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Digital Karnak: An Experiment in Publication and Peer Review of Interactive, Three-Dimensional Content

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The Digital Karnak computer model is a 3-D interactive reconstruction of ancient Egypt's temple of Karnak, one of the largest temple complexes in the world. The full model documents almost two thousand years of temple history, including thirty temporal phases, dating from 1971 BCE into the Roman period. Designed to function primarily as a large-scale, temporal exploration of the temple precinct, the model visualizes how the main architectural elements relate to one another across long periods of time (Figure 1). By tracing the larger patterns of construction and destruction over the temple's life span, the model attempts to isolate how each phase at Karnak was built in response to existing architecture, elucidating how individual royal preferences shaped the eventual overall structure. Teasing apart the phases of the temple also removes the emphasis often put on the later stages of the temple, the phases consistently reproduced in maps and plans (Figure 2). This is especially important for features of the temple whose original forms are known because their building blocks were found in the foundations and other parts of later buildings, but whose original locations are sometimes speculative. A number of these structures are not represented in any way at the site today (such as the obelisks of Thutmose III and IV, both later moved to parts of the Roman Empire) or have been reassembled in the temple's Open Air Museum (such as Hatshepsut's Red Chapel and the Peristyle Court of Thutmose IV) and so have been stripped of their original context and significance within the larger space.

This article describes the use of the interactive Digital Karnak model as the core of an experiment to develop a new form of publication for scholarly 3-D reconstructions. An excerpt of the model, covering the extensive changes made at the temple during the approximately 175 years of Egypt's early and mid-Eighteenth Dynasty (1523–1349 BCE, part of the New Kingdom), was heavily annotated directly within the 3-D environment (i.e., "in-world") using VSim, a software interface designed for the educational use of academically generated 3-D content. VSim was developed at the University of California, Los Angeles, with funding from the National Endowment for the Humanities (grants HD-50958-10 and HK-50164-14). Academic citations, comments on choices made in the reconstruction (the "paradata"), photographs of the site in modern times showing the extent of the model reconstructions, and guided linear narratives focusing on research themes were all embedded within the 3-D space of the model. The final package includes 639 of these in-world annotations, introductory material that describes how to interact with the content, and five narrative arguments. The narratives demonstrate how a number of historical issues can be explored in new ways in the 3-D space. Specifically, they make the case that changes in function, form, access, sequencing, visibility, and circulation across time at the temple can be tested and examined in ways that are impossible on the ground. While the model cannot re-create the past, it provides new methods for interrogating

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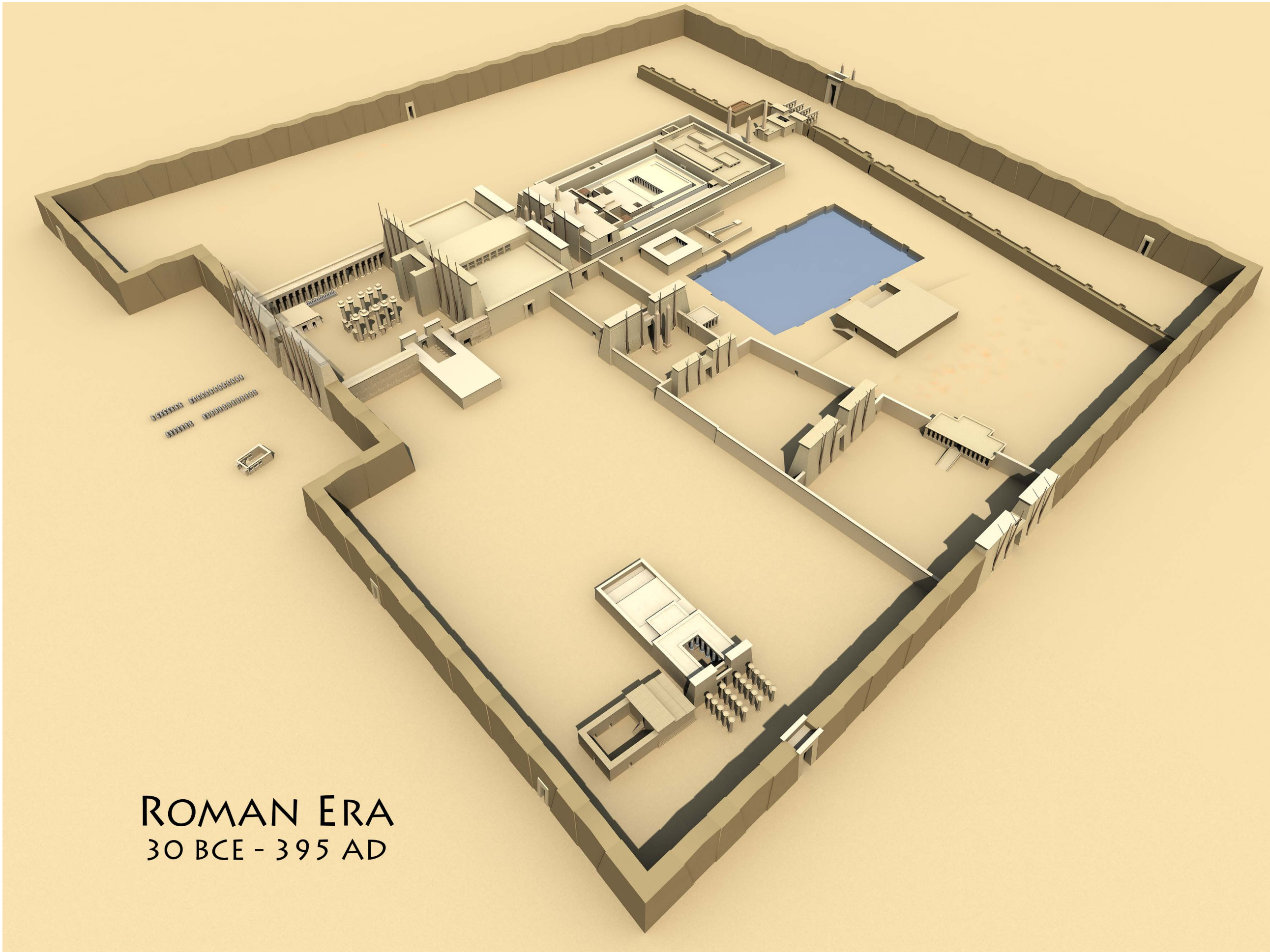

Figure 1 The full Digital Karnak 3-D model (© Regents of the University of California). See *JSAH* Online for a video that visualizes architectural change at the temple across two thousand years.

historical problems within "potential pasts," re-creating now-lost places based on current research.[1]

This article is composed of two parts: (1) the fully digital Karnak publication package (available for download at vsim.library.ucla.edu/digitalkarnak), and (2) a traditional textual explanation of the history and methodology of the Digital Karnak project and the development and use of the VSim software interface for 3-D scholarly content. Our goal in this publication is to foreground the interactive version of the Digital Karnak model and make it the central element in discussions about the use of 3-D for scholarship, peer review, secondary scholarship, and pedagogy. By packaging the Karnak model into a downloadable, interactive, pedagogical resource, we intend to demonstrate the viability of born-digital scholarship as an alternative to printed scholarly argument. It is our hope that this project can help prove the intellectual worth of this new form of scholarly research.

History and Project Methodology

The Digital Karnak model was created at UCLA in 2007–8 as part of a larger NEH-funded project to develop teaching and learning resources about the temple complex. The Karnak proposal originated from a sense of frustration and had at its inception a decidedly pedagogical bent. In teaching courses on Egyptian history, archaeology, and architecture, UCLA professors Diane Favro and Willeke Wendrich could not find adequate resources on Karnak, one of the architecturally and historically richest temple complexes in Egypt. The temple's monumentality, phasing, and complexity could not be expressed successfully with traditional 2-D maps and plans found in textbooks. While looking at the temple at its final stage in the Roman period is certainly important, a great deal of the interest in the site lies in its long history—a complex history that is obscured by the 2-D plans that conflate all the chronological periods into a single image. There had to

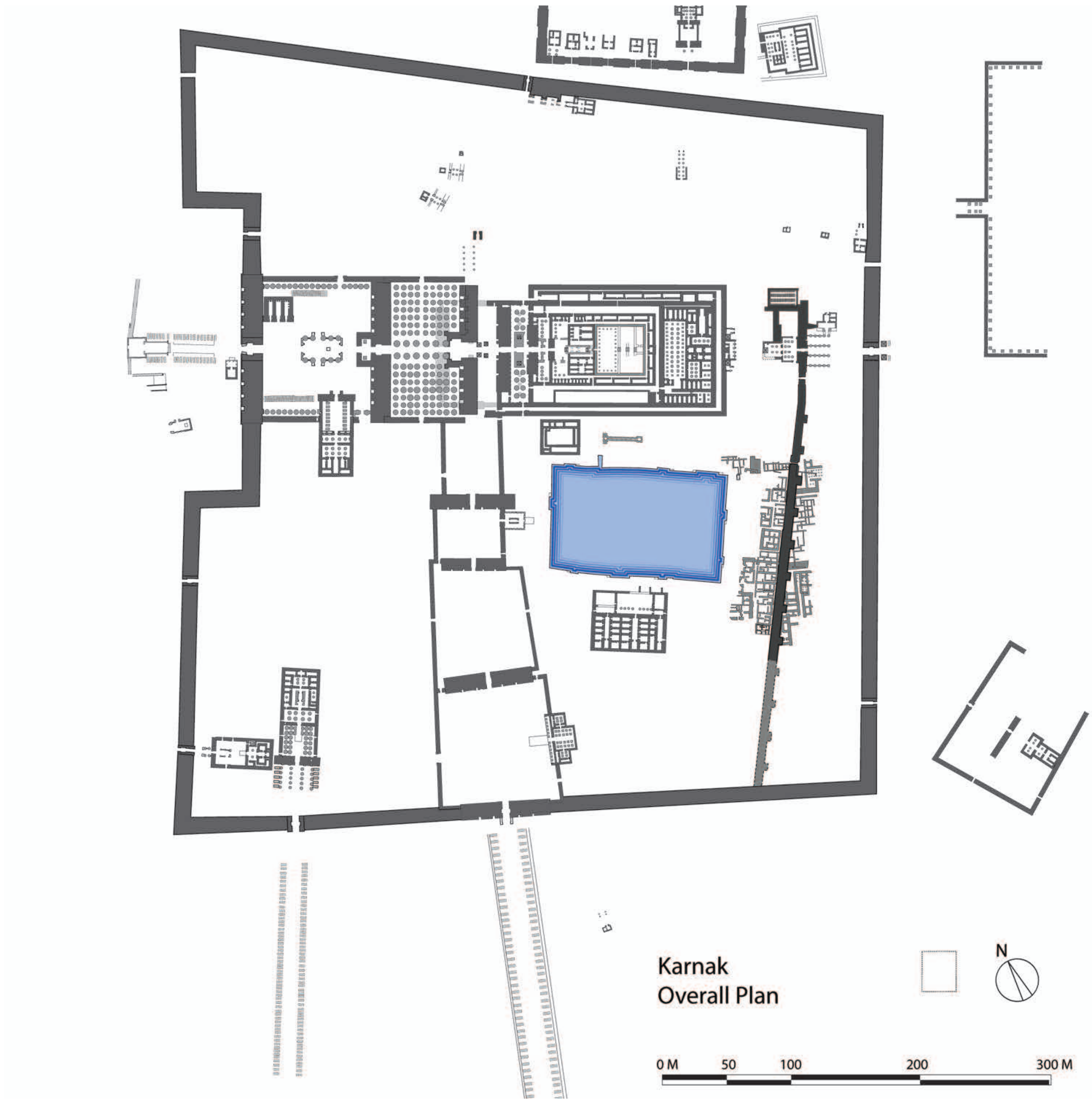

Figure 2 Ground plan of Karnak Temple (© Regents of the University of California).

be a better way to understand the temple. Favro's experience as part of a collaborative effort to build a 3-D model of the Roman Forum led her to suggest a possible solution, and a temporal 3-D model of Karnak was imagined.[2]

Favro and Wendrich applied for and received an NEH grant titled "Instructional Resources for Spatial and Cultural Analysis of an Ancient Egyptian Temple Complex (Karnak)" (EE-50432-07), which was supplemented with funds from

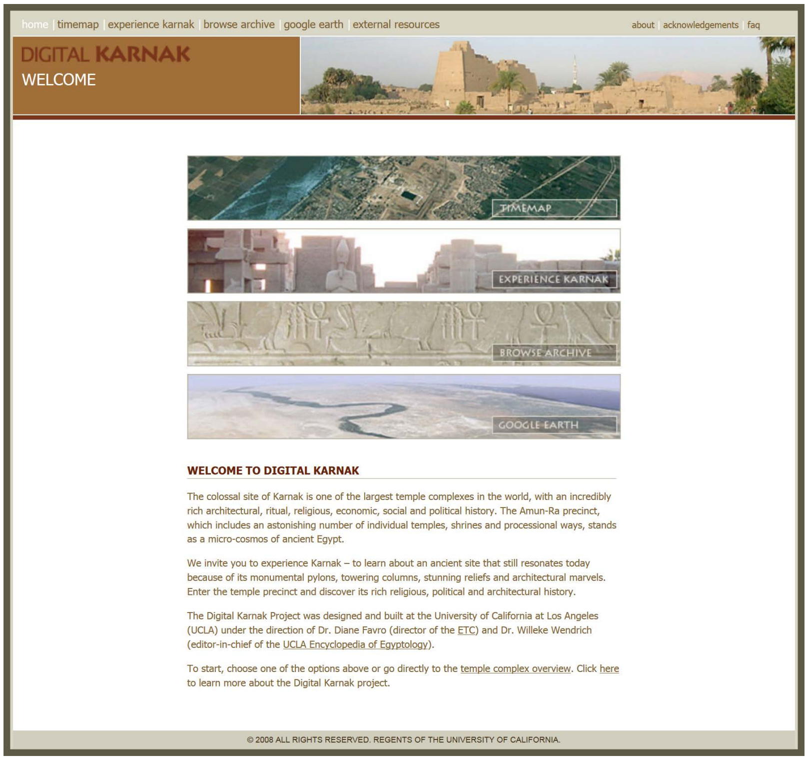

Figure 3 Home page of the Digital Karnak website (© Regents of the University of California).

the Steinmetz Family Trust. We contributed to the project as coordinator and content researcher (Sullivan) and chief technologist (Snyder).[3] The grant funded one year of resource development with the aim of producing materials for use in the undergraduate classroom. Along with the construction of a 3-D historic reconstruction model of the famous ancient Egyptian temple, the grant also funded the creation of a number of resources for sharing information from the model. Launched in 2008, the project website included a geo-referenced "time map" of the temple that animated the traditional 2-D plan of the temple, descriptive web pages for each building at the temple linked to modern photographs and renderings of the 3-D model, high-resolution temporal 2-D maps of the temple at different chronological phases, a low-resolution version of the model for interactive use in Google Earth, and QuickTime videos of the model with accompanying essays on topics of special interest for those studying Karnak (Figure 3).[4] Links to other websites and data repositories with Karnak-related information were also gathered and integrated on the site.

Each of Digital Karnak's more than fifty-five reconstructed features is based on meticulous individual study published by scholars over a period of more than one hundred years. The full model spans almost two thousand years of temple history, including thirty temporal phases. No single scholar could adequately document all this material, in three dimensions, across such a time span, in traditional print format. Indeed, the publication *Cahiers de Karnak*, the main location for work on Karnak excavations, currently includes fourteen volumes.

Knowledge Representations and Visualizations as Interpretations

The increasing use of 3-D models to address research questions in humanistic fields such as archaeology and history has begun to quell outmoded assumptions that visualizations are merely representations of data. In an article on the visualization of knowledge forms, Johanna Drucker points out that the visual expression of data is not a simple transmission from textual to visual; rather, the transformation inherently necessitates new forms of knowledge production.[5] She argues that the very act of data visualization is interpretation, and "every graphic representation is a rhetorical device. Every presentation structures arguments—it doesn't 'reveal' facts in all their purity."[6] Drucker refutes the idea that data have some sort of pure, "absolute identity" outside of representation at all. Instead, she views the presentation of information as subjective and transformational at every stage.[7]

Indeed, Drucker's situating of visualized data within a framework of choice and argumentation fits closely with the Digital Karnak project's conceptualization of the 3-D model. In a certain sense, historic reconstruction models like Digital Karnak operate as "knowledge representations," artificial surrogates that aim to aggregate information and accurately portray data, with specific goals in mind.[8] In building the Karnak model, we attempted to closely represent scholarly interpretations of temple structures based on archaeological research. As a result, the model does not re-create Karnak Temple as it existed in reality at any time in the past; rather, it represents what the field of Egyptology knows about Karnak (as of 2008, the date of the model construction) during a variety of past moments. It is, in one way, an aggregation and representation of data. But this characterization is too limiting, and it does not fully describe what takes place during the process of modeling aggregated data. Per Drucker's discussion regarding the fundamental interpretation involved in visualizing any data, we see the model as moving past representation, creating new knowledge through the very act of generating a new visual means of data expression.[9] In both the process of building and the process of exploring within the 3-D model, new understandings of how Karnak's pieces fit together are possible. The model enables users to envision how each phase of construction altered the experience of seeing—and moving through—the temple space.

Limitations and Challenges of the Karnak Model

One of the major challenges of creating a sequential 3-D model lies in dealing with issues of temporal granularity.[10] Inconsistencies in historic data, problems of uncertainty, and alternative understandings of time (such as nonlinear calendar systems like that used in Egypt) make fitting temporal variation into another system complex.[11] While some monuments at Karnak have inscriptions dating their construction within the years of a king's reign, dates for other monuments are unknown or relative. Tracing the building program of even one king year by year would necessitate a great deal of hypothesis. Since the goal of the model was to look at changes at the scale of individual reigns, a higher level of granularity was not sought. Thus the model combines the many moments of change that would have taken place during a single king's reign (with the reigns of some kings lasting more than twenty years) and conflates these into one or two major phases. This design choice facilitates understanding of the larger overall patterns in construction by each king while obscuring temporal variance within the individual reigns.

Highlighting important texts and reliefs in their original locations—showing how the meanings and uses of these works are best considered within the frameworks of their original architectural contexts—was a secondary goal of the model. In order to keep hypothetical reconstruction in the model to a minimum, imagery from Karnak in modern times was used at key points in the model. Users viewing recent imagery or publications would therefore see those same works represented in their original locations within the temple space. Texts and reliefs were not amended or filled in to appear as they originally did at the time of construction. This admittedly creates an anachronism—the features in the model represent their possible forms at time of construction, but texts and reliefs are visualized as they are today, with areas missing and damaged. However, this technique fit the educational goal of the model, presenting users with the general contexts and locations of important texts and reliefs that might be under study in the classroom. A full reconstruction of such works in an entire structure would necessitate additional levels of research and explanation.

We would like to reiterate here that the 3-D reconstruction model of Karnak temple is not an attempt to "recover the past." As stated previously, the model is an abstraction of information. Missing are signs of structure degradation, dirt, landscaping, smells, human activity, and the state of incompletion during monuments' construction periods. Archaeologists know quite well that most buildings have many stages during their occupation, with multiple floor levels, moments of collapse and subsequent shoring up, and small modifications over time. Karnak can never be re-created fully. Every model will be a sterilized representation of reality, limited in nuance. And although the model traces architectural change at Karnak, it is not an architectural model representing elements of structural engineering or construction details. Texturing (the laying of photographic imagery onto the geometry of the model) provides a general sense of the size and scale of building materials, but the model was not built brick by brick to replicate variety and difference, for example, within a single structure. Karnak also does not represent the temple at the scale of accuracy achievable by reality-based 3-D models (i.e., created using LiDAR scanning or photogrammetry), which have captured the actual centimeter-by-centimeter shape of the temple today. Such work has been accomplished at Karnak by the Centre Franco-Égyptien d'Étude des Temples de Karnak and will provide interesting comparative models if the results are released to the public.

While the accomplishments of the one-year Digital Karnak project were substantial, the scope of the work was greatly limited by the short time frame, the total project funding (just shy of $200,000), the grant's specific pedagogical agenda, and the available technologies. The first two constraining factors, time and money, primarily affected the scale of the project. Not all the buildings at Karnak were included in the model, and a number of subsidiary temples, chapels, and less monumental features (such as the mud-brick temporary housing for priests) were excluded. The use of texturing was highly uneven across the complex as well. The time-consuming process of joining and sizing high-resolution photographs and layering them onto the model was accomplished in certain areas of special focus (such as the White Chapel, Red Chapel, and Akhmenu, as well as select obelisks). In almost all the other areas of the temple, generic stone patterns created from digital photographs were used to give only a very general sense of the color and stone patterning. These were sized to reflect the basic appearance of the structures today, but they do not accurately depict the great variation in construction techniques and materials that a more detailed texturing would portray. As well, this programmatic texturing does not include the hieroglyphic texts, relief carving, and statuary that decorate much of the temple. The time, research, and computer memory needed to fully texture the Karnak model were beyond the capabilities of the project.

The pedagogical nature of the grant also affected the initial output of the project in 2008. Creating multiple visualizations of every building whose original appearance is under debate was prohibitively time-consuming, and such work did not lie within the general educational purview of the project, which aimed to create a single, understandable narrative. Thus the model represents only one reconstruction for each building. With an undergraduate audience as the target of the project, advanced discussion of reconstruction issues was kept to a minimum, with information on conflicting reconstructions mentioned on each feature's web page at the Digital Karnak website, but not visualized. Likewise, the model does not illustrate the many parts of Karnak Temple that in ancient times would have been plastered, painted, gilded, and adorned with wooden elements. Visualizing the possible polychrome appearance of rooms or features at the temple would have constituted a separate study and necessitated a great deal of conjecture. While such research is one potential future use of the model, this did not align with the general goals of the funded project, and thus a color reconstruction was attempted for just one room at the temple, and there only partially.

The most profound limitations on the project came in the area of technology. In the early stages of the project, real-time interaction with the high-resolution Karnak model used a homegrown 3-D flight simulator program that allowed project researchers at UCLA to experience the interior modeled space in a way that replicated human movement and provided a sense of scale, but this software was not robust enough to share with outside users. The Digital Karnak website therefore included video clips of the full model, model renderings, and a Google Earth version of the model to allow for user interaction. While successfully distributing content about Karnak to the public with the launch of the website in 2008, these solutions failed to give dynamic, user-controlled, experiential access to the high-resolution model.

Digital Karnak clearly met a need in the larger academic and public community interested in Egypt. Since the launch of the website, the resources have been used in university courses around the country. Images and video from the project were part of the *Cleopatra's Needle* exhibition at the Metropolitan Museum of Art (2013–14), the *Ägypten—Land der Unsterblichkeit* exhibition at the Reiss-Engelhorn Museum in Mannheim, Germany (2014–15), and a display at the Harvard Semitic Museum (2015). The "Temple Development" video posted to UCLA's YouTube channel has been viewed (as of July 2017) more than forty-five thousand times. Although the model was originally designed for such educational purposes, it has also proved valuable for Egyptology research. Scholarship published by the project team has utilized the original model (included in argumentation as 2-D still-image renderings) to explore questions of cultural memory and monumentality in Egypt as well as the size and movement of portable barks for festival processions connecting Karnak to other Theban ritual zones.[12]

Challenges for Peer Review and Publication of Interactive 3-D Content

Academic interest in 3-D computer modeling for research and pedagogy has kept pace with a proliferation of software programs designed to generate or capture three-dimensional form. Examples of research grounded in 3-D work—like the Digital Karnak project—can be found across a diverse range of disciplines, including anthropology, archaeology, art history, and architectural and urban studies.[13] The range of 3-D tools available to address the research questions explored by these scholars is equally broad, and the technological choices made for any individual project are ideally driven by the research objectives and the intended end use of the resultant 3-D content. Historians exploring reconstruction alternatives for long-lost buildings or cities are likely to use software developed for manual modeling (e.g., 3ds Max, SketchUp, Creator, Vectorworks), archaeologists interested in documenting their excavations and artifacts or publishing their field data have embraced laser scanning and photogrammetric techniques for capturing 3-D form, and academics focused on ephemeral events or social interaction can turn to online virtual worlds and gaming engines.[14]

Despite this growing interest, peer review and publication of 3-D work has been limited. It is commonplace for static 2-D images generated from computer models to be used in publications (or on websites) to bolster academic arguments or publicize digital projects, but the models themselves are typically inaccessible.[15] While such static images could be considered as factors contributing to the success of an academic piece, they themselves have not been peer-reviewed. An early effort to prove the "scholarly meat" inherent in academic 3-D projects was the Digital Roman Forum project, which combined imagery generated from a computer model with the source material that informed the reconstruction.[16] But while this project and other online resources have been the subjects of reviews in academic journals, they have not been peer-reviewed in the strictest sense.[17]

To date, true peer review of 3-D content happens only within the context of textual academic publications. *JSAH* formerly accepted 3-D content for its online edition; the submitted models were displayed in a browser through Google Earth and were treated as illustration for written text. The first test of this feature was Diane Favro and Christopher Johanson's article "Death in Motion: Funeral Processions in the Roman Forum," published in 2010.[18] Similarly, Elsevier has developed viewers for 3-D content that supplement textual articles submitted to the publisher's various online journals, including *Digital Applications in Archaeology and Cultural Heritage*.[19] Again, the focus of the peer review is on the article text, with limited model interaction (e.g., simple zoom, rotate, and pan functions). At the monograph level, a number of recent projects show the potential for rich, 3-D-enabled publication. In 2016, a multi-institutional team working with the University of Michigan Press launched a hybrid archaeological publication about the Roman site of Gabii that includes interactive 3-D scenes of excavation trenches that link to field data and show stratigraphy and reconstructions.[20] Similarly, the Oplontis Project developed a navigable 3-D model that links to a database of archaeological information to complement a series of open-access publications distributed by ACLS Humanities E-Book.[21]

Acceptance of 3-D work as scholarship worthy of consideration in assessments for academic promotion requires peer review on par with the peer review of written work. This statement presumes that academe broadly defined is willing to accept 3-D content as a new (and viable) form of knowledge production. While fully addressing this issue is beyond the scope of this article, suffice it to say that the general movement of academic organizations toward developing guidelines for the review of digital scholarship and the growing number of research-based digital modeling projects suggest that this challenge will soon be overcome.[22] In January 2015, we convened a meeting to discuss peer review of 3-D content; participants included invited scholars, technologists, publishers, and representatives from granting agencies.[23] The agenda included a discussion of the peer-review process as it pertains to 3-D work, a blue-sky brainstorming session about the ideal peer-review environment for 3-D content, and a discussion of the documentation required for 3-D projects submitted for peer review. The assembled group articulated four key needs that must be met in order for 3-D scholarship to advance: (1) the need to create peer-review opportunities at the discipline-specific level, so that 3-D scholarship can become an integral part of academic knowledge production; (2) the need to establish a mechanism through which content creators can articulate the objectives and importance of their work for peer reviewers; (3) the need to establish a sustainable "home" for 3-D work to ensure long-term access; and (4) the need to define a workflow that connects the peer-review processes of discipline-specific journals and publishers with the university libraries and archives that will likely host academically generated 3-D content and the software required to interact with such content in its native format.

There are both technical and procedural challenges to applying the established peer-review process to 3-D content. The technical questions begin at the point of creation. At issue is how to package the computer model in a way that facilitates its peer review as a stand-alone piece of scholarship (as opposed to an illustration that augments a textual argument). This requires a mechanism through which the content creators can explain and defend their interpretive choices, create citations to source material, provide bibliographic and explanatory information, and articulate an academic argument within the modeled environment—in short, a mechanism that allows the substantive integration of scholarship into the 3-D space. It also requires a format for easily sharing models so that reviewers and users can experience the interactive content in its native format.

A second technical challenge is at the point of submission. Restricting scholars, as Elsevier does, to a limited suite of file formats belies the complexity of 3-D work. A possible alternative would be to uncouple the hosting and software process from the publishing houses to accommodate the breadth and depth of 3-D work. As Angel David Nieves, codirector of the Digital Humanities Initiative at Hamilton College, suggested at the January meeting referenced above, a consortium of academic libraries could serve as repositories for 3-D work, with connections to the journals and publishers overseeing the peer-review process. This approach would provide a mechanism for the stable delivery of content and free the journals and publishers from the responsibility of hosting multiple 3-D file formats and the software interfaces required to engage with them.

The procedural challenges of peer-reviewing 3-D content are more complex. With the submission of a 3-D project, an editor is faced with the difficulty of finding reviewers with both technical aptitude and content-area knowledge willing to engage with a new form of scholarship. There is also a question of what within the project could be changed based on reviewer comments (i.e., what can be changed if the ruling is "revise and resubmit," and what is impossible to change?). As we will describe below, the Digital Karnak package includes four components that could potentially be the subjects of reviewer comments: (1) the computer model itself, (2) the Digital Karnak website and its assets (videos, imagery, and documents), (3) the interface software (VSim), and (4) the academic arguments and interpretive information associated with the model. Of these, only the academic arguments and interpretive information could be easily modified in response to reviewer comments. The grant that funded the model and website has long been concluded, so major changes would be impossible, although small changes could be entertained. A new version of the interface software was under development at the time of peer review, and planned changes included those recommended by the reviewers, but that level of flexibility is atypical. Critical for the process is the establishment of such boundaries in instructions for reviewers.

VSim Interface

Development of the VSim interface made the Digital Karnak publication prototype and its peer review possible. VSim is an NEH-funded generalizable and extensible software interface for real-time exploration of highly detailed, three-dimensional computer models of historic urban environments.[24] It was designed to foster educational use of 3-D content, encourage broad dissemination of academically generated reconstruction models, and facilitate peer review, publication, and secondary use of 3-D content.[25] The software includes three key features: the ability to navigate through the modeled environment in real time; the ability to create linear narratives within the 3-D space, akin to a PowerPoint or Prezi presentation; and the ability to embed annotations and links to primary and secondary resources within the model.[26]

The Digital Karnak package was built using the proof-of-concept prototype of the VSim interface. As we will discuss below, development relied heavily on the narrative and embedded resource features of the software. The narrative feature includes three nested functions. From the Narrative Player level, a user can play a narrative provided with the computer model or begin constructing his or her own narrative. The Narrative Editor controls and displays thumbnails of the individual nodes that constitute the narrative. The Node Editor allows the content creator or user to augment these nodes, or keyframes, with text and imagery. As appropriate to their purpose, VSim narratives may be purely descriptive (e.g., formulated as a simple tour through the modeled environment) or may contain formal research arguments.

The embedded resource feature allows the content creator to create the in-world annotations that transform the computer model into an information-rich environment that can be peer-reviewed, broadly disseminated, and integrated into secondary scholarship.[27] Snyder has identified five layers of information required in-world to facilitate academic use of 3-D content: source material, introductory information for users, paradata, academic argumentation, and paratext.[28] Any information used by the content creator to inform the construction of the model would be considered source material, and the creator could share this information with the reviewer/user through annotations (e.g., bibliographic entries), visual materials (e.g., digital images or scans of architectural drawings), and links to library or web resources (e.g., articles, books, or visual materials available online). Introductory information provides the necessary context for the modeled environment. Paradata document the process of the creation of a computer model and, as Bentkowska-Kafel argues, must be fully integrated into computer-based visualizations of cultural heritage before they can be "recognized as a valid scholarly method for studying and presenting cultures of the past."[29] It is the academic argumentation that elevates the computer model to a site of knowledge production, whether comparing and analyzing reconstruction alternatives or articulating new theories about the use of the space represented by the virtual environment. The final layer of information one might want within a computer model is paratext, which could include comments, questions, and analysis from peer reviewers, editors, and secondary users.

The VSim design also includes features to protect the content creator's intellectual property. Logos and similar branding elements can be locked onto an overlay that displays on-screen throughout the simulation. Individual narratives and embedded resource files can be locked for distribution (unlocked files can be edited; locked files are effectively "read-only" copies). And model files can be assigned expiration dates to control the contents' distribution.

An Experiment to Develop a New Form of Publication with an Interactive Computer Model at Its Core

The creation of the Digital Karnak publication prototype was an iterative process that spanned two years. Below, we describe the methodology employed, the challenges faced, and the key decisions made. At the core of the publication is a real-time model (excerpted from the original high-resolution reconstruction model of Karnak) that depicts the changes made at the temple over the reigns of eight kings from 1523 to 1349 BCE. The textual material was calibrated for an academic audience, but introductory material about the temple was included to make the text accessible for undergraduates, so that it could easily be used in the classroom. Sullivan was responsible for the academic content; Snyder and Joy Guey, then a student in UCLA's Digital Humanities Program and now with UCLA's Center for Digital Humanities, managed the technical content and implementation issues. VSim's functionality dictated in broad strokes the ultimate form of the publication prototype, but there were still hundreds of decisions to be made as the project team worked through the process.

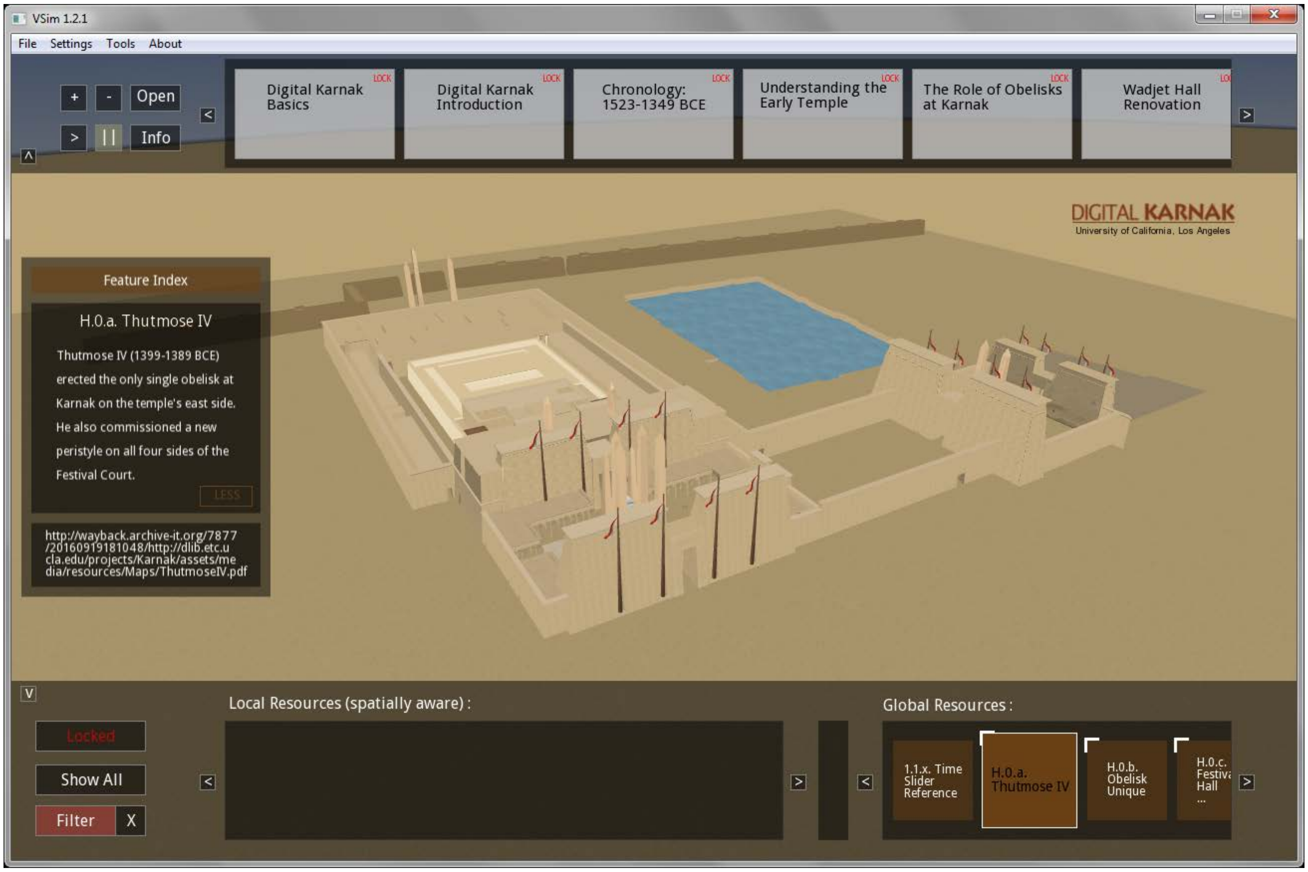

Figure 4 The narratives developed for the Digital Karnak publication prototype are accessed from the Narrative Player at the top of the VSim simulation window, shown in an early version of the interface (© Regents of the University of California).

Academic Argumentation

As a main feature of VSim, it was presumed from the start that the Karnak package would include a series of linear narratives, and the team agreed that it was important to identify academic arguments that would take full advantage of the transformative power of the 3-D model. (While the original Karnak model has been used for published research investigations, readers have never before been able to interact with and interrogate the 3-D space of the temple model.) Seven narratives, each focused on a specific research issue, were thus originally created for the publication prototype (Figure 4). Later condensed and reworked, the five resulting narratives focus on specific elements of the temple, relating individual constructions to the larger physical and historical context.

One broad narrative, "Chronology: 1523 to 1349 BCE," investigates the larger patterns of change across time at the temple, tracing modifications through eight royal reigns and showing the possible location of the Nile. In scale, the temple itself defies single-period study, its monumentality placing it outside the control of any one king as it expanded and changed in response to continually evolving religious and political trends.[30] The model allows the researcher to isolate and examine each major phase while firmly grounding the modifications within the larger architectural context. Indeed, to understand the impact of one building campaign, how a king's changes compare in scale or ambition to those of another, one must constantly refer back to the whole. That which previously existed (to be added onto or subtracted from) must be considered, as the standing temple structure shaped every change. As well, this narrative examines the alternating emphasis of the temple's axis over time—from west–east to north–south and back again—which appears to be a response to the gradual westward shift of the Nile and the opening up of new lands for development. While the desires of individual kings and the Karnak priesthood certainly influenced the forms and locations of additions to the temple, larger forces were also at play. Trends in construction at Karnak were therefore responses to long-term historic, religious, and environmental situations, and the resulting sequencing can best be understood and integrated through this macro-scale lens.

New digital 3-D formats also enable the scholar to drill down, isolating each specific moment in time, investigating

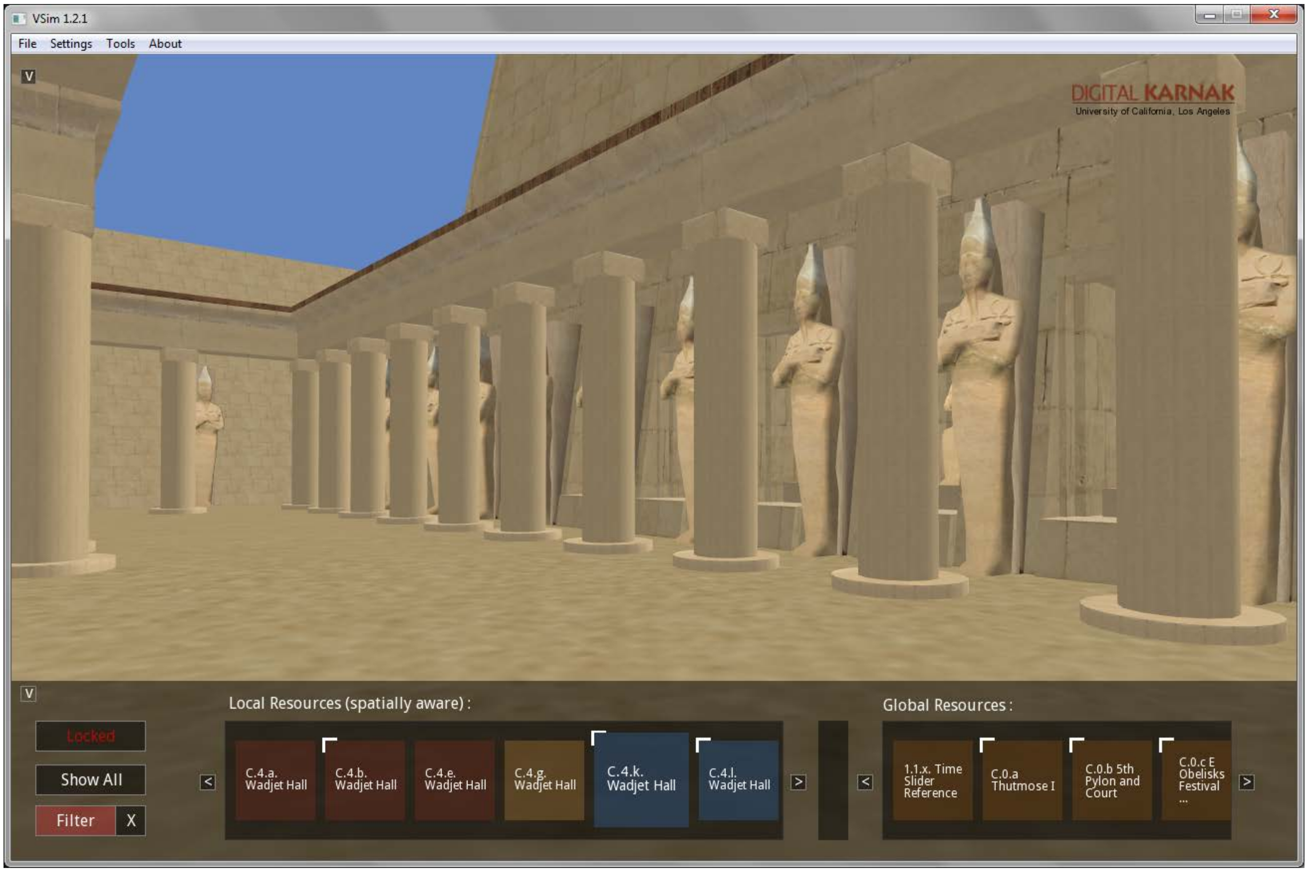

Figure 5 A visualization of the Wadjet Hall in the Digital Karnak model, shown in the interface prototype (© Regents of the University of California).

the parts that make up the whole in detail. VSim does not limit the user to "flying" over the Karnak model while considering the long-term development; it also allows for pedestrian-level movement, letting the user examine each feature as a single architectural and temporal unit. The bulk of the narrative arguments explore the temple thematically or within short time spans, utilizing this "close-reading" capability of the model. The narrative "Wadjet Hall Renovation," for example, centers on the reconstruction of a single space, the Wadjet Hall (Figure 5), which changed rapidly (through at least five architectural building phases) during the reigns of three successive kings over a span of only one hundred years. Understanding the dramatic transition of this hall from an open-air court to an enclosed monumental hypostyle is possible only through the use of 3-D modeling, as the ruined condition of the hall today offers the visitor no sense of the intense focus on this site. Visualization of these transformations, especially when contrasted with many of the other "stable" areas of the temple, highlights the special nature of this space and naturally leads to questions concerning the changing nature of ritual activity at this time. For example, the significant reduction in visibility, circulation, and standing space within the hall, as examined in the narrative, suggests that cult ceremonies taking place here could not have remained unaltered across such changes. Here the architectural record suggests ritual shifts that are not preserved in texts.

Detailed examinations of objects can also be uniquely situated within the larger temple context in the Karnak model. The narrative "The Role of the Obelisks at Karnak" looks at all these monuments reconstructed at the temple, discussing their collective function and impact (Figure 6). Here again the narrative investigates spatial and visual considerations of now-disappeared elements of the temple: From where (and to whom) were the monuments visible? What was their prominence? How did they relate to cultic structures already standing at the temple? As only two of the original fifteen obelisks that stood at Karnak's Amun temple remain upright on-site today, 3-D modeling offers new potential for researching the original influence of these monuments at the precinct.

While intensive photographic texturing was accomplished in only a few select zones of the model, it is these types of fine details that help trace the historical importance of individual structures at Karnak. The narrative focusing on core areas of the temple added by Hatshepsut and Thutmose III, "Royal

Figure 6 A visualization of the obelisks in the Digital Karnak model, shown in the interface prototype (© Regents of the University of California).

Legitimacy and the God Amun," incorporates details relating to the queen's proscription at the temple after her death. For example, the reliefs on (the female) king Hatshepsut's Red Chapel and rooms in the north section of her Palace of Ma'at offer testimony of her posthumous proscription at the temple and beyond due to her transgression of gender norms. Many of the titles and images of Hatshepsut portraying her as king were carefully erased during the reign of her stepson Thutmose III; the monuments were later disassembled and replaced. The narrative asks the viewer to consider the modifications of these two individuals at the temple as part of a larger story about the use of monuments in the negotiation over power and legitimacy by New Kingdom kings.

Graphic Design

The graphic look and feel of the publication prototype were tied as much as possible to the visuals already established for the Digital Karnak website. The VSim branding overlay feature was used to place a Digital Karnak logo in the upper right-hand corner of the simulation window, identifying the project as a product of the University of California, Los Angeles. Each of the narratives was assigned a color sampled from or complementary to the website graphics. The "Chronology" narrative, for example, uses the same color as the Digital Karnak logo, while the "Introduction" narrative uses teal. The colors were intended to help users differentiate among the narratives; on each narrative node, the assigned color was used for background screens for the major headings and "tombstone" identifiers, for minor heading text, and for labeled elements. Across all narratives, dark gray was used for the body text, and white was used for major heading text and the background screen for text elements. A narrow white border was added around all images for visual clarity against the computer model. Similarly, each of the embedded resource categories was assigned a unique color, either sampled from or complementary to the website. The Feature Index resources, for example, are dark brown, while Video resources are purple. These colors show as the background screens for the local and global resources and are intended to provide users with visual cues for the type of content available to them as they interact with the computer model.

The placement of the narrative text and graphic elements was largely driven by the VSim interface design. VSim

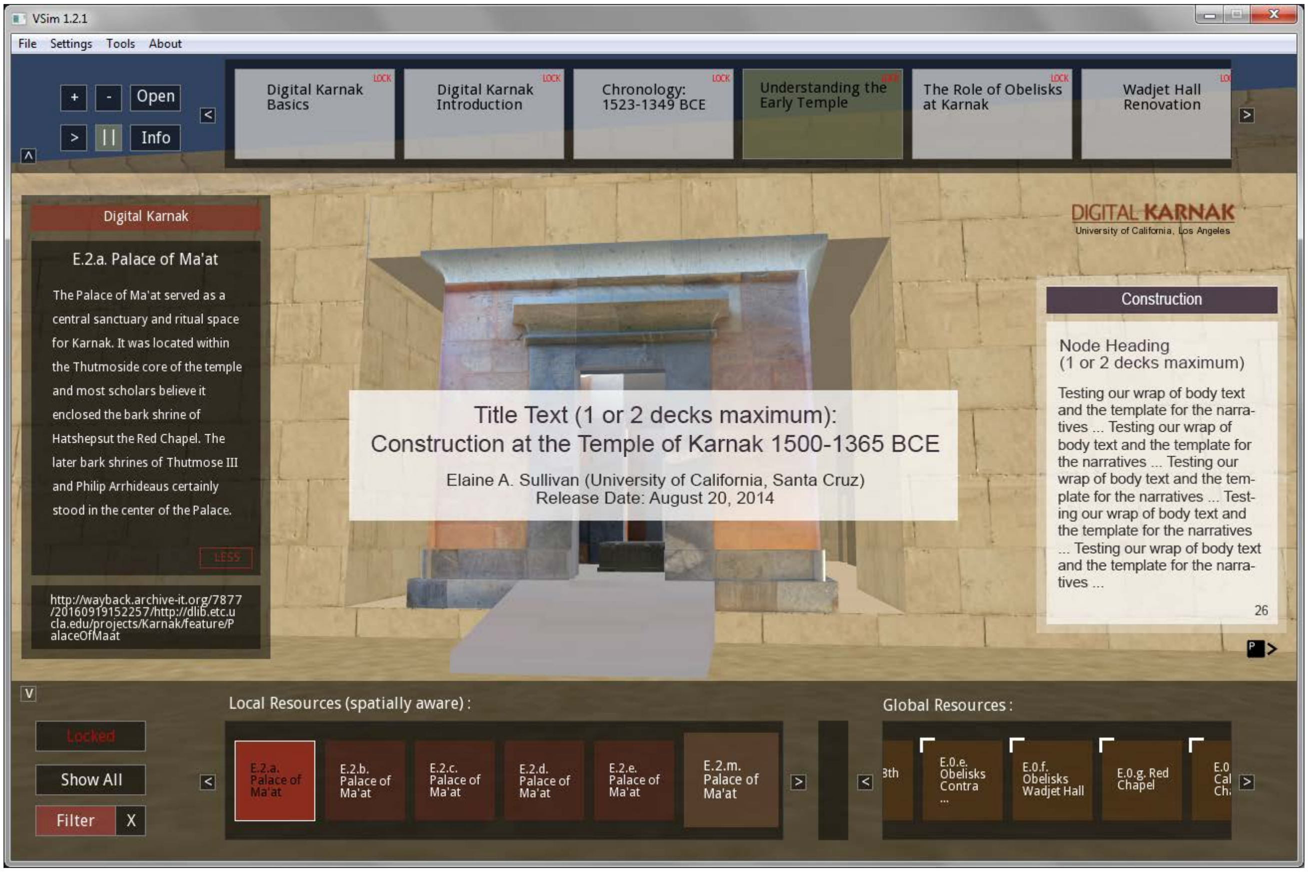

Figure 7 A "safe zone" for the overlay text and graphic elements in the Digital Karnak package was established at the center and right of the simulation window to avoid conflicts with the narrative and embedded resource bars of the interface prototype (© Regents of the University of California).

already includes collapsible bars across the top and bottom of the simulation window for the narrative and embedded resources, respectively, and the text portions of the embedded resources are positioned on the left side (Figure 7). A "safe zone" was established to avoid conflicts with these elements and was used to guide placement of the text and graphics associated with the narratives. The introductory text elements for each of the narratives were centered in the simulation window, narrative text blocks were positioned along the right side of the simulation window, and both labels and images were positioned as needed, but always within the safe zone. Graphically, the directions to the user to change the time slider were kept consistent across all narratives.

The size and proportion of the simulation window were locked for the publication package because the VSim prototype does not scale narrative node content when the simulation window is changed. While this decision prevents users from expanding the model to their full screen, it provided the project team with more control over the visuals and ensures adequate screen real estate for when embedded resources are launched.

Annotation, Paradata, and Primary and Secondary Resources

The development of the embedded resources was an iterative process, more so than any other element of the prototype publication. The finished package includes 639 individual resources, a combination of annotations and links to online content, primarily the Digital Karnak website (Figure 8). (The software also allows embedded resources to link to and launch a variety of multimedia formats, but only when those files are resident on a defined path on the computer running the simulation. By design, a VSim package intended for broad distribution is best limited to annotations and URLs.) Resources are broken into eight categories: Digital Karnak (content from the Digital Karnak website), Reconstruction (information about the construction of the computer model, including information about source materials used), Renderings (links to rendered single-frame images on the Digital Karnak website), Site Photos (links to images of modern-day Karnak), Web Resources (links to related content), Feature Index (annotations about each feature, organized by ruler), Bibliography, and Videos. Most of these resources are tagged as "local," which means they are spatially aware and made

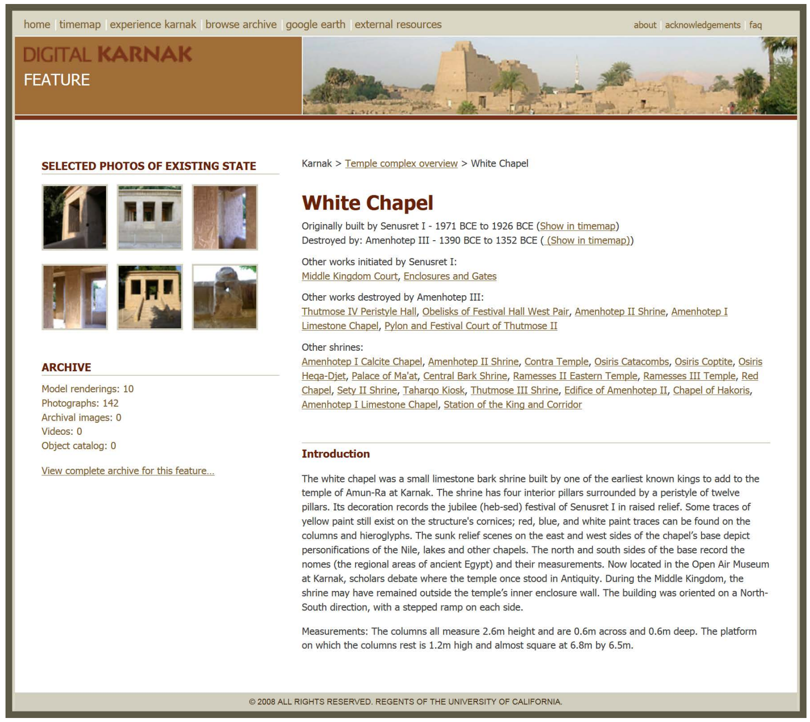

Figure 8 Many of the annotations embedded in the computer model include links to the Digital Karnak website (© Regents of the University of California).

available to the user depending on his or her position in the model and the time period being explored.

Midway through the development of the Karnak package, it became apparent that two critical changes to the VSim prototype were needed. In the original software, resources could be set to auto-launch as the user approached their anchors. This worked well for annotations, but it was problematic when links to web resources were triggered, because that action interrupted the user's navigation through the environment to launch a new browser window or tab. A third launch condition was added that launches only the resource's text description (thereby leaving the decision to the user to launch the associated URL or file). This allowed the project team to launch annotations selectively and deliver "just in time" information in response to the user's exploration. The second change to the embedded resource function was the introduction of a date range so that resources could be associated with specific time periods, allowing the team to further refine the information available to users. The addition of the date-range filter led directly to the creation of the Feature Index resources, a suite of resources tagged as "global" (i.e., always available to the user during interaction) that serve as tables of contents for the discussions of the architectural contributions of each ruler. Due to funding limitations, these software changes were made only to the Windows version of the VSim prototype.

User Interaction

Throughout the development process, the project team was mindful of how end users might interact with the virtual environment. Instructions for recommended interaction are included in the "Digital Karnak Basics" narrative: the user is told to begin by reading through each narrative, then explore the Feature Index, then click through the embedded resources, and finally explore the model through free-form navigation. In designing the narratives, the team decided to accommodate different reading speeds by requiring key presses from the user to advance through the nodes. A graphic legend is included at the beginning of each narrative, and instructions about changing the time slider were inserted as appropriate in the narratives (Figures 9 and 10). Graphic cues for users were developed: an icon of a red calendar page signals a time change, a black calendar page icon is a reminder of the date that should be displayed for each individual node, an icon of a *p* key reminds users to press *p* on the keyboard to continue, and an icon marked ER reminds them that additional information is available in the embedded resources.

The project team also had to develop a system for embedding the annotations and links to the Digital Karnak website resources in the Karnak model so that they would properly display to the user during free-form interaction. Behavior of the resources depends on four VSim settings: their anchor coordinates in the 3-D environment, trigger zone (the distance from the anchor point within which the resource will display to the user), launch condition (automatically launch when triggered, launch description only, or no action), and reposition condition (reposition on trigger or no action). For general placement, the team clustered resources with their

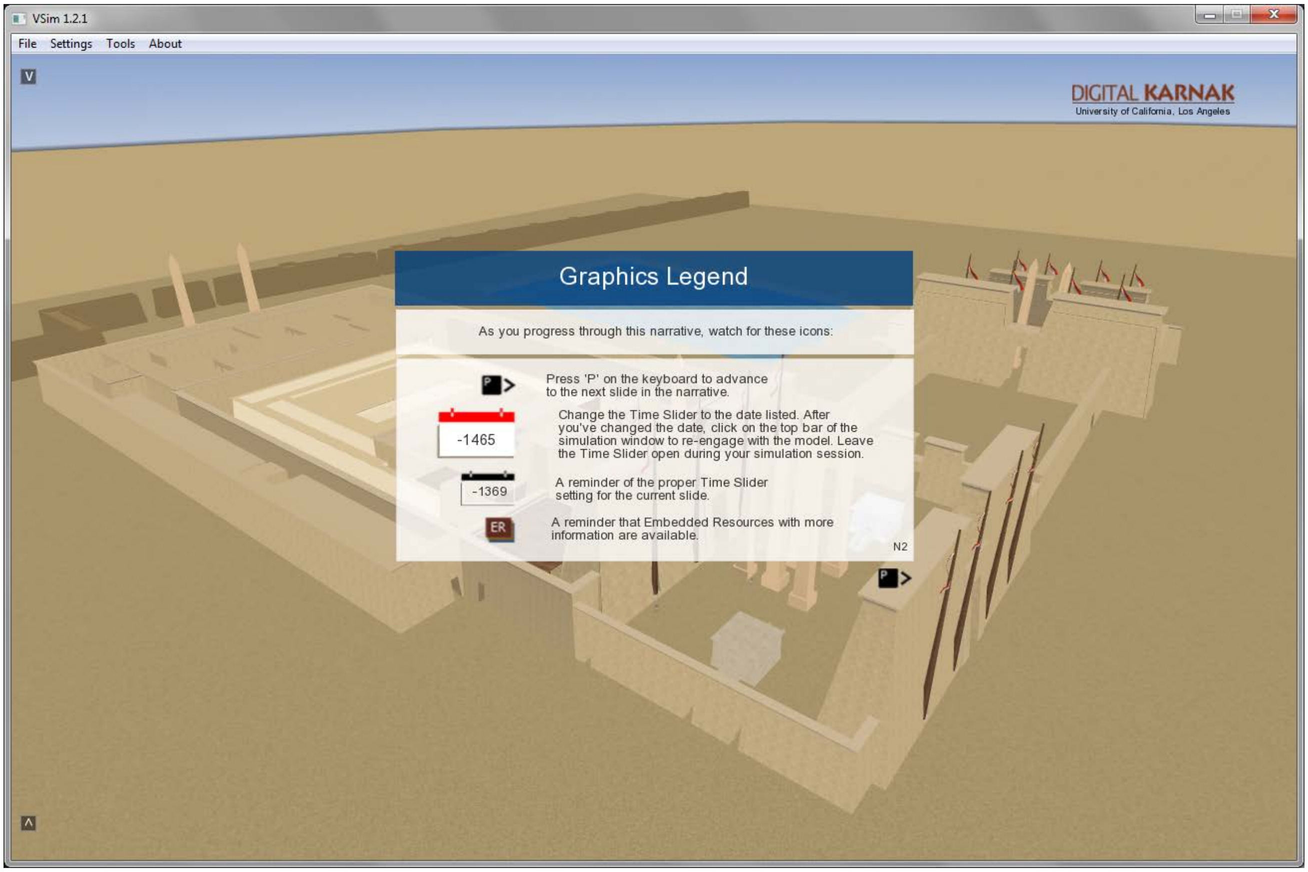

Figure 9 A graphic legend is included at the beginning of each of the narratives packaged in the Digital Karnak publication prototype (© Regents of the University of California).

anchors at the centers of the features (e.g., resources for a pylon are anchored in the central doorway of that pylon so that they will be displayed during typical movement through the temple). In dense areas of the model, resources had to be set with small trigger zones so they would not conflict with resources of nearby structures. Resources that provide view-dependent information were set to reposition the user on launch to a view that synchronized the information and the visuals. Finally, annotations that provide key descriptions about the features were set to auto-launch in order to provide information continually during the user's ground-level interactions with the model.

Citations

Critical for peer review and publication was defining a citation system for the model and its components. One could imagine a secondary scholar wanting to cite the publication prototype package generally, a specific place within the model during a specific time period, a narrative, a specific narrative node, textual or graphic information on a narrative node, the text associated with an embedded resource, or the linked content from an embedded resource. Accommodations for the first three are built into the VSim interface: information about the Digital Karnak package and model coordinates can be found under the "About" tab along the top of the simulation window, and authorship information about individual narratives can be accessed through a click on the "Info" button in the Narrative Player with a narrative selected. The individual nodes of each of the narratives were manually numbered for the publication prototype. For the embedded resources, a three-tiered alphanumeric system was developed to ensure that each resource had a unique identifier showing ruler or content area, feature associated with that ruler, and specific embedded resource. In the identifier for resource B.1.c., for example, the B refers to Amenhotep I, the 1 refers to the Calcite Chapel (the first feature associated with that ruler), and the c indicates that this is the third resource associated with that feature.

The resultant citation system flexibly accommodates a broad range of possible citations for 3-D content or academic argument and information embedded in a 3-D environment. A simple citation that references the Digital Karnak package might include only the following: model author(s), model title, media type, publisher, date of publication, DOI or URL, and date last accessed. But a more complex citation

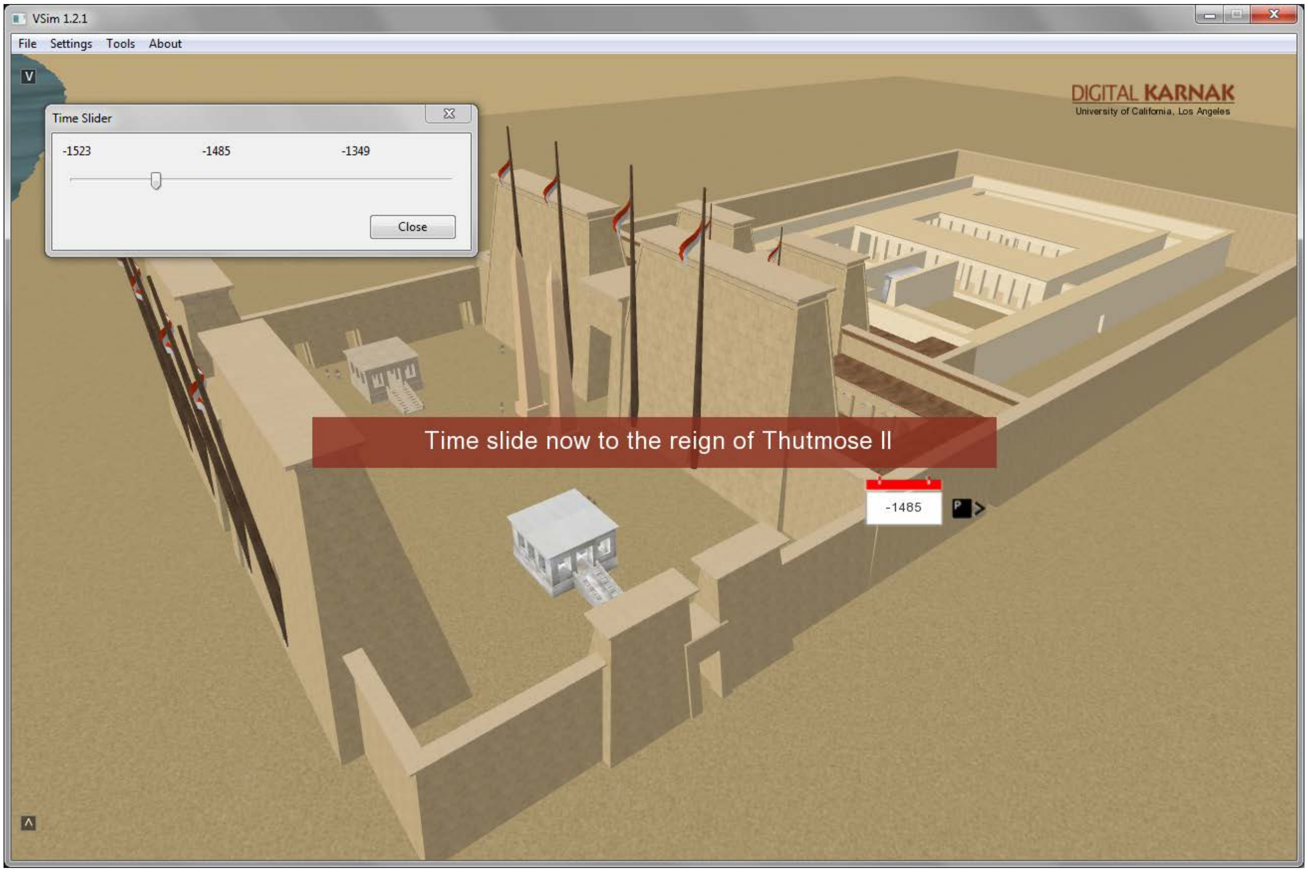

Figure 10 On-screen instructions to change the time slider help users navigate the temporal changes in the Digital Karnak model, shown in an early version of the interface (© Regents of the University of California).

that references a specific narrative or embedded resource within the Digital Karnak package is also possible: narrative author(s), narrative title, publisher, date of publication, model author(s), model title, media type, publisher, date of publication, model coordinates (if desired), node number (if desired), embedded resource identifier (if desired), DOI or URL, and date last accessed. This level of complexity within a single citation is in keeping with the guidelines laid out in the sixteenth edition of *The Chicago Manual of Style* for citing online multimedia and other nonprint items.[31]

Analysis and Future Work

An alpha version of the Digital Karnak publication prototype was posted online in November 2014 and presented in a workshop that month at the annual meeting of the American Schools of Oriental Research.[32] Feedback has subsequently been solicited from colleagues, students, and participants at the NEH-funded summer institute "Advanced Challenges in Theory and Practice in 3D Modeling of Culture Heritage Sites," held at the University of Massachusetts Amherst.[33] In addition, two Egyptologists offered a detailed critical review of the prototype. Provided with the model and user guides, they were left individually to interact with content for two hours. A one-hour follow-up evaluation session with Snyder and Sullivan (via Skype) took place immediately following their review.

Based on this user feedback, a number of changes were made to the alpha version of the publication prototype before the release was provided to *JSAH* peer reviewers; the original introductory narrative that described how to use the software and the package was renamed "Digital Karnak Basics"; an introductory overview narrative was added to provide those outside the field of Egyptology with basic contextual information about the temple complex; the thematic narratives were condensed and rewritten with stronger academic argumentation; diachronic maps for each time period, intended to help users situate themselves within the model, were developed, uploaded to the website, and linked to the primary node of each Feature Index (Figure 11); the date-range convention for the embedded resources was changed from a reign-based system to one aligned with the dates used on the time slider; and two user guide documents were developed (a four-page document and cheat sheet).

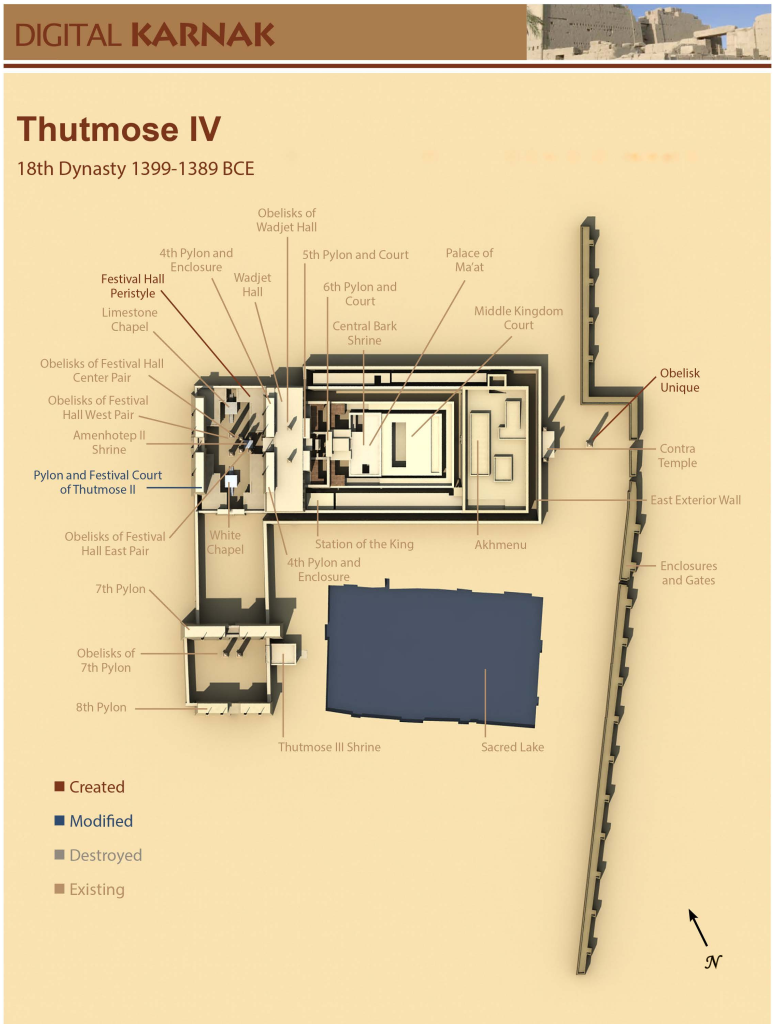

Figure 11 Links to maps for each of the phases represented in the Digital Karnak model were added to the publication package following initial user testing (© Regents of the University of California).

Software Changes

Creation of the publication prototype brought to light a number of changes that should be considered for the production-level version of the software. One general change would be the addition of scroll bars to make it easier for users to move through the narratives and embedded resources, and to accommodate long passages of text in the text boxes. Two changes to the narrative function would be helpful: more sophisticated transitions and better camera control. In the VSim prototype, control is limited to the amount of time a node is displayed or spent moving from one node to the next, there is a fixed shift in acceleration before and after each node, overlay text and imagery appear only while the node is displayed, and the movement from one node to the next is a basic linear translation between keyframe coordinates. Desirable enhancements would include settings that allow content creators to adjust the display of the overlay information relative to the keyframe (e.g., text might appear during the approach to the node), control acceleration, animate overlay information, and program sophisticated routes through the virtual environment.

Three of the desired changes to the software involve the embedded resources function. The prototype software locks all narratives and embedded resources when they are packaged with a model. With this "read-only" version of the model, users can interact with the environment and develop their own narratives, but they cannot add to the embedded resources. While this effectively protects the content creator's intellectual property, it also means that reviewers and secondary users have no in-world mechanism to embed paratextual information. The solution would be to lock only the categories or the individual resources established by the content creator, so that reviewers and secondary scholars would be free to create their own resource categories for in-world comments and annotations. A second critical change would be to accommodate separate coordinates for resource anchors and triggers (the software currently uses one coordinate for both functions). Separating these settings would allow pedestrian-level triggers for resources that auto-reposition to aerial views. (In the Digital Karnak package, there are a number of resources that reposition the user and compare beautiful renderings with the same views in the real-time model. These are difficult for users to access because their single anchor/trigger coordinate is in the sky above the temple.) An extension of this modification would allow for multiple triggers for the same resource. A third change would be to introduce a user-friendly mechanism for managing the sheer number of resources required to create an information-rich virtual environment.

Future Work

The Digital Karnak publication prototype has been made freely available to scholars, educators, and the lay public. The project team will actively promote use of the package for secondary scholarship and encourage other researchers and educators to engage with the model, use it in classes, and create their own narratives for sharing with others. Feedback from users will be incorporated into subsequent releases of the package. A summative evaluation of the process—from conception to publication—will be developed into an article to share lessons learned. The team members will also work to establish communities of scholars within their disciplines to address the outstanding challenges related to 3-D work, with a specific focus on peer review, publication, and acceptance of this new form of knowledge production in tenure and promotion cases.

Development on VSim continues with NEH funding (HK-50164-14). Some of the interface changes suggested by the Digital Karnak project team have been incorporated into planned modifications to the software. While the choice to begin testing the software with a multiphase model increased the complexity of peer review, it also pushed the limits of the software and uncovered conceptual challenges that might not have been revealed with a simpler test case. At the time of this writing, three new project teams have begun using VSim as a publication platform for their 3-D content, and the expected feedback from these users will be folded into the ongoing development of the software. The VSim team is also actively soliciting the participation of educators interested in exploring educational applications for the software. In addition to work on the software, the VSim grant has funded the construction of a 3-D project repository and archive under UCLA's Digital Library Program. This repository is intended as a clearinghouse for academically generated 3-D content and is positioned to be a long-term hosting solution for the publication of 3-D scholarship.

Conclusion

In this article we have proposed a reconceptualization of 3-D reconstruction modeling as a new form of knowledge production. We have argued that the visual and spatial expression of historic data allows for entirely new means of investigating the past. Such models are not neutral, unambiguous representations of the past; rather, they constitute complex arguments about the intersections of space, human action, and meaning. They explore specific questions based on the goals and limitations of each project. Thus they should be evaluated as scholarly products, with the explicit aims of each project, and the integration of those aims with technological choices, considered in the review.

The Karnak package clearly demonstrates the usefulness of interaction for communicating research problems that focus on contextualizing historic materials within time and space. We submitted the publication prototype for peer review to demonstrate the scholarly potential of such new, fully digital and dynamic forms of publication. By presenting the model in the VSim platform, which allows for full in-world annotation, we have shown how the link between the source material and the model can be made clear. The richness of the prototype, with linear narratives, annotation and citation, and 360-degree movement in full-color, 3-D space, offers a means to create visual and spatial argumentation not possible in other publication formats.

The prototype and this article also constitute an example of how the publication process can be adapted for 3-D content. The VSim interface offers a framework for the publication of computer reconstruction models and a possible solution for problems with 3-D content such as intellectual property control, annotation, and citation. Most important, the interface facilitates in-world annotations and links to provide information to the user about the environment and the interpretive decisions made during its construction, thus transforming the computer model into a stand-alone publication. We offer this test case to advance discussions about new forms of knowledge production and to push the boundaries of traditional publication, asking readers to engage with and critically evaluate a fully digital product in its native environment. We do this expressly with the hope of providing a starting point for a discussion on how 3-D content can be annotated, evaluated, and published as a stand-alone research object. Our goal here is to offer content creators and journals one possible method for integrating 3-D materials more fully into the mainstream scholarly dialogue in the fields of history, art and architectural history, and studies of visual art and culture.

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Lisa M. Snyder is director of campus research initiatives for UCLA's Office of Information Technology and Institute for Digital Research and Education. She holds a PhD in architecture from UCLA, and her primary research is on educational applications for interactive computer models of historic urban environments. lms@ucla.edu

Notes

1. On "potential pasts," see Maurizio Forte, "Cyber-archaeology: Notes on the Simulation of the Past," *Virtual Archaeology Review* 2 (2011), 7–18.

2. For the 3-D model of the Roman Forum, see "Digital Roman Forum," Regents of the University of California, https://wayback.archive-it.org/7877/20160919161927/http://dlib.etc.ucla.edu/projects/Forum (accessed 14 July 2017).

3. For a list of the full project team credits, visit the "About" page of the Digital Karnak project website: "Digital Karnak," Regents of the University of California, https://wayback.archive-it.org/7877/20160919152116/http://dlib.etc.ucla.edu/projects/Karnak (accessed 14 July 2017).

4. Ibid.

5. Johanna Drucker, "Graphesis: Visual Knowledge Production and Representation," *Poetess Archive Journal* 2 (2010), 1, 17–19, 23–24, 33–38.

6. Ibid., 23.

7. Ibid., 33–34.

8. Diane Favro, "In the Eyes of the Beholder: Virtual Reality Re-creations and Academia," *Journal of Roman Archaeology*, supplementary ser., 61 (2006), 326–27; Christopher Johanson, "Visualizing History: Modeling in the Eternal City," *Visual Resources* 25 (2009), 410–11. The term *knowledge representation* originated in the field of artificial intelligence.

9. Drucker, "Graphesis," 38.

10. Robina E. Hetherington and John P. Scott, "Adding a Fourth Dimension to Three Dimensional Virtual Spaces," in *Proceedings Web3D 2004: 9th International Conference on 3D Web Technology* (New York: ACM Press, 2004), 163–72; Chiara Stefani, Livio De Luca, Philippe Véron, and Michel Florenzano, "Time Indeterminacy and Spatio-temporal Building Transformations: An Approach for Architectural Heritage Understanding," *International Journal on Interactive Design and Manufacturing* 4, no. 1 (Feb. 2010), 61–74.

11. Iwona Dudek and Jean-Yves Blaise, "Visualising Time with Multiple Granularities: A Generic Framework," in *Archaeology in the Digital Era: Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26–29 March 2012*, ed. Graeme Earl et al. (Amsterdam: Amsterdam University Press, 2013), 470.

12. Willeke Wendrich, "Visualizing the Dynamics of Monumentality," in *Approaching Monumentality in Archaeology*, ed. James Osborne (Albany: State University of New York Press, 2014), 409–30; Elaine A. Sullivan, "Visualising the Size and Movement of the Portable Festival Barks at Karnak Temple," *British Museum Studies in Ancient Egypt and Sudan* 19 (2012), 1–37, https://www.britishmuseum.org/PDF/Sullivan.pdf (accessed 19 July 2017).

13. Anna Bentkowska-Kafel, comp. and ed., "3DVisA Index of 3D Projects," 3D Visualisation in the Arts Network, http://3dvisa.cch.kcl.ac.uk/projectlist.html (accessed 29 June 2017).

14. For examples of the work of archaeologists, see the past proceedings of the meetings of Computer Applications & Quantitative Methods in Archaeology, available at http://caa-international.org (accessed 29 June 2017).

15. A case in point is the Villa Domitian reconstruction developed at the University of Cologne. The project website includes static images generated from the computer model. "Villa Domitian Reconstructions," University of Cologne, http://vis.uni-koeln.de/villadomitian.html?&L=1 (accessed 29 June 2017).

16. The model associated with the Digital Roman Forum project (principal investigators Bernard Frischer and Diane Favro) was under construction from 1997 to 2003. The Digital Roman Forum website was released in 2005. See note 2 above.

17. See, for example, Neal Spencer, "Review of Digital Karnak [Website]," *Internet Archaeology* 27 (Oct. 2009), http://dx.doi.org/10.11141/ia.27.6 (accessed 29 June 2017).

18. Diane Favro and Christopher Johanson, "Death in Motion: Funeral Processions in the Roman Forum," *JSAH* 69, no. 1 (Mar. 2010), 12–37, http://www.jstor.org/stable/10.1525/jsah.2010.69.1.12 (accessed 29 June 2017).

19. Elena Zudilova-Seinstra and Julien Jomier, "Bringing 3D Visualization to Online Research Articles: Various Journals on ScienceDirect Now Have Tools to View Scientific Models in 3D," Elsevier, press release, 12 Dec. 2013, https://www.elsevier.com/connect/bringing-3d-visualization-to-online-research-articles (accessed 27 Aug. 2015). Enrichments available to authors in 2017 included 3-D molecular, radiological, and neuroimaging data, as well as two general-purpose 3-D viewers utilized by publications related to archaeology.

20. Rachel Opitz, Marcello Mogetta, and Nicola Terrenato, eds., *A Mid-Republican House from Gabii* (Ann Arbor: University of Michigan Press, 2016), https://doi.org/10.3998/mpub.9231782 (accessed 18 July 2017).

21. "The Oplontis Project," University of Texas at Austin, http://www.oplontisproject.org (accessed 14 July 2017); "ACLS Humanities E-Book," American Council of Learned Societies, http://www.humanitiesebook.org/default.html (accessed 14 July 2017).

22. See, for example, the Modern Language Association's "Guidelines for Evaluating Work in Digital Humanities and Digital Media," revised 2012, https://www.mla.org/About-Us/Governance/Committees/Committee-Listings/Professional-Issues/Committee-on-Information-Technology/Guidelines-for-Evaluating-Work-in-Digital-Humanities-and-Digital-Media (accessed 28 June 2017); the American Historical Association's "Guidelines for the Professional Evaluation of Digital Scholarship by Historians," June 2015, http://historians.org/teaching-and-learning/digital-history-resources/evaluation-of-digital-scholarship-in-history/guidelines-for-the-evaluation-of-digital-scholarship-in-history (accessed 28 June 2017); and the College Art Association's "Standards and Guidelines," http://www.collegeart.org/standards-and-guidelines/guidelines (accessed 28 June 2017).

23. The meeting was hosted by UCLA's Institute for Digital Research and Education and held in the IDRE Visualization Portal on 31 January 2015.

24. The prototype was funded by an NEH Start-Up Grant, and development of the software and the construction of an online project repository/archive for 3-D content continues under an NEH Digital Humanities Implementation Grant.

25. Lisa M. Snyder, "The Design and Use of Experiential Instructional Technology for the Teaching of Architectural History in American Undergraduate Architecture Programs" (PhD diss., University of California, Los Angeles, 2003).

26. The term *real time* refers to the generation of the graphic frames needed to simulate movement. With an interactive model, those graphic frames are generated in real time in response to the user's actions (as opposed to a prerendered animation sequence). VSim supports three types of interactions: WASD (a gaming convention where movement is controlled with the

W, *A*, *S*, and *D* keys on the keyboard), flight simulation mode (referenced on-screen as USim navigation), and object rotation (similar to the movement used with Google Earth).

27. Doug Bowman and others have used the term *information-rich* to describe virtual environments augmented with related abstract information. See Doug A. Bowman, Chris North, Jian Chen, Nicholas F. Polys, Pardha S. Pyla, and Umur Yilmaz, "Information-Rich Virtual Environments: Theory, Tools, and Research Agenda," in *VRST '03: Proceedings of the 10th ACM Symposium on Virtual Reality Software and Technology* (New York: ACM Press, 2003), 81–90.

28. Lisa M. Snyder, "VSim: Scholarly Annotations in Real-Time 3D Environments," in *DH-CASE II: Proceedings of the 2nd International Workshop, September 16, 2014, Fort Collins, Colorado* (New York: ACM Press, 2014), http://dx.doi.org/10.1145/2657480.2657483 (accessed 18 July 2017).

29. Anna Bentkowska-Kafel, "Processual *Scholia*: The Importance of Paradata in Heritage Visualization," in *Paradata and Transparency in Virtual Heritage*, ed. Anna Bentkowska-Kafel, Hugh Denard, and Drew Baker (Farnham, England: Ashgate, 2012), 245.

30. Wendrich, "Visualizing the Dynamics of Monumentality."

31. See "Documentation I: Notes and Bibliography," in *The Chicago Manual of Style*, 16th ed. (Chicago: University of Chicago Press, 2010), sec. 14, 14.279 and 14.280.

32. Lisa M. Snyder and Elaine Sullivan, "Digital Karnak and VSim: Real-Time Exploration of 3D Models for Ancient Sites" (workshop presented at the annual meeting of the American Schools of Oriental Research, San Diego, Calif., Nov. 2014).

33. Alyson Gill and Lisa M. Snyder, "Advanced Challenges in Theory and Practice in 3D Modeling of Cultural Heritage Sites" (institute held at University of Massachusetts Amherst, 2015, and UCLA, 2016), http://advancedchallenges.com (accessed 29 June 2017).