

# Measuring the Face of the Past and Facing the Measurement

William Fred Limp

**Abstract** We are in the midst of major changes in the practice of archaeology and heritage studies. Technologies for high-precision, high-density measurement of objects, sites and landscapes coupled with computer-based methods for the visualization of these data and other (re)creations of the past are growing in use. These approaches have and will continue to fundamentally alter our field. The term “high density survey and measurement” (HDSM) covers methods such as airborne lidar, real time kinematic GNSS/GPS survey, robotic total stations, terrestrial “laser” scanning, structured light scanning and close range photogrammetry (CRP, also known as structure from motion—SfM) and UAV-based SfM/CRP and scanning. The analytical process that characterized our field before HDSM can be (over-)simplified to a sequence of **observe, interpret/abstract, measure, record, and analyze**. HDSM breaks us out of this process in that it pushes us toward a recursive and reflexive engagement with the data, in which we **observe, record, measure, analyze, and abstract/interpret** repeatedly, and in various orders. The growth in the use of HDSM methods is paralleled by increasing applications of computer-based visualization. Effective use of both requires attention to a scholarly digital ecosystem that addresses the archive and reuse of these digital objects and includes strategies to reuse these digital objects in other scholarly representations along with the tools for citation and other aspects of scholarly discourse.

## The Dimensions of the Past

In this paper I will examine some of the implications of the new approaches to the measurement and representation of space and form in archaeology and heritage studies that are emerging early in the 21st century. I suggest that these new approaches are not simply evolutionary developments but, instead, represent an inflection point in our approaches to the past. The word revolutionary has been

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W.F. Limp (✉)

Department of Geosciences, University of Arkansas, Fayetteville, USA  
e-mail: flimp@uark.edu

overused in archaeology and I will not use it here but I firmly believe that future historians of our field will clearly be able to define the first decade of the 21st century as a point of major change. Up to this point in time investigations of the past can be (over-) simplified to a sequence of **observe, interpret/abstract, measure, record, analyze**. The new tools for measurement break us out of this process as it moves us toward a recursive and reflexive engagement with the data, in which we **observe, record, measure, analyze, and abstract/interpret** repeatedly, and in various orders.

The reason that the use of new methods of measurement are changing our field in fundamental ways is simple. A central focus in archaeology from the very beginning has been the measurement and analysis of the properties of objects and sites and their constituent features and (more recently) the landscapes around them. More than half a century ago Gordon Willey stated that the objectives of archaeology are “approached by the study and manipulation of three basic factors: form, space and time” (Willey 1953, 361). Later Albert Spaulding identified what he termed the “dimensions” of archaeology. He defined dimension as “an aspect or property of the subject matter which requires its own special measuring device” (Spaulding 1960, 438). Over the last five decades we have seen the dramatic improvement in the measurement of the dimension of time—using “instruments” such as radiocarbon, archaeo-magnetism, thermo-luminescence and others. Prior to these measuring “devices” time was commonly inferred (not measured) using stylistic or classificatory methods. It was a dependent variable in the process of analysis. Once the proper instruments were available it became, properly, an independent measure. This change was (and continues to be) profound. We no longer infer time from other properties—we measure it directly and, thus, can use these independent observations in our analyses. As an aside, it can be argued that the late 20th century’s “New (aka processural) Archaeology” was simply the inevitable consequence of time becoming an independent measurement.

## High Density Measurement

While we have applied many techniques to the measurement of space and form it is only recently that we have been able to apply measurements that are simultaneously intensive and extensive, both precise and comprehensive. In another recent paper Rachel Opitz and I (Opitz and Limp 2015) have coined the term “high density survey and measurement” (or the natural acronym HDSM) for the suite of new methods that allows form and space to become, properly, independent variables in our studies.

“HDSM is the collective term for a range of new technologies that give us the ability to measure, record and analyze the spatial, locational and morphological properties of objects, sites, structures and landscapes with better resolution and more precision than ever before. The particular technologies considered include airborne lidar, real time kinematic GNSS/GPS survey, robotic total stations, terrestrial “laser” scanning, structured light scanning and

close range photogrammetry (CRP, also known as structure from motion—SfM) and UAV-based SfM/CRP and scanning” (Opitz and Limp 2015)

HDSM is both precise and dense; it is also three-dimensional. For objects these measurements are typically in the millimeter to sub-millimeter range while for structures they are typically sub-decimeter to millimeter and for sites and landscapes are typically decimeter to sub-meter in density and precision (and hopefully accuracy).

These dense and precise measurements have the ability to move our consideration of form and space from their past roles as *dependent observations* to **independent**. By dependent observations I mean the use of classificatory terms that were (and are) used to communicate form such as “excurvate,” “jar,” “beaker,” “Clovis point,” “Mesa Verde black on white bowl.” These classificatory terms were meant to encompass simultaneous considerations of shape, size, surface and embedded within were many other properties. At the structure or landscape scale we applied similar logic. Descriptors such as “village,” “palace,” “terrace,” “mound,” “house” were dependent classificatory terms that encoded multiple characteristics and implications. Since time immemorial archaeologists have believed that statements such as “there were four Clovis points in Level 4” or “the pit had a two-handled lidded chytra” or “there were four houses in the village” are statements of data. They are not. If we use Ackoff’s (1989) classification—which is among the foundational statements in the field of knowledge management—as elaborated by Bellinger et al. (2004):

Data... data is raw. It simply exists and has no significance beyond its existence (in and of itself). It can exist in any form, usable or not. It does not have meaning of itself.

Information... information is data that has been given meaning by way of relational connection. This “meaning” can be useful, but does not have to be (Bellinger et al. 2004: 1)

The typical type of statements of archaeological “data” that we constantly encounter are in fact “information”—a second step up (or down?) the abstraction (interpretation) stairs—though it often appears as a slide rather than a stairs. The data are the measurements, surfaces, and other physio-chemical properties of the object (or feature, or site or landscape). The reason that this is an important distinction is because of the extensive, unconscious encoding and assignment of meaning, interpretation, that is embedded in even the simplest classificatory statement. Classifications move (often without thought) from data to information. There is a perfectly good reason for our classifications. If we did not use these information-laden terms even a short descriptive report would be of an impossible length. It would appear absurd to always provide a paragraph length listing of the metric and physical properties of each object when a simple term will do. There is logic to that. What we lose, however, is that once we are provided information and not data we can never follow the chain of logic back to the origin. We cannot reproduce the results—and the ability to reproduce results is essential. Kansa emphasizes that, “[s]cholarship is better served if claims about the past can be evaluated in terms of appropriate use of evidence to support arguments and

interpretations.” (Kansa 2005, 100) and the most effective approach is to be able to provide the original data.

This concern has been around a long time in archaeology. For a discussion that is foundational but still timely see (Read 1974) or, more recently, (Niccolucci et al. 2015) and it is far beyond the remit of this article to do the topic justice. While no panacea HDSM provides a strategy to approach this problem with more nuance.

“HDSM allows us to decouple measurement from interpretation—data from information, leading to a fundamental alteration of the abstractive process in archaeology. Consider the common task of profiling a wall or mapping a floor in an excavation. The first step is to visually process the “data” and abstract from it relevant “objects” of interest to be recorded—a pit, post mold, layer or sediment change, and so on. These abstracted elements are then recorded, usually by selecting relevant two-dimensional points and recording them on graph paper. The traditional process can be intentionally (over-) simplified to a sequence of **observe, interpret/abstract, measure, record, analyze**. HDSM breaks us out of this process in two ways. First, it pushes us toward a recursive and reflexive engagement with the data, in which we **observe, record, measure, analyze, and abstract/interpret** repeatedly, and in various orders” (Opitz and Limp 2015).

## Representation

HDSM is not the only significant aspect of the “great inflection” of the 21st century. The second is representation. The increasingly wider and wider adoption of new methods of representation of the past are equally “inflectionary.” These methods include a range of computer-based approaches to first (re)create and then present realistic 3D representations of archeologically derived/investigated objects, structures and landscapes. Increasingly these approaches include virtual realities and explorations via gaming technologies.

The co-occurrence of HDSM and new methods of representation is not coincidental but has, at their base, the common development of computational tools and techniques. I would argue that beyond their common computational foundations the two are inextricably linked—any representation should have as its foundation high quality measurement—but this is not as frequently the case as it should be.

## Abstracting the Past

As we consider these arguments it should be quite clear that the ways in which we describe the past(s) are based on processes of extensive abstraction and essentially reductive. “Science” is reductive—that’s why it is so powerful but it is also clear that much of human behavior must be understood as “expressive” built on direct experience. Perhaps the “opposite” of reductive is “artistic”? Such a view is not new, for example, in 1938 “Dewey saw reality as fundamentally an ongoing

process whose parts could not exist independently of the interactions in which they participated” (Rockwell 2005, ix).

We are all quite familiar with the argument by C. P. Snow that there are “two cultures” separating the sciences and humanities. Whatever we think about the specifics of his argument it is clear that there was and is a divergence between these two ways of knowing. Within the last few years this gap has increasingly been reduced, however, as reflected in the growth of the “digital humanities.”

## What Would Leonardo Do?

Even before the divergence of the sciences and the humanities, we can see an earlier one where art and science diverged. While pinpointing the time of the divergence is an exercise for others I would think it very clear that both science and art are seamlessly merged in the work of many Renaissance “artists,” with no more powerful example than Leonardo da Vinci. We can see in his work that his art was grounded in observation and recording of the natural world and the discovery of basic principles. His position is clear when he states.

“[t]hus, you who observe rely not on authors who have merely by their imagination wished to be interpreters between nature and man, but on those alone who have applied their minds not to the hints of nature but to the results of their experience” (da Vinci 1906, 147).

Without entering into the debate it seems to me [and others (Cochrane and Russell 2007)] that the divergence of art and science accelerated in the later 19th century and the 20th century because “art” (particularly after the development of photography) moved increasingly towards an abstract forms of representation. Fortunately, with the development of computational visualization, this distance is now again closing.

The separation of art and science has led to the separation of observation and representation. It usually comes as a serious criticism of a modern artist to suggest that her representation has photographic realism. Since we are no longer encouraged to “draw what we see” our process of representation has become one of conversion of the observed “data” into symbols that encode the content not the data. This encoding is a process of mental abstraction (but not necessarily abstraction as in abstract art) where the complexity of the “real world” is encoded into a much reduced set of symbols. The ways in which this process is deeply embedded in all our thinking can be illustrated in a simple experiment. Consider the photograph shown in Fig. 1. If the great majority of us were asked to “draw” the image we would very likely come up with something like Fig. 2. I believe we would all agree that the drawing looks nothing like the photo but is, instead, a symbolization of the content. Our brains “see” the house or people and reduce them to the “standard” abstractions of the drawing. I was first exposed to this issue in the late 1970s by a popular book *Drawing on the Right Side of the Brain* published by Edwards (



**Fig. 1** An artistic diversion. *Image source* Flickr CC 2.5 license

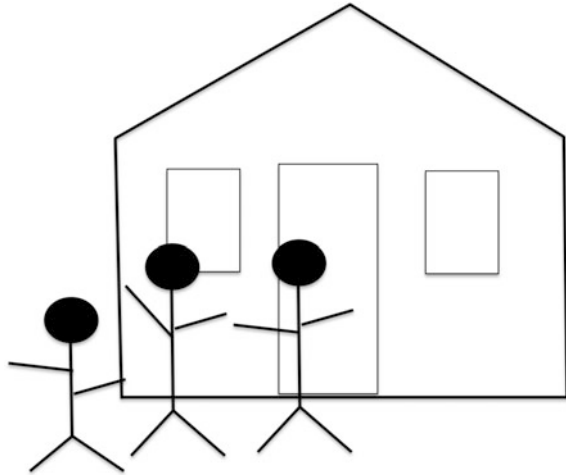
1979). The premise of the author is encapsulated in this quote from the neurosurgeon Richard Bergland.

“You have two brains: a left and a right. Modern brain scientists now know that your left brain is your verbal and rational brain; it thinks serially and reduces its thoughts to numbers, letters and words... Your right brain is your nonverbal and intuitive brain; it thinks in patterns, or pictures, composed of ‘whole things,’ and does not comprehend reductions, either numbers, letters, or words.” (Bergland 1986, 1).

As some one who could not draw Edward’s book and ideas attracted me. The first exercise in the text is to take a complex drawing and “copy” it. Unless you are already an “artist” the results are always embarrassing, similar to the results in Fig. 2 above. Edwards then says that you should rotate the original drawing until it is upside down and try again. The results are astounding. Your drawing will look so very much better. Edwards proposition is that the inversion “turns off” the abstracting pathways of the brain. The pathways that convert people to stick figures are blocked and your hand simply draws what the eye sees. It works. The point of all this is to argue that for many (most?) archaeologists the past is deeply embedded in abstracted representations and that the great majority of us are deeply challenged to understand the past in any formulation that would begin to approximate a “lived experience,” as we are always abstracting (reducing) and then symbolizing the complexities that are world as it is experienced.

Not all of us have this limitation, of course. We know that archaeologists who have been the “great synthesizers” of our field process massive amounts of visual

**Fig. 2** A typical artistic rendering of Fig. 1



data to derive “grand patterns” and they have strong visual memories. They do not abstract and symbolize the data—they just store it. Some examples:

“[V. Gordon Child’s] already extensive command of European literature and an acute visual memory enabled him to visit and assemble data from museums and excavations across the whole of Europe” (Trigger 1989, 169).

“A good visual memory ... allowed him [John Griffin] to recall the shape, decoration, and composition of any artifact he had ever seen” (Griffin and Griffin 1996, 11).

“The extent of this visual memory [in archaeology] is never realized until one meets with some who are so unlucky not to possess it” (Petrie 1904, 19).

“[Joffre Coe’s] ability to extract meaning from a handful of pottery sherds or the shape of an arrowhead was legendary. This ability was rooted in his broad interests and a keen visual memory” (Anon 2001, 2).

By way of example of the value of the visual representational strategy lets compare two strategies for displaying the “information” about the nature of an archaeological site. The traditional abstraction-based representational approach is shown in Fig. 3. This is a classic example of the “Cartesian gaze.” Such a representation is so common to us that we have all developed complex decoding processes that allows us to “understand” what these symbolic representations “mean” but it is only through this reverse decoding that we can create any sense of an understanding. This understanding is not clearly encoded in this abstraction but follows traditional disciplinary encoding protocols. This encoding process, when learned, not only allows us to reduce the content to a minimum (keeping publishers happy) it also excludes the uninitiated from participating. Compare the information content in Fig. 3 with the “same” location represented in Figs. 4 or 5.

Notwithstanding the visual memories of many of our prominent archaeologists, vision as a “way of knowing” can seem alien—particular to scholars.

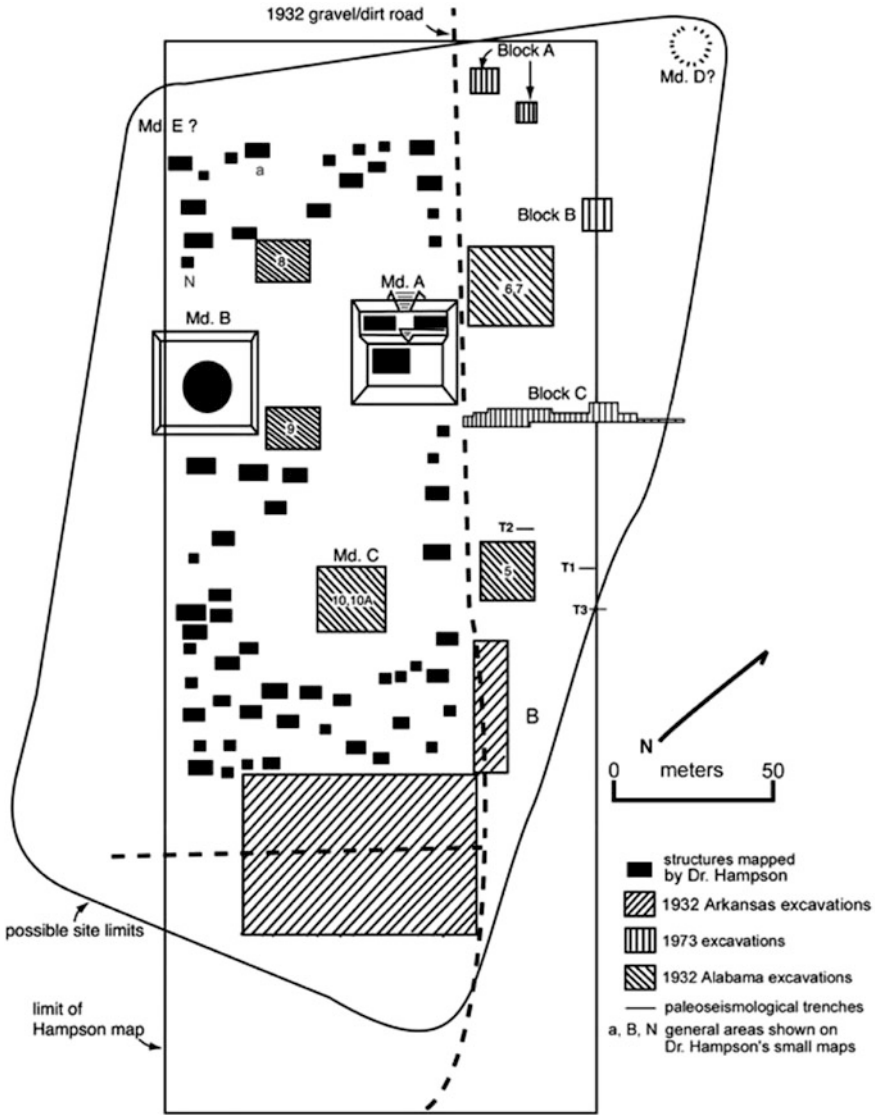


Fig. 3 The traditional site map for the Nodena Site (Payne and Limp 2008)

“Some people are so deeply accustomed to a linear view of intelligence and potential that they find it almost impossible to believe that certain persons may find advanced subject matter quite easy while they find some elementary subject matter quite difficult. ...They may have had difficulty learning from books and lectures, .. [but are] better adapted to learning from simulations of reality. For these people, it is sometimes far easier to learn firsthand from nature than it is to learn secondhand from books” (West 2009, 24–25)





Fig. 4 The Nodena “site map” as a visualization (Payne and Limp 2008)



Fig. 5 An alternative Nodena “site map” representation (Payne and Limp 2008)

It seems clear that a full understanding of the world (especially of the past) must be

- Abstracted **and** Contextualized
- Artistic **and** Scientific
- Analyzed **and** Experienced.

## Visualizations and Phenomenology

Many authors in this volume have discussed the implications and values of virtual reality and of representations of the past that have high verisimilitude and there is little need to repeat these. In addition to the other rationales for visualization, however, I would also emphasize that such representations have a role to play in the issues that underlie the debate around the value of phenomenological approaches in archaeology. Again there is a massive body of literature on the topic but to briefly (and relatively superficially) to summarize archaeologically-relevant phenomenology would be to emphasize that it is, at its core, an appreciation that experiential (e.g. “sensuous”) elements are key to understanding human life and (very specifically) the past and that space is lived and meaningful constituted. It is generally understood as having entered archaeological visibility with Tilly’s work but also Thomas and others. The use of phenomenology in archaeology has been one of the most provocative theoretical developments in the discipline in recent years (Brück 2005). Computer visualization representations of the past serve as an effective transition between the “scientific” way of knowing and the “sensuous” one. Much of the argument to date has seen these two ways as conflicting or competitive but with the growing use of computerized tools, visual reality and immersive experiences the boundaries between scientific and phenomenological ways of knowing are blurring.

## Linking Measurement and Representation

It would initially appear reasonable that measurement and representation are fundamentally linked but this is not always the case. We could imagine a process where (perhaps) laser scanned data of a structure was “brought into” a visualization package and used as the foundation for a representation. Until relatively recently, however, this has not been the case. There are a number of reasons for this but one technical reason has been the difficulty in bringing the massive and extensive measurement data (scanned, photogrammetry, etc.) into the software used to create the representations. Developments in both the visualization software and data acquisition communities will certainly reduce, if not eliminate, this constraint in the near future.

Much of this measurement data and our representations are “floating” in space—at best using a local grid system. In order to make comparisons and to place these in proper context it is necessary to convert these “local grid” measurements to recognized coordinate systems (Limp and Barnes 2014). Again there are often technical constraints in that many systems that record and process these data and to develop the representations do not support map system coordinates. This too will change as the systems evolve and practitioners should be attentive and adopt these tools as they emerge.

## A Digital Ecosystem

I believe it is fair to suggest that substantial portions of the efforts towards both measurement and representation in archaeology are the result of enthusiastic efforts by single or small groups of scholars. Such as it ever was in new approaches in our field. While such efforts are nimble and creative they are not, inherently, sustainable. For these to continue they must be an embedded part of a comprehensive digital ecosystem (Limp et al. 2011). Key elements of this ecosystem are

- Access via search
- Re-use by others
- Lineage of idea, representation, measurement and authorship
- Elemental decomposability
- Scholarly—“cite-ability”—authorship
- Archive
- Sustainability.

Like the biological ecosystem the digital one requires that **all** aspects be “healthy”—in the following I consider some strategies.

A central aspect to any sustained scholarly endeavor is that the results can be accessed by others and “reused”—in this case made part of the next cycle of scholarly product. This goal is accomplished by placing all the “digital objects”—measurements, representations etc. in an accessible digital archives well populated with “finding aids”—metadata.

There are extensive materials on strategies and proper metadata elements for many of archeology’s measurement systems at the Archaeology Data Service/Digital Antiquity’s Guides to Good Practice. Some particularly relevant ones are:

- Scanning (Payne 2011)
- Close range photogrammetry (Barnes 2009)
- Aerial photography (Bewley et al. 1998)
- Virtual reality (Fernie and Richards 2002).

Other essential recent reading on the topic includes Corsi et al. (2013), Bentkowska-Kafel et al. (2012) and Remondino and Campana (2014) to select a key few. The requirements of quality metadata are substantial. For example Table 1 is the project level metadata for scanning while Table 2 is the metadata needed for each scan. Given the finite amount of time/money in any field or lab project there is always tension—one can scan another object or record the metadata for the ones already done—but not both. Just as we would not pull an object from a pit wall and not record its provenance and its other “metadata” we need to be fierce in our certainty that digital metadata is essential for digital objects. Without metadata they will have been “digitally looted” from their contexts.

While comprehensive metadata is essential for the evaluation of data by future scholars it is also essential that the digital objects are accessible and can be found through search and can be readily cited when reused by others. The requirements

**Table 1** Project level laser scanning metadata. *Source* Payne (2011; Table 3.2.1)

Element	Description
Project name	Name of the project
Name of monument, survey area, or object	Name of object, monument, or area scanned
Monument/object number	The ID number or code, if applicable, of the object or monument
Monument/object description	Brief description of the monument/object being scanned
Survey location	Exact location of survey with complete address and/or coordinates
Survey date(s)	Dates(s) of survey
Survey conditions	The overall weather trend during survey (sunny, overcast, indoors, etc.)
Scanner details	Details of the instrument(s) with serial number(s) and scan units
Company/operator Name	Details of company and scan operator name
Control data collected?	If yes, then list <i>control_file_name.txt</i>
Turntable used?	Yes/No
RGB data capture?	If yes, then specify whether: – Internal or external? – Was an additional lighting system used? If yes, then provide a brief description of the lighting system
Estimated data resolution	The estimated data resolution across the monument or object
Total number of scans in project	Total number of scans
Description of final datasets for archive	What datasets will be archived (include file names if possible)
Planimetric map of scan coverage areas	If applicable, then provide the image name.
Additional project notes	Additional notes
Images from survey	Optional, if yes, then provide the image file names

**Table 2** Laser scan level metadata. *Source* Payne (2011; Table 3.2.2)

Element	Description
Scan filename	The name of the scan. A suggested filename for original raw scans for archiving is in this format: <i>ProjectName_scan1.txt</i> .
Scan transformation matrix	The name of the transformation matrix used in Global Registration. Suggested file name: <i>ProjectName_scan1_mtrx.txt</i>
Matrix applied to scan?	Y/N Has the matrix been applied to the archived scan?
Name of monument/object	Name of monument or object being scanned
Survey date	Date of scan

(continued)

**Table 2** (continued)

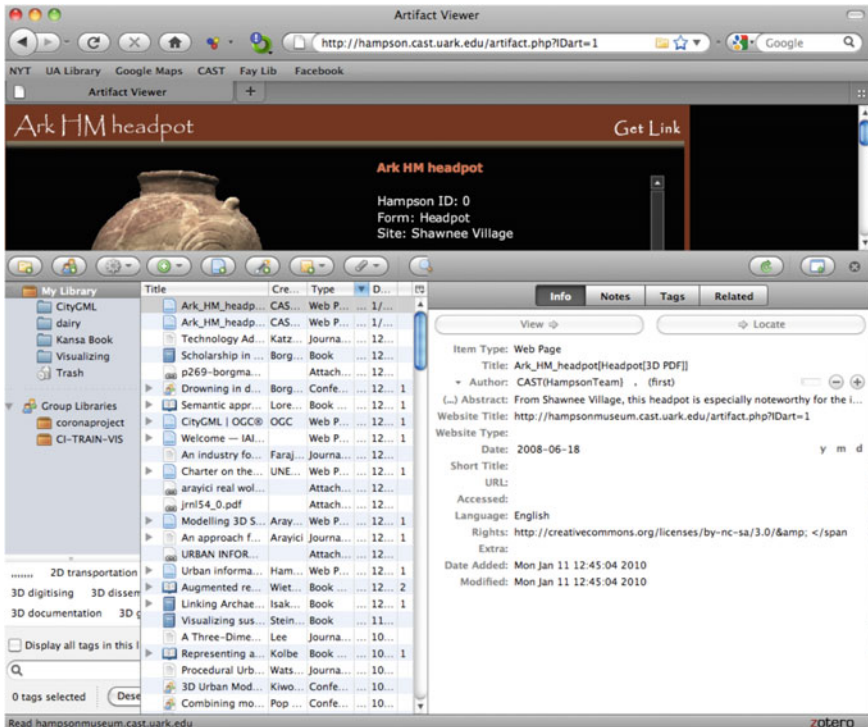
Element	Description
Data resolution	Fixed resolution or data resolution at specific range.
Number of points in scan	Total number of points in the scan file
Additional scan notes	Additional notes
Scanner technology	TOF/phase/triangulation
First or last return (TOF scans only)	Indicated whether first, last, or both returns were specified
Camera exposure settings (If RGB acquired) (TOF and phase scans)	Exposure settings set on scanner
Frequency settings (Phase scans only)	Frequency settings set on scanner
Noise settings (Phase scans only)	Noise settings set on scanner
Lense or FOV details (Triangulation scans only)	Indicate which lense or FOV was used during scan

and issues associated with creation of capable digital archives have been well document (Chan 2004). I would only highlight two key ideas. The first is the critical role of persistent uniform resource locators (PURL). For digital objects created through visualization or measurement the PURL is the citation that follows the object. The second is the use of Context Objects in Span (COinS—[ocoins.org](http://ocoins.org)) in the web pages that provide access to the digital objects. The presence of COinS code means that scholars using any capable citation software (e.g. Zotero, EndNote, etc.) can immediately obtain the appropriate citation data and utilize it in their future publications.

Figure 6 visually illustrates the importance of COinS to effective scholarly re-use of digital objects. The Zotero screen displays the citation data that is automatically populated by a single mouse click when the user access the digital object.

## Decomposition of Representation

If we are to have robust and defensible representations we must move from a single “take it or leave it” image, video, game or other visualization to one that is constructed from multiple elements. Our scholarly articles are composed of individual paragraphs (each usually an idea) and those who would wish to use, attack or build on our work can cite a specific section or extract text and embed it in their publications. These are the essential parts of the scholarly armature. Many of our visualizations, however, are “of a whole” and difficult, if not impossible to decompose. What I would urge is that each element in a representation should have the same status as a paragraph or a sentence in a text. Each post, each object, each surface should have its own digital existence so that the next scholar may “reuse” or cite the specific content and critique each element. By way of illustration Fig. 7 shows a Hampson digital object that has been placed in the (then) Google 3D

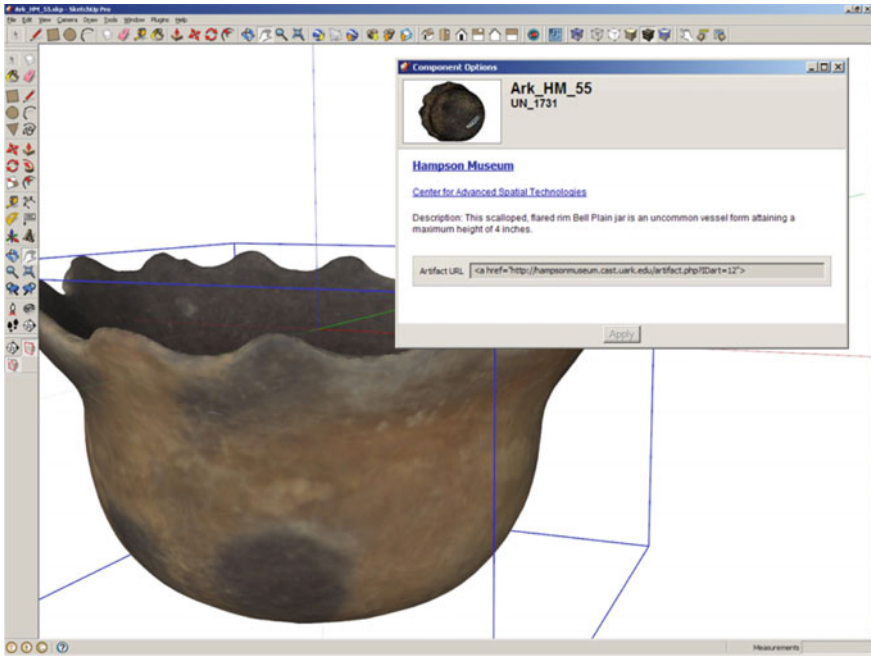


**Fig. 6** CoINs produced output for digital objects from the Hampson Virtual Museum ([hampson.cast.uark.edu](http://hampson.cast.uark.edu))

warehouse. The following illustration (Fig. 8) shows how that specific digital object can be easily added (simply drop and drag) to an existing representation and (via the metadata and COINs) it is then possible that each individual element can be referenced and discussed. Until we have a structure in which we can readily decompose and “cite” specific elements in a representation, as we do a paragraph in a text, our representations will never have a robust place in scholarly discourse.

## Reuse—The Ultimate Objective

All of these steps are designed to provide the lineage and accessibility for digital objects such that the objects themselves, and, more fundamentally, the measurements and/or ideas that underlie them can be re-used and/or critiqued. The Hampson Museum, accessible on the web since 2008 under a CC 3.0 license (Limp et al. 2011), provides an illustration of the potential for re-use. Since its creation the digital objects themselves have served as analytical elements in five different research projects by others with objectives completely different from the ones that



**Fig. 7** Digital object from the Hampson Museum in the Google (now Trimble) 3D Warehouse ([3dwarehouse.sketchup.com](http://3dwarehouse.sketchup.com))

served as the basis for the initial project (Gilboa et al. 2013; Koutsoudis and Chamzas 2010, 2011; Sfikas et al. 2013; Savelonas et al. 2015). In an unexpected reuse the digital objects were used as the basis for a 2013 art installation in Toronto (Hanes 2013).

Published HDSM data allows others to produce 3D printed versions of the object and Olson et al. (2014) and Reilly and Beale (2014) provide examples of the value of 3D printing. Figure 9 shows 3D printed versions of a digital object from the Hampson project discussed above. We are very early on in the use of 3D printing but it is clear that the explosive growth of the “maker culture” (c.f. Tanenbaum et al. 2013) and the tools and strategies that it enables will impact archaeology and heritage studies even more over the next years.

## Sustainability

All our extraordinary measurement and representation efforts will be for naught unless we can insure that they will be available for future scholars and not just in the next few years but over decades and centuries. Archaeology’s digital record, so far, is not encouraging. I was fortunate enough to part of one of the earlier



**Fig. 8** Introducing scholarly content (a digital object) into a new narrative



**Fig. 9** Two 3D printed versions of one of the Hampson digital objects. Photo courtesy Hanna Ford



summaries of the state-of-the-art in computer data bases (then called “databanks”) in the late 1970s published as *Databank Applications in Archaeology* (Gaines 1981). The edited volume described 10 different “databanks” then in use (see also Loewen 2015). As best as I can determine today, some 35 years later, only two are still “alive.” In general those “systems” that were not part of an institutional infrastructure (as opposed to individual researcher or even groups of researchers) did not survive. The two that did, AZSITE and AMASDA have had the ongoing commitments of the Arizona State Museum and the Arkansas Archaeological Survey, respectively. Even an institutional home does not insure continuity. The Oracle System (oh how I wished we had trademarked that name) developed in the late 1970s at the Glenn Black Lab of Archaeology at Indiana University (Limp 1978a, b) died a slow death more than 20 years ago. Both AZSITE and AMASDA are examples of Washington’s axe—the one he used to cut down the cherry tree. It is still his axe but it has had three new handles and two new axe heads. IN AZSITE and AMASDA it is only the data that endures. AMASDA, with which I am more familiar, has gone through multiple software incarnations. Originally developed in GRIPHOS (Scholtz and Chenhall 1976) it has since had versions in INFORMIX and MySQL across a number of operating systems. Each time the existing data was migrated. It is clear to me, at least, that no matter the capabilities, work and enthusiasm of any individual or group of individuals data, especially digital data, cannot long survive unless there is institutional support. Institutions are complex and often slow moving and it’s much easier for a research team to move ahead on their own. We must address the long-term sustainability of a project’s digital products. Not recording metadata is digital looting—not placing the digital objects in a sustainable archive will mean that, very shortly, they will be lost and inaccessible.

## Digital Publication Issues

The growing use of HDSM and computer based representation are straining the traditional structures of publication. We have seen a new journal *Digital Applications in Archaeology and Cultural Heritage* that has adopted the publication of 3D models as a central focus. The ongoing projects at Catalhöyük (Forte 2014, Forte et al. 2012, 2015) and Gabii (<https://sites.lsa.umich.edu/gabiiproject/gabii> digital and <http://m-gabii.adsroot.its.umich.edu/gabiigoesdigital/>) have both extensive HDSM efforts and are developing strategies for 3D publication of the results. We are early in this process and many conceptual and practical matters still need resolution. But they will be resolved and our communications about the past will be much richer.

## Conclusions

We must always be aware that our excitement surrounding new methods in our field should be mediated by our failures (and successes) in the past. Our attitude towards new methods in research, like serial polygamy, can often be seen as the triumph of hope over experience. Nonetheless I do think that what we are seeing with HDSM and new directions in representation do imply significant changes in our study of the past. A key impact of HDSM is the potential to avoid or at least reduce inattentive blindness.

“[A]nyone who has followed the ground breaking work of Simons and Chabris (1999) on “inattentive blindness” is well aware that we [truly] only see what we are prepared to see, a point discussed in an archaeological context by Barceló (2010, 93). Semi-automatic and metrics-driven analyses, promoted by HDSM simply by dint of the scale of the data, provide a parallel abstractive process and the results of these analyses may point us at aspects of the data or information sitting in our inattentive blindspots” (Opitz and Limp 2015).

At the same time we must also recognize that these methods come with a cost. They add complexity to our field activities, developing practitioners is demanding and the equipment can be expensive. Our “budgets” for projects, whether calculated in actual money or in the time and effort involved, are likely fixed. Thus “something must give.” There is the hope that some methods can actually speed up field recording (see the Catalhöyük and Gabbi projects) but it seems likely that all in all these new approaches will add to the total “budget.” What is it that we don’t do when we do HDSM or computational visualizations?

As I hope I have made clear robust institutional structures are necessary, to field these methods in the first place, but more critically to insure that the results will be around for future scholars to use. Recent efforts by NSF and NEH to require data management plans send a strong signal to the field that storage, maintenance and access to these digital products are an essential part of research and most universities are moving to set up institutional repositories to insure that they meet NSF requirements. But the great majority of these efforts do not anticipate the complex digital objects created by HDSM or the digital products created by visualizations. The success of the Archaeology Data Service in Britain and the Digital Archaeological Record in the US provide a basis for optimism that we can address this need but also give us a clear sense of the complexity and cost that sustainable digital archives require.

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