INTRODUCTION
FROM DIGITAL ILLUSTRATION TO DIGITAL HEURISTICS

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This book is timely. As the following articles show, 2D and 3D modeling of cultural heritage is no longer used just to illustrate the location and appearance (past or present) of archaeological sites, but also as a tool to discover and recover data from archaeological remains. We have better ways of predicting where this data might be found under the surface (see **Gerlach *et al.***, **de Boer *et al.***). When applied to the legacy excavation data of a cultural heritage site—as **Lieberwirth** does in a pioneering study in this volume[1]—or when used to record the progress of a new excavation,[2] 3D modeling has the potential to mitigate the irreversible and destructive nature of archaeological excavation, an unfortunate, ironic, and unavoidable central fact of archaeology as traditionally practiced.[3] Up to now we have had, perforce, to murder to dissect. With the widespread adoption of 3D technologies to record and reconstruct archaeological sites, we can virtually preserve the site through 3D data capture as we dig it up. And, once we model the 3D data gathered in the field, we can allow our colleagues to retrace our decisions and to test the validity of our conclusions with more precision and confidence.

This application of 2D and 3D digital tools in archaeology is not surprising. 2D and 3D models of cultural monuments permit us to visualize their use and evolution from inception through their latest phase. As neurobiologist Semir Zeki has emphasized, vision rarely involves mere sensation; it usually leads spontaneously to cognition as well. First we look, then we see and understand (Zeki 2003: 21, 24, 26, 93). A classic instance is Mendeleev's table of elements, whose power 'was not just that it functioned as a tool for arranging properties but that the gaps in the sequences predicted the discovery of yet *unknown* elements'.[4] A second famous case concerns John Snow's solution of the cause of an outbreak of cholera in London in 1854. By displaying all the cases on a map marked with streets and public water pumps, Snow was able to establish the likelihood that the disease had spread through water contamination at a specific pump. Its handle was removed, and the epidemic promptly ended (Tufte 1997: 27-37).

According to information scientist Colin Ware, a visualization can promote understanding in the following five ways:

- It may facilitate the cognition of large amounts of data
- It can promote the perception of unanticipated emergent properties

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[1] As predicted by Reilly 1991.

[2] Cf. M. Bradley 2006; B. Bobowski 2007; W. Day, J. Cosmas, *et al.* 2007.

[3] Cf., in general, Ananiadou *et al.* 2005; Borgman *et al.* 2005; Lord and Macdonald 2003. For the 'unfortunate irony' of archaeology, see Reilly 1989: 569.

[4] Kemp 2000: 69; for details, see Scerri 2006: 123-158.

- It sometimes highlights problems in data quality
- It makes clear the relationship of large-and small-scale features
- It helps us to formulate hypotheses (Ware 2004: 3)

The role of visualization in cognition has not yet become a major theme in discussions of 2D and 3D archaeological models. This is undoubtedly a normal case of theory-lag: since most uses of computer modeling have been for purposes of illustration, it is not surprising that theoreticians should have stressed this application. The field into which 2D and 3D modeling falls was aptly called 'virtual archaeology' by P. Reilly in 1990 (see Reilly 1991; Forte and Silotti 1995; Earl 2006). Reilly defined virtual archaeology's mission as 'enrich[ing] the perception of the material under study" (Reilly 1989), and "offer[ing]…the most faithful re-presentation of the ancient world possible: highly realistic in information and with a high scientific content' (Forte and Silotti 1997: 10). In support of this mission, theoreticians of the new field focused on such matters as what software should be used to create or view a 2D or 3D model;[5] viewshed analysis using standard GIS tools;[6] how uncertainty or degrees of probability should be represented;[7] and how 3D models could be used to improve interpretation in museums, in virtual museums, and in the classroom.[8] That they were right to do so emerges from a quick sketch of the history of computer modeling in our field. In 1973, J.D. Wilcock set forth a prophetic vision of computer applications to archaeology at the first meeting of Computer Applications and Quantitative Methods in Archaeology. This organization—often known by the shorter name, Computer Applications to Archaeology (or CAA)[9]—was destined to become the most important in the field.[10] Wilcock predicted four main uses of the computer in our field (Wilcock 1973: 18): data banks and information retrieval; statistical analyses; recording of fieldwork; and the production of diagrams. He also had a fifth, miscellaneous category, and it is into this *omnium gatherum* that we find him talking about computer reconstructions of temples and other monuments (Wilcock 1973: 20). One thing that Wilcock failed to predict was the application of Geographic Information System software (GIS) to archaeology and historical studies generally.

In the next twelve years, most of the work presented at CAA fell into Wilcock's first three categories. Thus, E. Webb wrote in the preface of CAA 13: 'Until recently, the bulk of the papers presented were mainly concerned with the application of multivariate statistical packages to large bodies of archaeological data…on a University mainframe…. In the last few years…there has been a shift in computer-based archaeological applications from numerical analysis towards on-site recording systems and…database management systems' (Webb 1985: iii). In the same 1985 issue of CAA we find the first major article on 3D (Biek 1985). Biek wrote about the application of digital panoramic photography as a way of documenting an archaeological excavation. He was perhaps inspired by the first known large-scale digital capture of a contemporary city, the Aspen Project of 1978 (see Negroponte 1996: 65-67).[11] The

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[5] For two early examples, see Baribeau *et al.* 1996 on 3D data capture with the use of a laser scanner; and Bloomfield and Schofield 1996 on 3D hand modeling: for an early survey of the topic with extensive bibliography, see Barcelò 2000.

[6] For a survey and critique of early work see Gillings and Goodrick 1996: parts 4-4a.

[7] E.g., Scagliarini Corlàita *et al.* 2003: 246-247; Frischer and Stinson 2007; Corallini and Vecchietti 2007: 19; Stinson 2007: 74-76. Note that although the last three articles cited were published in 2007, the authors presented the ideas in papers presented at conferences held in 2002. For subsequent work in this area, see Zuk *et al.* 2005 and Kozan forthcoming.

[8] E.g., M. E. Bonfigli and A. Guidazzoli 2000; Loscos *et al.*, 2004; S. Pescarin *et al.* 2005; Helling *et al.* forthcoming.

[9] See http://caa.leidenuniv.nl/.

[10] CAA's most recent meeting was held in Berlin in April, 2007 and attracted over 600 scholars who presented over 200 papers. See http://www.caa2007.de/.

[11] For the final report, see http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5385627. Negroponte describes

first example of 3D hand-modeling of an archaeological monument followed four years later (Arnold, Huggett, Reilly, and Springham 1989).

In the early 1990s, Wilcock's prediction that computers would be used for digital reconstruction of archaeological sites started to be realized. Two early papers were published in 1992 by Reilly and by Wood and Chapman. A collection of occasional papers published by the British Museum in 1996 included four studies utilizing 3D reconstruction.[12] A well-known overview of the scene was given in 1997 in Forte and Siliotti's *Virtual Archaeology*, which looks at several dozen computer reconstructions of sites around the world. We can see that early computer models served the purpose of illustration and resulting publications tended to focus on methods and technologies supporting the creation of such illustrations. In his foreword, C. Renfrew defined the purpose of virtual archaeology as harnessing 'the power of the computer in helping us to recreate and to visualize anew the sites that archaeologists have excavated and studied' (Forte and Silotti 1997: 7). It is noteworthy that almost all the computer models described in Forte and Silotti were built by private companies and that no authorship credit was given to a professional archaeologist. By the late 1990s the situation had changed, and with the drop in the costs of creating computer models, many archaeologists started their own 3D projects. Many of these were presented at CAA 1998 in Barcelona.[13]

Looking back at Ware's list, the work done in these years can be considered examples of the first and fourth use of visualization. A computer model can help us to understand, for example, how the hundreds or thousands of fragments of an archaeological monument can be fitted back together, as well as the relationship of a single fragment to the monument as a whole. The central theoretical assumption was perhaps best articulated by Goodrick and Gillings as an exploration of reconstructed landscapes that is both embedded and embodied (Goodrick and Gillings 2000: 52).

By the late 1990s, the focus shifted from simply making models to developing and encouraging best practices. This was understood to entail not only making a model but also providing proper scientific documentation, developing a visual language to enable users to quickly distinguish between definitely attested and hypothetical elements of a model, and creation of metadata standards. This period is well represented by Frischer *et al.* (2002) and by Fernie and Richards (2003). We can see this as exemplifying Ware's third use of visualization, highlighting problems in the quality of the data.

Progress in applying the 2D technology of GIS to archaeology and historical studies generally followed a comparable trajectory. Several early papers were presented at CAA 1991 (Castleford 1991; Gaffney and Stancic 1991; Kvamme 1991a, 1991b; Rooda and Wiemer 1991; Ruggles 1991). An important article on the potential of GIS for archaeology was published in 1992 by Lock and Harris. A colloquium devoted to GIS in archaeology was held in 1996 at the XIII^th^ Congress of the Union Internationale des Sciences Pré- et Protohistoriques (Sept. 8-14, 1996, Forlì, Italy). In 1997, the Electronic Cultural Atlas Initiative (ECAI) was started at the University of California, Berkeley, with the mission of 'enhancing digital scholarship and cultural heritage preservation by using time and space for data sharing'.[14] In the early years of the organization's existence, ECAI members I. Johnson and A. Osmakov developed TimeMap, an important tool that adapted

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the project as creation of a network of nodes covering the city. Each node was three feet from the next and at each node, a panoramic photograph was taken. The photographs were placed on a videodisc. Users had random access to the photographs and could create the illusion of moving through the city, pausing to look in any direction desired.

[12] Baribeau *et al.*; Hughes; Boland and Johnson; Bloomfield and Schofield.

[13] See Juan A. Barcelo, Maurizio Forte and Donald H. Sanders, eds. *Virtual Reality in Archaeology*, B.A.R. International Series 843 (2000).

[14] http://h-net.msu.edu/cgi-bin/welcomeletter?list=h-ECAI.

GIS to the needs of historians.[15] In North America, the Polis Center at Indiana University has been a leader in promoting ECAI.[16] At CAA, papers using GIS were common by 1996 (Wheatley 2000), and in the current decade they have become as frequent as those dedicated to 3D modeling. A strong impetus was given by the joint meeting of ECAI and CAA in 2003 in Vienna. In general, as van Hove and Rajala (2002) noted in an important editorial in *Internet Archaeology*, in the 1990s GIS was viewed mainly as a tool for assembling and viewing digitized information about terrain and its uses,[17] but in the early years of this decade, GIS started to be seen as supporting Ware's fifth function of visualization, analysis and hypothesis formation.[18]

This historical sketch brings us to the present day and allows us to take stock of not only of which of Ware's five applications of visualization archaeologists have clearly already embraced, but also to see those that still remain to be employed, at least on a large scale, in our field. Clearly, these are the second and fifth types: promoting the perception of emergent properties; and facilitating the formation of hypotheses. This type of work does more than illustrate an archaeological monument. It helps us to respond to the often tacit assumption that 2D and 3D modeling is primarily for teaching and has little, if anything, to contribute to scholarship (cf. Kolb 1997; Earl 2006: 192-193). It also allows us to use the computer model as a research tool to generate new knowledge. The purpose of this book is to collect some of the pioneering efforts in this promising field.

In applying digital modeling, archaeologists have been recapitulating the history of physical modeling, which started no later than the fourteenth century. As noted by C. Piga, Filippo Brunelleschi (1377-1446) used physical modeling to show that his radical design for the cupola of the cathedral of Florence could function. Like the earlier architectural models of the fourteenth century, Brunelleschi's model simply operated as a means of persuasion (Piga 1996: 56, 60). But Leon Battista Alberti (1404-1472) saw the physical model as a tool to verify the correctness of an architectural design, both in terms of aesthetics and structure (Piga 1996: 68). [19] Following Alberti, the model quickly becomes a tool to

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[15] http://www.timemap.net/. The development of ECAI can be followed through the directors' reports, available at http://ecai.org/about/directorsRpts.html.

[16] http://www.homepages.indiana.edu/021105/text/technology.shtml.

[17] Hence F. Vermeulen (2002: 121) could write that 'GIS remains clearly the motor of the machine for the efficient study, rational management and attractive disclosure of the archaeological data and results'.

[18] Cf. van Hove and Ryala 2002: 'In the past, there has been a tendency to use GIS solely as a tool… without any link to archaeological theory. We emphasise that although GIS are a useful tool for storage and visualisation of multiple forms of data, manipulation and analysis should take centre stage, emphasising theory driven research questions and the exploration of traditional archaeological interpretations with new research methods…. New theoretical concepts can also be tested using GIS, which might lead to the formulation of alternative theoretical perspectives to be examined further…'.

[19] Cf. L.B. Alberti, 1988. *On the Art of Building in Ten Books*, translated by Joseph Rykwert, Neil Leach, and Robert Tavernor (Cambridge, MA) 33-34, 313: '…I will always commend the time-honored custom, practiced by the best builders, of preparing not only drawings and sketches but also models of wood or any other material. These will enable us to weigh up repeated and examine, with the advice of experts, the work as a whole and the individual dimensions of all the parts, and, before continuing any farther, to estimate the likely trouble and expense. Having constructed these models, it will be possible to examine clearly and consider thoroughly the relationship between the site and the surrounding district, the shape of the area, the number and order of the parts of a building, the appearance of the walls, the strength of the covering, and in short the design and construction of all the elements discussed in the previous book. It will also allow one to increase or decrease the size of those elements freely, to exchange them, and to make new proposals and alterations until everything fits together well and meets with approval. Furthermore, it will provide a surer indication of the likely costs—which is not unimportant—by allowing one to calculate the width and the height of the individual elements, their thickness, number, extent, form, appearance, and quality, according to their importance and the workmanship they require….I must urge you again and again, before embarking on the work, to weigh up the whole matter on your own and discuss it with experienced advisors. Using scale models, reexamine every part of your proposal two, three, four, seven—up to ten times, taking breaks in between, until from the very roots to the uppermost tile there is nothing, concealed or open, large or small for which you have not thought out,

stimulate the architect's creativity (Piga 1996: 56). As Baldinucci wrote in 1681, the model 'is the first and principal undertaking of the entire work.... Through it, the Craftsman achieves the summit of Beauty and Perfection. It helps the Architect determine lengths, widths, heights, and thicknesses...and to identify the diverse skills that will be needed to build the structure and to find the funds that will be needed to finance it' (*Vocabolario toscano dell'arte del disegno*, cited *apud* Piga 1996: 57 [my translation]).[20] Meanwhile, physical models of fortified cities and the surrounding territory started to be made in the sixteenth century for analogous purposes: they were a visualization tool that helped commanders to plan the defense of or attack on a fortified town (Warmoes 1999: 13). Louis XIV was the acknowledged master commissioner of city models. Of the 144 models built during his reign, thirty survive (Warmoes 1999: 8).

We digital archaeologists have been catching up with our colleagues in the physical sciences who have been using digital models as tools of discovery since at least the mid 1990s when, for example, the VR application called 'Crumbs' was developed by the National Center for Supercomputing Applications at the University of Illinois. Crumbs has been described as 'an application used for visualizing, exploring, and measuring features within volumetric data sets. Crumbs is a...tool that makes use of a variety of display paradigms and data manipulation options, allowing a researcher to explore volumetric data in intuitive and powerful ways.... The motivation for developing Crumbs [was] that many biological structures are difficult to identify and measure with traditional image analysis techniques and two-dimensional visualization interfaces' (Sherman and Craig 2003: 484). Scientists such as T. Karr of the University of Chicago have used Crumbs to measure the length of sperm tails in *Drosophila*, a very difficult task which Crumbs made easy (Sherman and Craig 2003: 506). H.E. Buhse, Jr. of the University of Illinois at Chicago used Crumbs to localize an antibody (OF-1) to the feeding apparatus of *Vorticella convolavia*. Using Crumbs, Buhse discovered that besides localizing to the feeding apparatus, the antibody localized to contractile fibers near the cell membrane (Sherman and Craig 2003: 509). This is a good example of 'promoting the perception of emergent properties that were not anticipated' (Ware 2004: 3).

By the late 1990s, such uses of visualization—whether 1D, 2D, 3D, or, indeed 4D--were common in the natural and social sciences. In a report on cyberinfrastructure commissioned by the National Science Foundation, among the major threads linking the traditional scientific disciplines today is the use of models, simulations, and visualization (Atkins *et al.* 2004: 91-11, 18, 21, 26). In 1999, Card, Mackinlay, and Shneiderman's *Information Visualization: Using Vision to Think* was published, providing a useful bibliography of more than 700 publications and an anthology of over forty classic articles.[21] In their conclusion, the editors wrote:

> [P]owerful visual tools can support discovery; Galileo's telescope enabled him to discover the moons of Jupiter, and microscopes revealed the structure of cells. Now, information visualization tools are supporting drug discovery by pharmaceutical researchers and credit card fraud detection by financial analysts. Visual data mining complements the algorithmic approaches for exploring

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resolved, and determined, thoroughly and at length, the most handsome and effective position, order, and number'.

[20] As Piga notes, Galileo contradicted the idea found in, e.g., Alberti and Baldinucci that architectural models can help to predict the static properties of a building since, as Galileo recognized, the static properties of a given form are not scalable but change with size (Piga 1996: 89-106). To be useful for structural engineering, physical models must have a mathematical basis, and this combination of the physical and mathematical in modeling occurred in the nineteenth and twentieth centuries (Piga 1996: 115, 141-144). One way of thinking of 3D digital models would see them as the logical climax in the merger of the physical and the mathematical approaches to representation (cf. Karasik: 118: '...3D scanners [and one might add, 3D hand-made models—*eds*] typically produce output in vector format, which is more amenable to mathematical manipulation'.

[21] Stuart K. Card, Jock D. Mackinlay, Ben Shneiderman, eds. *Readings in Information Visualization. Using Vision to Think* (San Francisco 1999).

> data warehouses. Surprising patterns that appear in data sets can sometimes be found by algorithms, but visual presentations can lead to deeper understanding and novel hypotheses. These in turn can be checked with algorithmic processes such as cluster analysis, factor analysis, hierarchical decomposition, or multidimensional scaling…. The breadth of applications for information visualization is large and growing…. (Card *et al.* 1999: 625-626)

In this volume, **Gooding** gives us the 30,000-foot overview of our subject, allowing us to place visualization in the historical sciences into the broader context of science per se. **Forte** issues a manifesto calling for nothing less than a new archaeology where the bottom-up process of data collection can properly merge with the top-down process of interpreting the data and building theories around them. **Hermon** agrees with Forte that visualization technologies have been underutilized in archaeology and surveys some of the principal ways in which they can be applied to research in archaeology. On the simplest level, there is the accessing, management, interpretation, and sharing of data. Then there is the conversion of alphanumeric data to a visual display. The conversion can stimulate new understanding but also raise new questions. Moreover, the 3D visualization can be enhanced through predictive models that allow us to define and evaluate possible scenarios implied by the raw data.

In archaeology, we have thus far seen examples of Ware's second and fifth applications in two realms that could be called experimental archaeology and experimental architectural and urban history. The remaining papers in this volume exemplify what has been done to date along these lines.

In a study using a 2D approach with admittedly crude representations of the data (cf. p. 50), **Premo** shows how an agent-based model of Lower Paleolithic landscapes called SHARE ('Simulated Hominin Altruism Research Environment') can throw into question the previous explanation of archaeological features of areas of East Africa, which had been formed on the basis of analogies to modern hunter-gatherers. The agent-based approach does not necessarily result in a new explanation, but offers a tool for developing alternative explanations and testing that are more compatible with the results of fieldwork. Premo argues that when we have two or more explanations consistent with the empirical data, we should choose the simplest one, even if it is very different from the explanation derived from modern analogies.

In a second 2D study, **Indruszweski** and **Barton** use cost surface DEM modeling to reconstruct Wulfstan's late ninth-century voyage from Haidaby (Schleswig-Holstein, Germany) to Truso (near the Visula River mouth in Poland), as told in King Alfred the Great's *Orosius*. Here, interestingly enough, the goal was the opposite of what Premo had pursued: instead of questioning the validity of arguing from present analogies to lost past phenomena, Indruszweski and Barton used an actual physical reconstruction of a Viking boat and a recreation of much of Wulfstan's route to validate the itinerary suggested by application of some standard GIS least-cost analyses. Their point of departure was to dispute the correctness of an alternative reconstruction of the route by Crumlin-Pedersen (1983), which was based on depth sounding along a preselected bathymetric line. As they write, 'we can employ GIS-based simulation as a new way to develop precise and testable hypotheses about Wulfstan's sea route from the meager historical information. The simulation presented here does not operate on fictitious values, but is based on both historical information provided by Wulfstan's account and real-time data provided by experimental archaeology' (59).

Gerlach, **Herzog**, and **von Koblinski** report on work using 2D GIS and 3D terrain mapping to develop a method for distinguishing true archaeological sites from pseudo-sites in the Lower Rhine area as part of a project of the Rheinisches Amt fűr Bodendenkmalpflege in Bonn, Germany, to assess the amount of change in the natural landscape owing to modern construction work, pits, and other sources. The problem is very important: in the Lower Rhine area many pits were dug in the nineteenth and twentieth centuries in order to extract material for making bricks. Most pits were then filled in with dumps of earth and artifacts from elsewhere. In fieldwalking, the filled-in pits are indistinguishable from the rest of the terrain and hence have given rise to the discovery of false archaeological sites. By creating a digital elevation model of the region and using relief shading, the Rheinisches Amt fűr Bodendenkmalpflege has been able to easily identify these pits on the surrounding landscape, thus enabling it to make a much more accurate census of the area's true archaeological sites.

In a similar vein, **Lechterbeck**'s work comparing contour lines in 100-year-old historical maps of Preussische Neuaufnahme of the Rhineland against modern digital elevation models supports the use of digital GIS data when investigating archaeological sites. Changes in topography and in data collection methodology mean that the *Preussische Neuaufnahme* is not suitable for visualizing and quantifying mass movements and slope processes of the last 100 years for that region.

De Boer *et al*. show how LIDAR can provide archaeologists with 3D data needed to reconstruct historical landscapes and to trace sites. As in Gerlach *et al*., the point of this study is to use a new approach to improve the calculation of an area's potential to contain archaeological sites, to identify specific sites, and to eliminate pseudo-sites.

As noted at the beginning of this introduction, Lieberwirth's contribution is *bahnbrechend*. She uses 3D GIS to reconstruct an archaeological site in Greece that was excavated stratigraphically more than thirty-five years ago. The model she creates of the site prior to its excavation permits her to interpret the stratigraphy independent of the explanation offered by the excavators. The result was very promising: while the excavators' interpretation was largely confirmed, important new information emerged. Much more important than the specific advances is the general point implicitly made by Lieberwirth's study that 3D software can permit us to reconstruct with great accuracy a site that has been excavated using the stratigraphic method. Much more along these lines can, and one may safely predict, will be done.

Whereas the archaeologist who uses GIS software can take advantage of a large kit of sophisticated, built-in tools (cf. the study in this volume of Indruszweski and Barton), the virtual archaeologist who creates or uses 3D models generally finds that the only tool available by default is the simple navigation tool permitting either movement of the camera or of the 3D object. Thus Lieberwirth's tools are fairly limited: the software she uses is able to spatialize legacy archaeological data, to calculate volumes of stratigraphic units and to color code them. Her methodology is thus limited to volumetric analysis and visualization of spatial (stratigraphic) relationships (which does not in any way diminish her results). She would undoubtedly be among the first to welcome software with enhanced analytical functionality. It is the merit of **Ozmen** and **Balcisoy** to begin to provide these tools. The point of departure is recognition of the important distinction between the software used to create a 3D model and that used by the end-user to visualize and explore the model. Up to now, production software (e.g., 3D Studio Max, Maya, MultiGen Creator) has had tools that permit the modeler to determine the distance between two points on an object; but standard end-user navigation software has lacked such a basic tool. Unless end-users can learn to use production software, they have been unable to unlock much of the precise data that scientific 3D models contain. Ozmen and Balcisoy argue that the solution can be found in the development of end-user software for medical applications: the software designer should provide digital tools similar to the real-world tools with which end-users are already familiar. This they have started to do with the creation of CH ('Cultural Heritage') Toolbox. This allows a user to move through virtual space, to move 3D objects found in virtual space, and finally to apply tools to the object, once it has been located and positioned for study. The tools in the early version of CH Toolbox are simple but powerful for the archaeologist: a virtual caliper and a virtual tape measure. CH Toolbox was authored in C++ using the library of OpenSceneGraph, one of the most popular open source scene graphs currently in use by virtual archaeologists.

If Ozmen and Balcisoy create two universally useful tools for archaeologists, **Johanson** and **Frischer** (who also use OpenSceneGraph) created a special virtual ephemeris tool to run a 'virtual-empirical' test of the Dearborn-Bauer thesis (Dearborn, Seddon, and Bauer 1998). This thesis entails an explanation of the positioning and alignment of two Inca towers at the north end of the sanctuary of the Sun, on the Island of the Sun in Lake Titicaca (Bolivia). According to Dearborn and Bauer, the towers in questions were not (as has sometimes been thought) tombs but markers of the position of the sun at sunset on the winter solstice. These markers functioned as a means for large-scale audience participation in the solstice ritual. The thesis was originally argued using 2D analyses on a limited subset of data. An *in situ* empirical test could only be performed at a limited time during the year (sunset on or near the June solstice), and only limited sampling of viewsheds could be examined. Furthermore, the empirical test could only be performed on partial data, since many of the critical architectural elements are only partially preserved.

The 'virtual-empirical' test undertaken by Johanson and Frischer eliminates the constraints of time and space. To conduct the test, a 3D computer model of the topography of the island and the sanctuary was built. Ephemeris data supplied by NASA's Jet Propulsion Laboratory made it possible to reconstruct the apparent course of the sun at sunset on dates surrounding the winter solstice in the year 1500 CE, the approximate date for Inca ceremonies attested by the Spanish chroniclers. Thus, using more accurate tools, the hypothesis was able to be further validated and more easily communicated to a general audience.

Karasik tackles the problem of how 3D scanning of pottery can lead not only to more accurate illustrations of the profiles of ceramics but also to new discoveries. Profiling pottery is based upon the assumption that pots are perfectly axially symmetrical, so that one profile serves for all possible profiles that might be made. But in the real world, as Karasik notes, no vessel shows perfect axial symmetry. 3D data reveals the deviations from perfection and these, in turn, can be used to determine intravessel and intervessel uniformity of pottery belonging to the same assemblage. Uniformity in this sense has never been taken into consideration in pottery studies, doubtless because without 3D vector data, it is extremely difficult to calculate. Why might uniformity be of interest to the archaeologist? As Karasik succinctly notes, 'the former [intravessel uniformity] represent[s] the quality of the production of a single vessel, and the latter [intervessel uniformity] the reproducibility of the manufacturing process.' At the end of his article, he sketches out a research program that could be based on this ability to calculate uniformity/deformation with high precision. It could lead to assessments of the motor skills of the individual potter, the ability to differentiate home-made from mass-produced pottery, the detection of individual potters' signature characteristics within a type or tradition of ceramic production that otherwise looks to very homogeneous to the naked eye; and the ability to distinguish between a fast wheel and a tournette.

If Karasik's contribution ends with a vision of possible new discoveries just around the corner as 3D scanning technologies are applied with greater frequency to the study of pottery, then **Koller** closes with some spectacular concrete results that could only have been achieved through 3D scanning. He was part of a group, led by Stanford Computer Scientist M. Levoy, that digitized and made 3D models of each of the 1200 surviving fragments of the Severan Marble Plan. This is an enormous and detailed map of Rome dating from the beginning of the third century CE. Koller played an important role on the team and wrote his dissertation on the project (Koller 2007). In his contribution in this volume, he describes the map, recounts the campaign to digitize and publish it to the Internet,[22] and reports on how he used various algorithms to find new joins

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[22] See http://formaurbis.stanford.edu/.

among the fragments.[23] The ability to find such joins is remarkable and represents a major early triumph for virtual archaeology: the map was discovered in the sixteenth century and for centuries has been the subject of scholarly interest, including two major monographs in the decades immediately preceding Koller's work (Carettoni *et al.* 1960; Rodríguez-Almeida 1981).

For all its strengths, Koller's study does have one major weakness: the user interface he helped create for the project does not contain the tools that he developed to achieve his results. Like most 3D user interfaces, it simply allows the user to move the fragment around on the screen. To empower the end-user, the interface would need to be enhanced with tools reflecting the searching and matching algorithms developed or used by Koller to solve the puzzle of the Marble Plan (Koller: 135-139), and it would need to support the simultaneous viewing of two or more fragments at a time, each manipulated independently so that potential joins could be virtually tested. As Koller notes, to do this now the end-user needs to load the fragments of interest into a 3D modeling software program (Koller: 134). But not all end-users have such a program, and such programs often take a great deal of training to use effectively.

Let me conclude with several observations. First, I do not mean to imply that computer models of archaeological sites do not have other legitimate uses. Illustrations, documentation, education, site presentation, etc. have become standard applications of archaeological computer models, and I certainly see nothing wrong with that. To the contrary, I predict a rosy future for such models as cities and states around the world start to create virtual cultural heritage centers.

To make progress in going 'beyond illustration', we need more tools—tools that are in part replicas within the VR interface of existing tools, such as those found in several contributions in this volume; and, of course, brand new tools. In the first category, I would put the tools created by Ozmen and Balcisoy and discussed in this volume. Into the second category, I would put tools that exploit the specific strengths of VR: for example, we need haptic tools, not just to move objects around in our illustrations, but to provide analytical data about those objects, such as their weight and other physical properties. We need tools that enable us to test lighting conditions in the virtual environments we create. A good example of the potential of this for scholarship is provided by Jabi & Potamianos. In two studies (Jabi & Potamianos 2006 and Potamianos & Jabi forthcoming), they use lighting tools to study how Anthemius of Tralles, the architect of Haghia Sophia in Istanbul, used geometrical principles to control the lighting of the apse and dome. We need sound tools, not only to populate our representations with localizable 3D sound but also to give analytical feedback about the acoustic properties of our virtual environments so that we can determine in a serious way whether, for example, the Roman Senate House with its marble floors and marble-clad walls functioned well or poorly as a place of deliberation and debate. To date, models have been used mainly to represent landscapes and built structures unenhanced by physical properties. We need to add physics engines to our 3D viewers. They will permit us to incorporate in the user interface a variety of structural engineering tools for studying the statics of our buildings, ventilation and circulation through them, and to simulate how they were subjected to damage and destruction through disasters such as fire, flood, earthquakes or by their own deficient design. Similarly, few (if any) archaeological models utilize artificial intelligence to represent the behavior of people, animals, and artifacts. The potential of doing so was recognized by the contributors to the session on 'Avatars and Virtual Humans' at VAST 2004 (cf. de Heras Ciechomski *et al.*, Gaitazes *et al.*, Ryder *et al.*) and signs of interest are scattered elsewhere throughout the scholarly literature.[24] Further progress in this direction is presented in this volume by Premo.

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[23] In Koller 2007 he discusses over 20 new 'highly probable' joins.

[24] Balck and Keller 2004; Gutierrez *et al.* 2005; Gutierrez, Frischer *et al.* 2007; Andreoli *et al.* 2007.

Finally, we need tools that reflect the strength of digital technology generally to make links and connections. Foremost among these is the ability to link the reconstruction in the 3D scene to the underlying archaeological documentation and argumentation behind the scene. Such transparency has long been called for (see Forte 2000) and a good groundwork for how this might be done using the Resource Description Framework (RDF) encoded in the eXtensible Markup Language (XML) was laid by Ryan 2001. It should be possible for the end-user to click a key, open a window with documentation and metadata, and find out what the evidence is for each element of the 3D reconstruction in a virtual tour.

These are just some examples of the toolkit we ideally need to be creating to make our virtual environments more than pretty pictures but places where we can run experiments, collect new data, and empower the end-user to question or build on our work in a way that would simply not otherwise be possible.

Beyond tools, we need a standard user-interface that can both run the scientific cultural heritage models being made by scholars in increasing numbers and be enhanced by the new tools we need, which might be added as plug-ins. This might be a high-quality but inexpensive proprietary game engine such as Torque[25] or, perhaps, an Open Source scene graph such as OpenSceneGraph[26] or Open SG.[27] We also need an online, peer-reviewed scholarly journal in which scholars can publish their models and tool plug-ins. Up to the present, there have been very few examples in this field of fully interactive, real-time models that have been published to the Internet. Generally, scholars have only been able to publish articles about their modeling projects with, at most, several color 2D illustrations. This must change.[28]

It is not difficult to predict that 2D and especially 3D modeling of cultural heritage spaces and monuments will shortly gather momentum, especially as the tools we need and standards or best practices for creating and viewing models become available. Use of these technologies will spread through new sub-disciplines of archaeology and the humanities. In art history, for example, recent work by Dellepiane, Callieri, Fondersmith, *et al.* (2007) shows how 3D can be used in artistic attribution. The authors used 3D modeling technology to create a digital representation of a small bronze horse in the Florence Archaeological Museum. The statuette had been attributed to Benvenuto Cellini. One of the co-authors of this paper (Fondersmith) attributed the statuette to Leonardo da Vinci on the basis of a drawing of a similar horse in a Leonardo manuscript (Leonardo drawing 358, Windsor Royal Library). The drawing was digitized and then mapped to the model at the vantage points the artist could have used to draw the statuette. The digital versions of the drawing and statue could then be aligned, and the authors found that the alignments from two vantage points were very precise. Other Leonardo drawings of horses (though not of the horse depicted in the statuette) were tested, but no good alignments were found. A second horse, also in the Florence Archaeological Museum and also datable to Leonardo's lifetime (though not attributed to him) was also studied for possible alignment with the drawing. In this case, too, no good alignment was found. The authors conclude that their study may not prove that Leonardo sculpted the statuette but it does throw doubt on the attribution to Cellini.

In the field of archaeology, use of 3D has been most prevalent in Old World archaeology. But the New World is starting to shows signs of interest. Thus the 2007 annual meeting of the Society for American Archaeology had a session entitled 'Beyond Illustration: 3D Reconstructions, Virtual Reality, and Archaeological Communications in the Early 21st century', organized by graduate students D. Hixson and B. Just. If the use of

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[25] http://www.garagegames.com/company/.

[26] http://www.openscenegraph.org/projects/osg.

[27] http://opensg.vrsource.org/trac.

[28] The Institute for Advanced Technology is pursuing research on a proposed new journal to fill this gap; see http://www.iath.virginia.edu/save/. For a useful survey of the current scene in electronic publication in the field of archaeology see Richards 2006. On digital scholarship generally, see Borgman 2007.

3D is spreading in space, it is also being applied to ever earlier time periods. Thus 3D technologies have recently enabled Gaffney and Thompson to succeed in the heroic task of reconstructing the submerged Mesolithic terrain of the enormous basin that is larger than the entire United Kingdom. Known as Doggerland, this landscape is presently submerged beneath the North Sea (Gaffney and Thomson 2007: 1-9). Through the use of visualization as a cognitive tool, a large area of *terra* formerly *incognita* has become *cognita*.

Looking ahead to research streams not yet represented in this volume, one can repeat the prediction made in 2000 by Goodrick and Gillings that virtual archaeology and cultural studies will intersect.[29] As they note, fundamental to this project is Tilley 1994, which introduced the powerful concept of the social construction of landscape. Tilley was himself anticipated by Berger and Luckman 1967, who wrote:

> The origins of a symbolic universe have their roots in the constitution of man. If man in society is a world-constructor, this is made possible by his constitutionally given world-openness, which already implies the conflict between order and chaos. Human existence is, *ab initio*, an ongoing externalization. As man externalizes himself, he constructs the world *into* which he externalizes himself. In the process of externalization, he projects his own meanings into reality. Symbolic universes, which proclaim that *all* reality is humanly meaningful and call upon the *entire* cosmos to signify the validity of human existence, constitute the farthest reaches of this projection (Berger and Luckman: 104)

Berger and Luckman consciously downplayed space in favor of time in their analysis of the social construction of reality.[30] Tilley redresses this imbalance, taking as his point of departure the claim that ‘space is socially produced, and different societies, groups and individuals act out their lives in different spaces’ (Tilley 1994: 10). The field of archaeology did not need to undergo the famous ‘spatial turn’.[31] It was already, by definition, a spatially sensitive and organized discipline. But as other humanistic disciplines such as cultural studies have become spatialized, the possibility has arisen of new interdisciplinary interactions.

In a brief but striking way, Paliou and Wheatley (2007) met Goodrick's and Gillings' challenge to relate objective to subjective spatial data. They created a 3D model of two adjacent rooms in an impressive building (possibly used for public, ceremonial purposes) in Late Bronze Age Akrotiri on the island of Thera (3 and 3a of Xeste 3). Room 3a contains a long fresco known as the ‘Adorants’. It is accessed through a pier and door partition in room 3. The 3D model allowed Paliou and Wheatley to see how the artist designed the fresco in room 3a to take into account the occlusions caused by the partition. These blocked the view of the entire

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[29] Cf. Goodrick and Gillings 2000: 52: ‘…there is enormous potential to use VR techniques to provide a much needed practical dimension to the more phenomenological lines of enquiry being advocated within landscape research (e.g., Tilley 1994)’. Several years earlier, the same authors had written, along similar lines: ‘it is clear that if archaeologists are to utilise GIS-based approaches in their attempts to explore and articulate the archaeological record on the basis of more reflexive and experiential modes of enquiry, a more explicit discussion as to the conceptual status of the underlying space and time of the GIS is in order. The uncritically received dominance and adherence within archaeological-GIS of notions of geography and cartography as the abstract representation of the world as organised in measurable space, may have to be enriched by paying equal attention to notions of chorography, as a subject-centred sense of place…. In addition, discussions as to the role of temporality in GIS should give equal weight to more phenomenological notions of time, what Thomas refers to as “the time of the soul” (Thomas 1996: 33), as to the already prevalent Kantian notions of time as an abstracted container’ (Gillings and Goodrick 1996: part 2a).

[30] Cf. Berger and Luckman: 26, ‘The world of everyday life is structured both spatially and temporally. The spatial structure is quite peripheral to our present considerations. Suffice it to point out that it, too, has a social dimension by virtue of the fact that my manipulatory zone intersects with that of others. More important for our present purpose is the temporal structure of everyday life’.

[31] On the history of this term, see Kaufmann 2004: 3-4.

fresco for someone moving through room 3, but from most points of view in room 3 the fresco's central figure of a wounded girl could be seen. They note that this objective fact jibes well with the iconographic (and subjective) observation of art historian L. Morgan (2000) that the focal point of the painting is the central figure.

Early evidence of an even more profound confluence can be found in a collection of articles on ancient Rome edited by Larmour and Spencer (2007). Here one catches glimpses of how the gap between positivistic approach of virtual archaeologists and the phenomenological methodology of cultural studies, ultimately inspired by Berger and Luckman 1967 and Tilley 1994, might be bridged by approaches using psychogeography,[32] gaze theory,[33] Lacan's notion of *objet a*,[34] and Baktin's concept of the chronotope.[35] In Larmour and Spencer, the emphasis is on how ancient authors such as Livy, Horace, Ovid, Tacitus, Juvenal and Plutarch imagined and experienced the ancient city. At least one of the contributors uses some fairly rudimentary illustrations of the city to make her case (Spencer 2007: 98-99). Others use words to make their point, but the words almost cry out for dynamic illustration in real-time 3D imagery, as, for example, when Spencer writes:

> Physically, one **looks down** from a building or a hill, **up from** a valley, **off into** the distance or **up to** high stories from street level. Such angles of gaze, and the perceptual and cognitive possibilities that they open up, inevitably generate and respond to key sites in an urban topography. The narratives that coalesce at these conjunctions of space, place, and point of view themselves draw together further associations between people and places, personal and collective stories and myths, societal expectations and longings. Hence, at the heart of each individual's unique reading of urban topography lies a complex nexus of standpoints and angles of gaze—personal, psychological, aesthetic, mnemonic, imaginary, and experiential. Inside Augustan Rome, all of these cluster with particular urgency around the Fora, Capitoline, and Palatine.... Livy's conceptual map makes notably complex retrospective demands of his audience. It operates a space which requires that readers bring to bear a full set of urban sight/site lines even before the city proper is brought into narrative existence. (Spencer 2007: 62, 78)[36]

Equally graphic (but unillustrated) is Larmour's purely verbal analysis of the use of Roman space in the satires of Juvenal, where we would like to have not only an urban digital model but a simulation enlivened by people and their activities:

> The specific locations in the Satires appear fleetingly, flashing before us very much in the manner that sites on a museum display of Ancient Rome might do. Having surveyed them, we can say that, in the Juvenalian corpus, these locations almost always appear in the following three ways:

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[32] Larmour and Spencer 2007: 9.

[33] Vout 2007: 305.

[34] Blevins 2007: 280.

[35] Banta 2007: 239.

[36] Similar passages can be cited in Tilley 1994, e.g., 'Looking at the two-dimensional plane of the modern topographic map with sites and monuments plotted on it, it is quite impossible to envisage the landscape in which these places are embedded. The representation fails, and cannot substitute for being there, being *in place*. Similarly, an unfamiliar landscape remains invisible. You do not know where, or how, to look. This process of observation requires time and a feeling for the place. After being there, after making many visits to the same locales, the intensity of the experience heightens. Monuments that were initially hidden from view on a first visit to a place can now be seen, and patterned relationships between sites and their settings become apparent' (75). Of course, Tilley is talking about actual field walking, but there is no reason why such exploration cannot occur in virtual space.

> 1. They are inherently repulsive, like the Subura or the Colosseum or the Circus Maximus, places—whether a jumbled conglomeration of small buildings like the Subura district or a massive architectural expression of the desire for solidity and containment like the Colosseum or Circus—characterized by overflowing, oozing, and pollution….
>
> 2. They are important public spaces, freighted with historical and cultural significance, where repellent behavior or individuals can all too easily be witnessed—like the Forum or the Campus Martius. These public spaces, including such well-known ones as the Temple of Concord, are viewed from a 'liminal' perspective, from the position of the marginal, alienated, and about-to-depart gaze….
>
> 3. They are previously 'clean and proper' places that have become repulsive because of their penetration or contamination by outside elements. The Grove of Egeria is the most detailed description of how public space has become objectionable in various ways, but other examples include the Gallery of Triumphatores in the Forum Augusti…. (Larmour 2007: 207-208)

At times, one also can see how the 'chronotopian' method cannot simply benefit from 3D illustration so that we can see with our own eyes what the scholar has seen in his mind's eye, but how it can also offer depth and meaning to an 'objective' urban simulation that, for all its outward, physical accuracy, is lacking in cultural resonance and psychological depth. How much more meaningful from both our point of view and that of the ancient Romans to view the Capitoline Hill, dominated by the temple of Jupiter Optimus Maximus, with the following passage in mind:

> …Tacitus offers us a richly layered narrative of the cataclysm surrounding the Capitoline Temple that exploded on a single day (19 December 69 CE), but his presentation opens up much broader temporal and textual vistas which, when viewed closely, sharpen the moralism of his account and interrogate *Romanitas* at a disastrous moment, which ultimately might have been more comfortable for his readers to forget. This is indeed a bitter and painful form of memorializing through monuments. The collective sense of *Romanitas* has, by Tacitus' own day, been progressively (if imperfectly) reconstructed, much as the Capitoline Temple itself has been restored, but a reading of *Histories* 3 shows how fragile the new 'edifice' of Roman identity remains; and even the restored temple burned down again in 80 CE.
>
> We are left with a strong sense that although the physical fabric of the city and its focal point, the Capitoline Temple, could always be reinstated (again and again, if necessary), the broader emotional fault-lines were still there in the collective memory, rendering an unexpectedly open-ended narrative for Tacitus' readers sensitive to the possibility of history repeating itself…. (Ash 2007: 236-237)

Ash's work suggests that the best examples for the merger of objective and subjective approaches under the sign of digital archaeology will come from societies like ancient Rome whose remains are both physical *and* literary. The social construction of space is almost always as peculiar and unpredictable as is Tacitus' reaction to the Capitoline Temple.[37] In this regard we may note, for

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[37] Cf. the Avatip on the Sepik river in northwest Papua New Guinea: 'To the villagers all land and bodies of water are fertile because they contain the rotted bodies and body-fluids of totemic ancestors. Many parcels of land are criss-cross complexes of old levees left by shifts in the course of the river; people say these have human outlines, and still bear the shapes of the ancestors who "fell down" upon them in mythical times' (Harrison 1988: 323 *apud* Tilley 1994: 58). It is noteworthy that Van Dyke and Alcock 2003 structure their anthology of phenomenological studies on world archaeology into two main

reasons observed long ago by Karl Mannheim,[38] that Tilley's analyses of contemporary small-scale societies are far more convincing than those he offers of Mesolithic and Neolithic landscapes in England and Wales, where, in discussing the original cultural significance of the physical remains, he is usually reduced to formulations such as 'I want to suggest…' (109), 'it is not hard to imagine…' (198), and 'it is not unlikely…' (200).

I conclude by expressing the hope that as virtual archaeologists are able to publish fully stocked analytical toolkits along with highly detailed 3D models of the spaces excavated by modern archaeologists or mentioned by ancient authors, cultural-studies scholars will be eager to use these resources to explore the *Schein und Sein* of 'topography…, in its broadest sense, as it (re)appears in time, space, and memory' (Larmour and Spencer 2007: ix). As this happens, chronotopians will infuse our urban simulations with historical memories and emotional associations that are every bit as indispensable to re-experiencing a lost world as are the virtual people, furnishings, and the 'bricks and mortar' themselves.

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parts, "Memory Studies with Access to Texts" and "Memory Studies in Prehistory." Reflecting on this division, the editors write, "This is not to claim that texts 'solve' all our problems—far from it—but they unquestionably grant some richness and nuance to the relevant analyses" (7).

[38] Cf. Mannheim 1971 (originally published in German in 1921): 29-30: 'That the spectator can grasp the intended expressive content of a picture is no less and no more of a miracle in principle than the general phenomenon that we can associate the sensual content of the work with any kind of meaning-function at all. Expressive meaning also is a "given"; and if interpretation of this type presents peculiar difficulties, it is only because, unlike objective meaning (such as, for example, the composition of a picture) which is self-contained and hence ascertainable from the picture alone, the expressive meaning embodied in aesthetic elements such as the subject matter, the sweep or foreshortening of a line, cannot be established without an analysis of the historic background...This difficulty, however, need not induce us to become sceptics on principle; all we have to conclude from it is that intended expressive meaning is only discoverable by factual historical research, i.e. that in investigating it we have to employ the same methods as are used in any factual historical inquiry. *That the intended expressive meaning will not remain inaccessible...is guaranteed to some extent for those periods and cultures which are in a continuity of history with ours.* The historical structure of consciousness itself is guarantee that some understanding of the intended meaning may be possible even in respect of works remote in time, the reason for this being that the range of emotions and experiences available to a given epoch is by no means unlimited and arbitrary. These forms of experience arise in, and are shaped for, a society which *either retains previously existing forms or else transforms them in a manner which the historian can observe.* Since historical consciousness can establish contact with works of the past in this fashion, the historian is able gradually to make himself at home in the "mental climate" of the work whose expressive intent he is seeking to understand; thus he secures the background against which the specific intent of the work, the unique contribution of the individual artist, will stand out in sharp detail' (my emphasis).

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