Making “The Parthenon”

(Invited Paper)

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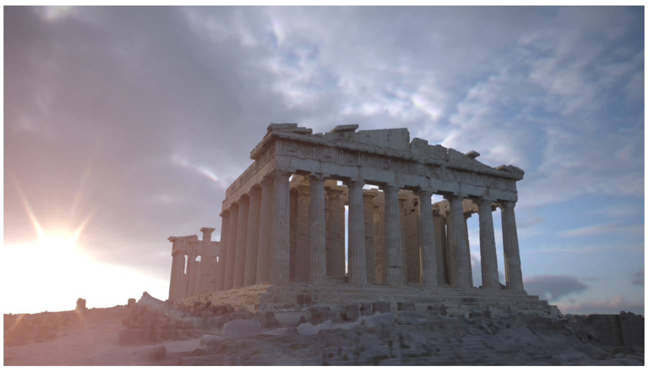

Fig. 1. Virtual model of the modern Parthenon acquired with laser scanning and surface reflectometry. It is rendered using the Arnold global illumination system using light captured in Marina del Rey, California.

***Abstract*— In this paper we overview the technology and production processes used to create “The Parthenon”, a short computer animation that visually reunites the Parthenon and its sculptural decorations, separated since the beginning of the 19th century. The film used combinations of time-of-flight laser scanning, structured light scanning, photometric stereo, inverse global illumination, photogrammetric modeling, image-based rendering, BRDF measurement, and monte-carlo global illumination in order to create the twenty-some shots used in the film.**

I. Introduction

Since its completion in 437 B.C., the Parthenon has stood as the crowning monument of the Acropolis in Athens. Built at the height of classical Greece, the temple to the goddess Athena was the most architecturally refined structure ever constructed, and featured sculptural decorations that represent some of the greatest achievements of classical art. Over time, the structure has been damaged by fire, vandalism, and war as Athens became part of the Roman, Byzantine, Frankish, and Ottoman Empires. In the early 1800’s, with Athens under the waning control of the Turks, the British Lord Elgin negotiated to remove the majority of the Parthenon’s frieze, metopes, and pediment sculptures from the Acropolis, and since 1816 these sculptures have been in the collection of the British Museum. Whether the sculptures should be repatriated to Greece has been the subject of a longstanding debate between the two countries. With the sculptures far removed from the Parthenon, the possibility of visually reuniting the sculptures and their architecture presented itself as a worthy application of recently developed graphics technology. Recently, our computer graphics research group has completed a program of research and production that realizes this goal.

At the SIGGRAPH 96 conference, our research group at UC Berkeley presented results describing a technique for modeling and rendering architecture from photographs [1]. The genesis of the Parthenon project came in August 1996 upon receiving an Email from the Foundation of the Hellenic World organization in Greece. The Email asked if the same techniques could be applied to creating a virtual version of the Parthenon. Since the Parthenon is a geometrically complex ruin, our photogrammetric modeling techniques were not fully applicable – they were suited to more modern architecture with regular geometric forms. Nonetheless, this instigated investigation into on the Parthenon’s architecture and history and a visit to the World Heritage Museum at the University of Illinois that featured casts of many of the Parthenon sculptures. Upon seeing these casts and reading a summary of the Parthenon’s complex history, it was clear that visualizing this topic using computer graphics would be a uniquely rich and challenging project.

The work we performed on this project involved extending currently available research techniques in order to: 1) Acquiring 3D models of the Parthenon’s sculptures, 2) Acquiring a 3D model of the Parthenon, 3) Deriving the surface reflectance properties of the Parthenon, and 4) Rendering the Parthenon under novel real-world illumination. With these techniques in place, our group created a 2.5 minute computer animation, “The Parthenon”, that includes visualizations of the Parthenon as well as its sculptures, both as they exist in the British Museum and where they were originally placed, with the goal of providing a visual understanding of the sculptures’ relationship to the architecture of the temple. In the remainder of this paper, we overview these processes in the context of the completed film.

A. Scanning the Sculptures

The film’s shots can be divided into four sequences. The first sequence of the film begins by showing shows 3D models of sculptures from the Parthenon’s frieze, metopes, and pediments. Obtaining these models was complicated by the fact

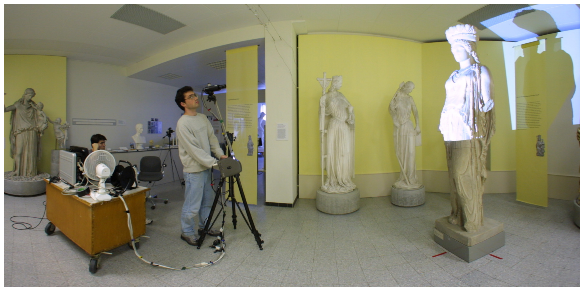

Fig. 2. Scanning a cast of a Caryatid sculpture in the Basel Skulpturhalle Museum using structured light.

Fig. 3. The virtual Caryatid model included in a virtual reconstruction of the Erechtheion. The model was formed from 3D scans of a cast augmented by photometric stereo albedo and surface normal measurements derived from photographs of the original.

that while the majority of these sculptures are in the British Museum, a significant proportion of them remain in Athens, with only about half of them currently on display. Fortunately, our team's achaeological collaborator Philippe Martinez set up a collaboration with Switzerland's Basel Skulpturhalle museum that features high-quality casts of nearly all of the Parthenon sculptures that exist today. We designed a custom structured-light based 3D scanning system [2] using a 1024 $\times$ 768 video projector and a 1k $\times$ 1k video camera, able to capture the $1m$ high Parthenon Frieze at approximately 1mm accuracy. In five days, our team of four acquired 2,200 3D scans including the Parthenon's 160m of frieze, 52 surviving metopes, the East and West pediment arrangements, and a cast of a Caryatid figure from the Erechtheion (see Fig. 2). To assemble the individual scans into 3D models, we used the MeshAlign 2.0 software [3] developed at CNR Pisa, which implements a volumetric range scan merging technique [4]. Our process is described in detail in [5], and sample models can be found at: http://www.ict.usc.edu/graphics/parthenongallery/.

In the film, the introductory sculptures were rendered using a photographic negative shader to emphasize the sculptures' contours and to provide an abstract introduction to the film. The second half of the sequence maintains this look but chooses new images that hint at the history that connects the Parthenon to the present day. These images include a Byzantine cross (Fig. 4) carved into one of the Parthenon's columns, a cannonball from one of the site's battles, and a cannonball impact in one of the cella walls. The carving and the impact were recorded on-site with a photometric stereo technique, in which the surfaces were illuminated from using a camera flash unit and the appearance of the surfaces under different lighting directions were analyzed to determine the surface orientations and geometry at a fine scale. The cannonball model was scanned from a real cannonball found on the Parthenon site using the structured light scanning system.

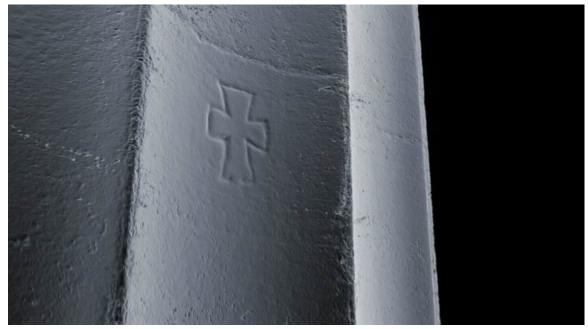

Fig. 4. A rendering of Byzantine Christian inscription from the film; the geometry was recovered using photometric stereo.

B. *Scanning and Rendering the Parthenon*

The film's second sequence shows a time-lapse day of light over the modern Parthenon. The Parthenon was three-dimensionally scanned over a period of five days in April 2003 using a Quantapoint time-of-flight laser range scanner (Fig. 5). Each eight-minute scan covered a 360 degree horizontal by 84 degree vertical field of view, and consisted of 57 million points. Fifty-three of the 120 scans taken were assembled using the MeshAlign 2.0 software and post-processed using Geometry Systems Inc.'s GSI Studio software, producing a 90-million polygon model of the Parthenon and a 300K polygon model of the surrounding terrain.

The surface colors of the Parthenon were recovered from digital photographs using a novel environmental reflectometry process described in [6]. A Canon EOS 1Ds digital camera was used to photograph the Parthenon from many angles in a variety of lighting conditions. Each photograph shows

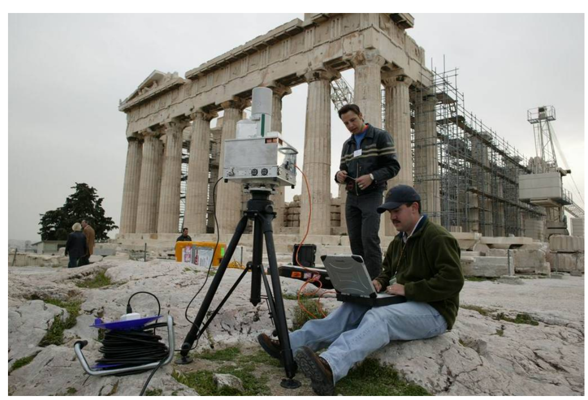

Fig. 5. The QuantaPoint 3D scanner on-site at the Acropolis.

the surface colors of the Parthenon, but modulated by the shading and shadowing present within the scene. In order to show the Parthenon under new illumination conditions, we needed to be able to determine the percent reflectivity of each point on the surfaces for each color channel: the surface's lighting-independent reflectance properties, where zero represents black and one represents white. To determine these colors we constructed a special device based on that in [7] to measure the incident illumination from the sun and sky upon the Acropolis every time a picture of the structure was taken (Fig. 6). We then applied an iterative algorithm to determine surface texture colors for the Parthenon model such that, when lit by each captured lighting environment, they produced renderings that matched the appearance in the corresponding photographs. The surfaces reflectance properties were stored in texture maps, one generated for each 4m cubed volume of the Parthenon. An orthographic view of the surface reflectance properties obtained for the front of the Parthenon's West Facade is shown in Figure 7.

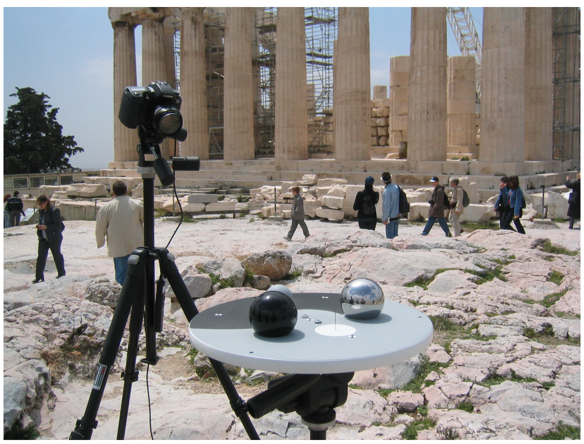

Fig. 6. Our Lighting Capture device in operation near the Parthenon on the Acropolis, used in determining the surface reflectance colors of the Parthenon.

Fig. 7. Recovered surface reflectance properties for the West Facade of the Parthenon.

Once the surface reflectance properties of the Parthenon were recovered, we had the ability to virtual re-light the Parthenon under any form of illumination. The time-lapse image-based lighting was chosen from one of several days recorded in Marina del Rey, CA using a new high dynamic range [8] capture process [9]. This capturing process involves using a camera equipped with a fisheye lens pointing at the sky, taking a seven - or eight-exposure HDR image series beginning every minute. To cover the full dynamic range of the natural sky, from the blue dawn to the direct intensity of the disk of the sun, required carefully using a combination of shutter speed variation, aperture variation, and a density 3.0 neutral density filter attached to the back of the fisheye lens. The exposure variations — over 21 stops in total — were captured by a custom software on a laptop computer controlling the Canon EOS 1Ds camera over its firewire port. Each captured sky image was converted into an image of the sky, plus a specially modeled sun disk light source for efficient rendering. We rendered the sequence (and the rest of the film) using the Arnold Monte-Carlo global illumination rendering system written by Marcos Fajaro. Rendering this sequence virtually allowed us to show the Parthenon without scaffolding and tourists and to design the camera moves and lighting in postproduction.

The sequence ends seen from a virtual reconstruction of the Caryatid porch of the Erechtheion (Fig. 3). Our scan of a single Caryatid from the Skulpturhalle was replicated several times to form the complete Caryatid porch.

C. *Recreating the British Museum*

The film's third sequence takes place in a virtual recreation of the Parthenon Sculptures Gallery in the British Museum. This gallery is the most recent space to exhibit the sculptures since they were transported from Athens by Lord Elgin in the early 1800's. The dimensions of the Gallery were obtained from photographs using the Façade photogrammetric modeling system [1], with details added using traditional modeling in Maya. Texture maps were created from "unlit" digital photographs, with absolute color and reflectance values determined using a reference chart to correctly simulate indirect light within the museum. Photographs of the real sculptures were projected onto models from the cast collection to produce the virtual models in the museum. The torso of Poseidon, perhaps the most dramatic sculptural fragment in the collection, was challenging to visualize since the scanned 3D model from the Basel Skulpturhalle included a reconstruction of the front abdominals and the head which are not part of the British collection. Lacking a useful model of the torso of Poseidon, the final shot in the sequence was accomplished by Tim Hawkins through a silhouette-based reconstruction and view interpolation taken within the museum.

D. *The Final Transition Sequence*

The final sequence is a continuous shot with five cross-dissolves between the sculptures in the museum and their original locations on the Parthenon, made possible by having three-dimensional models available for all of these elements. In many of the components, the control over the illumination is used to match the lighting of computer-generated elements to

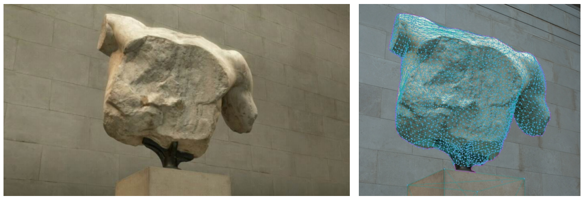

Fig. 8. A shot of the torso of Poseidon (left) was created by deriving geometry from points and silhouettes (right).

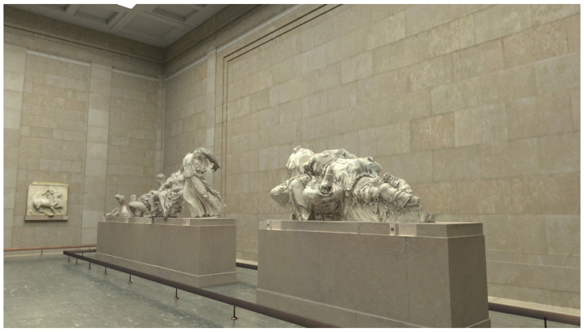

Fig. 9. Virtual model of the Parthenon Gallery in the British Museum, obtained through photogrammetry and structured light scanning.

real-world models and imagery. In a near-final transition, the coloration of the frieze is restored to its conjectured painted appearance based on archaeological reconstructions, and the Parthenon is briefly seen standing in its original glory amongst its neighboring buildings on the ancient Acropolis.

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Fig. 10. The painted frieze of the ancient Parthenon.

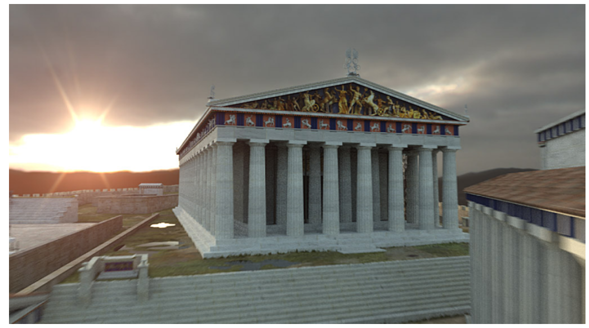

Fig. 11. The restored Parthenon on the ancient Acropolis.

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