved upslope of the modern highway. There, the ancient road traverses a number of *quebradas* (ravines) as the road directed traffic to and from the highlands. In these crossing points between the *quebradas* and the road, the highway was reinforced with large stone-faced revetments. These revetments are variably preserved and threatened. The orthoimagery enables monitoring of ongoing and active alluvial and colluvial flows through these *quebradas* and across the ancient road, thus facilitating prioritization of conservation efforts. Because of the low cost and time investment in this method, site monitoring could be completed on a regular (e.g., annual) basis to monitor site changes and erosion. The area documented can also be observed in 3D by exporting a COLLADA (COLLABorative Design Activity) 3D solid model. This model has been uploaded to Sketchfab.com, a 3D model-sharing site, for viewing and downloading (<https://skfb.ly/HwDP>).

Finally, the orthoimagery provided a guide for fast vector-based representation of the architectural core, which was done using a computer-aided design (CAD) program in compliance with Ministry of Culture reporting requirements (FIG. 7). Though CAD editing was done on a desktop computer, such digitization work could also be accomplished on a mobile GIS platform on a tablet (or laptop) in the field (using, e.g., the FAIMS mobile platform (Federated Archaeological Information Management System; see Sobotkova *et al.*, Ch. 3.2),



Figure 7: Tambo Colorado: site core vector mapping.

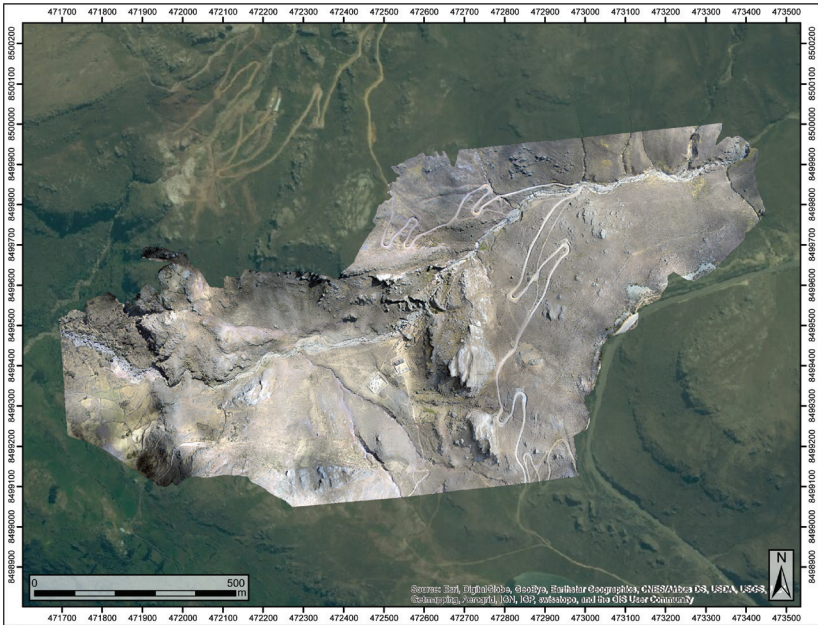


Figure 8: Inkawasi de Huaytará: overview of the area mapped by UAV.

GIS Pro, or QGIS for Android). As discussed below, this methodology offers considerable advantages in speed and richness of attribute data registry compared to traditional total station–based approaches to producing site architectural plans.

Case Study: Inkawasi de Huaytará

Inkawasi de Huaytará is the next major Inka imperial site inland from Tambo Colorado on the Pisco–Vilcashuamán tramo of the Qhapaq Ñan. Located high in the western range of the central cordillera, Inkawasi is situated at 3,850 m, at the lower edge of the *puna* (high elevation grassland). Inkawasi is a curious site, and its basic functions remain in question. It is small and isolated from local settlements, but other attributes point to highly exclusive elite-only access to certain sectors of the site. Unlike Tambo Colorado, Inkawasi has been the subject of very little systematic study. During the same 1901 expedition that produced the architectural map of Tambo Colorado discussed above, Uhle briefly visited the site and speculated that it may have served as a *tambo* (waystation) for the Inka to rest after one day’s journey inland on the Qhapaq Ñan from Tambo Colorado (Protzen and Harris 2005: 87–88). John Hyslop reconnoitered Inkawasi de Huaytará as part of his survey of the Inka road system (Hyslop 1984: 105–106) and drafted a sketch map. Given that the road climbs another 1,200 vertical meters in just the 14 km between Inkawasi and Huaytará, the next Inka site to the east (Hyslop 1984: 104), facilities for lodging, water, and food might be expected there.

Inkawasi was certainly more than a waystation, however, since its architectural complexes include features such as double-jamb trapezoidal doorways (which marked thresholds to exclusive elite spaces) and buildings made of fine precision-fitted Inka stone masonry—clearly the work of specialized imperial stonemasons and features found only at elite Inka imperial sites (Gasparini and Margolies 1980; Protzen 1993; Niles 1999). It may have functioned as a provincial estate for traveling Inka nobility and the emperor himself (S. Chacaltana, pers. comm. 2015). Typical of Inka “aesthetics of alterity” (van de Guchte 1999), the site also appears to have been emplaced in the local landscape with an eye toward fitting its highly exclusive spaces in relation to a prominent cliff band and rock outcrop in the gorge

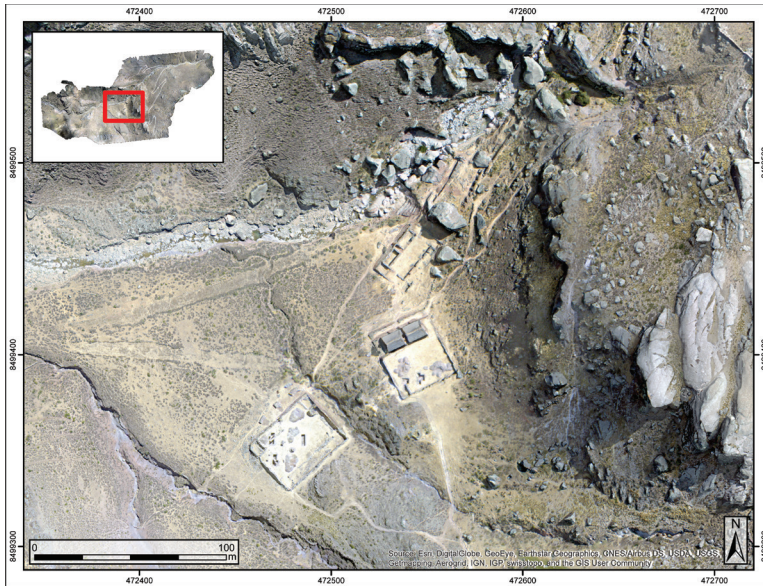


Figure 9: Inkawasi: UAV orthoimage detail: site core.

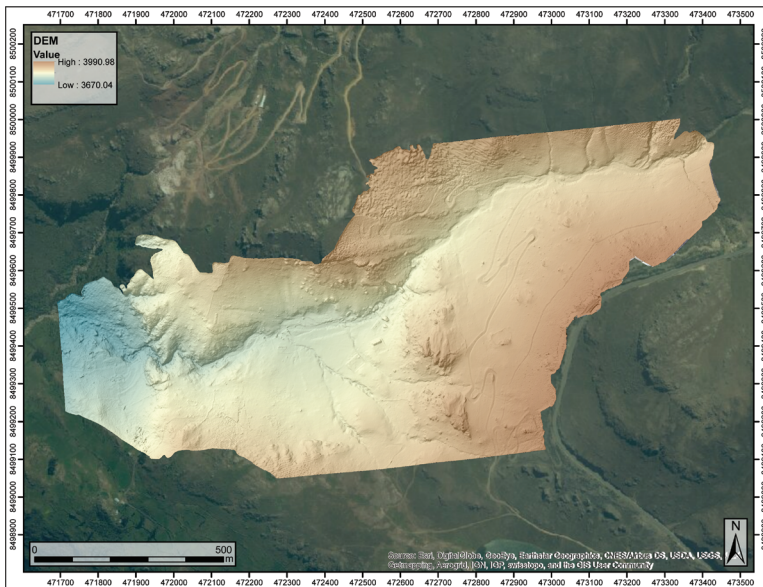


Figure 10: Inkawasi: DEM generated from UAV imagery.

of the Inkawasi River. The royal highway itself passes through a cleft in this outcrop, producing a dramatic framing of the site as travelers descend from the highlands. Rituals connecting humans to the chthonic beings in the landscape were almost certainly central to its placement and design. Understanding or conveying these aesthetic and functional possibilities requires something beyond a basemap: spatial representations at finer resolution than off-the-shelf satellite-based DEMs or imagery, and richer than traditional topographic and architectural survey. UAV-based high-resolution 3D mapping meets these requirements.

Most recently, the Proyecto Qhapaq Ñan completed follow-up conservation work at Injawasi to check and repair earlier site conservation by the Ministry of Culture, Peru, and it is working with the local community to develop an integrated conservation, tourism, and community development plan, which includes the site and its surrounding landscape (Antezana Ruiz 2015). Our collaboration to produce UAV-based mapping was designed as an integral part of the information that the Proyecto Qhapaq Ñan and local community authorities will use in formulating this plan. Thus, both research and heritage management goals are addressed by the project.

Our UAV work at Inkawasi was completed in one afternoon, following a day of work placing the ground control points with a RTK GNSS. We used the same flight parameters, motor, and propeller as at Tambo Colorado, and the TechPod performed well. Achieving takeoff required throwing the UAV from a steeply sloping hilltop (download short video online at http://www.vanderbilt.edu/sarl/Images2/Inkawasi_first_flight.mp4), permitting an initial drop in altitude to gain speed and sufficient lift. The imagery was captured over three brief flights (all lasting about 10 minutes). The intervalometer was again set to four seconds, and the imagery used in photogrammetric processing was captured in about 25 minutes over the course of three flights. Of the selected photos, 343 were aligned to produce an orthomosaic and DEM covering an area of 99.8 ha. Within this large area, the orthomosaic resolved to a pixel size of 8.6 cm (FIGS. 8, 9), while the DEM provides 17.3 cm resolution—resolution very close to that achieved at Tambo Colorado (FIG. 10).

The orthoimagery, DEM, and 3D models will be integral to this project's subsequent operations, obviating the need for costly and slow traditional topographic survey, with much higher resolution

topographic results, combined with precise color orthoimagery of the site in its fuller landscape context (see the 3D model online at <https://skfb.ly/HwEo>).

ARCHITECTURAL SURVEY AT A PLANNED COLONIAL TOWN: MAWCHU LLACTA

The speed and resolution of UAV-based photogrammetry are of obvious utility, especially in this era of accelerating loss of archaeological patrimony. But the technological advances in both the UAV and photogrammetry fields have been so fast that methodological frameworks have generally not yet adapted to the new capabilities and challenges they present. Building on previous work in integrated photomapping and mobile GIS excavation workflow (Tripcevich and Wernke 2010), Wernke recently began a new archaeological project focused on a planned colonial town with extensive well-preserved architecture in the high reaches of the Colca valley of southern Peru. This settlement, Santa Cruz de Tuti, is known today as Mawchu Llacta (“Old Town”) by its descendent population in the modern community of Tuti, who reside just a few kilometers downslope from their ancestral town.

Mawchu Llacta was built as a *reducción* (literally, “reduction”) town as part of the mass forced resettlement program known as the *Reducción General de Indios* (“General Resettlement of Indians”) in the Viceroyalty of Peru. This was one of the largest forced resettlement programs enacted by a colonial power, affecting some 1.4 million native Andeans (Mumford 2012). The Viceroy Francisco de Toledo, charged with establishing a new colonial order after a generation of Spanish plunder, indirect rule, and Inka insurrection, ordered the forcible resettlement of indigenous communities as part of a general survey of the Viceroyalty of Peru between 1570 and 1575. This massive social experiment was premised on the notion that by rebuilding indigenous communities literally from the ground up, they would become more like model subjects and Christians and a new social order (*policia*) would emerge.

A theory of built environment was at the core of the *Reducción*. But archaeological research on the topic is just beginning, and surprisingly little archival research has focused on it to date. Basic questions remain about how the actual resettlement and construction of these

towns was enacted, how decisions were made about where and how many to build in a given area, and how domestic and public life within them was organized. Mawchu Llacta is both exceptionally well-preserved and exceptionally documented in written texts, providing a virtually unparalleled opportunity to elucidate these dimensions of the resettlement. As an archaeological microhistory, the archaeological research at Mawchu Llacta would have to begin with detailed mapping and architectural survey and surface collections. Wernke's project has just completed this first phase, with the subsequent phase of excavations beginning in 2016 (see Wernke 2015).

Mawchu Llacta site is situated at 4,100 m in the high puna grasslands, and it is quite extensive, comprising a regular checkerboard grid of urban blocks extending about half a kilometer on a side, with a total site area of about 40 ha. Within this gridded street plan are over 500 standing fieldstone buildings in varying states of preservation. The site is also situated in the location of a major Inka site, which was likely the administrative center for the upper section of the Colca valley. The site core centers on two plazas—one of which is trapezoidal and was likely the center of the Inka settlement, and the other rectangular with six chapels. The church, facing the trapezoidal plaza, is very large with a 50 m long nave. The arched entry to the church and one of its bell towers remain intact as well.

The site thus presented both major opportunities and major challenges: an accurate “base map” was clearly required to address the core research questions, but producing one through traditional methods (via total station survey) would be a daunting, slow, and ultimately expensive undertaking with relatively data-impooverished results. Ideas for producing something “beyond a basemap” during the first phase of the project developed at a time when a number of the technologies (widely discussed in this volume) were only nascent (but quickly ramping up): iPads and early Android tablet devices were introduced to the market in 2010; a relatively small number of manufacturers and “do-it-yourself” hobbyists and professionals were coalescing in a burgeoning UAV market and maker culture. It seemed opportune to design a project building on these tools from the outset.

Technical details of the project design have been presented elsewhere (Wernke *et al.* 2014), but in outline, the concept for mapping and architectural survey was to conduct UAV-based low-altitude photogrammetry combined with tablet-based mobile GIS. The

orthoimagery from the UAV would serve as the primary spatial reference for digitizing buildings, walls, and other features directly on screen in the field using a mobile GIS app. Mapping and architectural survey could thus be conducted simultaneously, producing rich datasets that combined color orthoimagery with vector based plans of building and other architectural elements, with attribute data associated with each feature.

The project eventually succeeded in executing this methodology, but not in sequence and not without initial setbacks, most of which were a consequence of the immature nature of the technologies at the time of the first phase of fieldwork (during July and August of 2012 and 2013), and the difficult conditions of the site setting—especially the challenges of high-altitude atmospheric conditions for UAV flight. Experimentation with two different UAV platforms in 2012 and 2013 failed to produce reliable flight in these extreme conditions. These difficulties were the initial impetus for moving to the TechPod and developing the collaboration with the Qhapaq Ñan Project discussed above. Though we did capture over 2,000 images with the UAVs at the site, image quality and coverage were uneven and photogrammetric results did not meet the project requirements. Thus, during the 2013 season, we opted to use a tethered meteorological balloon as the photographic platform (a widely used and proven method; see Bitelli *et al.* 2004; Olson *et al.* 2013; Poehler 2015). This technique was not without its difficulties and was much slower, but it did produce virtually full-coverage orthoimagery of the site.

The architectural survey with tablet-based mobile GIS proceeded apace despite the challenges the project faced with the UAVs. The project was experimental in this aspect as well, since we initially acted as alpha testers for an early version of the Android-based mobile application for the FAIMS (see Sobotkova *et al.*, Ch. 3.2) project. The FAIMS project is now several generations beyond this early version and is a field-proven product, but at the time, we were just starting to work out issues of user interaction, data structure, and data synchronization, so it was not yet ready to be used as a primary data collection system. After these FAIMS field experiments, we switched to a commercial mobile GIS for iOS—GISPro by Garafa Inc. Fortunately, GISPro met most requirements of the project: the user can create point, line, and polygon themes (exported as shapefiles) that can be generated by activating the tablet GPS (with options for using an external antenna)

or by plotting on screen. It is designed as a single-user/team system, however, and it has no central database. Therefore, data synchronization to a central geodatabase was manual, requiring considerable data-management effort.

In the field, however, GISPro worked quite well, especially in terms of user interaction, requiring minimal training (most students could learn the interface and data entry aspects in a single day). We drew features on-screen for nearly all aspects of the project since we were digitizing architectural features using a georeferenced airphoto as reference data. It was critical for our teams to be able to draft in the field while directly observing the feature in question to ensure proper registry of wall joins and seams and many other architectural details (e.g., niches, doorways with lintels intact, which are not evident in plan view). GISPro also allows user specification of attributes using an intuitive form-based interface (including options for controlled vocabularies in the form of drop down menus). For buildings, we produced an extensive form with up to 65 attributes on building style, form, dimensions, and a range of architectural details (e.g., niches, doorways, and other features). We also made polygon themes for miscellaneous features and for collection areas within structures, line themes for walls that define unroofed areas (domestic compounds, corrals, blocks, and streets) and for canals, and point themes for lichenometric specimens (we measured specimens of the *Rhizocarpon* lichen to date architecture at the site), piece plotted surface collections, and dogleash surface collections. Using this system, four survey crews moved through the site and collected all data, generally covering 1–2 blocks (depending on architectural complexity and density) per team per day. In approximately three months of fieldwork, a draft GIS of the site was completed, with all attributes recorded in the field.

Our balloon-based imagery capture was completed over the course of three days. The low atmospheric pressure at this altitude requires a larger volume of helium, and thus a much larger balloon than would be needed nearer to sea level. We used a 3 m³ latex meteorological balloon to ensure adequate lift for our camera (the same Canon Elph 300 HS). We used two tethers to help control the balloon and to minimize the visibility of the string in the frame (by spreading the two walkers widely). Also, the camera was strung between the tethers on a picavet to aid in maintaining a nadir camera orientation. The balloon was generally flown 25–40 m in altitude, with the camera

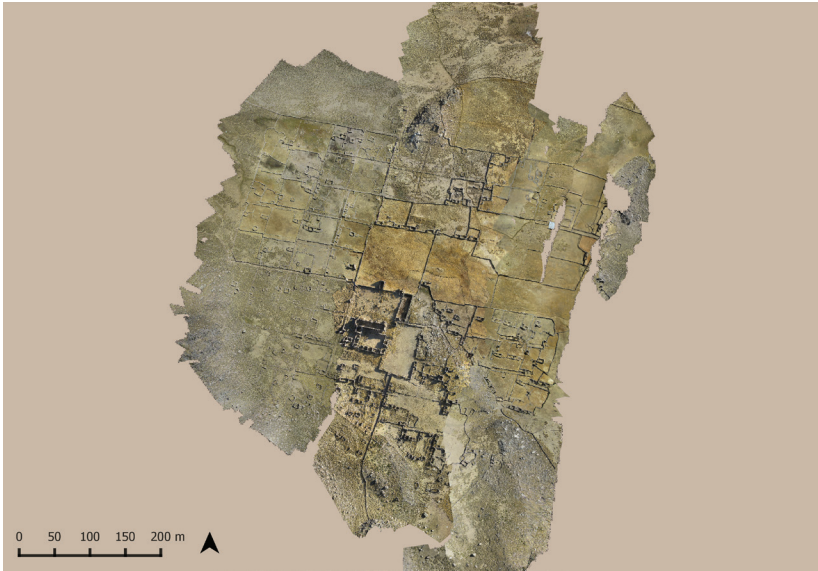


Figure 11: Mawchu Llacta: overview of the area mapped by meteorological balloon.



Figure 12: Orthomosaic details: Mawchu Llacta: site core (top); domestic compound (bottom).



Figure 13: GIS architectural map: Mawchu Llacta: overview (top); detail of site core (bottom).

intervalometer set at 10 seconds, as operators walked in a lawnmower pattern through the site.

Over 3,000 usable photos resulted from the balloon flights. Photo sequences were divided into eight chunks for photogrammetric processing. These chunks provide virtually full coverage of the site (with a few small voids). The resulting orthomosaics are quite detailed, with 5 cm resolution in most cases. At this resolution, individual stones that make up the tops of walls are generally clearly visible (FIGS. 11, 12).

With the processed orthomosaic finished in 2014, we then revised the draft geometry of the architecture digitized in the field from the coarser airphotos. The key to maintaining fidelity in this process is that the original field data, though geometrically imprecise, was topologically correct—that is to say, wall joins and the like were drafted as observed. These are the key data for relationships of horizontal stratigraphy, and they were preserved through the editing process. Of course, this step would be obviated had the original workflow gone according to plan. But our situation can be considered something of a special case given the extreme conditions of the site compared to most archaeological projects. In any case, now, with our larger UAV and experiences from the Qhapaq Ñan collaboration, we expect that the UAV-orthoimagery-feature digitization/attribute registry workflow will work in future projects. Also, consumer multirotor UAVs have emerged in just the last year that far outperform anything that was available when we started the project: the DJI Phantom 3, DJI Inspire, and 3DR Solo are all rated to fly at least to 4,500 m (the Solo and Phantom 3 can go considerably higher). As a measure of the rapid evolution of these technologies, during July, 2016 (just prior to the time this paper goes to press), we successfully flew several photogrammetry missions over the site with a DJI Phantom 4 quadcopter, producing sub-5 cm orthomosaics. In short, the technical barriers that impeded the UAV aspect of our project have been overcome.

The resulting GIS for Mawchu Llacta is composed of 495 structures (themselves composed of 597 structural elements), 1,258 walls, and a number of other features with all field-collected attribute data integrated in a PostGreSQL/POSTGIS database with remote access (FIG. 13). This is now the central database for the project, which we are accessing and editing both locally and remotely via QGIS.

Pole Aerial Photography for Detailed Architectural Rendering

Lastly, in preparation for the excavation phase of the project, we selected areas of interest for excavation for more detailed photogrammetric survey using pole aerial photography (PAP). Pole-based photography is inexpensive, simple in execution, and enables closer and more precise camera placement with respect to the subject matter than UAVs. We used an 11 m carbon fiber fishing pole modified for PAP through the Public Lab (<http://store.publiclab.org/collections/mapping-kits/products/pole-mapping-kit>). We set ground control points with RTK GNSS (ca. 1 cm horizontal accuracy) and photomapped domestic compounds and other areas of interest, using a Canon S110 and GoPro Hero4, set at an interval of 5–6 seconds. We inserted the base of the pole in a flag pole holster to distribute the weight of the pole/camera rig and improve maneuverability.

Three days of fieldwork produced photos of four areas of interest: three compounds we identified as likely households of ethnic lords (*kurakas*) and an area adjacent to the trapezoidal plaza that we hypothesize was a ceremonial platform or other important shrine (*huaca*) in the original Inka center. A chapel is oriented in one corner of this area, its entry facing the opposite direction, oriented toward the primary entry and facade of the main church. The (nominal) resolution of the resulting orthomosaics is remarkable, with subcentimeter to submillimeter pixel resolution. The 3D models are sufficiently detailed to view and explore architectural details on-screen. These “digital surrogates” are important for both analytical purposes and use as virtual archives of these areas before archaeological interventions. Examples of the resulting models can be viewed and downloaded from Sketchfab (for the chapel and shrine area, see <https://skfb.ly/HwOn>; for the elite domestic compound, see <https://skfb.ly/JN6X>).

CLOSING THOUGHTS

The projects discussed here took place through different phases of the UAV and photogrammetric revolution in archaeology—from an era of early adopters to the current era in which it is approaching standard fieldwork practice among an increasing number of practitioners. As a piece on computational archaeology, this chapter plays a simi-

larly transitional role. It is likely that essays like this arguing for the benefits of UAVs and photogrammetry in archaeology will become less common in the near future, as technical barriers are lowered to the point that they are part of standard practice. But we have also argued that “standard practice” will need to change to capitalize on the extended observational capabilities that these technologies allow. We share the concern that the growing dominance of digital recording can, if used in traditional research designs, impede observation and interaction with the actual stuff of archaeological research: the tactile and sensory—observational—experience of primary archaeological data collection (see Caraher, Ch. 4.1). We have spent many hours both in the field and with archaeological digital surrogates in the days, weeks, and years following fieldwork (Rabinowitz 2015). Designing new workflows which minimize the extent to which digital surrogates interfere with primary field observation presents perhaps the central epistemological challenge going forward. It is likely, for example, that excavation project designs will be best served to move to a more specialized mapping/photogrammetry team model so that crew chiefs and excavators can focus on the primary instruments of observations rather than manipulating various digital-sensing instruments at a remove (see Castro López *et al.*, Ch. 3.1; Wallrodt, Ch. 1.1).

But from a heritage management perspective, the world will not wait. The inexorable loss of patrimony to deliberate destruction, urban sprawl, development, and a host of other threats compels us to find new ways to rapidly document global archaeological patrimony. In this case, however, usual compromises between speed, granularity, and accuracy do not apply. There is no downside that we can see as long as the digital surrogates we can produce quickly, cheaply, and easily do not displace our continued advocacy for the importance of conserving and experiencing ancient places.



<https://mobilizingthepast.mukurtu.net/collection/23-beyond-basemap-multiscalar-survey-through-aerial-photogrammetry-andes>

http://dc.uwm.edu/arhist_mobilizingthepast/12

REFERENCES

- Antezana Ruiz, D. 2015. *Proyecto de Investigación Arqueológica Inkawasi de Huaytará con fines de diagnóstico para la puesta en uso social*. Technical Report to the Ministry of Culture, Peru.
- Bitelli, G., V. Girelli, M. Tini, and L. Vittuari. 2004. Low-Height Aerial Imagery and Digital Photogrammetrical Processing for Archaeological Mapping. *Proceedings of the XXXV Congress of the International Society for Photogrammetry and Remote Sensing*. <http://www.isprs.org/proceedings/XXXV/congress/comm5/papers/605.pdf>
- Cassana, J. 2014. "New Approaches to Spatial Archaeometry: Applications from the Near East," *Near Eastern Archaeology* 77: 171–175.
- Chiabrando, F., F. Nex, D. Piatti, and F. Rinaudo. 2011. "UAV and RPV Systems for Photogrammetric Surveys in Archaeological Areas: Two Tests in the Piedmont Region (Italy)," *Journal of Archaeological Science* 38: 697–710.
- Danti, M. D. 2015. "Ground-Based Observations of Cultural Heritage Incidents in Syria and Iraq," *Near Eastern Archaeology* 78: 132–141.
- Fallavollita, P., M. Balsi, S. Esposito, M. G. Melis, M. Milanese, and L. Zappino. 2013. "UAS for Archaeology: New Perspectives on Aerial Documentation," *International Archives of Photogrammetry and Remote Sensing* 61 (1/W2): 131–135.
- Gasparini, G., and L. Margolies. 1980. *Inca Architecture*. Bloomington: Indiana University Press.
- Harmansah, Ö. 2015. "Isis, Heritage, and the Spectacles of Destruction in the Global Media," *Near Eastern Archaeology* 78: 170–177.
- Hesse, R. 2013. Using Structure-from-Motion to Document Threats to Archaeological Heritage in Coastal Peru. https://www.academia.edu/4610499/Using_structure-from-motion_to_document_threats_to_archaeological_heritage_in_coastal_Peru
- Hyslop, J. 1984. *The Inka Road System*. *Studies in Archaeology*. Orlando: Academic Press.
- Ioannides, M., D. Fritsch, J. Leissner, R. Davies, F. Remondino, and R. Caffo, eds. 2012. *Progress in Cultural Heritage Preservation: 4th International Conference, EuroMed 2012, Limassol, Cyprus, October 29–November 3, 2012: Proceedings*. *Lecture Notes in Computer Science* 7616. New York: Springer.

- Kosiba, S., and A. M. Bauer. 2012. "Mapping the Political Landscape: Toward a GIS Analysis of Environmental and Social Difference," *Journal of Archaeological Method and Theory* 14: 61–101.
- Mozas-Calvache, A. T., J. L. Pérez-García, F. J. Cardenal-Escarcena, E. Mata-Castro, and J. Delgado-García. 2012. "Method for Photogrammetric Surveying of Archaeological Sites with Light Aerial Platforms," *Journal of Archaeological Science* 39: 521–530.
- Mumford, J. R. 2012. *Vertical Empire: The General Resettlement of Indians in the Colonial Andes*. Durham, NC: Duke University Press.
- Nair, S. 2015. *At Home with the Sapa Inca: Architecture, Space, and Legacy at Chinchero*. Austin: University of Texas Press.
- Neuman, W., and R. Blumenthal. 2014. "New to the Archaeologist's Tool Kit: The Drone." *New York Times*, 13 August 2014, <http://www.nytimes.com/2014/08/14/arts/design/drones-are-used-to-patrol-endangered-archaeological-sites.html>
- Niles, S. A. 1999. *The Shape of Inca History: Narrative and Architecture in an Andean Empire*. Iowa City: University of Iowa Press.
- Olson, B. R., R. A. Placchetti, J. Quartermaine, and A. E. Killebrew. 2013. "The Tel Akko Total Archaeology Project (Akko, Israel): Assessing the Suitability of Multi-Scale 3D Field Recording in Archaeology," *Journal of Field Archaeology* 38: 244–262.
- Opitz, R. 2015. "Three Dimensional Field Recording in Archaeology: An Example from Gabii," in B. R. Olson and W. R. Caraher, eds., *Visions of Substance: 3D Imaging in Mediterranean Archaeology*. Grand Forks: The Digital Press at The University of North Dakota, 73–86.
- Poehler, E. 2015. "Photogrammetry on the Pompeii Quadriporticus Project," in B. R. Olson and W. R. Caraher, eds., *Visions of Substance: 3D Imaging in Mediterranean Archaeology*. Grand Forks: The Digital Press at The University of North Dakota, 87–100.
- Protzen, J.-P. 1993. *Inca Architecture and Construction at Ollantaytambo*. New York: Oxford University Press.
- Protzen, J.-P., and D. Harris, eds. 2005. *Explorations in the Pisco Valley: Max Uhle's Reports to Phoebe Apperson Hearst, August 1901 to January 1902. Contributions of the University of California Archaeological Research Facility* 63. Berkeley: Archaeological Research Facility.
- Rabinowitz, A. 2015. "The Work of Archaeology in the Age of Digital Surrogacy," in B. R. Olson and W. R. Caraher, eds., *Visions of Substance: 3D Imaging in Mediterranean Archaeology*. Grand Forks: The Digital Press at The University of North Dakota, 27–42.

- Roosevelt, C. H., P. Cobb, E. Moss, B. R. Olson, and S. Ünlüsoy. 2015. "Excavation Is Destruction Digitization: Advances in Archaeological Practice," *Journal of Field Archaeology* 40: 325-346.
- Tripcevich, N., and S. A. Wernke. 2010. "On-Site Recording of Excavation Data Using Mobile GIS," *Journal of Field Archaeology* 35: 380-397.
- van de Guchte, M. 1999. "The Inca Cognition of Landscape: Archaeology, Ethnohistory, and the Aesthetic of Alterity," in W. Ashmore and A. B. Knapp, eds., *Archaeologies of Landscape: Contemporary Perspectives*. *Social Archaeology*. Oxford: Blackwell Publishers, 149-168.
- Wernke, S. A. 2015. "Building Tension: Dilemmas of the Built Environment through Inca and Spanish Rule," in M. Barnes, I. de Castro, J. Flores Espinoza, D. Kurella, and K. Noack, *Perspectives on the Inca: International Symposium from March 3rd to March 5th, 2014*. Tribus, special ed. Stuttgart: Linden-Museum, 165-189.
- Wernke, S. A., J. A. Adams, and E. R. Hooten. 2014. "Capturing Complexity: Toward an Integrated Low-Altitude Photogrammetry and Mobile Geographic Information System Archaeological Registry System," *Advances in Archaeological Practice* August 2014: 147-163.
- Wernke, S. A., and V. Siveroni Salinas. 2013. *Proyecto Arqueológico Tuti Antiguo, Valle del Colca. Fase III: Levantamiento y prospección de los sitios de Mawchu Llacta y Laiqa Laiqa*. Technical report submitted to the Ministry of Culture, Peru.