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The Virtual Site Museum: A Multi-Purpose, Authoritative, and Functional Virtual Heritage Resource

Abstract

The Virtual Site Museum is an interactive virtual reality interface for various purposes including archaeological research, education, and public demonstration. Its virtual environment contains precise, authoritative, and integrated archaeological and historical files culled from published and unpublished excavation records and the various art museums, which preserve artifacts from the real archaeological site. Running in real-time, it provides full-body immersion, 3D ancient figure animation, and a virtual artifacts interface and corresponding user-oriented interactions in a functional virtual environment. The first of the sites to be documented in the Virtual Site Museum was the Northwest Palace of King Ashurnasirpal II (883–859 BC), located in northeastern Iraq, a famous Assyrian world heritage archaeological site. In this paper we describe how we applied Virtual Reality (VR) to a cultural heritage in peril, and how we are adapting previously generated PC versions to UNIX platforms. We also explain our experiences and achievements in archaeological research and classroom accessibility.

1 Introduction

1.1 Archaeological Background

The ancient Mesopotamian city of Nimrud is situated east of the Tigris River and north of that river's intersection with the Greater Zab River. The most visible remains at the site are on the late Assyrian citadel, planned and constructed with a palace and temples during the reign of King Ashurnasirpal II (883–859 BC) (Oates & Oates, 2002; Mallowan, 1966; Paley, 1975). Today there are rolling farmlands, partly in the flood plain and partly east of it (Figure 1).

When the Tigris is within its banks, the land is fed by rain and canal water. There are ancient roads across the landscape from the east toward Nimrud and the Tigris River (M. Altaweel, personal communications, winter and spring 2003). Austen Henry Layard and Hormuzd Rassam originally excavated Nimrud in the middle of the nineteenth century AD; and, especially from 1949 until 1991, Nimrud continued to be researched by the British, Poles, Italians, and Iraqis (Oates & Oates, 2002; Reade, 2002). Even in the present heritage crisis (VHN, 2003), the site remains one of the most important of several thousands of sites in northern Iraq.

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Figure 1. *The site of the Northwest Palace and its location on the citadel of Nimrud. Photo courtesy of M. Altaweel, digital version by Learning Sites, Inc.*

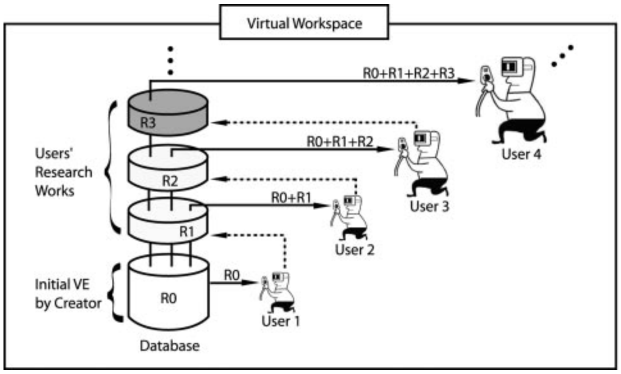


Figure 2. *The advantage of cumulative work in a virtual environment.*

1.2 Dire Needs for Virtual Reconstruction

Because of the political situation in Iraq today, it is impossible to maintain—both police and conserve—all the archaeological sites in Iraq sufficiently well to preserve very many of them. The site of the Nimrud citadel is in dire need of conservation—both the excavated sun dried mud brick and the alabaster bas-relief decorations on the walls of the palace and temple buildings. There have been two recent looter raids at Nimrud, one in April and the other in May of 2003, in which at least two fragments of bas-relief were stolen. There are no fixed plans for conservation or restoration at the site. American soldiers and Iraqi guards have recently protected it. Because of the possibility that the present crisis will have no imminent resolution, we think that one of the main resources for the preservation of Nimrud for history will be a VR reconstruction with proper scholarly documentation available on the World Wide Web and in CD-ROM or DVD versions. Iraqi permission for this plan has been in part made possible by the inclusion of the site of Nimrud on the World Monuments Watch's list of 100 most endangered world historical sites. We also have to think of the future of the site as a tourist attraction.

Therefore, an integrated VR model with appropriate documentation would be a useful tool both for scholars and the interested public, as well as support for claims for cultural heritage preservation and conservation. Developed for scholars, scientists, and students who want to carry out authoritative archaeological or historical research, the UB Virtual Site Museum takes advantage of virtual reality technology for the use of the archaeological research community. Of various virtual heritage applications today, the Virtual Site Museum is unique in that its virtual space is the venue where research and educational activities take place (Kim, 2001; Kim, Kesavadas, Paley, & Sanders, 2001). Its real-time, full-body immersion gives visitors the sense of presence in an ancient era. The reenactment and interaction with the Assyrian king provides an understanding of ancient society. It offers user-oriented interfaces so that a user can navigate the palace and activate prepared information. The user can also grab virtual artifacts and then put them in another location (Kim, Kesavadas, & Paley, 2003; Paley & Sanders, 2003). There are future plans to develop our concept of virtual workspace, to help users to further cumulative research by saving their work so that they can continue during their next visit (Figure 2).

1.3 Related Works

Many cultural heritage projects have developed virtual museums depending on their own concepts and policies. The primitive virtual museum of the early 1990s, almost exclusively of image displays, has evolved into new and different kinds of virtual museums as powerful and various digital technologies have evolved. Recent advanced virtual museums can be classified by evaluating their capabilities of interactivity, immersion, and real-time interfaces. A few examples of these VR Museums with descriptive technical notes are relevant to this discussion.

1.3.1 ViRtual Notre Dame. ViRtual Notre Dame (VRND, 2003) is a reconstruction of the Notre Dame Cathedral. This is a non-immersive, PC based network application using the internet. The realistic architecture, rendered by Epic Unreal engine, is normally used in creating video games (Burdea & Coiffet, 2003).

1.3.2 Jerusalem Temple Mount. The Jerusalem Temple Mount (Doyle, 2001; UST, 2001) was created as an interactive simulation of the Herodian Mount for the Jerusalem Archaeological Park. It is a real-time immersive fly-through visualization on an SGI Onyx2 IR3. The architectural design was created in solid modeling and the people in the simulation were authentically dressed static 2D figures from still photos provided courtesy of Archives & Collections, Universal Studios.

1.3.3 Shared Miletus. Shared Miletus is a reconstruction of the ancient city of Miletus (Pape et al., 2000). The archaeological site is no longer accessible; its ruins have sunken into a swamp near the Turkish coast. The main goal was to give remote visitors a full-body immersion at a shared virtual heritage site for exploration at their own pace using high-speed telecommunication. The international Grid (iGrid) was used for networking, and real-time interactions were accomplished in the CAVE with C++ and VR libraries, such as Performer (SGI, 2000), CAVELib (VRCO, 2003), CAVERNsoft, and Ygdrasil (EVL, 2003a, 2003b).

1.3.4 Gyeong-Ju VR Theater. The Gyeong-Ju VR Theater (Park, Ahn, Kwon, Kim, & Ko, 2003) is a real-time immersive theater for the replication of Korea's ancient city of Sorabol, the present city of Gyeong-Ju. This work is an artistic and storytelling tour for a large audience of 651 people in a theater. The audience experiences various human stimuli such as stereo view, 3D sound, and fragrance, with simple multi-user interaction.

1.3.5 MetaMuseum. The MetaMuseum (Mase, Kadobayashi, & Nakatsu, 1996) focused more on the functions of the public museum. The project used a series of non-immersive wall-screens at individual viewing stations in the museum. Each viewing station had a terminal with access to the data base. A specialist could input new data via the project's network. A visitor could use a PDA as a site guide. The purpose of the project was to arrive at a capability in which there was easy creation and communication among experts (creators) and visitors. The system provided *knowledge exploration*, using related information about and among the actual artifacts from several museums (Kadobayashi & Mase, 1998).

1.3.6 Northwest Palace of Ashurnasirpal. Learning Sites, Inc. built the original digital model of the Northwest Palace of Ashurnasirpal (Learning Sites, 2003), as an authentic reconstruction of the archaeological site, with VRML (VRML, 1997), interaction, and animation. Easily disseminated by digital media such as CD, DVD, or internet, it runs on a PC platform with VRML viewers. This model of the palace was used as the basis for the Virtual Site Museum. From this base model, optimized 3D models were recreated for the real-time, high-end VR application described in this paper. Learning Sites built links in the model to access data (photos, drawings, and notes) that were used to create the VR model. We come back to this point below, in the following section.

2 Method

2.1 Historical and Archaeological Resources

Ashurnasirpal's palace is one of the best-preserved monuments on the site of Nimrud. There are over 150 years of various kinds of documentation just for this building alone. For explaining Assyrian architecture, there are few monuments that lend themselves to this level of scrutiny. Our resources are published and unpublished documents acquired from the actual site or

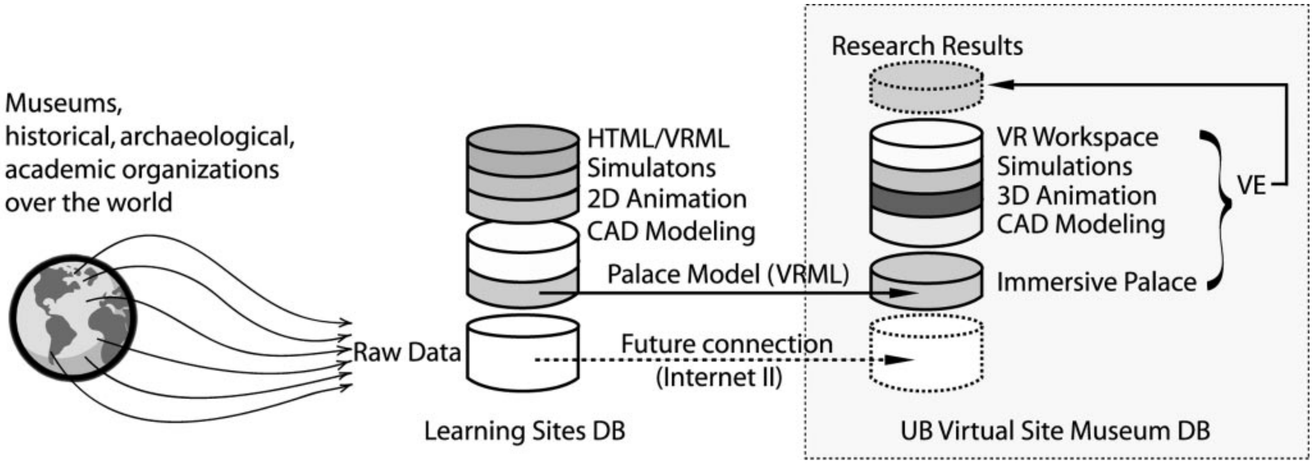


Figure 3. *Digital resources of the Virtual Site Museum.*

other historical, archaeological, and academic organizations over the world. Seventy institutions provided information for this project. Among them are The British Museum, the British School of Archaeology in Iraq, the Iraqi State Organization of Antiquities, the Polish Center of Mediterranean Archaeology, the Metropolitan Museum of Art in New York City, and the MIHO museum in Japan. The acquired data are processed into digital format and sorted by the characteristics of the data, such as text, images, and 3D data. From the resource database for the supercomputer model, various types of software were used for popular or specialized documentation and presentation means, such as HTML, VRML, C/C++ with Performer, and Ygdrasil. The digital resources of the Virtual Site Museum are shown in Figure 3. We work together with Learning Sites to obtain the data. The detailed work procedure and technical descriptions are addressed below both in this section and in Section 3.

2.2 Issues of Authority

Every kind of theoretical reconstruction of an archaeological monument requires careful consideration of the evidence. Comparative material has been drawn from other archaeological sites (Nineveh and Khorsabad and other buildings at Nimrud) where certain of the preserved finds supplement the knowledge we have of the Northwest Palace. For Nimrud's Northwest Palace, the preservation of ceiling and roof elements at Khorsabad is a good example. The information from that excavation can be used to understand the method of construction and materials used to "build" the roofs and ceilings at Nimrud. Also, examples of carefully considered argumentation can be found in many publications in the refereed journals we use as our resource data. (See the bibliography in and the context of Reade, 2002, for example, and the article by A. B. Snyder on the Learning Sites Northwest Palace web page: http://www.learningsites.com/Frame_layout01.htm.)

A virtual model is our way of testing hypotheses about Mesopotamian building practices and styles and methods of decoration. The experience "in" the model itself often justifies theoretical ideas about the virtual reconstruction of the building (the model), regarding the placement of an architectural element or an element of the wall design. If we are not satisfied with the results at any one stage in the virtual reconstruction of the building, we can go back to the data and change the model.

We can adopt digital technology to overcome spatial, temporal, and financial restrictions on testing a number of possible hypotheses. Adopting a new technology may also produce edutainment elements. For example, there is no way to make people understand the heaviness of an ancient king's garment in a graphic rendering unless we simulate the characteristics of fabric (Kim, 2001; Kim, Kesavadas, Paley, & Sanders, 2001; Kim et al., 2003). In our virtual environment we reenact the ancient king's movement in his throne room. The ancient king and his garment were carefully modeled based on historical evidence. In our virtual environment, human-figure animation and cloth simulation produced the natural motion of swishing heavy fabric when the king walks. By doing this we could achieve both a sense of presence and an understanding of the tailoring of the garment the king wore.

Besides presenting a hypothesis about an idea we have had in the course of the development of the virtual model, it was also important to give experts options to track back to the originals or to explore other hypotheses. Technically this can be done by adopting data mining technology into the real-time virtual environment. In our research, we have broken down the categories of information to include not only the VR models with the reasoning behind the model's structures, but also the history of the excavation and photographic documentation of the excavation, conservation, and the present state of preservation. Currently, the web page at Learning Sites, Inc. reflects these areas of study; the Virtual Site Museum illustrates ongoing research for the supercomputer as shown in Figure 3. Eventually, the supercomputer version will be available for distance learning across internet II (Snyder & Paley, 2001; Paley, in press; Paley & Sanders, 2003). Not only will users be able to experience the proposed hypotheses from the scholars' reasoned arguments, but they will also be able to try out their own hypotheses from the resources available in the networked data, which is one of the roles of the virtual workspace.

2.3 Directions on Virtual Environment Creation

Today's powerful hardware, advanced VR devices, and real-time display technologies make it possible to create attractive scenes in virtual spaces. However, based upon our development experiences as our project matures, the following suggestions are worth noting for other virtual heritage creators.

2.3.1 Content Creation. Rendering, animation, and simulation should have authoritative meaning for the application's users (Sanders, 2001). Modelers need to be directed by archaeological and/or historical specialists for an appropriate level of simplification. Programmers should recognize possible misleading information and confusion in the presentation. Meaning and authenticity is important especially for heritage education applications (Spencer, 1998).

2.3.2 User-Oriented Interface. Users often have difficulty accommodating to the virtual environment in many immersive applications. This happens mainly because device controls and action guides remain. A virtual environment needs to provide user-oriented interfaces instead of the conventional device-oriented interfaces for efficient and accurate knowledge transfer. This is especially true in the case of the Virtual Site Museum, which is visited frequently by individuals who are not initiated in the technology of VR.

2.4 The Integration of Digital Technologies

Virtual museums are venues for the presentation of archaeological documentation in a digital format. The flexibility of digital media leads archaeologists and engineers to develop new and innovative, human-friendly presentation methods using the relatively cheap computational power available today. Thus the preservation activity for physical and nonphysical cultural heritage can be considered as a digitization process ranging from data acquisition to information dissemination.

As digital resources, virtual heritage projects usually require large amounts of disk space and CPU memory. The geometry and texture databases are constantly being added to and modified by new archaeological documentation. The source codes are always being updated with better algorithms and more device interfaces. Thus data management affects overall project performance because heritage reconstruction is not a one-time pro-

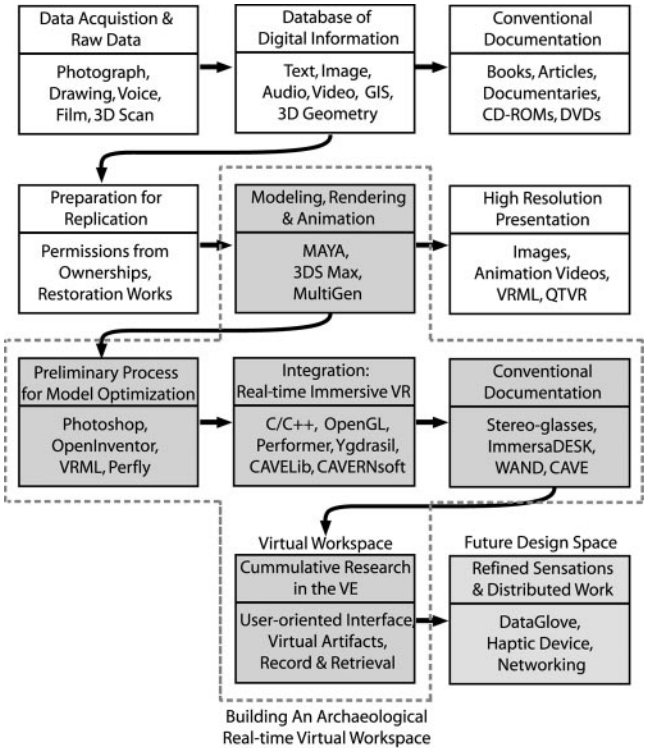


Figure 4. *The Virtual Site Museum's work flow for digital data.*

duction. More important, there always is data heterogeneity between modeling software and programming languages. Thus, data exchange has an important role in collaborative VR projects. When commercial conversion software is used, thorough testing is needed to avoid data loss from inappropriate combinations of export/import options.

We built the virtual environment using diverse software with extensive testing upon data conversion. Data exchange also encouraged the creators to bring the modeling software's various simulations into the VR so that the user could experience those simulations in the virtual environment. Diverse sources of documentation and various simulations have been imported into the virtual environment. (The documentation will be enhanced as further data is acquired.) Figure 4 shows the work flow of the digital data processing, including the software, data formats, and programming languages used for the Virtual Site Museum.

2.5 Functional and Productive VR

A virtual environment can be used not only for presentation and/or sensation, but also for production space. The routine of office or physical work can be fused with VR. For example, a user's voice and motion can be recorded and retrieved in the virtual environment (Laurel, Strickland, & Tow, 1994). Keeping these ideas in mind, we built the virtual environment not only as a presentation space, but also as a workplace. Thus users are viewers and workers as well. The Virtual Site Museum furnishes a workspace, functional objects, and corresponding interfaces. Users come into the completely immersive site of the ancient palace where there are touchable virtual objects or artifacts. The virtual objects have fundamental functions in them, such as creation, user controls, storage, and retrieval. Once created, the object is grabbable and it functions by commands created from user interactions.

The concept of design space is the expansion of this fundamental workspace. The virtual objects have more refined functions, such as data sorting, organizing, and simulating. Then the user can accomplish complicated design tasks with precise, reliable, and comfortable user interfaces. The design and implementation of workspace interfaces are discussed in Section 4.

3 Achieving Authentic Realism

The level of detail (LOD) has long been one of the critical issues in the virtual reality community. It affects the application's real-time run adversely, which is the key point that distinguishes interactive and functional VR applications from pregenerated animations. This means that a virtual environment should allow the user to perform any action in the designated space at will: a real-time application offers controls to the user in runtime while pregenerated animation gives only one or two choices. However, most real-time applications often result in less visual realism because developers struggle to save rendering computation time by reducing the time spent for visual display such as simplifying or making differing levels for 3D geometries and realistic lighting algorithms. The developer's desire for realism can easily push computational resources to the limit so that the sophisticated trade-off techniques between realism and performance are unavoidable, especially in the case of virtual heritage applications. The contributing parameters for real-time run, such as hardware, software, geometry models, and algorithms should be carefully considered and thoroughly tested for decisions about how to make the virtual environment most effective. In the following sections we describe the techniques for building highly elaborate scenes in the real-time virtual environment.

3.1 The Northwest Palace

As far as both authenticity and real-time run are concerned, three factors are necessary at the modeling stage: the modeler's full control of polygon generation, the programmer's reasonable setup for polygon count, and the scholar's directions for an authentic appearance. The modelers' desire for realism often results in large amounts of geometric data and it becomes a burden to performance. Before or during the modeling, a guide for the programmer concerning polygon creation is helpful. Then there should be directions for modeling from the archaeologists to avoid any loss of authenticity from too much simplification.

The Virtual Site Museum's solid modeling achieves authoritative realism with the elaboration of its elements (Kim, 2001). Archaeologists, modelers, and programmers contributed jointly to the realistic models and a correct presentation. For the palace model, the Northwest Palace was originally modeled for animations in discreet 3D Studio Max and later used for simulations (Learning Sites, 2003). For the supercomputer version of the VR, it was exported to a VRML97 format as a single structure and lighting effects were rendered on the texture images for the reduction of computational load (Kim et al., 2001). At the time of this stage of the VR development, the only available model was the single VRML97 file; thus it had to be imported into Maya Unlimited (Alias-Wavefront, 2003b) or 3D Studio Max (Discreet, 2003) for easy model division. It was broken into pieces and exported into Open Inventor (SGI, 2003) in ASCII format for debugging and refined division. In the case of the conversion for the large data set, either Creator (MultiGen, 2003) or PolyTrans (Okino, 2003) was used. Divided geometric pieces were manipulated by culling algorithms for performance acceleration. Finally model files were converted into a Performer-optimized geometric data format. These divisions decreased polygon counts; an optimization process reduced file sizes. These efforts later contributed to achieving a real-time run.

3.2 The Reenactment of an Ancient Figure

To extend the use of VR in education and public presentation for the supercomputer environment, we built a virtual space of the Assyrian era where historic characters go about their lives, while the observer either discreetly watches or perhaps interacts with the events of that period. This reenactment and activated action provide a sense of presence and understanding of the era.

The first figure developed was the king (Figure 5), which also provided us a chance to illustrate detailed garments and ornaments. The 3D model of the king was implemented using a mixed model of polygons and NURBS techniques with Maya Unlimited (Kim et al., 2001). Polygon modeling was implemented with a simple primitive geometry, which consists of a set of U-V vertices. Non-uniform relational B-spline (NURBS) surface modeling was applied for the parts that were covered by the garment because these parts were needed for collision with the cloth when draped and skinned over the body skeleton. All the ornaments, garments, and body were modeled based on the document images as interpreted by Paley.

To obtain the proportions for the king's body, the image of an ancient statue was used. The height was assumed to be 5′ 8″ (about 175 cm). The king appeared young in this representation, suggesting that it was carved during the early years of his reign. The initial posture of the model was made much like that of the statue image. The animation of the king started from this posture. The king's body skeleton was modeled as an assembly of joints or links that determines position

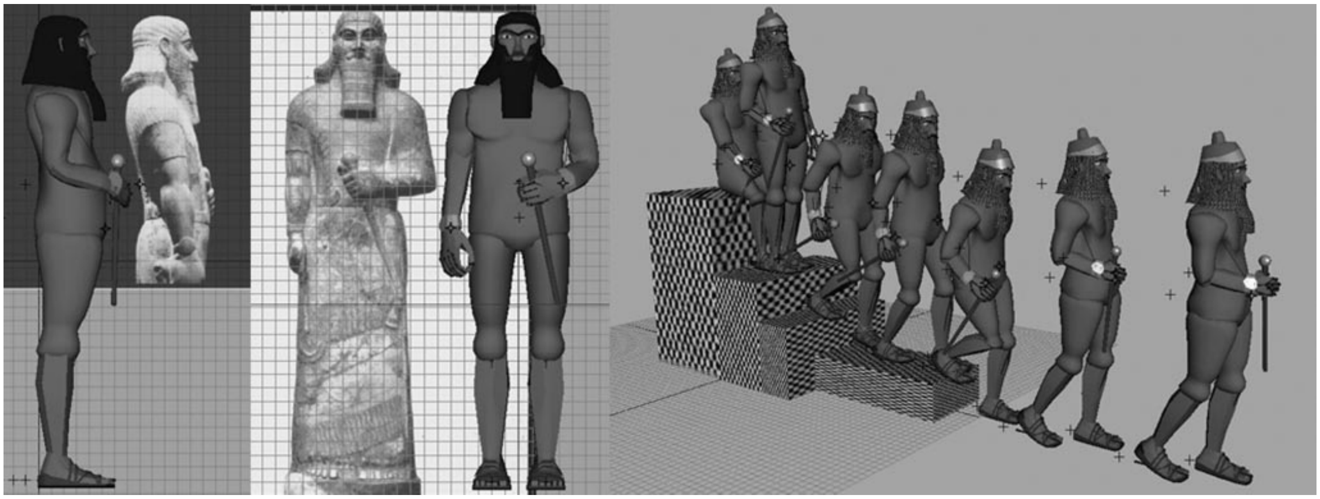


Figure 5. *Body proportion (left), skeleton-skin model (middle), and animation sequence (based upon an image of an ancient statue in the British Museum: see Strommenger, 1964, plate 196).*

and orientation with the next joints. An inverse kinematics (IK) technique was used for the king's motion control. The technique seeks a solution only between the root and the end-effectors instead of cumbersome, whole joint controls of forward kinematics (FK). The surface deformation of the king's body was implemented by skinning, which is the calculation process of deformation around the skeleton. Bound with the skeleton, the skin easily deformed based on the relative position or motion of the skeleton.

We also modeled and simulated the details of the king's garment using Maya Cloth (Alias-Wavefront, 2003a). The garment was prepared as a relatively simple shape to minimize the number of polygons for real-time application. The positioning of texture was important for the king's highly decorated garment. To accomplish accurate positions of its decoration, a mapping number chart was prepared, mapped to the garment, and draped to see the final position of each mapping number. Then the garment texture was mapped on the king's garment (Figure 6).

The animation sequence used a total of 126 frames including the walking cycle. The models of every frame were exported to the ASCII format of OpenInventor or VRML97 for later polygon editing, debugging, and attribute manipulations. After the polygon optimization processes, the interaction between user and king was finally programmed. A user can activate the narration and motion of the king in the throne room. The king stands up, steps down off the throne and then walks across the throne room. The user watches the king's garment swishing, its elaborate ornaments moving naturally, and listens to the king explaining the history of his reign.

3.3 Model Optimization

It is often said that there are at least three performance goals for real-time display: more frames per second, higher resolution and more realistic objects (Akenine-Möller & Haines, 2002). The first two goals can be achieved by setting a reasonable upper limit of human recognition (for example at 60 frames/sec and 1600 × 1200 pixels). However there is no real upper limit for realism or scene complexity, thus acceleration algorithms are always needed.

For any solid model, the easiest and most effective way for achieving real-time realism is polygon reduction. This simple rule should be kept even for a set of level-of-detail (LOD) models, because the polygon counts directly affect the application loading time and

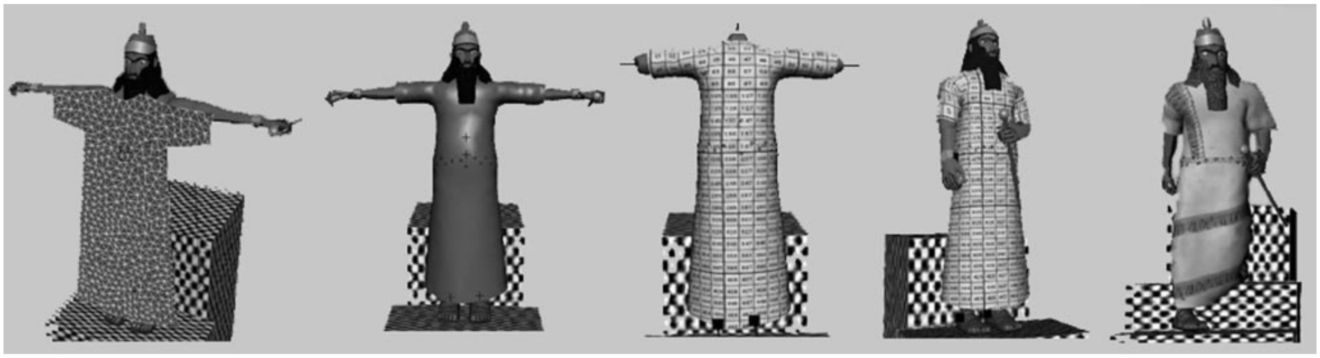


Figure 6. *The cloth simulation process: draping, positioning, and animation with cloth.*

smooth model switching. With this fact in mind, modelers can simply use commercial modeling software for realistic models in VR. For the further advanced features, however, one must take more into account, not only because of the refined surfaces but also because most software applications use their own data formats and algorithms. Eventually the special surfaces are exported as a large number of simple polygons. Especially for character animation and cloth simulation, NURBS surface modeling is widely used owing to its "nature of readiness" and effectiveness with fewer control points but smoother surfaces (Foley, van Dam, Feiner, & Hughes, 1995; Woo, Neider, Davis, & Shreiner, 1999). When the models are imported into the different application domains of VR, the fancy surfaces result in a large number of polygons. This situation has been an obstacle or a burden for high-bandwidth networks and especially for real-time VR applications.

In the Virtual Site Museum, the large number of surface polygons was effectively reduced by sophisticated modeling techniques, such as the partial use of NURBS surfaces, model simplifications, and polygon editing. In the modeling stage, NURBS surfaces were only used for collision detection of cloth simulations and then excluded in the conversion stage. All the overlapped surfaces were cut or excluded based on their appearance in the VR space. After the software's conversion process to a reasonable polygon number, manual polygon editing was quite useful for the king's face, largely reducing the number of polygons with little difference in appearance (Figure 7).

We took advantage also of software-specific, database formatting. After we applied all other polygon reduction and acceleration techniques, all the geometries were finally converted into a Performer-optimized geometric database (SGI, 2000). The geometric optimizations effectively reduced polygon count and file size (Figure 8).

In the programming stage, we used visibility culling (or view frustum culling) for performance acceleration. Rendering, collision detection, and related algorithms are all excluded for the models outside the view frustum. A portal culling (or "portaling") technique was also used. As an extension of view frustum culling, portal culling is often used for architectural model display because the walls can be rendered as large occluders in indoor scenes (Akenine-Möller & Haines, 2002). The model division was also implemented for the large data set models; divided model pieces were manipulated for the culling.

Rendering techniques were eventually integrated in order to build a realistic virtual environment (Figure 9). Chiu & Shirley (1994) classified elements of the realism into two categories: perceptual and visceral. The rendered display of the Virtual Site Museum included the elements of perceptual realism, such as spatial coherence, shadows, and level of detail. The elements of visceral realism (suspension of disbelief; Mantovani & Castelnuovo, 2003), such as complexity or interactivity, are discussed below in Section 4. Over the past three years we have made many public demonstrations and class sessions with the Virtual Site Museum. The visitors ranged from primary school students to experts in the

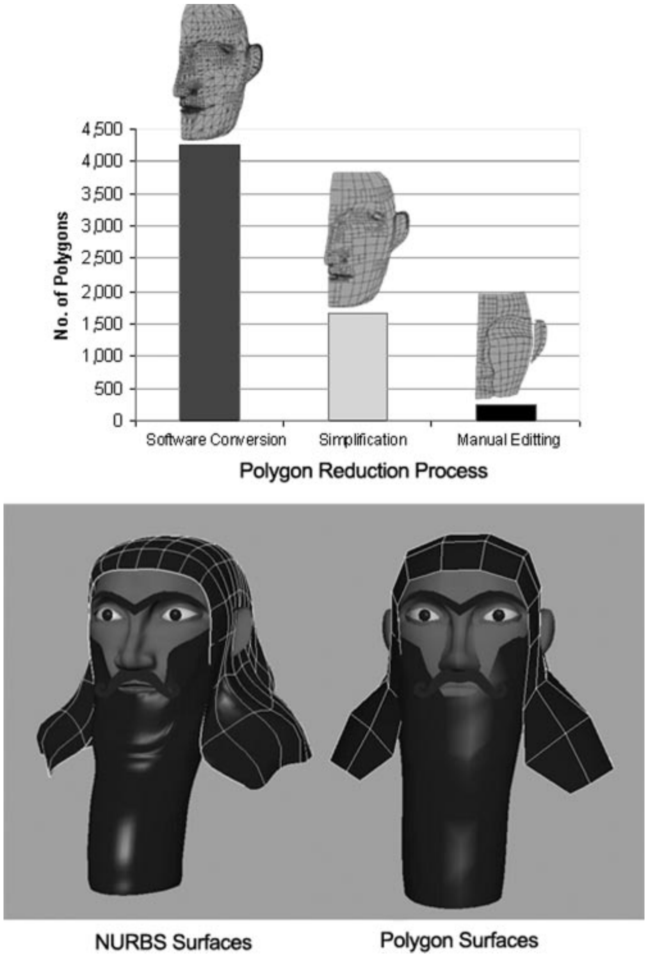


Figure 7. *The polygon reduction for half face (left), and the comparison of the original NURBS and simplified model (right).*

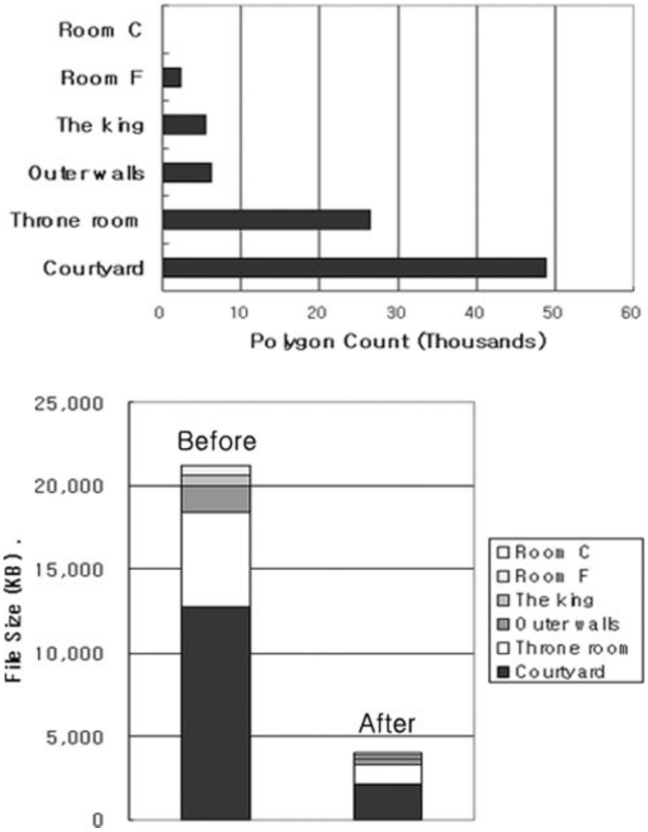


Figure 8. *The polygon count for each space (upper) and the file size reduction by optimized geometric data, excluding texture size (lower).*

field. The experts have agreed that the rendered scenes seamlessly transferred appropriate scale and highly elaborate details enough for an understanding of the era. The younger students went away with an appreciation of the size and complexity of the monument. The PC version has elicited a similar response, though the reactions are more intense on the supercomputer's larger screen. (See Section 4 below and the NHK film; NHK, 2004).

Overall runtime performance was tested, in frames per second, along with view angles while displaying the scenes inside the courtyard. The optimized model used in the current version of the virtual palace improved overall performance from an average of 4.7–36 frames/sec to an average of 16–48 frames/sec. The range of 30–210° is the "bottleneck" or "computationally highly loaded region" where elaborated lamassu (the sphinx-like door figures), bas-reliefs, and entrance geometries are present (Figure 10).

4 Presentation and Workspace Interface

The virtual environment of the Virtual Site Museum is a venue where presentations and workspace simulations take place. For presentations, we adopted narrative factors (Anstey & Pape, 2000) and created movie-like functions such as "fade-in & out introduction" and "dynamically angled navigation." We made a 10-minute

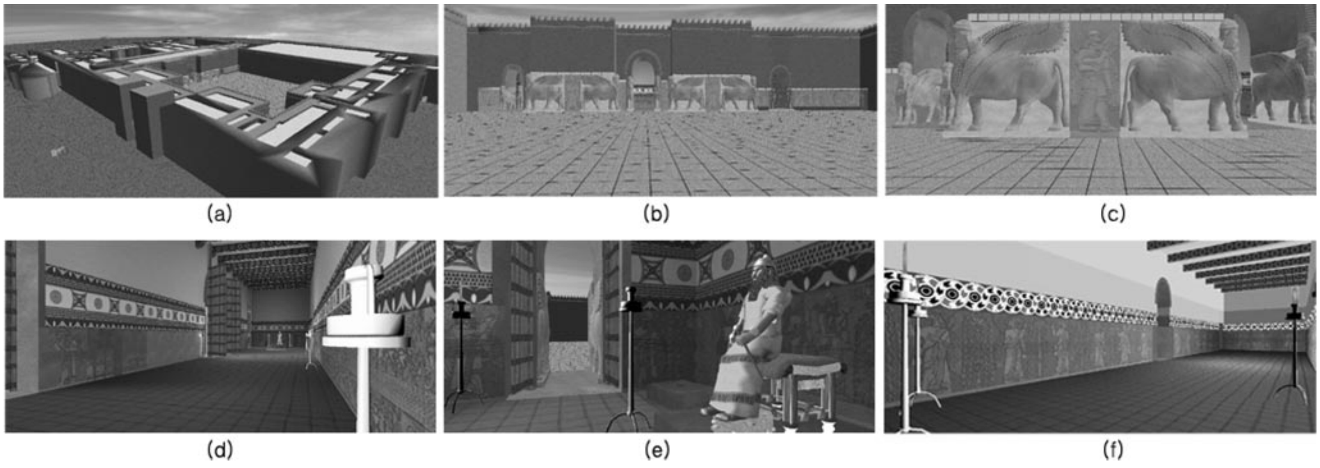
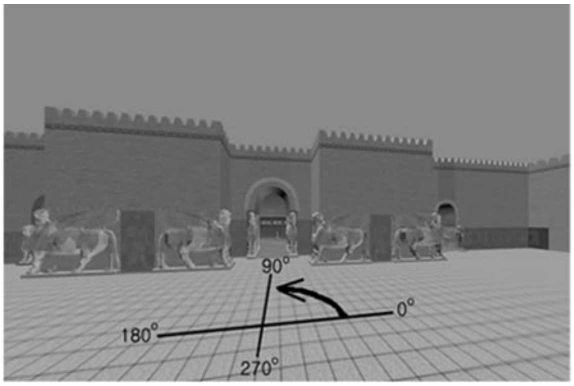


Figure 9. *Snapshots of the real-time rendering: (a) a view of the Northwest Palace, (b) the courtyard, (c) lamassu, (d) the throne room, (e) the king sitting on the throne, and (f) room "F."*

introductory tour for classroom use and public demonstration. The music and voice were produced by people from the Middle East to give the students the idea that they were in a foreign place, and the tour was shown either in a complete immersive view or in mono graphics, which was also useful for filming by third parties. After the tour, visitors took VR devices and walked around on their own and at their own pace. Based on a collision detection algorithm, the visitors can activate prepared interactions at designated spots. For example, the king's movement and voice were programmed to be activated by the visitors. As we discussed in Section 2, the interactions are designed to reflect our hypotheses, and to provide visitors with historical and archaeological background and evidence. The introductory tour and the actual VR experience provided an understanding of the architectural space in an Assyrian palace as well as the meaning of its bas-relief decoration. It also provoked interesting questions that an instructor (in the class situation) and an expert (in the demonstration situation) then answered.

The Virtual Site Museum also provides virtual workspace. A virtual environment is used as a workspace infrequently because there are many error-prone factors in both VR devices and human recognition. Most projection-based VR displays (Cruz-Neira, Sandin, & DeFanti, 1993)—the application CAVE-tracker, for example— have inherent display and calibration errors (Pape & Sandin, 2000). To overcome any adverse factors, we fashioned virtual artifacts and made corresponding user-oriented interfaces. The virtual artifacts have fundamental functions in them, such as grabbing, user controls, information storage, and retrieval (Figure 11). Because these virtual objects exist physically in the virtual environment, the users can take advantage of using a real world's physical experiences. Once activated by contact with user's virtual hand, the object is grabbable and can function by commands created from user interactions (Figure 12).

We implemented two types of tests to test handling of virtual artifacts in the virtual environment. The first test was a reassembling task with bas-relief fragments, since assembling artifact fragments is one of the fundamental archaeological tasks recently being studied using computer algorithms (Shape Lab, 2001). With a WAND (3D mouse), the user can pick up the fragments of a broken bas-relief and reassemble them so that the fragments make up a complete scene (Figure 13). The position and orientation of each piece was recorded and can be retrieved at the next visit by the same visitor or by the next visitor, who could change the position of the fragments to correct or improve the reconstructed



view angle in the courtyard

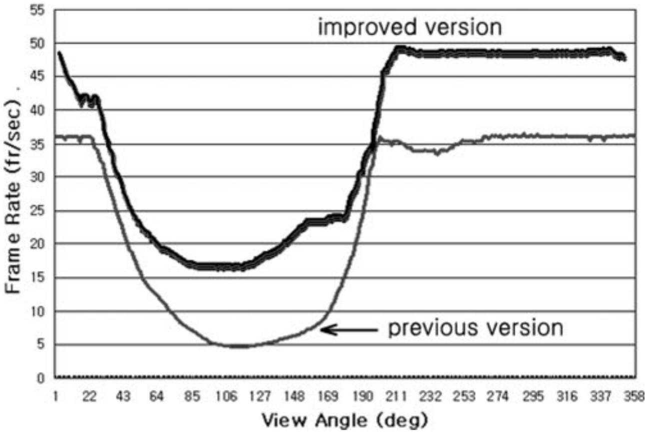


Figure 10. *The view angle in the courtyard (left) and the improvement of overall performance by model optimization and an acceleration algorithm (right).*

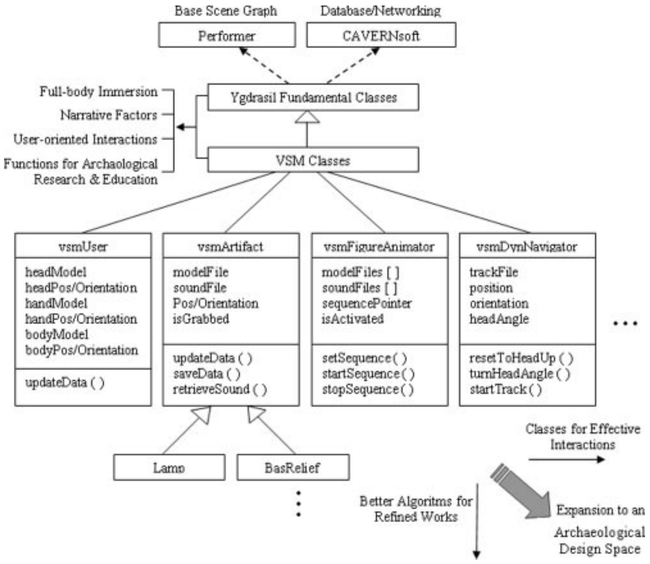


Figure 11. *The C/C++ class structure of the Virtual Site Museum.*

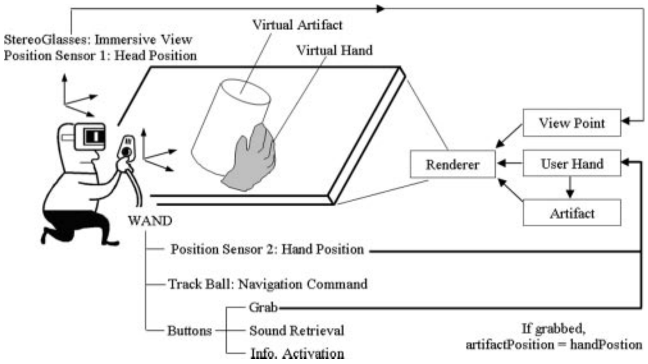


Figure 12. *A virtual artifact and its interface.*

scene. The second test was moving and placing a lamp on a lamp stand in the throne room.

Our tests showed satisfactory results at this stage of our project in the accuracy of the targeted position and the readiness of object manipulation in the virtual space. For the first test, the five bas-relief fragments could be easily picked up and put together in three minutes with less than a 0.33 inch (8.4 mm) crack between fragments. The second test took thirty seconds and showed more accuracy, with approximately a 0.25 inch (6.4 mm) distance between the bottom of the lamp and the top of the lamp stand. This can be reasoned by the simplicity of a task that has only two planar surfaces. These types of virtual activities can be made more accurate by using a spatial definition, such as a nonpenetrating polygon interface with collision detection, gravity, or more sensorial cues, such as a stone grinding sound (for the first test) or a metal clinking sound (for the second test). Eventually we will also add information cues, such as voice and motion data, for knowledge transfer from one user to the next.

The concept of design space is the expansion of this fundamental workspace (Kesavadas & Ernzer, 2003;

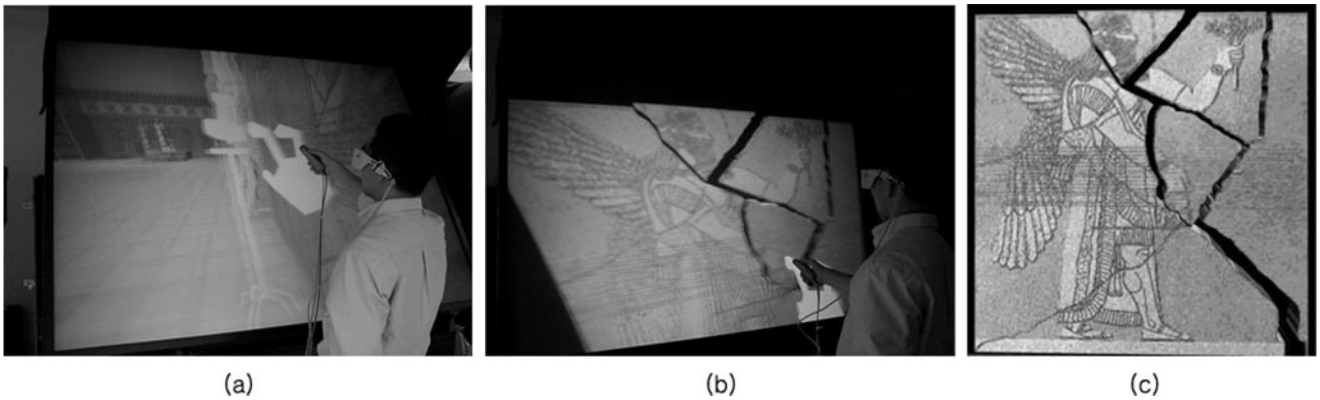


Figure 13. *Simulations in the workspace: (a) grabbing lamps with stereo-display, (b) assembling bas-relief fragments with stereo-display, and (c) assembling bas-relief fragments with mono-display. Reconstruction after a digital image courtesy of Learning Sites, Inc.*

Kesavadas & Subramaniam, 1998). We will add more refined functions to virtual objects, such as data sorting, organizing, and simulating. Human-factored VR devices will be added later so that tasks may be done more efficiently. Then the user will be able to accomplish complicated design tasks with precise, reliable, and comfortable user interfaces.

5 Achievements in Research and in the Classroom

If anything, digital archaeology and VR reconstruction can provide the means to collect and study vast amounts of data and organize material that can be retrieved and presented in ways that provide us with new possibilities to see, interpret, and present (after Sanders, 2002). As information is added and opinions change, the VR model can be easily corrected and the new data can be added to the database.

An excellent example of new ways of seeing and interpreting the relationship between architecture and design in the Northwest Palace came as a result of using the presentation of the palace in virtual reality. As an example of customized research, made available because of the nature of VR and the ability to retrieve digital data easily—it is possible to walk around the palace model quite freely in the Onyx2 version (this is also possible in the PC version, though the environment is much smaller and the experience less encompassing)—our students, with an instructor, are able to stop and observe the various iconographic representations of King Ashurnasirpal, his courtiers, and his protective deities. They can stand outside doorways and look into the various rooms of the palace or stop in doorways and look around, or stand where the king or his courtiers or the representatives of foreign countries may have stood during the various ceremonies associated with the various palace audience halls (cf. Russell, 1998).

Over the years, various scholars have noted the importance of the placement of various scenes depicting the king in his roles as priestly worshiper, administrator, warrior, and hunter, especially with reference to the throne room bas-reliefs (Winter, 1983, 1995; Russell, 1998; Paley, 1975; Paley & Sobolewski, 1992, 1997; Reade, 1994). One appreciates this best when one stands in the center of the throne room, at a point directly opposite the center doorway, and then walks in the direction of the king sitting on his royal seat (Figure 14).

The winged deities carved on the bas-relief behind the seated king on the throne seem to protect the king's images (those carved on the bas-relief) at the same time as they protect the seated monarch. The king's images

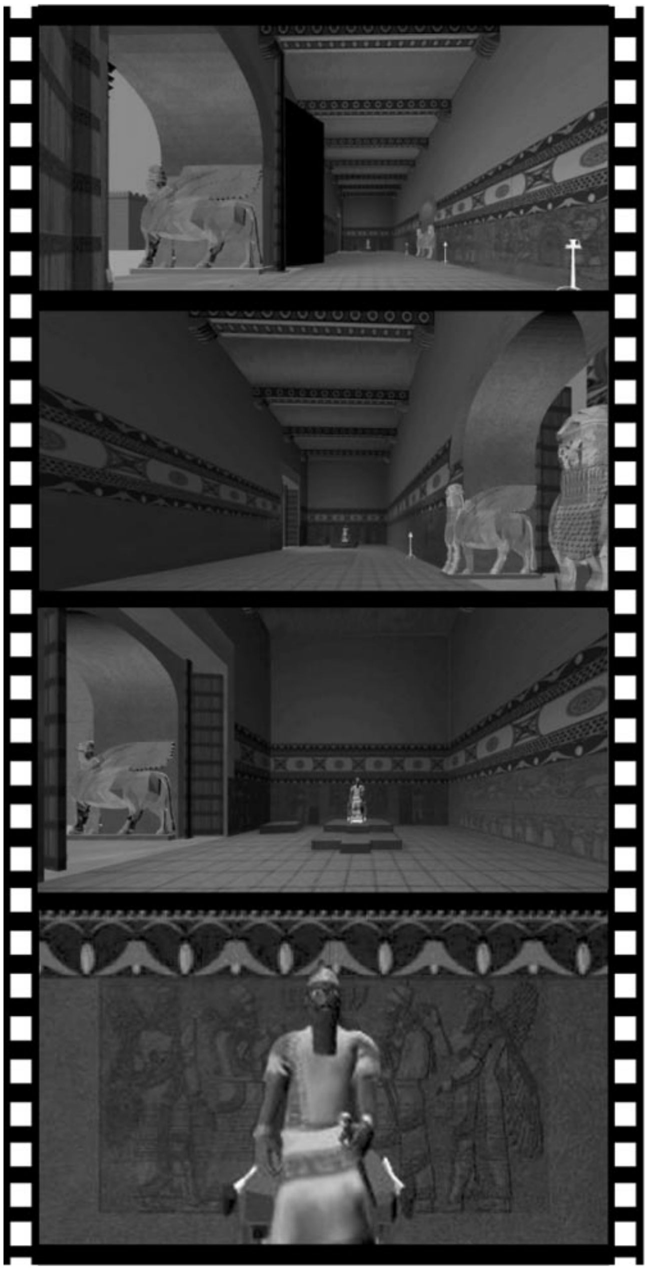


Figure 14. *Sequence of views from the center of the throne room across from the central doorway walking toward the enthroned king. The hypothesis on the placement of this bas-relief had acquired strong cogency in the spatial context.*

administer to a tree with a god crowning it. The paired images of king and deity (duplicated perhaps to simulate movement) seemingly care for the tree, the symbol of his empire, and worship the god who protects the empire from above. When one views the king on his throne in the VR environment, we see that he is seated directly in front of the tree; the figure of the god floats directly over the king's head. King is tree (=empire) and king protects tree (=empire) as the tree (=empire) and the king are protected by the god. We are in the presence of one of those situations where meanings double back on themselves. There are dozens of instances in the palace where place and iconography teaches new things about the way the king and his architects designed the royal environment to suit both the sensibilities of Assyrian religion and the public, royal image. Only in the reconstructed, virtual space can one experience and learn what must have been the concept that initiated the specific design of the ancient artist and architect who planned the iconography and architecture of the palace. None of this evidence survives at the archaeological site: almost 75% of the original artifacts have been removed to museums across the world.

Students can therefore learn different aspects of the ancient site. In the class setting in the virtual space at the supercomputer, they can experience the artifacts in their original contexts and at a nearly real scale. They can access the supporting data first digitally and then, in the conventional classroom, discuss—or look up at home and in the library—data in the traditional publications. They will, perhaps, come to different conclusions about reconstruction, or work on their own theoretical ideas of the meaning of the virtual space. In this case the connections between a hypothesis and the spatial context become immediately understood and the level of post-VR-experience discussion enhanced. Also, the palace can be taught more quickly and more effectively than by showing hundreds of slide images and poring over dozens of plans to try to understand the palace as a whole as is done in a conventional classroom. The slide and photo images and plans have become the references in the supporting databases to help understand the scholarship behind the VR model, to critique and/or expand it. The possibilities of new insights into the meaning of the palace as a result of looking at them in a virtual environment cannot be predicted. But for gaining a sense of the palace as a whole, there is no equivalent experience. Students and scholars in other schools could even collaborate with our students and invent projects in the palace over the web. This is in the planning stages at UB. So far, nine classes have experienced the VR environment, totaling perhaps 250 students. Several students have used the experience to write term papers on Assyrian art and architecture. One has written a workbook for schoolage students and, based on her research, brought the VR palace on a PC computer to the Archaeological Fair at the 2003, 2004, and 2005 annual meetings of the Archaeological Institute of America (Snyder, 2004). The same student used this knowledge as the basis for a teacher's outline for the Assyrian issue of *Calliope* magazine (*Calliope,* 2004).

6 Conclusions and Future Work

The Virtual Site Museum's authentic database together with advanced VR technology contributed positively to both our research and experience in the classroom. The full-body immersion and the reenactment and interaction with the king were effective means to engage the students. The user-oriented device interfaces assisted the researchers to expand their knowledge in surroundings displaying integrated information.

The collaboration of polygon reduction, data optimization, and display-acceleration algorithms contributed to the improvement of runtime performance in the virtual world. Part of the palace is a workspace for virtual artifacts and corresponding user interfaces. With real-time and user-oriented interfaces, we were able to simulate a work-space prototype that enables us to move lamp and/or lamps and lamp stands and to assemble bas-relief fragments into complete architectural units.

We are expanding this virtual workspace to a design space that is more precise, efficient, and comfortable. The design space will eventually be included in a shared network for remote classroom teaching. Currently we are simulating the touching of bas-relief with a haptic device and a pinch glove. These human-factored applications will make the Virtual Site Museum a more reliable and productive VR experience for archaeological research and education.

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