

Background

The growing availability and sophistication of digital technologies, particularly in the geospatial domain, has begun to profoundly affect how archaeologists and other scholars work. The things archaeologists study—from artifacts to sites to landscapes—almost always have a spatial component, and space is viewed as one of the central dimensions of archeological study (cf. Ashmore 2002; Ashmore & Knapp 1999; Clarke & Chapman 1978; Cowgill 1993; Kvamme 2003). The capability of geospatial technologies to enhance discovery and interpretation of these features not only offers new data, but creates entirely novel means of engaging with the archaeological record. For example, high-resolution satellite imagery makes it possible to locate and map archaeological features across vast expanses of terrain, enabling investigations to cross modern cultural and political boundaries and explore the spatiality of ancient polities at scales never before possible (cf. Casana & Cothren 2007; Hritz 2010; Ur 2003; Wilkinson et al. 2006). Subsurface geophysical investigations allow buried archaeological remains to be documented revealing complete, detailed plans of entire communities and by consequence offering new insights into community organization and past built environments (Casana, Herrmann, and Fogel 2008; Conyers 2004; Gaffney and Gater 2003; Kvamme 2003). Laser scanning and photogrammetric modeling techniques present new ways of recording artifacts and architecture in three dimensions and enable morphometric analysis at multiple scales – from small objects to large sites (Betts et al. 2011; Limp et al. 2011; Karasik and Smilansky 2008; Maschner, Betts, and Schou 2011).

While scholars across a variety of disciplines increasingly recognize the transformative potential of geospatial technologies across the social sciences (Goodchild and Janelle 2004) it has particular relevance to the study of the past. A reasonable argument can be made that the introduction of the range of spatial technologies is now having and will continue to have as significant an impact on archaeology as has chronometric methodologies such as radiocarbon dating. Like chronometric technologies, however, relatively few individuals have the combination of equipment, technical skills, and archaeological acumen needed to integrate geomatics effectively into archeological research. While an obvious approach to overcoming this limitation is to partner multiple individuals with complementary knowledge, it does not guarantee success. There is an extensive record of missed opportunities where a technical specialist partnered with an archeological research project but there was a lack of understanding of the archaeological requirements by the technical specialist and/or a lack of experience with the technology by the archaeologist.

Over the past two decades, the University of Arkansas Center for Advanced Spatial Technologies (CAST) and Archaeo-Imaging Lab (AIL) have steadily invested in the development of capacities (equipment and software, analytical practices, staff, expertise, etc.) in geospatial technologies and their deployment in archaeological research through collaborations between geomatics specialists and archaeologists. Today, CAST and AIL are global leaders in geospatial research across a variety of disciplines and applications, and are widely regarded among the best places for the application of these technologies in archaeology. CAST and AIL currently collaborate on archaeological research projects around the world . In these projects support for geomatics field data acquisition and lab processing analyses are funded piecemeal through a variety of grants and funding sources. More importantly, many projects where the

application of these methods would be transformative do not have resources to support the staff or equipment. We believe that an expansion of the effective application of these methods will have a transformative effect on the field as their benefits to addressing challenging archeological research questions are fully recognized.

Research Productivity Enhancements

This proposal seeks funding to provide more stable, dedicated financial support for the critical role that CAST and AIL has begun to play in archaeological research projects conducted by others, and to expand access to CAST and AIL facilities and expertise to a broader audience of projects – particularly NSF-funded projects. Support from the NSF Archaeometry program award will help outside researchers with existing grant funding make money go further, by offering essential geospatial “consulting,” field data collection, and post-collection data processing and analysis. We plan to focus on three primary areas of CAST and AIL’s established expertise: 1) site-based archaeo-geophysics and mapping, 2) three-dimensional scanning, photogrammetry, visualization, and morphometrics; and 3) aerial and satellite remote sensing, regional survey, and mapping. These investigations will be implemented within an outreach program that would make CAST instruments and (perhaps more importantly) expertise available on a collaborative basis to researchers from the US and abroad. The award will increase productivity for both CAST and AIL and, more significantly, for a wide range of individual research projects. The substantive results from such efforts will, we believe, achieve the “tipping point” that moves these research approaches from being viewed as “intriguing” or “potential” to *essential* parts of archeological study. Currently CAST and AIL equipment and facilities are not fully scheduled; therefore, with additional staff support, substantial additional data acquisition efforts can be accomplished within the current equipment configuration, increasing the efficiency of use of these expensive systems that have (largely) already been acquired with NSF support. With the support requested in this proposal we project that we can support at least 50 summer season “instrument-field weeks” across a range of projects (5 staff and/or students each with instruments for 10 weeks) and up to an additional 15-30 (perhaps more) additional instrument-field weeks throughout the remaining year.

While metrics are important, research productivity cannot be measured simply by the number of weeks in the field or by the hours of active equipment time. Using CAST and AIL equipment and expertise to improve the quality of research in those projects needing archaeological geomatics will also serve to increase overall research productivity. Under the current arrangement most collaborative projects are initiated because their researchers have an existing connection with CAST and AIL researchers and, consequently, are aware of the resources available. Many of the projects developed through informal research networking are of high quality, but we believe a formal, open, and competitive system for the submission and selection of research proposals, which would benefit from the support and collaboration of CAST and AIL, would greatly improve the quality of research produced, maximizing productivity both on the part of CAST, AIL and individual research projects.

CAST and AIL researchers will likewise benefit from increased collaboration. Participation in and consultation with a diverse range of high quality projects, which will expose the team to new methodological, technical, and intellectual challenges, will push us

continue to innovate and develop our practices. Substantial intellectual and research benefits for CAST/AIL are anticipated, as technical and methodological spin-off projects evolve out of collaborations funded through this program.

Sample Acquisition and Processing

Over the last two decades CAST and AIL research efforts have focused on the development of capacity in the acquisition and processing of a broad range of archeological geomatics data. Through this process we have identified a number of properties of these data that represent challenges to their application by archeologists and have developed strategies, software, and expertise to address them.

In archaeo-geomatics the samples collected consist primarily of spatial and spectral (i.e. returned signal strength and form) data. This catch-all description hides a plethora of sample types whose existence presents one of the core challenges of archaeological geomatics – selecting the appropriate characteristic(s) of an object, site, or landscape to investigate and choosing the right instrumentation and method for its study. A variety of instruments (see the Facilities section for a detailed list) are available for data collection across the spectral range and at different spatial scales. As different instruments are appropriate for sample collection, processing methods and algorithms for samples of various types and scales are used. Choosing the most appropriate technology or sensor for an application is a key step in a successful research project incorporating geomatics, and practical experience with a range of instrumentation is required. The main sample types relevant to archaeological geomatics correspond with CAST and AIL areas of expertise: geophysical data, morphometrics or geometric data (including those referenced to a geodetic coordinate system), and spectral data. It is not practical to detail the individual problems of each sample type here; rather, an overview of key general characteristics and their challenges is provided.

The successful acquisition of geomatics samples (better referred to as datasets as they are almost always collected as an aggregate) greatly depends on expertise regarding the selection of the correct sensor to use to record a given property, the proper configuration and limits of that sensor, and the impact of environmental factors. Since much geomatics data is collected in situ, with the sensors travelling to the object rather than the object coming to the lab, experience with the impact of field conditions on collection is vital. For example, knowledge of the correct distance between a sensor and its target, how the surface's reflectivity properties will affect the observation, whether a subsurface object is too highly magnetized to produce a useful signal, and whether a particular method will work in the rain all come into play. Unlike lab procedures, the field data recording is often a one-time event and either cannot be replicated (the site is destroyed) or could only be replicated at great expense. As a result, field methods and data recording must be highly structured, detailed metadata must be acquired (cf. Payne 2011, Barnes 2011, Ernenwein and Hardgrave 2010 and the ADS Guides to Good Practice generally) and data integrity must be assured.

Archaeological, as well as technical expertise, are needed for the successful integration of a geomatics survey into an ongoing or newly formed archaeological project. The collection of data should be designed to integrate with, rather than disrupt, complementary extant fieldwork and should be coherent with the research aims of the project. Technical specialists without the

necessary archaeological field experience often struggle to fit their work into the daily practice of field archaeology. Many members of the CAST and AIL team are practicing archaeologists as well as geomatics specialists, and have the necessary experience and understanding to smoothly integrate a variety of methods into complex fieldwork projects. In the applications of spatial recording methods to archeological data the use of multiple sensors in combination is often beneficial, resulting in multiple data types with different sampling rates and noise characteristics. To achieve the full potential of a multi-sensor approach, the data must be effectively fused using a variety of sophisticated software. While there are a growing number of free and open-source software (FOSS) options (e.g. the Point Cloud Library, MeshLab, ArchaeoFusion, Opticks, and libLAS), the majority of software solutions that manage and process these data streams are commercial and, frequently, very costly. CAST and AIL have acquired, and developed expertise in, a broad range of these commercial solutions (e.g. Cyclone, PolyWorks, RapidForm, LAStools, PhotoScan) as well as FOSS solutions and can make them available to the projects.

Most geomatics data is “born digital,” and since it is often collected in remote locations and under particular environmental conditions, what is being studied in the end is not so much an archaeological object or site as a model of it. Geomatics data generally, and specifically those derived from archaeological sources, are considered “big” data (Austin and Mitcham 2007). Typically large data volumes (multiple gigabytes to terabytes) are produced from the acquisition of densely spaced measurements in each dataset. To store and work with the data requires a dedicated computational infrastructure on a scale not available in most archaeological departments. CAST has developed the capacity to analyze, manage, and store these big datasets, and, through collaboration with the Arkansas High Performance Computing Center (via MRI-R2 #0959124 on which Dr. Cothren is a Co-PI), continues to expand its already significant cyber-infrastructure. Effective infrastructure also includes the management, manipulation, and analysis of truly large datasets and is not merely the scaling up of practices used for smaller datasets. At the gigabytes and terabytes (and soon petabytes) of data scale, search functions, versioning, metadata, compression, sampling, and level of detail are essential issues.

The final key element in the arena of archaeological geomatics is the dissemination and archiving of these digital data (Kansa, 2005:100). The archive and dissemination of the data products developed in CAST and AIL research are critical factors (Limp et al. 2011:19-21) that we address in some detail in the data management plan.

Analytical Developments

Much attention has been given to the practical and time saving value of the recordation aspects of the methods under discussion – and these benefits are undoubtedly important, especially given the continuing loss of the resources to development, looting, and other causes and to the time-consuming nature of traditional manual/analog methods of drawing and recording. However, archaeological recordation is not merely the act of noting down facts and information; it is an interpretive process. As geomatics technologies change the way in which we record in the field, they alter, sometimes radically and sometimes subtly, the way we see, interpret and ultimately create the archaeological record. Recognizing the intertwined nature of

the acts of recording and interpretation and the potentially enormous impact of the introduction of new technologies to archaeological practice, we consciously pursue reflexivity in the methods we develop and see explicit assessment of the interpretive impact of new recording methods as essential. Equally importantly, we believe that these methods present opportunities for new types of analysis that will allow researchers to ask new questions of their data and examine the material record of the past in exciting and innovative ways. The ability to record rapidly in fine spatial and spectral detail over large areas does not simply mean that we can more efficiently and cost-effectively do what we did before. Changes in the practical scale of recording and analysis fundamentally change the kinds of questions we can ask of the archaeological evidence. Where in the past studies of urbanism have been limited by the scale and pace of excavation, expanding our understanding of this basic phenomenon one house or city block at a time, researchers may now pose and address questions requiring the knowledge of entire city plans or detailed analyses of the architecture and arrangement of adjacent buildings – not just in a few, exceptionally well-studied locales, but across the board. The complete, if generalized, city plans, revealed by geophysical surveys at places like Wroxeter and Falerii Novi revolutionized our ideas about Roman Urbanism, and the expanding application of near-surface geophysics is key to the current renaissance in archaeological research into urbanism and urbanization. The growing use of photogrammetry and laser scanning has the potential to provoke yet another sea-change in the study of urbanism, as detailed records of the structure of spaces become widely available for interrogation, and studies based on affordance, the experience of place, and fine-grained inter-relationships between objects and structures and their viewers become practical at a variety of places and scales.

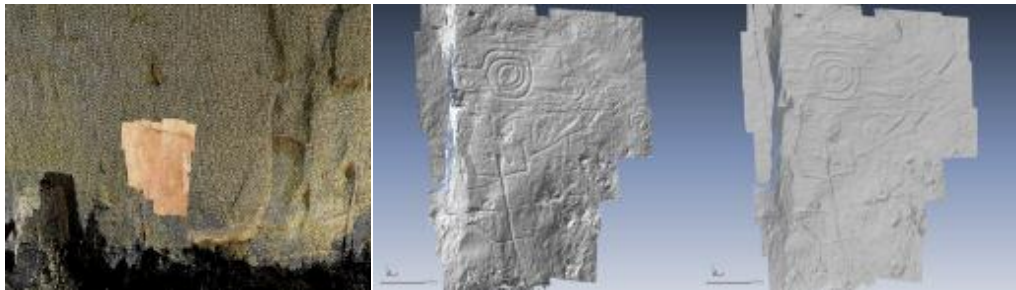


Figure 1: The left image is a small portion of the entire cliff face data at 7 mm with the high-resolution rock art panel in place. The middle and right images illustrate the panel detail with illumination at calculated dates and times.

In the area of object morphometrics (Slice 2005; Slice 2007; Zelditch 2004) there is a range of emerging analytical techniques that can be used to investigate the point cloud and meshed data sets produced by terrestrial laser scanners (TLS) and object scanners. As one example, in many situations site digital recordation efforts do not place the data into geodetic space but preserve it in a floating grid (like many archeological site grids). When these data are properly oriented in geodetic space many analytical opportunities emerge. For example, Figure 1 illustrates a highly detailed scan (0.15 mm point spacing) of a rock art panel at Chaco Canyon National Historic Park aligned with an intermediate resolution point cloud (7 mm) which is, in turn, located within a moderate resolution (0.5- 3.0 cm) dataset of the entire ca. 1 km long cliff face. The area is the cliff face between Pueblo Bonito and Chetro Ketl. The large area dataset

was geodetically oriented with survey grade GPS and the high-resolution data aligned to it. As a result it is possible to illuminate the panel based on defined times and dates in the past.

High precision digital representations of objects also support analytical operations and digital measurements that are difficult if not impossible to acquire directly on the actual object (see Figure 2).

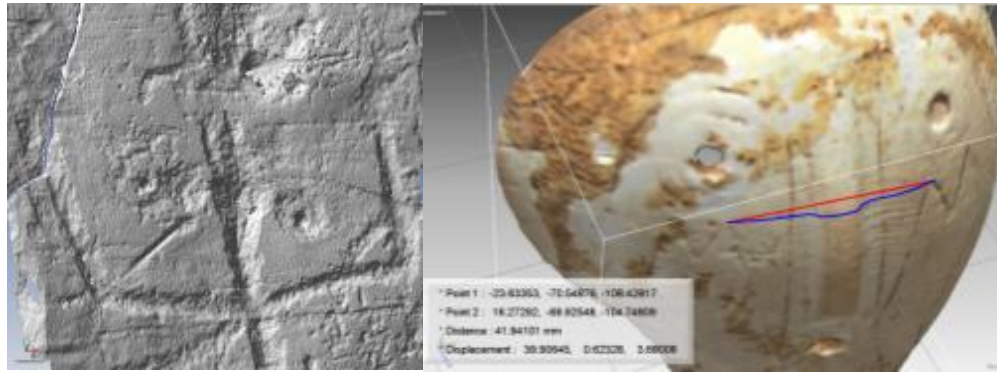


Figure 2: The left image illustrates the manufacturing detail evident in high-resolution scans of rock art elements from Chaco Canyon. The right illustrates measurements that can be acquired from the digital version of an object from the Nodena site (cf. Simon *et al.* 2009; Weeks *et al.* 2011).

Information on manufacture and construction can also be derived from the digital representations in ways that are challenging on the actual object. In Figure 3 the left-most image uses curvature analysis on the 3D point cloud (Cole 2008) to identify details in the incising on the vessels surface, the middle image illustrates the use of machine analytics to acquire detailed measurements and properties of stones in the façade of a structure at Machu Picchu, and the right image illustrates automatic extraction of “stylistic” elements from a Mississippian period pre-Columbian ceramic vessel. These can be investigated in true 3D or “rolled out” for traditional viewing. To illustrate the research goals of object morphometrics we can draw upon our collaboration with George Sabo, Alex Barker, James Brown, and others where we are currently developing strategies for the analysis of a range of objects recovered from the Spiro Mound Site. High precision morphometric analyses based on 3D point clouds and meshes can provide metric information on a range of key research objectives. For example, over/under cutting on shell can be measured, providing sequencing in the manufacturing processes used in the application of designs and their changes through time. Similar high precision 3D data coupled with imagery from Reflectance Transformation Imaging (RTI) photography is allowing the discovery and assessment of previously obscure design motifs on basketry used to hold the objects in the Great Mortuary. In a very different example we are working with Chavdar Tzochiev on the precise metric analysis of stamps on Greek amphora. In the industrial production of amphorae in the ancient Mediterranean each facility applied a stamp as the amphorae were manufactured. Through time these stamps wore, and by measuring the micro-wear of the imprints on various amphorae it is possible to determine the specific amphora’s position in the manufacturing cycle (c.f. Tzochiev 2009, 2010). New developments in high-performance computing (HPC) aided morphometric analyses of objects are opening new pathways to understanding classification as well. For example, work by Gilboa *et al.* 2012 and Koutsoudis *et al.* 2010 on automated analyses of dense point cloud representations of ceramic

vessels illustrates exciting new directions in the study of these traditional materials. Of particular note is that the work by Koutsoudis utilized pre-existing digital versions of materials from the CAST's Hampson Virtual Museum, illustrating the value of digital discovery and reuse.

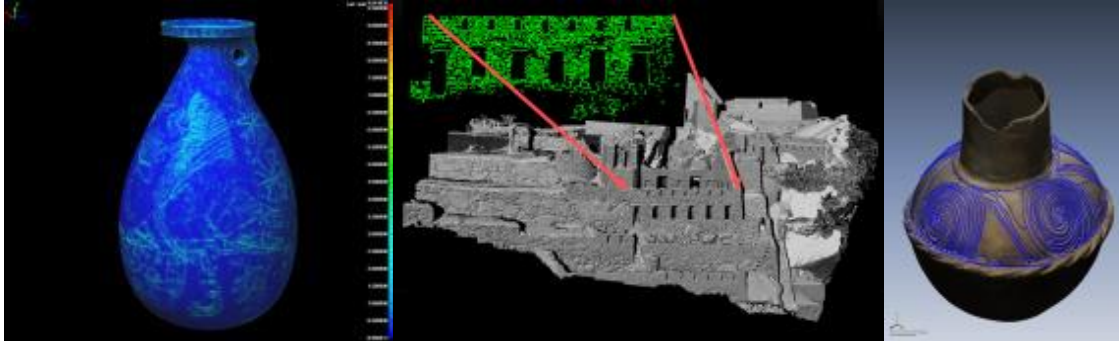


Figure 3: Examples of automated extraction of manufacturing or construction details – see text.

Another important area for the application of these 3D analytical methods is in the modeling of past built environments. Following the “spatial turn” (Warf and Arias 2009) in the social sciences more generally, there is growing recognition in archaeology that built environments, as the spatial contexts in which human action and interaction take place, play an active and central role in social reproduction and transformation (Blake 2004; Lefebvre 1991 [1974]; Low 2000; Soja 2000). Such an approach distinguishes space, which might be seen as the passive, neutral, physical location in which social action occurs, from place, which is “lived space” imbued with meanings, identities, and memories that actively shape, and are shaped by, the daily practice and experiences of its inhabitants and historically contingent social processes (Fisher 2009; Low and Lawrence-Zúñiga 2003; Preucel and Meskell 2004; Rodman 1992; Tuan 1977). Archaeologists are therefore faced with the difficult task of trying to reconstruct and scientifically analyze the experiential aspects of social life in past places, which are often preserved as little more than foundations. New 3D methods for recording, modeling, visualizing, and analyzing built environments hold tremendous potential for meeting this challenge. Researchers have made promising advancements in using TLS and photogrammetric data as a basis for creating models of rooms, buildings, and landscapes that can be integrated into geographic information systems (GIS) and rendered, using gaming engines and related VR software, to produce photo-realistic environments that can be “navigated” by users. This work provides important new insights into some of the scientific analysis of experiential characteristics of movement and wayfinding, including sophisticated 3D analyses of visibility and surveillance – all of which are implicated in people-place relations and social interaction (e.g., Entwistle et al. 2009; Paliou et al. 2010; Rua and Alvito 2011). CAST and AIL have been at the forefront of these developments, providing equipment and expertise for the 3D reconstruction and analysis of built environments in a wide variety of contexts, from Native American villages in Arkansas (Limp et al. 2011) to the Roman city of Pompeii (Cole, Merced, and Fredrick 2010), and at various scales, from individual monuments in Greece to entire sites, such as the Inka city and World Heritage site of Machu Picchu in Peru (Cothren et al. 2008).

Another key suite of methods is geophysics. Basic reconnaissance of the subsurface of archaeological sites is best achieved through magnetic gradiometry where two hectares per day can be surveyed at moderately high spatial resolutions. Magnetometry has been termed "nature's gift to archaeology" (Kvamme, 2006b), and rightly so, because so many human activities cause magnetic variations in the archaeological record (e.g., intense fires, mounding or removal of soil, importing of stone and foreign sediments, iron artifacts). In sites containing robust architecture of stone or brick with their inherently high resistivities, electrical resistance or soil conductivity surveys may prove even more beneficial. When soil conditions are suitable ground-penetrating radar (GPR) can yield not only the most detailed information but 3D data, permitting imaging at various depths and rendering of subsurface objects (walls, floors) three-dimensionally (Figure 4).

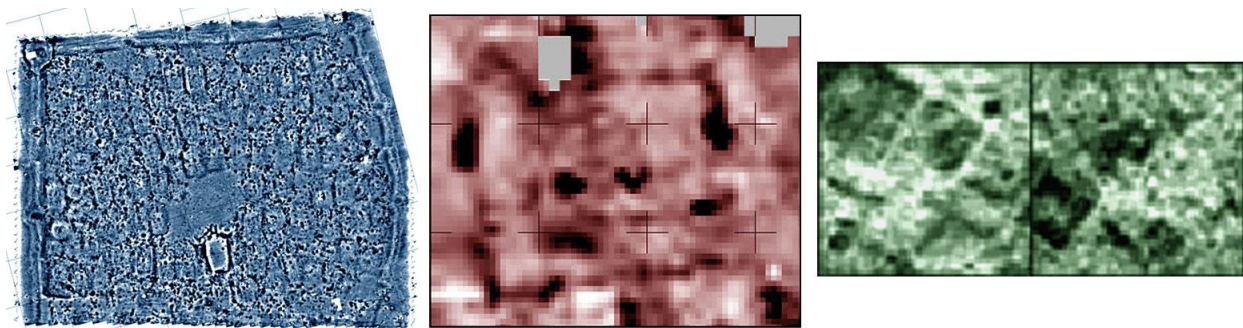


Figure 4: Magnetic gradiometry reconnaissance of a 5 ha region of a 15th century village, North Dakota (left), a 17 x 15 m electrical resistivity survey showing a mid-19th century church foundation in Arkansas (middle), and detailed GPR imaging at 60 cm below surface of a 20 x 40 m region in a 13th century pit-house village in New Mexico (right).

Multiple geophysical surveys of the same area generally offer improved insights because each one can yield information about a relatively different aspect of the subsurface, permitting maximum information about a site to be gained non-destructively. For the past decade AIL and CAST have conducted numerous projects under this premise, with consistently favorable results. More accurate anomaly identifications are also achieved because each geophysical dimension points to a different physical or chemical property of the subsurface.

At the Double Ditch site in North Dakota, a fortified earthlodge village occupied from about 1490-1780 CE, a wide array of ground-based and aerial sensing devices were explored to investigate this important site in a five-year program. Magnetic gradiometry revealed two previously unknown fortification systems that vastly increased the settlement's area and projected population to perhaps 2,000 individuals. Vast numbers of food storage pits that supported the population were also indicated. Ground-penetrating radar gave insights into mounded midden interior forms and yielded details about house interior components, while electrical resistivity improved definition of middens, other depositional areas, houses, and borrow pits. Aerial survey from a powered parachute acquired high-resolution digital color and thermal infrared imagery. A high-resolution digital model of topography was acquired by robotic total station that documents surface expressions caused by ditches, houses, borrows, and mounds; when combined with overlays of geophysical data, understanding of remote sensing responses is improved, and relationships between large mounds with village defenses are made clear. The multi-sensor remote sensing program at Double Ditch (Figure 5) permitted

discovery of new fortification ditches, dozens of hidden bastions, houses, and trails, thousands of subterranean storage pits and hearths, revealed the sites internal structure and overall layout, and reduced excavation costs by allowing a wide variety of archaeological features to be accurately identified and targeted.

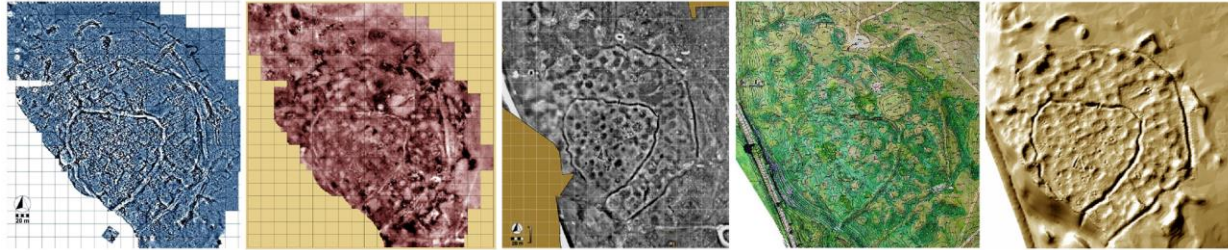


Figure 5: Project results at the Double Ditch State Historic Site in North Dakota showing, from left-to-right, magnetic gradiometry, electrical resistivity, aerial thermal infrared, enhanced color aerial, and shaded surface microtopography. The area depicted measures approximately 380 x 400m.

CAST and AIL have also been active in the development of new software and applications in archaeo-geophysics. With continuing support from the Department of Defense's Strategic Environmental Research and Development Program (SERDP) and its Environmental Security Technology Certification Program (ESTCP), the center has emphasized the use of an integrated, multi-sensor approach to investigation (Kvamme 2006; Kvamme 2007; Ernenwein and Kvamme 2008; Ernenwein and Hargrave 2007). The approach requires the use of several different co-registered archaeo-geophysical methods (magnetometry, electrical resistance, electrical conductivity, magnetic susceptibility, and ground-penetrating radar). Each method gives unique results due to the measurement of different physical properties or by focusing on different depths. Since archaeological sites are highly variable, using multiple sensors increases the probability that a variety of archaeological features will be detected. While multi-sensor studies have been shown to be extremely valuable, geophysical practitioners currently process data using a variety of software products that are often idiosyncratic, require repetitive actions, and do not provide a suitable medium for integrating data from diverse instruments. With support from SERDP/ESTCP CAST developed ArchaeoFusion, a freely available software application, which allow direct ingest of raw instrument data from more than 25 instruments and provides all necessary processing routines for each method, along with a variety of algorithms for sophisticated data fusion and analysis. Each analytical operation is recorded in an operations stack that can be distributed along with the raw data, making analytical steps reproducible. Preconfigured operation stacks will allow geophysical practitioners with modest levels of expertise to achieve reliable results.

As key developers for metadata and good practices standards, CAST and AIL researchers are well placed to support the dissemination and wider adoption of these standards and practices throughout the archaeological community. An Archaeometry award would further support this dissemination of good practices by bringing researchers into close collaboration with expert technologists at CAST and AIL early in their experience with new technologies. Participants collaborating with CAST and AIL on research projects would be assisted in the creation of appropriate metadata and in archiving their digital data appropriately – a key final step in the research process where many projects falter.

Technical Support and Selection of Projects

In our interactions with a wide range of archaeological researchers, with many different regional and theoretical interests, we have identified a consistent series of stages in the successful and effective use of geomatics technologies in their research projects. We should note that there are projects that are not good candidates for such methods, and it is equally important to assist researchers in determining that these methods are likely to not be useful in a specific case as it is to facilitate their use when it is appropriate. For purposes of discussion we will describe these stages as (1) information seeking (2) evaluation of alternatives (3) initial pilot studies (4) integration into practice. Our proposal here is designed to facilitate aspects of all of these stages as we describe below.

Table 1: Stages, or levels, of support

Stage	External Researcher Involvement	CAST and AIL Resources and Support
Stage 1 “Information Seeking”	<ul style="list-style-type: none"> Initial exploration 	<ul style="list-style-type: none"> GMV Website On-line inquiry System Web accessible FAQ Remote consultations
Stage 2 “Evaluation of Alternatives”	<ul style="list-style-type: none"> Focused information gathering Review of comparable efforts Cost and benefit assessments 	<ul style="list-style-type: none"> Workshops Webinars Week long consultation at Center Advice in proposal development
Stage 3 “Initial Pilot Studies”	<ul style="list-style-type: none"> Active collaboration in field and data analysis Active collaboration in publication and reporting 	<ul style="list-style-type: none"> Center staff and equipment in field Data processing Ongoing consulting Intermediate Center residency
Stage 4 “Integration into Practice”	<ul style="list-style-type: none"> Full implementation in current and future project(s) 	<ul style="list-style-type: none"> Continuing field participation as needed Continuing advice as needed Graduate student residence and training

The plan we are presenting here has been made possible by the results of the 3-year NSF CI-TRAIN project (EPS #0918970). In that effort we recognized that application of geomatics methods generally (not just in archaeology) required a comprehensive workflow approach – from data acquisition and processing through analysis to publication and archive (c.f. Limp et al 2011) – and that existing resources (e.g. texts, publications, equipment manufacturer’s manuals) did not provide useful practical guidance. Furthermore, and unfortunately, the pace of technical development makes traditional scholarly publication of detailed methods largely obsolete by the time they are available – though basic articles and texts on essential methods are an exception. As a result we have created the Geospatial Modeling and Visualization web resource

(GMV), a distilled suite of regularly updated workflows for a wide range of geomatics applications in archaeology and heritage generally.

In addition to the GMV resources, we have also developed a series of workshops on geomatics technologies that we have offered and will continue to offer at no fee at various archeological meetings (e.g. 2010, 2011, 2012 and forthcoming 2013 SAA National meetings), and we are developing a series of technical webinars on geomatics methods in archaeology as part of a newly announced professional development program by the SAA. In the effort proposed here we would expand on this foundation, offering more workshops in more venues and more webinars. Over the two years of the project we would offer no-fee workshops to the organizers of at least three (per year) regional conferences and/or to key groups such as the national SHPOs and NHTPOs. The workshops, webinars, and GMV resources address what we have defined as Stages 1 and 2. However, we have identified an initial constraint at Stage 1 that we will address by creating a “tech questions” and FAQ web resource. This will be a user-friendly web resource where individuals interested in considering these methods can submit various technical or operational questions that will be addressed by the project staff. This will allow archeologists who are considering the application of geomatics methods to obtain non-biased information early on in their consideration of possible use. These questions will be maintained in an FAQ format to assist others as well. Responses to the questions can draw upon the GMV materials, webinar content, and other sources for suggestions for “further reading.” In support of this approach (and not part of this proposal) we are also finalizing the creation of a publically accessible Zotero Library on geomatics application in archaeology and heritage. The library will have more than 1,000 citations when launched in early 2013 and will be constantly expanded.

Using these resources and others an archaeologist can then determine that a particular method (or suite of complimentary methods) may (or may not) be valuable for a project – moving the effort to Stage 3. Stage 3 efforts can take two forms. One involves the travel of an individual to the CAST facilities for a period of time where they can work closely with staff to better define their project needs and direction. We would anticipate that such interactions would occur over an intense period, usually a week. Transportation costs, local housing, and per diem for such consultation/interaction would normally be the responsibility of the individual, but we have budgeted support for up to four such sessions per year for those without such support. CAST will provide all needed technical facilities/support for the individual while in residence – computer facilities, access to equipment, consulting staff, etc. These visits can be scheduled at any point that is mutually agreeable to the participants. In some cases a researcher may wish to apply a technology not available through CAST, such as airborne LiDAR. While CAST does not have an aircraft or airborne instrument we have very extensive experience in both contracting for LiDAR aerial services and post processing various raw data. In cases such as these CAST can provide technical expertise/advice to with regards to procuring the proper services and/or developing proposal text for the acquisition of such services. CAST would respond to these types of requests for advice/technical assistance in the order in which they occur.

CAST also plans to host graduate students from other institutions who wish to attend for one or more semesters and participate in the standard academic offerings as well as

participate in ongoing research projects. These students will be offered full access to the CAST facilities, as well as all technical and staff capabilities. Projects that have or have had a student in residence will be able to schedule use of the equipment for which they have received training. As we note elsewhere in the proposal we have previously completed a very successful NEH funded Digital Institute in Archaeology with very similar structure. We have NOT included direct financial support for these students in the proposed budget – they will require support from their host institution.

In other situations, a more substantive effort will be needed and will require the participation of CAST staff and/or equipment in the actual project. Proposals to CAST for such substantive support will be accepted two times a year. Given the typical archaeological calendar we anticipate that the greatest demand may occur during the summers, and not all highly rated proposals may be capable of being supported because of limits to the equipment and staff - but projects that have a more flexible calendar may more readily be scheduled. Note that the main personnel costs in the budget are limited to those needed for Opitz and Simon. However, during the field season, we have set aside hourly funds in the budget to allow additional CAST technical staff/students to participate so that a full complement of instruments could be in simultaneous use at different projects, maximizing their use.

The process for selection of projects to support will follow the general strategies used by programs such as the University of Missouri Research Reactor Center (MURR), the National Environmental Research Council's (NERC) Geophysical Equipment Facility, the Airborne Research and Survey Facility (ARSF), and others. Applicants may submit short proposals (3 to 5 pages) requesting subsidized data collection, processing, and analyses using one or more of the instruments and associated commercial and/or free and open-source software available through CAST and AIL. Applicants requesting participation in this program must be graduate students or faculty members from colleges, universities, and institutes in the USA. Projects eligible for support must involve basic research in anthropological archaeology. The submitted proposals will be reviewed first by CAST and AIL staff for technical feasibility and estimated costs/efforts, and the proposal and estimate will be provided to an outside review panel that will rank the proposals with regard to their archaeological merit following standard NSF review guidelines but with three key criteria: "What is the expected long-term significance of research objectives of this project," "What is the likelihood that the project will be conducted successfully" and "Will the use of geomatics in this project significantly advance the project's research objectives?"

We have invited and the following individuals have formally agreed to serve on the panel during the project: **Sue Alcock**, Director, Joukowsky Institute for Archaeology and the Ancient World, Professor of Classical Archaeology, Brown University; **Alex Barker**, Director of the Museum of Art and Archaeology, University of Missouri; **Meg Conkey**, Class of 1960 Emerita Professor of Anthropology, UC Berkeley; **Charles R. Ewen**, Professor, Department of Anthropology, East Carolina University; **Michael Hardgrave**, Construction Engineering Research Laboratory, US Army Corps of Engineers; **Matt Johnson**, Professor of Anthropology, Dept. of Anthropology, Northwestern University; **Simon Keay**, Head of Archaeology, University of Southampton; **Margaret M. Miles**, Andrew W. Mellon Professor of Classical Studies, American School of Classical Studies; **Martin Millett**, Laurence Professor of Classical

Archaeology, Cambridge University; **Eduardo Góes Neves**, Laboratório de Arqueologia dos Trópicos Museu de Arqueologia e Etnologia, Universidade de São Paulo; **Tim Pauketat**, Professor of Anthropology and Medieval Studies, University of Illinois; **Christina B. Rieth**, State Archaeologist and Director, Cultural Resource Survey Program New York State Museum; **Nicola Terrenato**, Professor of Classics, University of Michigan and **Willeke Wendrich**, Professor of Egyptian Archaeology/Digital Humanities, UCLA.

Proposals will be reviewed and individually ranked by the panel, and we will utilize video conferencing to allow the panel to “meet” as a body to discuss the reviews and rankings. Center staff will attend in an *ex officio* manner to answer any technical questions but will not vote. The final outcome of the panel will be all proposals in rank order.

The Director of CAST and staff will take the proposals in rank order and contact the PIs in that sequence – developing individualized plans to provide technical support/equipment to the project. The primary potential constraint will be scheduling, as it is likely that multiple projects will be in the field during the same time. The highest ranked projects will be fully supported with as many projects supported in the award period as is feasible. Every possible effort will be made to maximize field time through methods such as coordinating project efforts so as to move from one to the next. If lower ranked but meritorious projects have scheduling flexibility they can increase their likelihood of being accommodated. If time/resources permit then we would propose that projects which were not ranked highly enough to have staff and equipment use supported may still utilize the equipment if they are able to provide support/travel for a graduate student or use some other vehicle to provide technically qualified operation. Again – every attempt will be made to maximize the productive use of staff, students, and facilities.

In some cases, applicants will have well-defined needs and place specific requests for what is essentially a routine use of particular instruments and methods. Where such needs and project resources correspond with the current offerings of commercial practitioners CAST will not perform the work but rather refer the project principles to appropriate commercial alternatives.

We anticipate a range of projects that will be appropriate for CAST and AIL. The first group involves those projects with the objective of a small-scale proof-of-concept effort where the project investigators may anticipate that the capabilities of CAST and AIL may be of considerable value, but they do not have experience with the alternatives, and/or the conditions or circumstances make success unclear. In such cases commercial options are not appropriate. CAST can complete such studies and, where successful, the project may then be encouraged to acquire commercial providers, if such exist to assist them. In the second case the project scope/budget does not permit commercial efforts, but the research results are expected to be considerable. The final acceptable project category is one where the problem is of a suitably technical nature that current commercial efforts are not focused/adequate, and/or there are key methodological research efforts needed to meet the project needs.

It is likely many potential applicants will have research that they suspect may be enhanced by the digital methods provided by the lab but are unfamiliar with the specific technical potentials and limitations. In these cases, the project staff will work with the applicants to develop an approach using one or several instruments and techniques. Calls for

Applications will be circulated to all major archaeological research organizations (e.g. the AAA, SAA, AIA etc.) and published on the CAST website. Funds requested in this proposal will pay for the costs of experiment design, data collection, and data analysis, while the collaborating researchers will pay a relatively small cost for any necessary staff travel and consumable supplies. Recognizing that emergency projects may arise, special “rapid response” proposals will also be accepted.

For researchers who desire or need a more hands-on role in the analytical work, a subsidized short-term visiting researcher program will be made available. Participants in this program will spend (typically) one to three weeks at CAST (but the timing is flexible), during which they would work closely with the project PIs, as well as CAST and AIL staff in the generation and interpretation of analytical results. This program will be modeled on the very successful Digital Institute for Archaeology at the University of Arkansas. The DIA program provided junior scholars in archaeology the opportunity to spend a semester in residence at CAST and AIL, during which time they enroll in specialized geomatics courses and pursued independent research projects with the support of CAST and AIL staff and facilities. The requested NSF funds will (in part) also support CAST and AIL staff to work with the visiting researcher while the researcher will self-fund travel expenses.

Results of Previous NSF Support

There have been three prior NSF projects that have directly supported the research activities described here. In addition to the directly funded projects, the research activities discussed in this proposal have supported two other NSF projects.

BCS 0321286. Acquisition of a High Accuracy/Resolution Landscape and Structure Characterization System (HARLS-CS) for Anthropology, Archaeology, Architecture, Biology and Geosciences. PI: Limp, W. F. Co-PIs: Kvamme, K., Beaupre, S., Burian, S., Bajwa, S. Award: \$349,452. 2003-2006. The High Accuracy/Resolution Landscape and Structure Characterization System (HARLS-CS) provides coordinated three dimensional, multi-spectral and metric image-based measurements necessary for a wide range of mensuration, classification, and quantitative characterization analyses. The system is comprised of an Optech ILRIS 3D laser profiler, a Konica Minolta Vivid 9i laser scanner, TerraVerde's TerraHawk airborne multispectral imaging platform, the ASDI field spectroradiometer, three Nikon digital cameras with calibrated lens, a Trimble 5700/5800 GPS survey system, a Trimble 5600 Robotic total station, supporting software (e.g. Innovmetric PolyWorks, Trimble Geomatics Office and EOS PhotoModeler) and a Genie TZ-50 towable boom.

IIS 0431070 Computing and Retrieving 3D Archaeological Structures from Subsurface Surveying. PI: Daniilidis, Kostas. Co-PIs: Limp, W. F., Vranich, A., Shi, J. Biros, G. University of Pennsylvania. Award. \$1,068,000. 2004-2007. CAST was involved in a multi-year collaboration with Dr. Alexei Vranich and the University of Pennsylvania GRASP lab to scan and document the Pre-Incan site of Tiwanaku, Bolivia. The field research at this site was conducted in 2005 and 2006 and involved an extraordinarily broad range of instruments and methodologies. Aerial photographs from 1972 and 1992 were used to create two separate digital elevation models (DEM). Two laser-scanning systems (TLS and object) were used to acquire high-resolution data for monumental structures, excavation areas, and artifacts. Ground-penetrating radar,

magnetometry, magnetic susceptibility, and electrical conductivity surveys were conducted in the monumental core area, revealing unexcavated building foundations, paved surfaces, water conduits, and revetments. Results from the photogrammetry, laser scanning, and geophysical surveys were merged into one software environment that allows all these and other multi-scale, multi-temporal datasets to be integrated.

ESP 0918070 Collaborative Research: Cyberinfrastructure for Transformational Scientific Discovery in Arkansas and West Virginia (CI TRAIN). PI Cothren, Jackson, Co-PIs, Limp, W. F. Ramaswamy, S. Bellaiche, L., Spearot, D. Award: \$3,370,951. 2009-2013. The CI-TRAIN project is designed to create a self-sustaining environment in which cyberinfrastructure is used to develop and deploy a multi-faceted workforce that is empowered to apply, sustain, and create cyber-based systems, tools, and services over the long term; develop a nationally competitive computational and visualization environment shared across the partnership, featuring shared and new supercomputing clusters for computation, visualization support, and training; develop visualization display resources; procure and develop software and new high-end data capture devices in support of the creation of new digital content. The project has allowed the acquisition of a number of instruments of direct relevance to the archaeometry proposed effort (see the Facilities section for a full listing).

BCS 917732. Collaborative Research: the Kalavastos and Maroni Built Environments Project. Investigating Social Transformation in Late Bronze Age Cyprus. PI Manning, S., Co-PI Fisher, K. Cornell University. Award \$107,570. 2009-2013. The Kalavastos and Maroni Built Environments (KAMBE) Project is an interdisciplinary and collaborative effort by Cornell University and Ithaca College to investigate the relationships between architecture, social interaction and social change in Late Bronze Age (c. 1650-1100 BCE) Cyprus. This important period saw the island of Cyprus shift from a relatively insular and egalitarian, village-based society to an urbanized, cosmopolitan civilization. Using large-scale, multi-dimensional archaeo-geophysics, the KAMBE Project is investigating these processes at the sites of Kalavastos-Ayios Dhimitrios and Maroni (Fisher et al. in press). After the project was underway, the important role of TLS for recording the sites' extant architecture as a basis for modeling and visualization was also realized. Initial fieldwork was conducted with CAST staff and equipment in 2011 and more extensive efforts conducted in summer 2012.

BCS 1115148. Doctoral Dissertation Improvement Grant: Botswana Iron Age Dynamics. PI: Denbow, J., Co-PI Klehm, C. University of Texas at Austin. Award \$20,000. 2011-2012. Carla Klehm is conducting archaeological excavations and analyses at the Iron Age sites of Bosutswe and Khubu la Dintsa, Botswana. The project investigates how the local political economy at Khubu la Dintsa shaped and was shaped by the broader political, economic, and social transformations at Bosutswe during the height of its participation in the Indian Ocean trade network. CAST researchers joined Klehm and Denbow in the field in 2011 and conducted geophysical work at Nyungwe, Mmadipudi Hill and Lose. In addition, at the Tsodilo World Heritage Site initial photogrammetric recordation was performed in mid-2011.