First Eurographics Workshop on Graphics and Cultural Heritage (2003)
A. Chalmers, D. Arnold, F. Niccolucci (Editors)

Photorealism and Non-Photorealism in Virtual Heritage Representation

Maria Roussou[1†] and George Drettakis[2]

[1] Department of Computer Science, University College London, UK
[2] REVES/INRIA Sophia-Antipolis, France

Abstract

The area of virtual heritage has long been concentrated on generating digital reconstructions of historical or archaeological artefacts and sites with enough fidelity to be truly accurate representations of their real-world counterparts. In some cases, the advancement of tools and techniques for achieving greater visual realism has distracted from the development of other directions that enhance a virtual experience, such as interactivity, sound or touch. Recent trends in the area of non-photorealistic rendering shift focus to the development of more "believable" environments, while maintaining the accuracy and validity of the visualised data, which is significant for archaeological research. In this paper we argue that it is important to enhance the perception of realism, achieved both through photorealistic and non-photorealistic visualisation approaches, with interactivity. This is illustrated by two example projects which develop prototype virtual environments created for specialists as well as novice users.

1. Introduction

Since its emergence as a distinct discipline, the field of computer graphics has concentrated on making images that are indistinguishable from reality. This is undoubtedly important for a number of applications where visual accuracy is critical, such as medical training, diagnostic imaging and surgical simulation, architecture, engineering, industrial tasks, audiovisual production, flight simulation and others. In virtual heritage representation, architectural walkthroughs and picture-perfect simulations of objects have defined a practice where photorealism is considered as perhaps the most important measure of a successful representation. The advancement of 3D scanning techniques with applications in virtual heritage[26] and the plethora of research projects that attempt to capture real-world properties such as shading, lighting, textures, and reflections in synthetic worlds[4, 11] indicate that the realism ideal in virtual heritage representation is still vivid, producing spectacular visual results. However, as the field matures and the VR medium itself starts to develop a "language", more experimental and expressive explorations take place, and alternatives to previous ideals are considered. There is a greater realisation that, in many cases, what may interest users is not so much about achieving realistic representation as it is about creating *believable* and convincing environments, regardless if the imagery emulates the physical properties of the real world or not.

In this paper, we argue that both the development of computer graphics techniques that enhance photorealism and the development of more artistic means of expression that do not necessarily hold true to a photographic view of a site, are important and must be considered in virtual heritage representation. Our position is illustrated through examples of research work that is currently underway and that explores both directions. Specifically, we will be looking at VR projects such as CREATE, an EU-funded IST project that aims to combine realism with interactivity for education and design use, and ARCHEOS, an INRIA-funded cooperative research initiative, that explores non-photorealistic rendering techniques for archeological research and dissemination.

† Also affiliated with the Foundation of the Hellenic World, Athens, Greece for one of the projects described in this paper.

2. Virtual Representation, Accuracy, and Authenticity

Virtual heritage, broadly defined, involves the synthesis, conservation, reproduction, representation, digital processing, and display of cultural evidence with the use of advanced imaging technology[19]. Particularly, the representation of landscapes, objects, or sites of the past, also known as virtual archaeology, has been identified with the "relentless questing for the elusive grail of photo-realism and ever more faithful simulation" [9]. One can argue that this, as an ideal, is similar to the quest of early impressionists' who sought visual realism by extraordinary stylistic means. The impressionists observed nature closely, with a scientific interest in visual phenomena. It is not difficult to draw parallels with the field of computer graphics, which has long been defined as a quest to achieve photorealism[8] in the same way that the impressionists sought to impress reality on a canvas.

However, as the mastery and "language" of painting evolved, the representation of reality became "distorted" to communicate an inner vision. The post-impressionists sought to transform nature on canvas rather than imitate it. Similarly, as the tools and techniques in computer graphics evolve, the development of different imaging techniques that transform the impression and perception of reality evolves as well. Similar patterns of evolution took place in other media; it took years for photography to develop from a tool that records present incidents into a medium and, eventually, an art form. During the first years of cinema, sequences of still images were put together to create a precise record of activity and motion; the invention of techniques such as montage helped to advance the cinematic language beyond the "illusion of a detailed description of space and time"[†]. Even today, it usually takes a certain mastery of the tools before the novice photographer, videographer, or cinematographer can begin to see beyond the "objective" representation of space and time. In computer graphics, the newly defined field of Non-Photorealistic Rendering (NPR) [10, 24, 8] reflects this evolution to a different impression in the representation of space.

When speaking of virtual representation, there are two points that are often brought up in the discourse and study of heritage and archeology[19]. First, the issue of validity of information, commonly referred to as "authenticity" and, second, the importance of accuracy in the representation of this information. Authenticity and accuracy are characteristics that archeologists, historians, and museum practitioners strive to achieve and that the general public comes to expect. On the other hand, technologists dealing with the virtual representation of heritage content are, naturally, less concerned with authenticity and accuracy of the content itself and more involved with the accurate visualisation of the content. This, in a sense, identifies photorealistic depiction with accuracy. Indeed, in a cultural heritage simulation, it is important that the representation of a site is accurate and "authentic", meaning that it must reflect as truly as possible the familiar-to-the-user situation of the surrounding environment. In other words, situating the user in an authentic environment presupposes the creation of a high-quality simulation that is as close to the real-world context as possible. It is in this respect that realness, or sensory realness, or photorealism is relative to representation[13].

On the other hand, the emphasis on achieving a high degree of realism runs the risk of limiting VR reconstruction to the creation of historically accurate yet static worlds that leave little room or flexibility for interpretative and/or educational use.

In what follows we argue, through two different example projects, that the combination of advanced realistic modelling-from-images techniques with realistic VE display algorithms and advanced interactivity, serve the first goal well. On the other hand non-photorealistic rendering techniques in an immersive and interactive context can provide appropriate tools for more flexible uses in virtual heritage applications.

3. Combining Photorealism and Interactivity

Several successful and technically sophisticated examples of virtual heritage representations have been developed in the past few years for research[4, 25], education[12, 19], entertainment[15], and artistic purposes[‡]. Nonetheless, most of these environments suffer either from a lack of realism or a low degree of interactivity, due to technological and methodological constraints. Moreover, typically, these environments are either developed for 2-dimensional desktop displays or, even when immersive systems are used, there is no provision for the stimulation of other senses (haptics or sound).

In the context of the research project CREATE[§], we are attempting to overcome these critical constraints by combining realism and interactivity. The project pertains to creating a virtual reality framework that enables highly interactive real-time construction and manipulation of photorealistic virtual worlds based on real data sources. This framework is applied to cultural heritage and architectural/urban planning settings in the form of simulations that aim at making users feel truly immersed in the VE while, at the same time, providing the ability to manipulate elements of the environment. These simulations are being developed for high-end display (single/multiple-screen stereoscopic immersive VR) systems

[†] Gary Winogrand, *Public Relations*, Museum of Modern Art, NY.

[‡] Over 100 different virtual heritage projects have been presented at related conferences such as VAST, Virtual Systems and Multimedia (VSMM), and CAA -to only mention a few.

[§] The CREATE project: Constructivist Mixed Reality for Design, Education, and Cultural Heritage, http://www.cs.ucl.ac.uk/create/

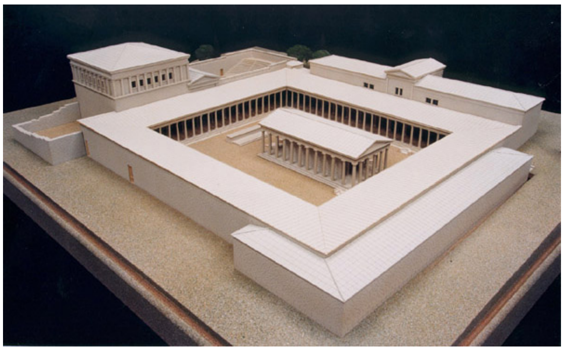

Figure 1: *Left: A view of the remains of the Hellenistic Asklepieion of Messene in Greece as they are today. Right: A full reconstruction as a 3D plaster model.*

with a variety of interfaces, which are located in research and public spaces around Europe. The preliminary prototype currently runs transparently on a PC/Linux-driven immersive workbench and an SGI/IRIX-driven RealityCenter^{TM} using an Onyx4.

In order to achieve simulations with a high degree of realism, we have chosen to create photorealistic models by capturing images of real scenes constructing 3D models with a modelling-from-images technique [4]. The resulting 3D models are then further enhanced with additional modelling to correct possible errors and complete the site by bringing it to a form that it once had, but keeping the surrounding environment in its current condition (Figure 2). Dynamic behaviour is then added to the models with which the user will interact, as specified by the usage scenario for each case. To achieve realism without sacrificing performance, we are adapting fast display techniques for complex geometry, consistent and realistic lighting, and natural elements (vegetation etc.) to a real-time context.

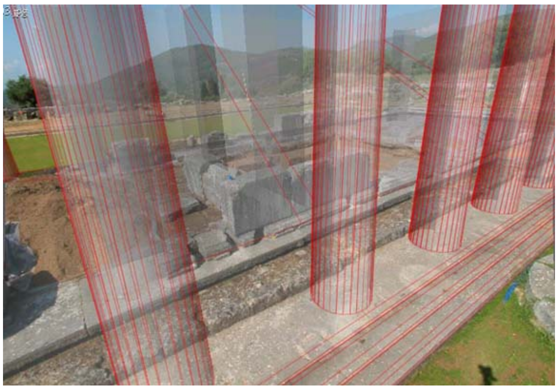

Figure 2: *Additional modelling of virtual elements is performed in order to complete the reconstruction of the site and bring it to the form that it once had.*

The users of the resulting virtual experience will be both experts (restoration architects, archaeologists, and archaeology students) and novices (children, tourists, museum visitors). A user needs analysis was performed which includes detailed user task descriptions in the form of scenarios for each case and each user group. As our interviews with prospective users indicated, visitors of a typical archaeological site are usually confronted with a multitude of remains and ruins that represent only a mere reflection of what once stood at the site (Figure 1, left). Even with the presence of an expert, this data cannot be easily interpreted or placed into context while the dissociation of information from the actual site makes it difficult to visualize and situate the gained knowledge of the site. This can lead to a variety of misconceptions and false assumptions about the site. Even for experts, a reconstruction is always a challenging task since a number of different interpretations and hypotheses exist that have to be evaluated, while the tools available to specialists today are usually low-tech, low-accuracy models that cannot give the correct impression of scale and context[21]. The results of this needs analysis process have informed the design and development of our prototypes, as well as the design of the formative and summative evaluation studies that have already begun.

3.1. Capturing Real Environments

Current work in image-based modelling and rendering shows promise for virtual reconstruction[4] but also demonstrates the complex challenge of making 3D computer models from images[13]. In our case, modelling-from-images techniques were considered as most appropriate for acquiring photorealistic 3D models of the sites. This is particularly true for the archaeological site where other techniques such as 3D scanning do not adapt easily to the size of the environment, and would be much more time-consuming to obtain a similar result.

The sites chosen for reconstruction are located in Greece

Figure 3: *Upper row, left: A photograph of the historical buildings of Place Massena in Nice. Right: Wireframe of the 3D model reconstructed from a series of such images. Lower left, a virtual image of a textured version of the above model. Lower right, addition of virtual elements, realistic shadows and lighting.*

and in Southern France. The site of the Asklepieion in the Hellenistic city of Messene (SW Peloponnese in Greece) was chosen due to its cultural, educational, and symbolic significance, since ultimately our goal is to use the reconstruction as an educational and presentation tool in a museum. The specific temple within the site, a 4th century BC Doric peripteral structure that is relatively big (13m wide x 27m long x 9m high) and simple, was selected according to technical and practical criteria that take into account the condition of the monument (has it been partially reconstructed, how well does it stand, how much data can be collected), the environmental characteristics (the amount of surrounding vegetation and its proximity), the archeological significance or educational value (what was it used for, does it need selective lighting, what can a user learn by reconstructing it, etc), and the amount of archeological documentation existing on the site (thus allowing simpler reconstruction of virtual elements). An initial survey confirmed that the site responds favourably to many of the above criteria, with characteristics that would aid in the final capture, such as the lack of vegetation in the foreground, the existence of numerous easy-to-identify blocks and a relatively flat terrain. Furthermore, the temple and surrounding monuments are very well documented and there is a considerable number of architectural members found in the adjacent area, all of them well documented and interpreted by the Society for Messenian Studies, the archaeologists responsible for the excavation of the site. There are also several conventional graphic reconstructions of the temple (ground plan and facade drawings, axonometric drawings etc.) and a 3D plaster model (Figure 1, right), which facilitate its virtual reconstruction. However, a disadvantage is that the temple is poorly preserved so the initial models resulting from the captured images gave limited information and thus require a fair amount of manual labour to produce a realistically rendered 3D environment.

In addition to the archaeological site of Messene, a couple of modern urban sites, the central Place Massena (Figure 3) and Place Garibaldi in Nice, France were also selected and are currently being reconstructed, in this case for more practical, design-related reasons. The City of Nice and the Urban Community Council (CANCA) have currently commissioned the construction of a tramway that will be integrated in the measures taken to improve urban life by reorganizing and augmenting open space, improving accessibility for pedestrians, stimulating economic life, and helping preserve and display the city's architectural heritage that is endangered by car pollution. The resulting virtual reconstruction will allow the presentation of several designs of the suggested urban intervention, allowing architects, decision makers and local inhabitants to evaluate the result from viewpoints they choose (for example, from street level or from the office they work in) or through "guided tours" of typical usage patterns of new infrastructures (for example, how a typical traveller will arrive at a station or cross a street). Such usage can allow thorough evaluation of the effects of the urban intervention on the environment and the landscape of the city.

The process of data acquisition from the above sites involved taking a large number of digital photographs of the sites (Figure 4), which are stitched into panoramas using REALVIZ Stitcher^{TM}. The resulting panoramas are imported into REALVIZ ImageModeler^{TM}, which is then used to calibrate the cameras, and create 3D models of the surrounding environments as well as the objects and buildings. Textures are applied either by extracting them using ImageModeler^{TM}, or by using an automatic approach for projective textures[18]. The modelling-from-images techniques used have produced textured polygonal models of the photographed scenes, forming detailed 3D reconstructions of the sites as they stand today.

Figure 4: *Hundreds of images from at least four different points of view were taken and calibrated in order to create a photorealistic 3D virtual environment of the site.*

3.2. Enhancing the "Realness" Factor

To achieve a high quality immersive experience, a number of different directions are being developed to enhance the virtual environment. First, through the process described above, the captured data of each of the scenes have resulted in a unique 3D model and a set of textures from several distinct viewpoints. To render this correctly, we need to be able to choose and blend the appropriate textures for each given viewpoint in the scene. We have implemented a prototype display application for this algorithm, which performs the correct choice of texture and the appropriate blending. As mentioned previously, an alternative approach using projective textures has also been developed [18], based on the approach by Debevec et al. [5] which optimizes texture memory and enhances texture quality. Additional algorithms to optimize rendering, including occlusion culling, are currently under development.

An important requirement of high-quality rendering is consistent lighting between virtual, inserted elements and the captured geometry corresponding to real objects. For this we are currently integrating the illumination from a sky and sunlight model[17] to achieve consistent lighting using efficient acceleration methods. Another important element is the use of shadows. Shadows add a very important dimension to the perception of realism in the environment, particularly when seen on an immersive display. We have developed high-quality shadowing algorithms, which we achieve by using perspective shadow maps[23] integrated into a VR system. This integration requires the adaptation of the basic algorithm to the particularities of scene-graph based solutions, such as OpenGL Performer^{TM} which we are currently using (see Figure 3, lower right).

Finally, the realness factor of the virtual experiences increases significantly if natural elements, real-time sound simulation and virtual people are included because, as Addison notes[1], heritage is "as much about the living and evolving place, people, and environment as it is about any single static monument". Rendering vegetation is a challenge for any VR display system, since it represents a high load in polygons, and thus slows down the system. We have adapted the solution presented in [22] and [6], in which complex geometry of trees and other vegetation are replaced by points and lines when their screen projection is small with respect to the viewpoint. Populating the environment with virtual humans is also a challenging area with a large number of technical as well as aesthetic considerations for heritage representation. On a technical level, the integration of dynamic elements such as people is done in consideration of the static elements, using appropriate illumination techniques that maintain the desired degree of realism in the rendering. In terms of the auditory effect, the inclusion of 3D spatialized sound is paramount in achieving a truly convincing experience. For this project, an approach based on perceptual masking, sound source clustering and the use of graphics hardware for 3D audio operations, has been adopted that allows the rendering of hundreds of spatialized 3D sound sources in real time.

The software engineering considerations allowing the development of these VE enhancements are important. In the work presented here a common software platform was used, based on OpenGL^{TM} Performer as the high-level API and CAVELib^{TM} for the platform-independent synchronization of the stereo displays and peripheral interfaces. In addition, we used XP [14], a high-level scripting language for programming environment behaviour. This scripting environment has the advantage of being easily extensible. In a nutshell, a scenegraph is maintained parallel to that of Performer, which handles message passing and all interface aspects. New nodes of the graph can easily be defined, and, when necessary, a Performer implementation is added for rendering. This combination of VR tools integrates the multiple hardware and software components of the project, and allows the seamless integration of the novel technologies presented here.

Figure 5: *The user in CREATE is able to manipulate virtual models with intuitive interaction methods.*

3.3. Achieving a High Level of Interactivity

The "learning-by-doing" and "hands-on" approach of interactive virtual representations can provide a strong motivator for the general public and scholars alike. In the final user experience of the ancient Messene example, the central Doric temple of the site provides a focussed activity space that is relatively restricted. The position, scale, and symmetry of the Doric temple concentrates the user's movement in a well-defined area and provides an ideal situation for iterative design, where activity can initially focus on a smaller section and then be replicated multiple times for application onto the whole. In this area, the novice user will be able to engage in the reconstruction of the temple in a manner that resembles creative child's play with a construction kit: the user may search for the correct pieces that allow to virtually "build", examine, compare, and manipulate parts of the temple as these are found (and accurately captured) in the environment, and, during this process, actively explore various levels of reconstruction for different historical periods. The users will be encouraged to make judgments, examine alternative scenarios of how the sites used to be, and experiment with different possibilities and solutions during their virtual reconstruction (observe, for instance, the effect to a temple's symmetrical harmony when placing a different than originally intended column). Through this active iterative approach, users can gain a better sense of the relative dimensions or interrelationships between the design elements, and learn about perspective, balance, proportion, or scale.

In the case of an archaeology scholar who intends to restore the ancient monument, the goal is to offer the possibility to try varied reconstruction hypotheses and choose the most plausible. Such an activity usually involves the assemblage of several alternative but partial hypotheses for each structural part of the monument: ground plan, elevation, number and position of columns (pteron), size and form of main building (cella), height and material of the roofing, etc. In current practice, this goal is usually achieved by means of one or two small-scale plaster models of low accuracy, which guide the restoration (Figure 1, right). In the virtual setting, the goal is to offer the possibility for the user to examine alternative models of higher accuracy before choosing the one to be adopted. As the user requirements analysis has indicated, in this scenario the kinds of actions a user would choose to do include the manipulation of all available architectural members (resizing, scaling, positioning), the repair/restoration of damaged members with the use of primary material (virtual plaster, wood, stone), the readaptation of general data such as the column distance (intercolumnium), the monument height, the thickness of the walls, and so on. These processes, if judged successful for a small part of the monument, may be repeated for the rest and thus result in a nearly complete restoration of the monument. Similar activity has been designed for the urban development case where the addition of interactive features may allow users to dynamically investigate alternatives by directly manipulating environmental elements (pedestrian crossings, stations, buildings, vegetation, etc.). By such direct manipulation in an environment, which preserves close-to-real spatial relationships, users can better understand the effect of specific actions, achieving better overall comprehension of the task.

The above high-level user activity requires seamless interaction methods that will facilitate the users' tasks. Therefore, we are extending the interactive experience to the other senses -such as touch- by developing haptic interfaces so that the virtual environment can be dynamically built by the learner/visitor/scholar/designer in a natural manner (see Figure 5).

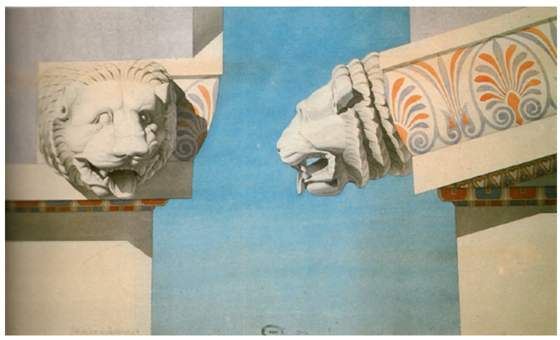

Figure 6: *A 19th century watercolor representation of part of the Parthenon. Note the importance of paper grain in the overall aesthetic result.*

4. Non-Photorealistic Representation for Virtual Heritage

A different visualisation approach has been developed in the context of ARCHEOS¶ The goal of this project is to bring together historians, archeologists and architects on the one hand, and computer graphics and virtual reality researchers on the other. To date, despite the advancements in virtual archaeology, the use of VR by specialists for archaeological research purposes has been sparse; even when VR tools are available, archeologists prefer to use other media (drawing, photography and traditional modelling). Setting all other practical issues aside, the basic idea of our work in this project is that, in many cases, archeologists are accustomed to using non-photorealistic or expressive forms of illustration. This is both due to tradition dating to pre-photographic days, and also due to the expressive power of more traditional illustration methods. This includes technical illustration representations such as vertical cuts of an artefact, but also the ability to abstract out detail of a monument, and concentrate the viewer's attention on specific parts.

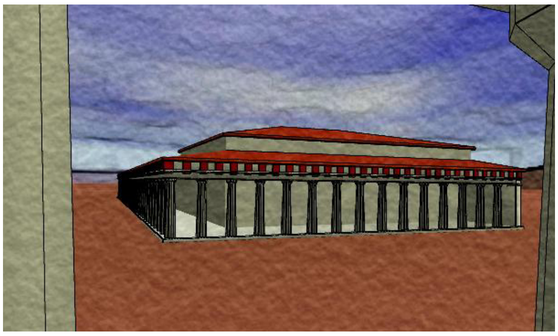

Figure 7: *Results of the paper-grain approach for walkthroughs*[2].

Non-photorealistic rendering is a relatively recent but very active area in computer graphics[10, 24]. The main thrust of NPR research in computer graphics has been in the automated reproduction of a given artistic effect, e.g., water color[3], pen-and-ink illustration[20], hatching[16] etc. The work has been quite general, usually without a specific application domain focus. Nonetheless, some such methods are often used in the traditional heritage community, e.g., stippling[7].

A typical example of archeological illustration is shown in Figure 6, where water color illustration is used to show a hypothesis concerning the Parthenon. Using such a non-photorealistic technique has the advantage that the viewer is immediately confronted with an abstraction, thus subconsciously underlining the hypothetical aspect of the reconstruction. A photo-realistic rendering of the same element would imply "historical truth", which may not be desirable.

In the context of ARCHEOS, the ancient Greek site of Argos has been studied. The main thrust has been to develop appropriate solutions to aid archeologists in their research. The main activity area of the ancient city was the Agora, and the Tholos monument (see Figure 8), for which multiple archaeological hypotheses exist.

The first goal, developed by ARTIS and MIT[2], was a novel algorithm permitting the maintenance of the metaphor of paper in the context of a "walkthrough". In Figure 6, we can see that paper grain plays an important role in the aesthetic quality of the illustration. The main challenge of the research developed in the context of the project was to correctly maintain this when the viewer is moving. This requires a subtle manipulation of paper texture with respect to viewer motion and paper grain feature size when zooming. The resulting walkthroughs maintain the aesthetic impression of paper grain, successfully transferring the paper metaphor to walkthroughs. This is illustrated in Fig. 7 ‖

4.1. Adding Interactivity

Current work in the context of the ARCHEOS project has concentrated on providing interactive tools which hopefully will be used by archeologists and the general public.

We have developed prototype interactive virtual reality experiences for the Argos Agora and in particular for the Tholos monument. The demonstration currently runs on a single-screen immersive environment, but we plan to port them to RealityCenter platforms in the near future. In Figure 8 we show snapshots of two different hypotheses for the Tholos monument which can be selected interactively.

More involved interactivity allows the users to manipulate archeological fragments found on the ground and place them in the appropriate positions. We show two snapshots of this demonstrator in Figure 9. We guide the user in the positioning of the pieces by "snapping" them to the correct position if they are released in the correct vicinity.

In the images shown, we have used textured "realistic" representations. For the different hypothesis however, it may well be desirable to use NPR renderings to underline the fact that we are not dealing with indisputable facts. An example of a "pen-and-ink" style rendering of our VR system is shown in Figure 10.

Combining interactivity with NPR, and in particular in a stereo/immersive context can be challenging. We are currently studying whether it is possible to transpose the canvas

¶ ARCHEOS is a cooperative research initiative, funded by INRIA. http://www.inria.fr/reves/Archeos/english/index.html

‖ See also http://www-artis.imag.fr/Publications/2003/CTPDGD03/index.en.html for movies of walkthroughs which illustrate the result much more clearly.

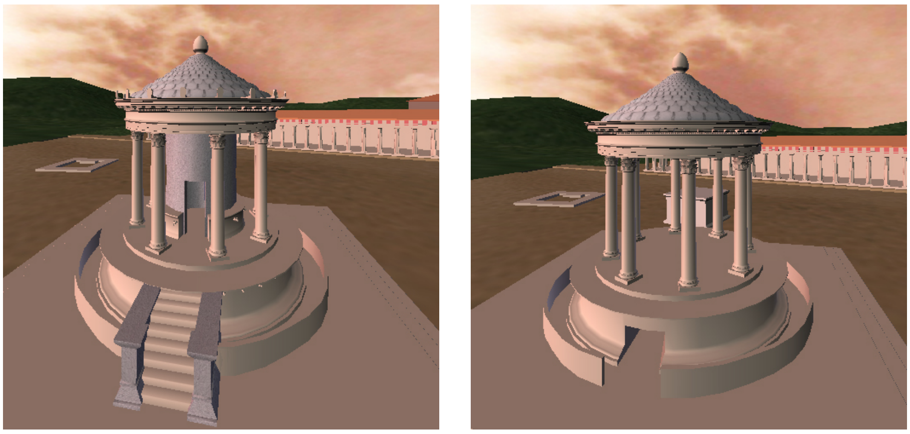

Figure 8: *Two different hypotheses for the Tholos monument. Left, the hypothesis of P. Marchetti, and right the hypothesis of M. Pierart. These are snapshots from our VR system. The user can switch between representations interactively.*

Figure 9: *Right: the monument with fragments. Left: the fragments placed in their correct positions.*

grain metaphor to a stereo viewing context. The metaphor evidently breaks down since paper is a fundamentally 2D medium; the goal is not to reproduce paper in a 3D/stereo context, but simply to maintain an equivalent aesthetic result within a stereo viewing context.

Preliminary results of this approach are encouraging, but require further investigation. Other considerations under investigation are when traditional "realistic" renderings are appropriate and/or sufficient, and when NPR/expressive renderings are more suitable. It is possible that combinations of different rendering styles may also be better adapted for certain contexts.

5. Conclusion

The area of virtual archaeology has primarily been involved with the advancement of tools and techniques for achieving greater photorealism. Recently, however, a trend has been evolving that shifts focus to the development of more "believable" environments that do not necessarily require that the virtual world be rendered with photographic accuracy. The projects mentioned in this paper explore both these visualisation approaches by developing prototype environments that target expert users (archaeologists, architects) as well as novices (students, the general public). The choice of the visualisation direction depends, in our view, on the intended purpose of the virtual representation. There is a difference between VR worlds intended for use as research instruments by archaeologists and worlds that target a broader public and are created for presentation or educational purposes. The former are developed as tools in order to assist the process of interpretation of a site and to help visualise multiple different hypotheses. In this respect, photorealism may be less important while NPR techniques that resemble traditional methods of depiction used by specialists may suffice, or even be preferable. In the case of the general public, a VR representation is developed to provide the public with a "window into the past", which incorporates the interpretations made

Figure 10: *An example "pen-and-ink" style rendering of the Tholos monument in our VR system.*

by specialists into engaging presentations. In this case, we believe that photorealism is a necessary aspect of the educational and recreational value of the representation.

Our belief is that development in both these directions is equally important for advancing the field of virtual archaeology as a scientific discipline that will aid scholars and attract public attention to virtual representation.

Acknowledgements

CREATE is a 3-year RTD project funded by the 5th Framework Information Society Technologies (IST) Programme of the European Union (IST-2001-34231). The authors wish to thank all the individuals from the partner institutions (University College London, INRIA, Foundation of the Hellenic World, REALVIZ SA., University of Cyprus, PERCRO - Scuola Superiore S.Anna, and CSTB - Centre Scientifique et Technique du Batiment) that have contributed to the development of the proposal and the project. Many thanks are also due to the archeologist E. Sioumpara from the Freien Universitaet Berlin, for her invaluable help in validating the captured data of ancient Messene.

ARCHEOS is an INRIA-funded Action de Recherche Cooperative (ARC). ARCHEOS is led by the REVES research group at INRIA Sophia-Antipolis; the main partners are the ARTIS group at INRIA Rhone-Alpes, the historians of the ERGA group at the University of Grenoble (Stendhal) and P. Martinez at the ENS Paris. Other collaborators include the graphics group at MIT, the Architecture School of Lyon and archeologists at the University of Fribourg. Many thanks are due to J. Thollot and all other individuals involved in ARCHEOS. Special thanks to A. Olivier-Mangon, for the production of many of the images used here, N. Damm, M. Negrel and B. Ruiz for earlier version of the models, as well as A. Reche, E. Gallo, N. Tsingos and R. Bayon for research and software development. Thanks to Alias|Wavefront for a generous donation of Maya, used to create the synthetic models presented.

References

1. A. C. Addison. Emerging Trends in Virtual Heritage. *IEEE Multimedia* **7**(2), pp. 22–25 (April-June 2000).

2. M. Cunzi, J. Thollot, S. Paris, G. Debunne, J-D. Gascuel, F. Durand. Dynamic Canvas for Immersive Non-Photorealistic Walkthroughs. *Proc. Graphics Interface 2003*.

3. C. Curtis, S. Anderson, J. Seims, K. Fleischer and D. Salesin. Computer-Generated Watercolor. *Proceedings of SIGGRAPH 97, Computer Graphics Proceedings, Annual Conference Series*, August 1997.

4. P. Debevec, C. Taylor and J. Malik. Modeling and rendering architecture from photographs: A hybrid geometry- and image-based approach. *Proceedings of SIGGRAPH '96*, ACM, pp.11-20, 1996.

5. P. Debevec, G. Borshukov and Y. Yu. Efficient View-Dependent Image-Based Rendering with Projective Texture-Mapping. *Eurographics Workshop on Rendering 98*

6. O. Deussen, M. Stamminger, C. Colditz and G. Drettakis. Interactive visualization of complex plant ecosystems. *Proceedings of IEEE Visualization 2002*, Boston USA, 2002.

7. O. Deussen, S. Hiller, C.W.A.M van Overveld, T.

Strothotte. Floating Points: A method for computing stipple drawings. *Computer Graphics Forum, Vol. 19(3), S. 40-51, Eurographics 2000 Conference Proceedings*, 2000

8. F. Durand. An Invitation to Discuss Computer Depiction. *ACM/Eurographics Symp. NPAR'02*.
9. M. Gillings. Plans, Elevations and Virtual worlds: the development of techniques for the routine construction of hyperreal simulations. *Virtual Reality in Archaeology*, Archaeopress, Oxford, 2000.
10. B. Gooch and A. A. Gooch. *Non-Photorealistic Rendering*. AK-Peters, 2001.
11. D. P. Greenberg. A Framework for Realistic Image Synthesis. *ACM Communications* **42**(8), pp. 45–53 (August 1999).
12. Y. Kim, T. Kesavadas, S.M. Paley and D. Sanders. Realtime Animation of King Ashur-nasir-pal II in the Virtual Recreated Northwest Palace. *Proceedings of 7th Int. Conference on Virtual Systems and MultiMedia - VSMM*, pp.128–136, 2001.
13. M. Naimark. Realness and Interactivity. In: B. Laurel (ed.) *The Art of Human Computer Interface Design*. Addison Wesley, Reading, MA., pp.455–459, 1990.
14. D. Pape, T. Imai, J. Anstey, M. Roussou, T. DeFanti. XP: An Authoring System for Immersive Art Exhibitions *Proceedings Fourth International Conference on Virtual Systems and Multimedia, Gifu, Japan, Nov 18-20, 1998.*
15. C. Park, H. Ko, I. Kim, S. Chul Ahn, Y. Kwon and H. Kim. The Making of Kyongju VR Theatre. *Proceedings of IEEE Virtual Reality Conference*, pp.269Ű271, 2002.
16. E. Praun, H. Hoppe, M. Webb, A. Finkelstein. Realtime hatching. *ACM SIGGRAPH, pages 581-586, 2001*.
17. A. J. Preetham, P. Shirley and B Smits. A Practical Analytic Model for Daylight. *Proceedings of SIGGRAPH '99*, ACM, pp.91-Ű100, 1999.
18. A. Reche and G. Drettakis. View Dependent Layered Projective Texture Maps. *Proceedings of Pacific Graphics 2003* October 2003.
19. M. Roussou. Virtual Heritage: From the Research Lab to the Broad Public. *Virtual Archaeology*, Proceedings of the VAST2000 Euroconference, Arezzo, Italy, November 2000. BAR International Series 1075, Oxford, Archaeopress, pp.93–100, 2002.
20. M. P. Salisbury, S, E. Anderson, R. Barzel and D. H. Salesin. Interactive Pen-And-Ink Illustration. *Proceedings of SIGGRAPH 94, Computer Graphics Proceedings, Annual Conference Series,* July 1994, pp. 101–108
21. A. Sideris and M. Roussou. Making a new world out of an old one: in search of a common language for archaeological immersive VR representation. *Proceedings of 8th Int. Conference on Virtual Systems and Multimedia (VSMM)*, pp.31–42, 2002.
22. M. Stamminger and G. Drettakis. Interactive Sampling and Rendering for Complex and Procedural Geometry. *Eurographics Workshop on Rendering 2001*.
23. M. Stamminger and G. Drettakis. Perspective Shadow Maps. *Proceedings of SIGGRAPH '02,* ACM, 2002.
24. T. Strothotte, S. Schlechtweg. *Non-Photorealistic Computer Graphics: Modeling, Rendering, and Animation*. Elsevier, Morgan-Kaufmann series in Computer Graphics.
25. L. Van Gool, M. Pollefeys, M. Proesmans and A. Zalesny. The MURALE Project: Image-Based 3D Modeling for Archaeology. *Virtual Archaeology*, Proceedings of the VAST2000 Euroconference, Arezzo, Italy, November 2000. BAR International Series 1075, Oxford, Archaeopress, pp.53–63, 2002.
26. VIHAP3D - Virtual Heritage: High Quality Acquisition and Presentation, *http://www.vihap3d.org*.