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THE IMPORTANCE OF SCIENTIFIC AUTHENTICATION AND A FORMAL VISUAL LANGUAGE IN VIRTUAL MODELS OF ARCHEOLOGICAL SITES: THE CASE OF THE HOUSE OF AUGUSTUS AND VILLA OF THE MYSTERIES

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The Ename Charter and Virtual Reality

The UCLA Cultural Virtual Laboratory, with which the authors of this paper are associated, was founded in 1997 and has two missions: creating scientifically authenticated virtual reality models of cultural heritage sites (which we call "CVR" models, for short); and of exploring ways of utilizing CVR models in research and instruction. Thus far, the lab has created models of sites from Lake Titicaca in Peru to Ani in Turkey; and from the Iron Age in Israel to the colonial period in the Caribbean. Our largest and most recently completed project to date is a digital model of the Roman Forum, the civic center of ancient Rome.

In support of the second mission, the laboratory has been actively researching distribution media and applications for its models. Media range from high-resolution 2D prints to immersive and interactive urban simulations. Applications include education, research, and tourism. A key example of the latter is site presentation, and the laboratory produced an orientation video for the early Christian Basilica of Santa Maria Maggiore in Rome and has related projects in the planning phase. One such project will be discussed in this paper: the documentary about the House of Augustus that we intend to produce with our partners in the Department of Archaeology of the University of Bologna.

In this paper we will discuss, from the point of view of practitioners of CVR, the general problem of the application of virtual reality technology to the presentation of cultural heritage sites, with special reference to the articles of the draft Ename Charter that mention or relate to virtual reality. (For the original text of the Ename Charter and its subsequent versions see p. 227)

The pertinent articles, as distributed in a text at the Ghent Conference in September 2002, are the following:

Article 9. In cases where the structural stability of a monument is not in danger, non-intrusive visual reconstructions (by means of artists' reconstructions, 3D computer modeling, Virtual Reality) should be preferred to physical reconstruction.

Article 18. The construction of 3D computer reconstructions and Virtual Reality environments should be based upon a detailed and systematic analysis of the remains, not only from archaeological and historical standpoints but also from close analysis of the building materials, structural engineering criteria and architectural aspects. Together with written sources and iconography, several hypotheses should be checked against the results and data, and 3D models 'iterated' towards the most probable reconstruction.

Article 20. Full scientific documentation of all elements in a presentation programme should be compiled and made available to visitors as well as researchers. This documentation should be in the form of an analytical and critical report, in which the archaeological or historical basis for every element of the work of presentation is included. This record of documentation should be placed in the archives of a public institution and should be published or posted on the Internet.

We begin by stating that, as practitioners of the art, we welcome the recognition accorded to virtual reality in the draft Ename Charter. We recognize the fact that the text of the Charter is simply a first draft and that suggestions for improvements have been invited by the authors. Thus, if we are critical of the draft Charter, it is solely with the aim of helping to craft the best possible final version of the text. Below, we will first provide some commentary on the draft Charter and discussion of some theoretical matters; and then we will examine two projects of the Cultural Virtual Reality Laboratory that can serve as case studies of the general issues raised by the application of virtual reality technology to site presentation; and, finally, we will conclude with some thoughts about the implications of this study for the Ename Charter.

Critical Commentary on the Language of the First Draft of the Ename Charter

To begin our critical commentary, we would note that, while the draft Charter does define several key terms in Articles 2, 3, and 4, it does not define what it means by "3D computer modeling" (Article 9), "Virtual Reality" (Article 9), "3D computer reconstructions" (Article 18), "Virtual Reality environments" (Article 18) or, for that matter, "3D computer simulations" (Article 10). It is possible that this omission is excusable because these terms do not have the fundamental importance to the Charter that the terms defined in Articles 2, 3, and 4 clearly have ("archaeological or historical site," "heritage presentation," and "public interpretation"). Nevertheless, even if a new Article 5 defining "3D computer reconstructions and Virtual Reality environments" is not needed, it would be desirable for the Ename Charter to state what it means by these and related terms, possibly in Article 18. It would indeed be advisable not to use so many terms (something probably motivated simply by a perceived stylistic need for variatio) but to limit the Charter to a single, well-defined concept such as "virtual reconstruction." This term has the advantage of contrasting nicely with "physical reconstruction," and it encompasses the various terms (which are by no means synonymous) that the draft Ename Charter utilizes.

The concepts of "model" or "simulation," which are implied by the term "virtual reconstruction," and that are used in the draft of the Ename Charter, need to be spelled out because they are by no means univocal. In the Cultural Virtual Reality Laboratory, we have found it useful to distinguish between four kinds of models: 1) original model; 2) state model; 3) restoration model; 4) reconstruction model. The Original Model shows just those bits of the ancient material that survive intact. The State Model shows the site just as it exists today, with the original surviving bits supplemented by later additions and any modern restorations. The Restoration Model is based on the Original Model and adds to it everything that has been destroyed over time. The Restoration Model may show any or all earlier phases in the history of the site. The exact phase or phases shown should always be specified. The Reconstruction Model is similar to the Restoration Model in that it entails fleshing out the actual remains to show an earlier phase in the history of the monument. The distinction is that we use the term Reconstruction Model when the surviving original bits are so few or exiguous as to require a great deal of hypothesizing to fill in the missing elements. For this reason, the Reconstruction Model is usually not built up from the Original Model, since so little remains that there is no point in creating an Original Model in the first place.

To a certain extent, the difference between the two terms, Restoration Model and Reconstruction Model, depends upon an intuitive judgment of the modeler, and it would be futile to quibble over whether, in a given case, one term or the other would be more appropriate. In practice, the Cultural Virtual Reality Laboratory tends to use the term Restoration Model for CVR models of structures such as the early Christian Basilica of Santa Maria Maggiore in Rome or the Cathedral of Santiago de Compostela in Spain, where the monuments still survive fairly intact and the CVR model mainly entails the removal of later additions to restore the aspect of an earlier phase. It uses the term Reconstruction Model for an archaeological site such as the Second Temple in Jerusalem, where there are almost no physical remains on which a CVR model can be based. In the case of some complex sites, such as the Forum Romanum, the individual constituent components of the site can be subject to either Restoration (e.g., the Curia Julia or Arch of Septimius Severus) or Reconstruction Models (e.g., the Basilica Julia and Basilica Aemilia). In this case, the practice of the Cultural Virtual Reality Laboratory is to create a Reconstruction Model across the entire site in order to provide a consistency of treatment.

In general, we view our categories as Weberian "ideal types," which are easy to distinguish in theory but hard to encounter in pure form in practice. For example, in the case of the House of Augustus model to be discussed below (see Section 4), for specific reasons to be mentioned we created a Restoration Model from a State Model, not an Original Model. Nevertheless, despite all the complexities of an actual modeling project, our taxonomy is useful because, like any Weberian typology, it forces us to define as clearly as possibly what, exactly, it is that we intend to model. Without such clarity, it could easily be possible, in making a virtual reconstruction, to commit the same kinds of fallacies (e.g., Cesare Brandi's famous "falso storico")[2] that have occurred in the history of physical restoration.

We now consider the three articles of the Ename Charter in which virtual reality technology is explicitly or implicitly mentioned.

In Article 9, it is not clear why the use of virtual reality, etc. should be preferred to physical reconstruction only in the cases when the monument is not in danger. Should this imply that virtual reality not be used in situations where the physical monument is endangered? We would argue that, as presently worded, there is a false antithesis between virtual (or, "visual") reconstruction, on the one hand, and physical reconstruction, on the other. In fact, both forms of reconstruction often can and should be used on the same site. Unlike physical conservation, virtual reconstruction has nothing to do with consolidation and preservation of the physical remains: rather, virtual reconstruction (not unlike physical reconstruction in archaeology)[3] is a tool that can be used, by experts, to generate new discoveries and insights and, by the general public, to understand a site more quickly and effectively. For their part, physical interventions have the primary goal of ensuring the survival of the monument and the secondary goal of displaying it to the public.[4] Thus, there is no reason why there cannot be a virtual reconstruction when there is also a physical reconstruction (assuming that budgetary limitations are not a factor). For example, a physical reconstruction typically restores the monument to a certain phase of its building history, whereas the related virtual reality reconstruction can depict all the building phases in the history of the site.

Indeed, the power of virtual reconstruction to illustrate the entire range of a monument's history provides an important tie-in of the proposed Ename Charter to the Venice Charter. Article 15 of the latter states that:

All reconstruction work should however be ruled out a priori. Only anastylosis, that is to say, the reassembling of existing but dismembered parts can be permitted. The material used for integration should always be recognizable and its use should be the least that will ensure the conservation of a monument and the reinstatement of its form.

If explicit reference were made in Article 9 of the Ename Charter to Article 15 of the Venice Charter, the preference for "visual" (or, as we would prefer, "virtual") reconstruction would be anchored in an existing international charter. It could, indeed, present itself as reconciling a latent contradiction in the Venice Charter which, on the one hand, except for anastylosis,[5] rules out all reconstruction work (which could be useful to show earlier phases of a monument for which only traces remain) and, on the other hand, in Article 12 calls for the equal respect for all periods.[6] Thus, virtual reconstruction solves the conundrum of the Venice Charter which calls for the equality of all phases but which forbids the physical reconstruction of phases whose remains happen to be slight, nonexistent, or considered of lesser importance. This solution is all the more necessary now that, even among experts in conservation such as Alessandra Melucco Vaccaro, the solution of anastylosis has come under attack after the examples of the Stoa of Attalos in Athens, the Library of Celsus in Ephesus, etc.[7]

In this connection, we also note a contradiction that might well be eliminated between Article 15 of the Venice Charter and Article 7 of the draft Ename Charter. The latter reckons with the possibility of "modern recreations of missing elements or modern reconstructions of missing fabric"; the former “rule[s] out” “all reconstruction work.”

Article 9 could also be profitably linked to Article 7 of the ICOMOS Charter on the Protection and Management of the Archaeological Heritage. This article states that:

The presentation of the archaeological heritage to the general public is an essential method of promoting an understanding of the origins and development of modern societies. At the same time it is the most important means of promoting an understanding of the need for its protection.

Article 9 of the Ename Charter might justify virtual reconstruction as one of the most effective known ways to implement Article 7 of the ICOMOS Charter on the Archaeological Heritage than the use of virtual reconstructions. This would also link Article 9 of the Ename Charter more closely to the fifth bulleted point in its “Background” section which implicitly criticizes the ICOMOS Charter on the Archaeological Heritage for “not further elaborat[ing] acceptable standards or methods” of public presentation of archaeological sites.

Article 18 concerns modelmaking methodology and is probably inspired by Article 9 of the Venice Charter.[8] Here we see two major problems. First, the recommendation that “3D models [should be] ‘iterated’ towards the most probable reconstruction,” gives off a quaint whiff of positivism. Presumably, the idea derives from the part of Article 9 of the Venice Charter which states:

“[Restoration] must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp.”

But one of the strengths of virtual reality and computer graphics is the ability to represent alternative hypotheses in a way that, obviously, cannot be done at all on a physical monument and which can be done even in a traditional print publication only with some difficulty. Through the use of software switches, individual elements of a structure (the ceiling, floor, doorways, etc.) can — and should — be easily changed in accordance with the different theories of qualified experts.

Secondly, in Article 18 the fundamental issue of authorship and authority is not addressed: who is supposed to make the “detailed and systematic analysis of the remains” on the basis of which the computer model is constructed? Whose alternative hypotheses are to be weighed and illustrated? Often in the history of

CVR, the analysis and authorship has been entrusted to the hands of computer experts, not of art historians, archaeologists, etc.[9] The Ename Charter presents an opportunity to reduce the likelihood that this will happen in the future. The inclusion of apposite language would be consistent with the Athens Charter, the Florence Charter, and other relevant charters,[10] which mandate a key role for experts in any restoration or conservation projects. In the case study of the House of Augustus below, we will discuss a project of our laboratory in which the team of experts included an archaeologist, an architect with profound archaeological experience, and a restorer. This is the kind of interdisciplinary expertise that ought to be called for in the Ename Charter.

Article 20, undoubtedly inspired by Article 16 of the Venice Charter,[11] concerns the transparency of site presentation, including, presumably, virtual reality models: the documentation utilized to create all elements of a site presentation should be made available to the public. But in specifying how this might be done, the draft Ename Charter does not make reference to virtual reality. But it is clear that a CVR model must be as transparent, with respect to its documentation, as any other part of the site presentation program. Moreover, CVR documentation has unique requirements and offers special advantages as compared to some of the other forms. To begin with the latter, it is possible to include the documentation within the CVR file and to make it viewable upon request by a user at the same time that the model is being inspected. Finally, the documentation of a CVR model is one part of its metadata,[12] and there are emerging metadata standards for CVR models that the Ename Charter might well take note of and support.

The Relationship of Scientific Authentication to Modelmaking

Driving our friendly critique of the first draft of the Ename Charter in section 2 is a key value that we strive to embody in the work of the Cultural Virtual Reality Laboratory: scientific authentication. This entails the transparency of metadata (Article 20), and the role of qualified experts (Article 18). In Section 4 below, we will use two case studies to exemplify what we mean by scientific authentication of CVR models. In this section, we set the stage for the case studies by discussion of some theoretical and practical aspects of scientific authentication.

Whereas conservation aims to ensure the survival of the physical fabric of the monument, virtual reconstruction is a representation of knowledge. The first point to note is that these two activities are complementary, not competitive or mutually exclusive. We must both conserve the physical remains and reconstruct them virtually. Indeed, the relationship between conservation and virtual reconstruction is not merely complementary, it is also fruitfully dialectical. Traditionally, conservators have debated which of Riegl's monumental values (*Alterswert, historischer Wert, gewollter Erinnerungswert; Gegenwartswerte; Gebrauchswert, Kunstwert, relativer Kunstwert)*[13] and which of his methods (radical, art-historical, conservative)[14] should guide the work of restoration. Should a monument be restored to show its state when new, the moment when it reached its historical or artistic peak of development, etc.? These difficult issues will never be definitively resolved (though impressive efforts have been made, e.g., by Cesare Brandi, to do so),[15] but virtual reconstruction at least reduces what is at stake. Previously, the decision facing conservators about which phase to privilege was "all-or-nothing": a physical intervention cannot be ambiguous. In the age of digital technology, the decision about which phase to highlight does not disappear in physical terms, but, whatever the decision, the public no longer has to be deprived of a chance to view the monument (or, to be more precise, a representation of it) at any place and in all other phases which are not physically restored.

Scientific authentication of virtual reconstruction is accordingly important, not only for the sake of science, but also for the sake of conservation. If virtual reconstructions are to become an integral part of the work of conservators and other cultural authorities responsible for site presentation, then there is a duty to ensure that the virtual reconstructions are as meticulously executed and documented by qualified experts as are the physical interventions themselves. Just because a reconstruction is virtual does not mean that it can be done shoddily, quickly, or unprofessionally. Once a public institution puts its imprimatur on a virtual reconstruction, it will have an enormous impact on the public understanding of the monument. It will also inevitably (given the hypothetical nature of almost all reconstructions, virtual or physical) give rise to debate and controversy, which, predictably, will require the sponsoring cultural agency to explain and, at times, defend itself. Scientific authentication thus becomes an essential responsibility of a cultural agency, both in fulfillment of its mission to educate the public it serves and of its need to maintain the same high professional standards it observes in the other spheres of its activity.

A full discussion of what is meant by *scientific authentication* would transcend our space limits. Here we emphasize just the main points, which are, as noted: authorship by qualified experts; transparency of metadata; and a clear understanding of the typology of virtual reconstructions.

Virtual reconstructions are knowledge representations that are expressed digitally. As such, they are analogous to other knowledge representations created in other media. They are not in themselves scientific or nonscientific, just as a knowledge representation published in a printed book is not, in itself, scientific or nonscientific. The Cultural Virtual Reality Laboratory sees itself as a digital publisher of knowledge representations that are analogous to those produced in print by a university press. A university press's books are scientific in that they have qualified authors, are vetted by recognized authorities, and are produced in conformity with the norms of good scholarship.

Even though digital knowledge representations are relatively new, they do not present entirely new issues of scientificness in this sense. They, too, must have qualified authors; must be evaluated by reputable scholars; and should reflect the norms of good scholarship. They should contain explicit reflections about method, sources, and their own place in the history of their subject.

Since the sites modeled by the Cultural Virtual Reality Laboratory are frequently extensive in terms of space, time, and structural types, authorship of a CVR model more frequently involves an interdisciplinary team—which we call the Scientific Committee—than a single individual, as often happens in the case of a print publication. For example, the Cultural Virtual Reality Laboratory's Scientific Committee on the Basilica of Santa Maria Maggiore included a scholar who participated in the excavations under the church; and the scholar who wrote the most recent technical monograph reconstructing the early building history of the basilica.[16] Moreover, since the information on which a CVR model is based is not always published but sometimes must be found in the archives of the agency superintending the monument, and at other times must be gathered afresh from the site itself, we have found it useful to ask a representative of the superintendency to serve on the Scientific Committee. The representative (who may herself be a highly qualified expert on the site) can facilitate access to, or collection of, unpublished data. The representative can also ensure that the model and related digital product are used for site presentation. In some cases, as happened with the laboratory's Santa Maria Maggiore project, the representative of the superintendency even took the lead in writing the script used for the documentary created for the museum on the site.

The fact that a model is authored by a highly qualified interdisciplinary team should not give rise to the false expectation that the modeling process will be speedy or without risks. In the laboratory's experience, the modeling process is never a simple translation of the authors' mental image—even when that image has been worked out in detail in scaled drawings—into pixels on the computer display. When scholars are given the opportunity to experience the two-dimensional representation of a site that they developed in the months, years, or even decades before the modeling process begins, they inevitably discover that they made errors of commission or omission. In the case of the Santa Maria Maggiore project, for example, questions arose about whether the interior of the church was surfaced with stucco or left as bare brick; whether the ceiling was coffered or exposed; and about the materials and design of the floor. The model went through four major revisions over eighteen months before being declared finished by the committee.

Throughout the modeling process, a record must be kept of such debates and the ensuing decisions taken. This record constitutes an important element of the model's metadata. Metadata can be published in a separate document, as is foreseen in the draft of the Ename Charter, or it can be incorporated into the digital product itself. As an example of the latter, we would cite the laboratory's recently completed model of the Roman Forum (shown in the year A.D. 400), seen in figure 1.

In figure 2, the model is seen as projected onto the screen of the UCLA Academic Technology Services Visualization Portal. On the right, a metadata window has been opened to provide instant information about a variety of topics.

Our metadata falls into three categories: (1) catalogue metadata, which serves as a finding aid (including fields such as: name of the model; name of the modeler[s]; name[s] of the member[s] of the Scientific Committee; software used to create the model; version of the software; holder of the copyright; etc.); (2) commentary metadata, which helps provide background information to users about the nature of the evidence used to create the model as well as about any disagreements on the Scientific Committee or between the model and previous reconstructions; and (3) bibliography.

Two Case Studies: The House of Augustus and Villa of the Mysteries Project

The purpose of presenting these cases studies here is to provide to examples of recent CVRLab work regarding aesthetic and technical standards or conventions for virtual models of heritage sites.[17] The House of Augustus and the Villa of the Mysteries are sites are of high artistic and historical significance, but we believe it should be possible to establish a methodology whose fundamental

Figure 1: Detail of the UCLA Cultural Virtual Reality model of the Roman Forum, 10:00 a.m., June 21, 400 A.D. Photograph shot in the UCLA Academic Technology Visualization Portal, February 10, 2003 (model by D. Abernathy, et al.; photograph by J. Suo)

principles can be applied to a variety of heritage sites from individual monuments or buildings to site topography, towns, cities and regions. One main problem is addressed here. We find is disconcerting that archaeological evidence is typically not distinguished from restored or reconstructed areas in virtual reality models. It can be very helpful, however, to distinguish between what is extant and what is

Figure 2: Detail of the UCLA Cultural Virtual Reality model of the Roman Forum, with the Metadata Window open, as seen in the UCLA Academic Technology Services Visualization Portal.

hypothetical in a conjectural reconstruction of any kind, whether in a digital model or a traditional drawing. Therefore, these case studies present ideas about how to represent archaeological evidence in a virtual reality model when significant evidence exists, and secondly, how to represent restored or reconstructed features in a model when significant evidence exists.

The excavations on the Palatine Hill in the 1960s undertaken by Carettoni exposed the remains of a complex series of residential rooms between the temples of Victory and Apollo.[18] The siting and certain architectural and artistic features fit the ancient literary sources that explain how Octavian in 36 BC bought an existing property from the orator Hortensius with the intention of renovating and expanding it for his own residence. But lightning struck, an omen meaning that the site must be used for religious purposes. The Temple of Apollo was built and dedicated around 28 BC. If Suetonius is correct, Octavian began the renovations of this residence in 29 BC, not long after his defeat of Marc Antony and Cleopatra at the Battle of Actium in 31 BC. Excavations uncovered several lavishly decorated rooms in late Second Style wall-paintings or frescos, the most famous being a small room, a cubiculum, on the upper east side of the peristyle court, that may correspond to the small study described by Suetonius where Augustus (as Octavian was called after 27 B.C.) made important decisions.

This room is the main subject of this study on establishing standards and conventions in virtual reconstructions. The room is just 3.5 meters square, but its four walls were completely covered--floor to ceiling, corner to corner--in elegant wall-paintings, the style of which is known to art historians as the late Second Style due to their integration of architectural imagery with figural and mythological scenes centered on each wall. The ceiling was a shallow barrel vault, and it was entirely covered with highly detailed geometric and figural designs of stucco incrustations and paint. Carettoni found the room in fragments only, however, and it took over a decade of painstaking conservation and restoration by Gianna Musatti to reintegrate the thousands of small fresco fragments into the physical reconstruction in an environmentally controlled and protected space on the original site. Although the Palatine Hill is one of the largest and most significant archaeological parks in the world, the room has never been open to the public.

We modeled another cubiculum decorated in wall-paintings of the Second Style, cubiculum 16 in the Villa of the Mysteries at Pompeii.[19] Maiuri excavated this villa in the late 1920s, and cubiculum 16 lies on the northwest side of it just off of the large atrium. *Cubiculum* 16 is only slightly larger than the studiolo, but unlike it, cubiculum 16 is comprised of an antechamber, two vaulted alcoves and a closet in the corner. The function of the room is debated, but it likely served as a bedroom or perhaps a small dining room.[20] The room is much better preserved than the *studiolo* in the House of Augustus. Its walls stand full-height, and one of the vaulted ceilings is well preserved. The room and the central portion of the villa are partially protected by a modern roof. Today the room is not open to the public, but visitors can look into it from a gated door.

Making the Original and State Models

Our study began by making models of the physical remains of each room. In the case of the *studiolo* in the House of Augustus, we refer to this model as a State Model, because the room today exists in a physically restored state, shown in figure 3.

Cubiculum 16 in the Villa of the Mysteries, on the other hand, has undergone only minor restorations since it was excavated, and therefore according to the terminology set out at the beginning of this paper we built an Original Model of it, shown in figure 4.

The subject matter of these sites consists primarily of wall-paintings or frescos, but the modeling methodology utilized here is adaptable to sites comprised of other materials such as architectural structures or topography. The methods described below can be repeated by others as well, although some trial and error is to be expected. The photographic equipment, hardware and software used are readily available and not expensive.

Making each model begins by recording the basic dimensions of the rooms and their wall-paintings as sketches in a field book, much like a traditional archaeological documentation. Particularly, the documentation included the horizontal and vertical articulation of each wall-painting, particularly the column heights and the centerline distances between them. These dimensions become invaluable later when the various photographs of each wall-painting are assembled to make a composite image.

Virtual reality models make extensive use of digital photographs, which are applied to the surfaces of wire frame computer models in a process known as texture mapping. The four walls of the *studiolo* were documented by dividing up each wall surface into 6 overlapping digital photographs. Two different digital cameras were used, a Nikon Coolpix and an Olympus Camedia. Both cameras seemed equivalent at first, but we eventually decided to use only the Olympus camera, because its lense caused less distortion. The size of each photograph was 2274 x 1704 pixels. We desired to obtain a resolution of one pixel to one millimeter, or better, in the final composite images.[21]

As in a traditional photographic documentation project, lens distortion and lighting conditions are the two greatest obstacles to overcome. Lens distortion must be minimized, because it cannot be easily corrected. The small size of these spaces, and in the case of cubiculum 16 the delicacy of the original floor mosaics still in situ, prohibited the use of scaffolding and even tripods. With practice it was possible to hold the camera the same distance away from the wall, horizontal to the floor plane and with the optical axis perpendicular to the wall. Small variations in the sizes of the images to be mosaiced together are easily corrected in image editing software such as Photoshop or GraphicConvertor. Errors in the horizontal rotation of the images as well as minor parallax distoration can also be corrected with standard Photoshop tools. Even though digital photography is more forgiving than traditional film cameras and chemical development, severe parallax distortion is impossible to correct, and even Photoshop cannot sharpen a completely blurred, out of focus image. Digital photography in larger spaces or of the exterior of a tall standing structure would require scaffolding or other mechanisms to properly

Figure 3: Room 15, the *studiolo* in the House of Augustus (30-20 BC), virtual reality model of the physical remains, referred to here as the "State Model" (by P. Stinson).

position and stabilize the camera.[22]

It is important that each digital photograph overlap the edges of the surrounding ones by at least ten percent, so that the common features would match in the composite mosaic image. We downloaded the photographs at the site onto a laptop computer to check for obvious problems and to make sure that they overlapped one another as they were being taken. Occasionally, the cameras malfunctioned as well.

Lighting conditions are another major problem, because they influence the representation of color in the photographs. Fortunately, the *studiolo* today is evenly illuminated by fluorescent tubes, and no flash was required. If flash had been necessary, it would have been best to take the photographs in as dark conditions as possible, rather than using additional lights, because the camera's flash source is more easily controllable than other light sources and can be quantified scientifically. The photographic documentation of cubiculum 16 in the Villa of the Mysteries was more of a challenge. Natural light comes into the room from several locations causing unwanted shadows and reflections on the wall surfaces, and photography at night was not permitted. Consequently, some

Figure 4: *Cubiculum* 16 in the Villa of the Mysteries, Pompeii (60-50 BC), virtual reality model of the physical remains, referred to here as the "Original Model" (by P. Stinson).

walls were photographed in the morning, and others at different times. This was less than ideal, with the risk being that the variation in lighting conditions would not be possible to neutralize. The flash was employed on every wall surface (even when not advised by the camera's light meter) in order to even out the lighting conditions as much as possible. This technique worked reasonably well, except for the "hotspots" that sometimes occurred. Hotspots can sometimes be avoided by taking the photograph at a slightly oblique angle to the wall surface, but this adds more distortion to the image that is not always easily rectified.

Once the photographs are taken at the site, the documentation phase ends and the processing of the photographs in the lab begins. The photographs of each surface must be incorporated properly into composite mosaiced images. In our experience, off-the-shelf software such as Photoshop is actually preferable to photogrammetric rectification software that typically does not allow for the full range of adjustments that need to be made, including scaling, rotations, skewing, color saturation, brightness and contrast, etc. Another problem with rectification software is that it often makes these adjustments "automatically," whereas Photoshop allows one to work more methodically. The process begins by correcting any minor parallax distortion in the individual photographs that are eventually mosaiced together to form one composite image. Proportional adjustments, if necessary, are made based on the dimensions of each wall-painting recorded in the field book. For instance, each image was rotated in order to establish the correct horizontal and vertical limiting lines. Once this was done for all the images for a particular wall, they were integrated into one Photoshop file as separate layers. The overlapping edges of each photograph provided guides to the assembly of the final composite image. Matching all the edges usually required some adjustment in scale, rotation, and color saturation and hue. It is important to archive the original raw data files and the adjusted image files for future reference.

The neutral wall and ceiling surfaces that served as the background for the physical reconstruction of the wall-paintings were erased using the selection tools of the Photoshop and filled with a neutral color and a granulated texture (Figure. 3). The added texture serves two purposes, to distinguish the background from the preserved fragments of fresco, and to help prevent the background in the eventual computer model from appearing too smooth--like the surface of plastic--which is a common aesthetic problem in virtual reality models. The final composite image of each wall-painting reached a resolution of approximately one pixel to one millimeter, which is enough to distinguish small cracks, the finest details and subtle variations in color and surface preservation.

Making the model itself is a process known as texture-mapping. The digital photographs are attached to a skeletal frame representing the three-dimensional geometry of the object being modeled. Virtual reality models are polygonal, meaning the surfaces of three-dimensional forms in the simulation are constructed of individual polygons, altogether known as wireframe geometry. Texture maps can be attached to single polygons or, more typically, to groups of polygons. Texture mapping is sometimes analogous to applying decorative wall paper to the walls of the room, although this is an oversimplication of the process.

We hope that the State Model of the *studiolo* and the Original Model of cubiculum 16 will serve as archives in the future. Models made solely for the purposes of recording the excavated physical remains are typically not made of cultural sites or excavated archaeological material, even though the value is obvious and indisputable. Virtual models solely of the physical remains, Original Models, or that record the state of the remains today including physical restorations and reconstructions, State Models, should not replace other forms of documentation such as photographs and two-dimensional drawings. We believe, however, that photographs and traditional drawings can only go so far in conveying the extent of preservation, and with virtual models, the palpability of scale and space become important use values as well.[23]

Making the Restored or Reconstruction Models

In addition, the *studiolo* and *cubiculum* 16 are both suitable for showcasing the strengths of virtual reality as a reconstruction tool. As mentioned earlier, the *studiolo* exists today in a physically restored state. The brilliant restorer Gianna Musatti painstakingly carried out the work over the course of a decade. Approximately 50% of the room's wall-paintings and stucco ceiling incrustations are preserved. The restorations fill in small to medium-sized losses in areas where significant original material remains. The fills, however, do not add a significant percentage of new surface area. The *studiolo*, therefore, is the ideal monument to continue restoration through digital means where Musatti prudently stopped. As stated earlier, these case study projects aim to assist scholars in the development of a set of standards and conventions for making virtual reality models when significant archaeological evidence exists, with the focus here being wall decorations rather than structural features. Secondly, we planned to carry out several restoration tests on the large portions of the north, south and west walls of the *studiolo* that are not fully preserved. These experiments were carried out solely on the *studiolo*. We had a different idea in mind for cubiculum 16 of the Villa of the Mysteries, which will be discussed later.

The methodology developed by Musatti for the restorations provided the basis for the digital restorative method. Her method integrates replacements for missing fragments harmoniously within the whole, while making them distinguishable from the original, so that the restoration does not falsify the artistic or historic evidence. This method is consistent with current conservation and restoration theory regarding historical sites, as prescribed in the Venice Charter of 1964 and subsequent charters. Specifically, monochromatic pigments fill in selected losses. The intervening new colors are less saturated than the originals, but the new colors retain a similar color temperature. The new colors are also given a subtle surface texture in order to further distinguish them from the original material. Fine details and chiaroscuro shading are intentionally not restored. Our approach for the digital restoration follows along the same lines. In order to minimize confusion with the preserved evidence, the digital restorations fill in lost areas in the wall-paintings with schematic forms and lighter colors than the originals. We assume simplicity of appearance to be an aesthetic value that conveys the sense of uncertainty or conjecture in interpretation.[25]

To do this efficiently and in an organized manner, each restoration color was assigned its own separate layer in the Photoshop file, organized accordingly to the lower, middle and upper registers of the composition. Therefore, changes can be made to individual elements of the restoration without having an affect on others or on the layer holding the preserved fragments of wall-painting. The colors chosen for the restoration layers vary from wall to wall, since the level of preservation varies greatly. For instance the famous red cinnabar is preserved at inconsistent levels throughout the room.[26] The colors of the digital restorations do not exceed the color intensity of actual preservation in any general area, or in any detail. The final colors chosen are finally recorded in a database, to be easily accessible in the future if necessary.

As in the actual restorations carried out by Musatti, determining an appropriate level of digital color restoration is somewhat of a subjective matter. To our knowledge, there are no scientific or agreed upon standards either among professional painting restorers or archaeologists and historians doing either traditional reconstructions on paper or virtual models for making these kinds of decisions, other than the general rules of thumb discussed above. The notion of restoration itself is today a highly controversial topic. In our experience archaeologists today are more cautious about interpretation and reconstruction than architectural historians and art historians who may consider it in some form or another as one of their professional duties. We hope that virtual means for restoration and reconstruction will be accepted among these varied disciplines that have cultural heritage in common.

Determining the aesthetic level of any digitally restored color begins by sampling the original color using Photoshop tools. The properties of this sample can then be easily modified to reach an appropriate hue for use in areas where it needs to be restored. The addition of a Photoshop granulation filter can provide a useful additional texture that removes aesthetic suggestions of plasticity from the digital fills. Four options of increasing color saturation or intensity are presented here for one portion of the south wall, shown in figure 5.

It is useful to study several options side by side one another. Generally, we arrived at colors somewhere in the range of 70-75% of the original intensity of the sampled colors. Below are rules of thumb for adjusting sampled colors. These guidelines, however, may not necessarily work for all reconstructions and all types of materials being simulated in a virtual model. Individual preferences may produce variations from these values, but we believe that the principle of 70-75% should be applicable in many cases.

Brightness and Contrast:
Brightness +20
Contrast -10

Grain Filter:
Intensity:10
Contrast: 50

For elements in digital reconstructions that are completely hypothetical--where no direct archaeological evidence exists--slightly different methods may be considered. For instance, no evidence for the floor paving of the studiolo exists. The floor paving design shown in the reconstruction is based on similar floors found in other rooms of the residence. Consequently, the floor reconstruction is represented only in grey tones. This method is comparable to the sketchy or loosely drawn lines that are sometimes used in traditional hand drawn reconstructions to convey a high level of speculation or hypothesis.

Of course, one could go much further and add more details to the restored areas where there is significant evidence. We plan to experiment with additional restoration, but arguably it is methodologically sound to concentrate on the overall impression and to restore in a conservative manner. Besides, no physical or digital restoration could ever match or recreate the complex aesthetic values of the *studiolo's* wall-paintings. The intent in the realization is to model the form of the paintings in a simulation of their ancient context, not to attempt a replication, as shown in figure 6.

For instance, simply copying and pasting preserved features into areas of significant loss would not be an appropriate method. It gives the false impression of complete preservation, and risks error. Moreover, the wall-paintings of the *studiolo* appear to be symmetrical, but closer inspection reveals many asymmetrical details and surprises.

These methods are adaptable to structural or architectural subject matter where significant physical evidence exists, as in the case of the CVRLab's Reconstruction Model of the ancient senate house of Rome, the Curia. The senate house survives today for the most part as a naked shell almost completely stripped of its original marble and stucco revetment.[27] Therefore it is appropriate to somehow

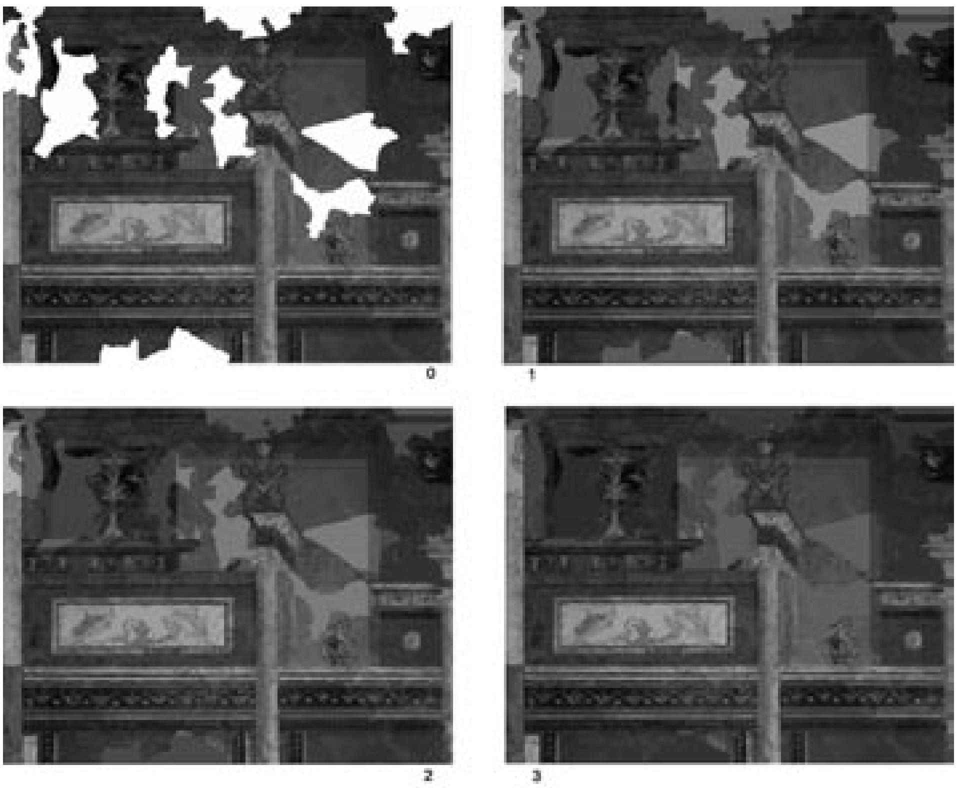

Figure 5: Room 15, the *studiolo* in the House of Augustus (30-20 BC), alternative "Restoration Models" showing four levels of color intensity in digital restoration of the south wall, top left corner (by P. Stinson).

indicate the presence of the surviving brick-faced walls as a monochromatic shade of red that can be turned on and off in the model. Most of the CVRLab's architectural models are Reconstruction models, because the physical evidence that does exist in situ or in loose fragments is usually too weathered, broken or battered as to be useful as texture maps in a virtual reality model. However, it is important to indicate which elements are still standing, or that can be positioned confidently near or exactly in their original positions, even if their surfaces and details have been restored or reconstructed.

Conclusion

In conclusion let us consider these projects in the wider context of computer visualization, archaeology and site presentation of cultural heritage sites. Proponents of virtual reality often tout it as the ideal tool for the reconstruction of ancient sites.[28] On the other hand, others have expressed reservations that virtual reality threatens to distance the archaeologist from objective archaeological data.[29] After nearly two decades of experimentation, one general perception remains that computer reconstructions of archaeological sites are expensive and sufficiently driven by scientific values.

Virtual reality does not have to distance the archaeologist from original scientific data, but this perception persists for real reasons. Virtual reality software is used today mostly by makers of flight simulators and video games, an association with commercialism that some archeologists and historians find disquieting at the very least. Also, what we refer to as the "Gee-Whiz!" factor holds too much influence on the content of many computerized reconstructions of heritage sites. It is clearly the time to propagate clear aims and purposes in our computer models instead of simply reifying our penchant for immersive and technical virtuosity.

This is why we propose here to establish a standard typology of virtual reality models that places a high priority on scientific authentication and the inclusion of the archaeological evidence as graphical representations in the models themselves. The main problem with computer reconstructions of archaeological sites (including virtual reality models and other types of computer models) remains that the language of visual and graphical communication in computer visualizations is not agreed upon. If virtual reality is to become a useful tool, we must place a priority on the development of a formal visual language that is relevant to the current aims in archaeology and cultural heritage.[30] Archaeological evidence, or scientific data in general, are not typically given an aesthetic value by the makers of reconstructions. Why this has happened is not easy to explain, but it seems that archaeologists have not taken enough responsibility to ensure that their data are respected during the modelmaking process. Archaeologists who once hired draftsmen to draw their pictorial reconstructions now hire graphic design students or young architects who may not be as interested as they are in historical or scientific accountability. Contributing factors must be that making a model of the physical remains before any restoration or reconstruction requires a commitment to a more thorough level of photographic documentation than is usually required, as well as additional funds and time.

It was true several years ago VR models often consisted of low-resolution, low-polygon count features, and at the same time they required the use of expensive supercomputers to number crunch their real-time experiences. This is no longer true. Low polygon count models still run faster in real time, of course, and real-time shadows are still not possible due to hardware constraints. The Cultural Virtual Reality Laboratory has worked very hard in recent years, however, to overcome these problems and others. For instance, our master models contain all

Figure 6: Room 15, the *studiolo* in the House of Augustus (30-20 BC), virtual reality model of the physical remains with losses restored, referred to here as a "Restoration Model" (by P. Stinson).

basic dimensions. Very detailed features such as Corinthian capitals are simplified considerably, for the time being, but in all other respects we have the capability of putting as much detail into the models as required by the scientific data at our disposal.[31] For that matter, it would be nearly impossible to "perfectly" model a Corinthian capital using traditional CAD tools and its interface. The "accuracy" of a model or a graphic representation on a computer screen is entirely idiosyncratic. There are many possible "accuracies."[32]

Virtual methods are not easily produced either; this is also a myth. Often it is said that one of the great advantages of computerized reconstructions is that they can be changed easily to accommodate alternative ideas and so forth. This is true in principle, but computer models, especially virtual reality models, are becoming so complex that making even relatively minor changes sometimes requires fundamental alterations to the underlying database structure of the model. Virtual reality models are much more complicated than standard CAD models. For instance, due to hardware limitations, VR models need to include multiple levels of detail or LODs (which may not be required in five years, however). A Roman Corinthian style column, for instance, should be modeled in at least three levels of detail. The user sees the low-resolution model from a great distance. The higher levels of resolution replace the lower ones in sequence as the user approaches nearer to the column, shown in figure 7.

For this reason and others, the term "database" is more appropriate to describe the vast network of integrated elements in virtual models. For instance, the studiolo and cubiculum 16 models are small, but their high-resolution texture maps require over 60 megabytes of memory each. Some of the technological problems of creating virtual reality models suitable for applications in archaeology are rapidly disappearing, though. Making these models on relatively low cost PCs is commonplace today, but was impossible just five to seven years ago. Virtual reality models were once constrained to using low-resolution texture maps because of hardware limitations as well. This is no longer the case, and within a few years LODs will probably be a thing of the past as processing power increases.

Few would dispute today, however, that the potential benefits of virtual reality applications in archaeology and the cultural heritage industry are wide-ranging, both as a communication tool and as an aid to archaeological and historical interpretation. In the future scholars and students of ancient art around the world might view and study models like the *studiolo* in libraries of digital information equipped with virtual reality theaters.[33] The Cultural Virtual Reality Laboratory has experimented with practical applications in several ways, from

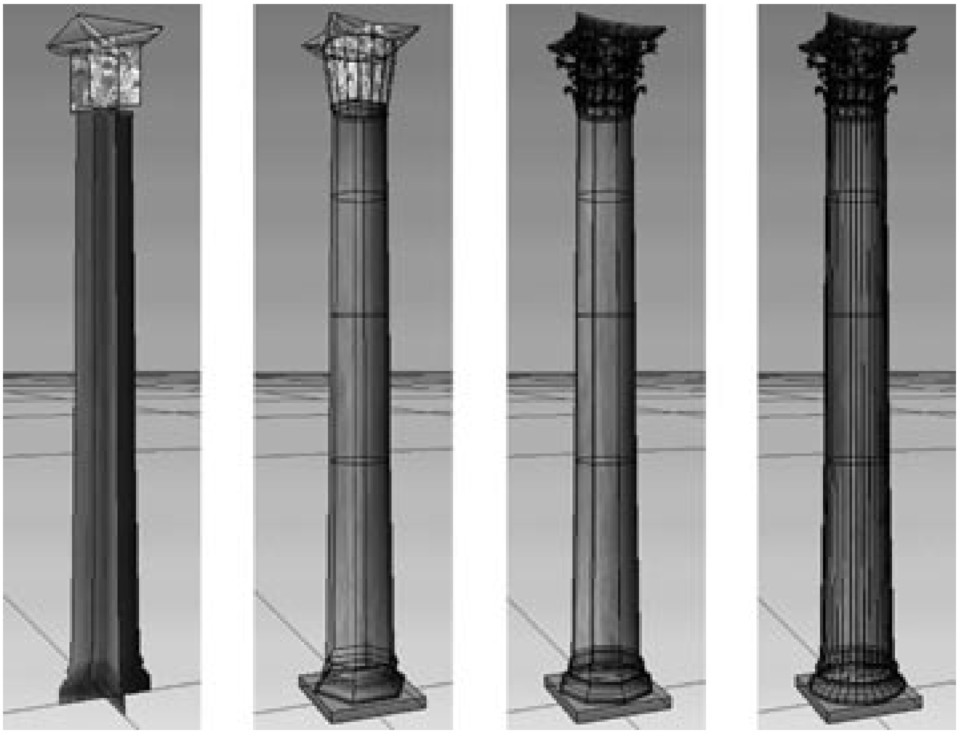

Figure 7: Levels of Detail (LODs) for a Roman Corinthian column.

its website to classroom environments to museum installations. On its website (www.cvrlab.org) is an interactive virtual environment that combines a dynamic time-line of the ancient Forum Romanum in Rome which changes dynamically with a mouse-driven time line slider, Quicktime reconstructions of monuments (including alternatives), and archaeological and historical metadata, shown in figure 8.

Recently, the lab in collaboration with UCLA's Academic Technology Services (ATS) created a similar interface in ATS's on-campus virtual theater, shown in figures 1 and 2.

These two solutions approach the problem of digital information dissemination on two important platforms, the web and the virtual theater classroom, or macro and micro scales, respectively. As mentioned, the laboratory has also produced one documentary for use in site presentation. Many other examples of the use of virtual reality and computer graphics can be cited. At Segedunum at Wall's End, UK, visitors ascend a tower, from which they look down on the Roman ruins. As they watch, reconstructions of the various phases of the site are projected on a screen located in front of them, so that they can contrast

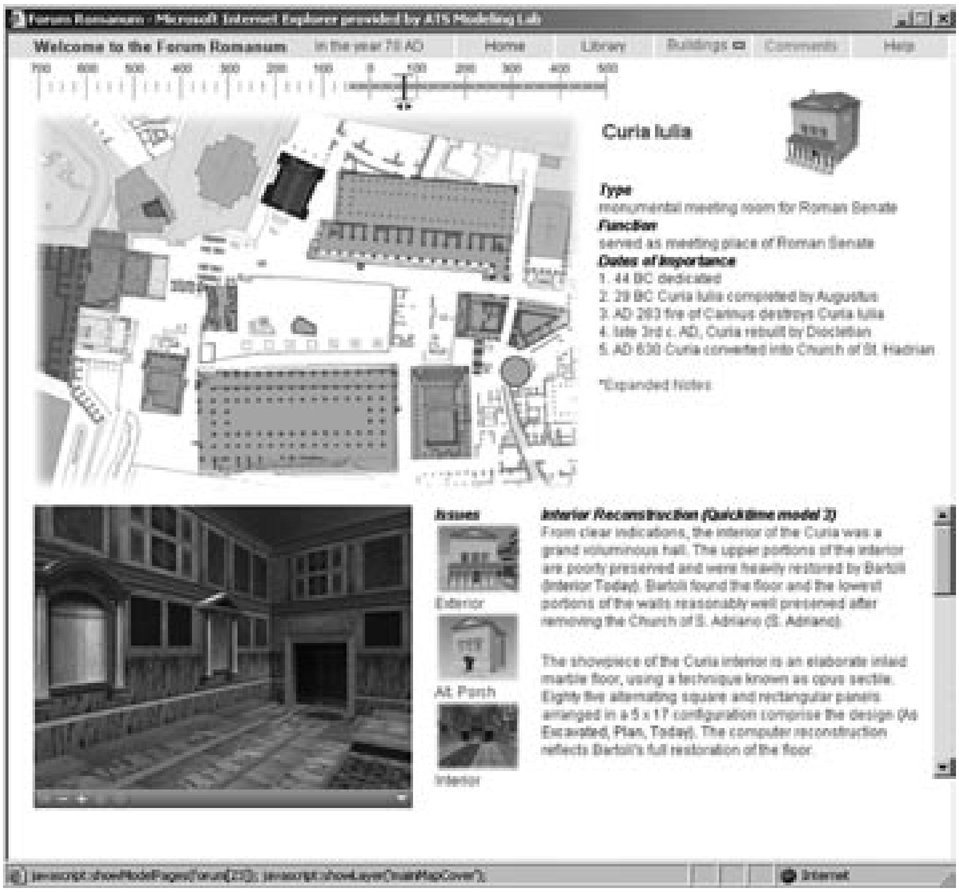

Figure 8: UCLA CVRLab website showing interactive Forum Romanum project (www.cvrlab.org).

"then" and "now." A similar system was created at the medieval archaeological site of Ename, Belgium, though using a kiosk on the ground rather than a theater in a tower. At the museum at the Foce del Sele near Paestum, Italy an elaborate multimedia display allows visitors to experience the excavations of the site, step by step. The ARCHEOGUIDE Project has taken the further step of bringing the virtual reconstruction from the museum or classroom to the site itself. Using Augmented Reality technology, it allows visitors to see both the real world of the archaeological site of Olympia, Greece along with reconstructions and scenes of ancient life.[34]

Visualization techniques of all kinds, whether two-dimensional plans, models of digital terrain data useful in GIS simulations, or virtual reality models of the like described here, have completely permeated archaeological publications of all periods and fields.[35] Daniela Scagliarini of the University of Bologna trains

Figure 9: Room 15, the "studiolo" in the House of Augustus (30-20 BC), State Model showing tondo in ceiling, view looking straight up from floor level (by P. Stinson).

her students of classical archaeology in similar documentation techniques we used for the *studiolo* and *cubiculum* 16. She and her students have built a virtual model of the excavated remains of a whole house at Pompeii.[36]

Archaeological research aims and interpretation can also be improved by virtual modeling techniques. In fact, digital modes of representation and interpretation call attention to difficult archaeological problems and to the methodologies used to decipher them. The full three-dimensional context must be considered. With traditional methods of orthogonal or perspective drawing, one is naturally inclined to focus on areas where the evidence is better preserved, or ignore areas where evidence is lacking. Often different or new interpretations are advanced or research aims are facilitated through the process of making the model or through the interactive viewing of a completed model. One example of this arose during the construction of the State Model of the studiolo that deserves mention here. Modeling the low vaulted ceiling of the studiolo was a challenge, especially the tondo in the center. For instance, a digital photo taken of the circular motif from below cannot be simply applied as a texture map to the wire frame model of the vault, because it would be distorted by the curved geometry of the

Figure 10: Cubiculum 16 in the Villa of the Mysteries (60-50 BC), virtual reality model of the physical remains, with hypothetical reconstructions of beds in the alcoves and lighting simulation, referred to here as a “Reconstruction Model” (by P. Stinson).

model and appear as an oval. In fact, the circle in the ceiling is actually an oval, but when viewed from below it appears as a circle, a simple form of cylindrical anamorphosis. Therefore, the texture map for the tondo was constructed almost as conceived of by the ancient artists--as an oval--so when it was applied to the curved wireframe model, the sides of the oval would be foreshortened; consequently the illusion of the circle is simulated in the virtual reality model, as shown in figure 9.

This example illustrates how virtual reality has the potential to further research aims. It is not that this realization about the tondo was not possible previously by studying photographs, plans, elevations, etc. Interacting with it in an immersive environment simulates what it would be like if one could be in the actual room as it exists today. Virtual interaction with the model, however, heightens the probability for the furthering of research aims. In this case, the process of making the model was crucial to making this discovery, but it is not difficult to imagine how further interaction with the finished model--panning around the room, zooming into particular details--increases the probability for more cognitive gains. In the case of the *studiolo*, the model could also provide exposure to its significant artistic works for many scholars and students who would have difficulty otherwise, because the room has never been open to the public; its wall-paintings are not published widely, and the published photographs are not comprehensive and are small.[37]

Another model of cubiculum 16 in the Villa of the Mysteries reconstructs lighting and a hypothetical furniture layout, shown in figure 10.[38]

Rooms in Roman houses rarely had windows that let in direct sunlight. Artificial lighting from oil lamps would have been necessary in most rooms beginning in the late afternoon. This model attempts to simulate an evening setting with the small room being artificially lit by two oil lamps.[39] The beds in each alcove illustrate the notion that the room was probably used primarily as a bedroom.[40] The model is not definitive, but it illustrates the vast potential for analyses of lighting and social settings. Several observations are now possible to make that would have been far more speculative if not for this model. For instance, the simulation of the lighting clearly indicates that several more lamps than shown here would have been required to completely illuminate the room at night. Also it might be interesting to art historians and archaeologists that the lamps illuminated mainly the upper parts of the walls and their elaborate architectural depictions in

Figure 11: Restored sculpture from the pediment of the Older Parthenon of the Athenian Acropolis (photograph by P. Stinson).

the wall-paintings, leaving the lower parts in the shadows. The lower parts of the alcove walls were also hidden behind the furniture. Also, the fall-off of light across the walls highlighted some aspects of the paintings more than others. What does this say about the composition of the paintings? In ways that traditional drawings could never function, simulations such as this one could potentially elevate the traditional methods of interpreting Roman wall-painting and the functions of rooms like this one in Roman houses of the mid-1st c. BC.

As mentioned earlier, for the *studiolo* and *cubiculum* 16 projects, we have studied carefully those successful physical reconstructions that clearly define the original materials from the restored interventions, that at the same time communicate an overall sense of unity and completeness, exemplified in figure 11.

We have also reevaluated many examples of the most extreme form of reconstruction of archaeological sites, anastylosis, or the rebuilding of an ancient monument using the original materials, as exemplified by the famous facade of the Library of Celsus at Ephesus, shown in figure 12.[41]

Although controversial, the methodology of anastylosis was executed consistently and clearly, following closely the principles set forth in the Venice Charter.[42]

Figure 12: Reconstructed Facade of Library of Celsus, Ephesus, ca. 114 A.D., reconstruction completed in 1978 (photograph by P. Stinson).

Virtual reality, however, provides an alternative solution to several problems currently plaguing site presentation. Mass tourist attractions like the Library of Celsus facade at Ephesus arguably jeopardize the quality of the each visitor's experience because of the resulting deterioration of archaeological sites, and the rising costs of site maintenance.[43] Anyone who has visited Ephesus on any given day during the height of the tourist season will understand immediately the real problems that monumental physical reconstructions create for themselves.

This raises a final issue: the relationship of article 15 of the Venice Charter and the article 9 of the Ename Charter. Should anastylosis still be exempted from the Venice Charter's prohibition on all reconstruction work on the actual physical remains? Based on the developments in the fields of both physical and virtual reconstruction recounted in this paper, we think that it should not.

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Endnotes

1 Bernard Frischer conceived the paper and invited P.T. Stinson to co-author it with him. Frischer wrote sections 1, 2, and 3; Stinson wrote section 4; both authors contributed to section 5.

2 Cf. C. Brandi 1963, 36.

3 Cf. the ICOMOS Charter for the Protection and Management of the Archaeological Heritage, Article 7: “Reconstructions serve two important functions: experimental research and interpretation.”

4 Cf., e.g., B. M. Feilden 1982, 3: “Conservation is the action taken to prevent decay. It embraces all acts that prolong the life of our cultural and natural heritage, the object being to present to those who use and look at historic buildings with wonder the artistic and human messages that such buildings possess.”

5 Anastylosis was earlier approved in Article VI of the Athens Charter: “In the case of ruins, scrupulous conservation is necessary, and steps should be taken to reinstate any original fragments that may be recovered (anastylosis), whenever this is possible; the new materials used for this purpose should in all cases be recognisable.”

6 Cf. Venice Charter, Article 11: “The valid contributions of all periods to the building of a monument must be respected, since unity of style is not the aim of a restoration. When a building includes the superimposed work of different periods, the revealing of the underlying state can only be justified in exceptional circumstances and when what is removed is of little interest and the material which is brought to light is of great historical, archaeological or aesthetic value, and its state of preservation good enough to justify the action. Evaluation of the importance of the elements involved and the decision as to what may be destroyed cannot rest solely on the individual in charge of the work.”

7 Cf. A. M. Vaccaro 2000, 231-232.

8 Cf. Venice Charter, Article 9: “The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and

is based on respect for original material and authentic documents. It must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp. The restoration in any case must be preceded and followed by an archaeological and historical study of the monument."

9 On this problem, see B. Frischer, F. Niccolucci, et al. 2002, 10-13.

10 Cf. Athens Charter, Resolution 2: "Proposed Restoration projects are to be subjected to knowledgeable criticism to prevent mistakes which will cause loss of character and historical values to the structures." Florence Charter, Article 15: "Art. 15. No restoration work and, above all, no reconstruction work on an historic garden shall be undertaken without thorough prior research to ensure that such work is scientifically executed and which will involve everything from excavation to the assembling of records relating to the garden in question and to similar gardens. Before any practical work starts, a project must be prepared on the basis of said research and must be submitted to a group of experts for joint examination and approval." ICOMOS Charter for the Protection and Management of the Archaeological Heritage, Article 8: "High academic standards in many different disciplines are essential in the management of the archaeological heritage. The training of an adequate number of qualified professionals in the relevant fields of expertise should therefore be an important objective for the educational policies in every country. The need to develop expertise in certain highly specialized fields calls for international cooperation. Standards of professional training and professional conduct should be established and maintained." See also endnote 44.

11 Cf. Venice Charter, Article 16: "In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published."

12 On the concept of metadata and the Dublin Core, see C. Borgman 2000, 69-71.

13 Cf. A. Riegl 1903.

14 A. Riegl m: Jokilehto 1999, 218. Other taxonomies could easily be cited, e.g., Gustavo Giovannoni's four types (consolidation; recomposition [=anastylosis]; liberation; completion or renovation); Giulio Carlo Argan's two types (conservative; artistic). See J. Jokilehto 1999, 222, 224.

15 Cf. C. Brandi 1963, 36: "il restauro deve mirare al ristabilimento della unità potenziale dell'opera d'arte, purchè cio sia possibile senza commettere un falso artistico o un falso storico, e senza cancellare ogni traccia del passaggio dell'opera d'arte nel tempo."

16 See Frischer et al. 2000.

17 This project results from collaboration between the UCLA Cultural VR Lab and the Department of Archaeology at the University of Bologna with assistance from the computing staff and resources at Cineca. Special thanks go out to Prof. Scagliarini of the University of Bologna, Gianna Musatti, the paintings' restorer of the *studiolo* in

the House of Augustus, the Archaeological Superintendency of the Forum and Palatine, and the Archaeological Superintendency of Pompeii. *Cubiculum* 16 model was the subject of Philip Stinson's MA Thesis at UCLA 2000 under the supervision of Prof. Diane Favro.

18 Carettoni 1983; Ling 1991, 37-41.

19 Maiuri 1931, 188-91; Ling 1991, 25-27.

20 For different theories regarding the function of *cubiculum* 16, traditionally known as *cubiculum* 16, see Maiuri 1931, 60-1; Richardson 1988, 175.

21 Cf. Lange 1996, 3.

22 Cf. Lange 1996

23 See the useful comments and ideas of Sanders 2000.

24 International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter), 1964, 1965; for a comprehensive discussion of conservation and restoration theory, see Vaccaro, 2000, esp. 189-259.

25 Ryan 1996, 95-6.

26 According to Musatti, significant color variation in the red cinnabar must have existed even in the original wall-paintings.

27 For information about this model, visit www.cvrlab.org. Click on Roman Forum Project. Currently, this part of the website only functions if you are using a PC.

28 Forte and Siliotti 1997.

29 Miller and Richards 1995; Eiteljorg 2001; Cf. Ryan 1996.

30 See the forthcoming Frischer 2002.

31 Multigen relies on a vertice-based input system similar to CAD programs. Dimensions can be inputed precisely, and dimensions of features can be measured vertice to vertice just like CAD.

32 We are reminded of the famous paper given by Mandelbrot about the essence of a coastline. He argued that the length of any coastline is essentially infinitely long, but any answer to the question depends on the length of your ruler. See Gleick 2000, 94-96. In turn, the accuracy of any model is dependent on the effect of observing it at different distances and scales on the computer screen, which is completely idiosyncratic.

33 See Frischer forthcoming.

34 See R. Carlucci 2002.

35 See the useful observations on virtual reality models and archaeological publications in Sanders 2000.

36 Scagliarini, et al. 2001.

37 Carettoni 1983.

38 Lucet 2000.

39 The wireframe model was created and texture mapped in Multigen Creator, and exported into Lightscape using NuGraf Polytrans software. The radiosity solution and ray traced images were created in Lightscape. For more information about illuminating digital models, see Lucet 2000.

40 For different theories regarding the function of cubiculum 16, traditionally known as cubiculum 16, see Maiuri 1931, 60-1; Richardson 1988, 175.

41 Hueber and Strocka 1975, 3 ff.

42 Schmidt 1997, 46-7.

43 Demas, 1997, 146; Sivan 1997, 51.

44 The texts of the Athens Charter (1931), Venice Charter (1964), Florence Charter (1982), etc. are cited from the versions posted on the ICOMOS Internet site at: http://www.international.icomos.org/charters.htm