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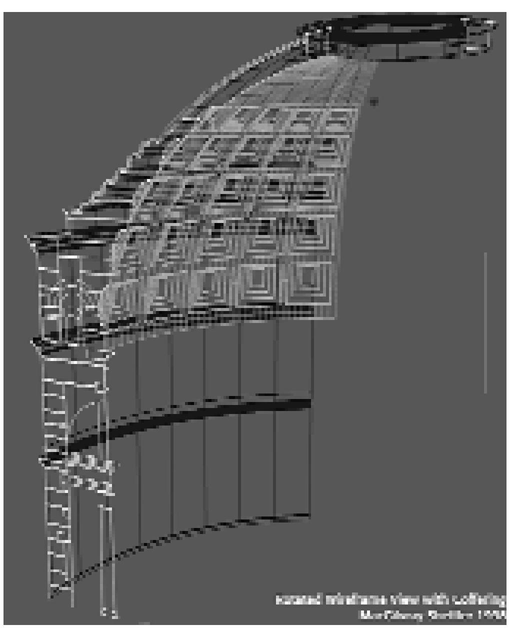
Visualizing the Construction of Hadrian's Pantheon

Visual material for teaching architectural history has typically been limited to photographs, drawings and slides. Until recently, the same visual materials have been used to teach the history of construction. Unlike the study of architectural history, however, the primary purpose of which is to understand the completed static object, the study of construction history requires the student to understand a dynamic process in which raw materials are first transformed into finished products which are then assembled in a systematic way to form a complex structure. Computer visualization and animation are not merely alternatives to slides and photographs but are an improvement: the dynamic processes of construction can be better illustrated with the dynamic imagery of computer animation. Many of the most interesting phases of the construction process are temporary and are dismantled and removed prior to project completion. Similarly, many important construction details, fastenings, and bracing systems are hidden behind the finished surfaces of the completed structure.

This paper describes a computer-animated visualization of the construction of the Pantheon, built by the Roman Emperor Hadrian in the second century AD. The Pantheon is relatively simple geometrically (a hemispherical dome on a round drum, with a pedimented pronaos), but is quite complex in its structure and construction. The builders used the most sophisticated construction materials and machines for its time, including elaborate scaffolding, centering and hoists, and combinations of Roman concrete and brick in a composite construction system.



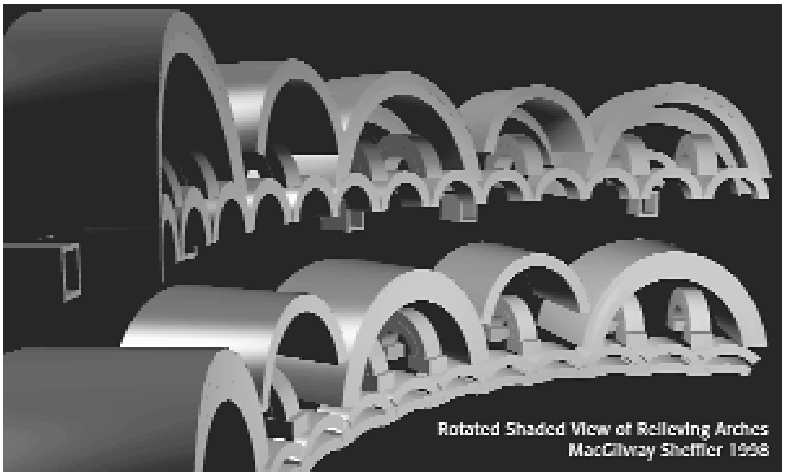
Rotated wire-frame view with coffering.

In documenting the dimensions and basic geometry of the Pantheon we were frustrated because most references contained only non-quantitative, descriptive written material illustrated with photographs, and not very useful for our purposes. Plan and elevation drawings lacked dimensions or graphic scales; there were contradictions and inconsistencies in many of the materials we did find. The most useful reference was *The Rotunda in Rome: A Study of Hadrian's Pantheon by Kjeld de Fine Licht*[1] which is an exhaustive work, complete with excellent drawings, descriptive text, and detailed dimensions. We relied primarily on De Fine Licht's drawings to establish the basic geometry and dimensions of the computer model. Large scale images of the plan and sections were scanned, as well as detail drawings of such things as entablatures and column bases.

Next, the two-dimensional images were rotoscoped into the computer to produce a three-dimensional volume. This was accomplished in Alias Studio® by importing an image plane into a window and tracing over the image with the straight lines and curves necessary to create an accurate model. This step was difficult; we needed to create a model with correct internal structure, rather than just a superficial façade . Since the construction of the Pantheon will next be animated in chronological steps, the model had to be designed such that it can be "sectioned" to illustrate the additive construction process. This was the point at which we learned the true structural complexity of the building!

It was necessary to create a detailed model that could be shown in high resolution images. To accomplish this, the model was built as a series of skins reflecting the parts of the geometry that would be seen during various camera moves. There are, for example, separate skins for the interior and the exterior of the structure. Thus, the computer will be required to render as little geometry as is needed to present to the camera the required complexity and form. Even so, some of the computer files are quite large; we divided the structure into parts to be composited in the final production.

In order to show the construction of the Pantheon in chronological sequence, it will be necessary to dissect the model into horizontal bands and/or vertical segments. This will be done using constructive solid geometry (CSG).[2] With this tool, negative volumes can be subtracted from positive



Rotated shaded view of relieving arches.

volumes to model such detail as the dome coffering. A separate model of the structural relieving arches was also made in sufficient detail to eventually show the placement of the centering and each brick making up the arch.

The granite columns and marble bases of the portico were modeled using rotoscoped curved lines taken from De Fine Licht. Rotoscoping around the z-axis allowed the incorporation of the complex torus curves of the base as well as the subtle entasis of the columns. The wooden trussed structure spanning the porch was modeled using simple parallelepipeds to define each structural member. The most complex part of the modeling was the coffering. For each of the coffers, three or four[3] unique parallelepipeds were created and deformed to allow for the curvature of the dome in each of two axes and non-parallel (radial) sides in the third axis. They were then united and subtracted from the dome volume. In order to model the hollow parts of the dome's interior structure, we decided to create them as positive volume (diagrammatically) CSG components; this also will allow them to be subtracted from the model for use in the modular animation.

Digital images by the authors.

The project is being developed in Alias Studio®, a premier modeling and animation package, on Silicon Graphic® (SGI) workstations, typically an R5000 or O2. Alias® is a NURBS-based[4] surface modeler with advanced ray-tracing, particle systems, hair generation, and non-photo realistic effects. Render times per frame are expected to be 20-30 minutes. This is a work in progress; the essential geometry has been completed, but computer modeling of specific details (i.e., column capitals), construction operations, and surface treatments continues. It is our intention to test the didactic value of the finished product with students of architectural and building construction history. A text describing the development of the Campus Martius, the earlier Pantheon of Agrippa and surrounding buildings, and the construction of Hadrian's Pantheon from foundation to occulus has been written and will be used to narrate a video that will present still images (maps, drawings, etc.), computer-animated construction operations, and a Quicktime Video™ interior spatial panorama.

Construction operations will be illustrated by cutting sections from the computer macro-model to isolate specific details, adding such things as construction centering and lifting devices, or by animating the placement of individual bricks or stones, or the raising of columns. Students viewing the video will be tested on the material and their results compared with a control group of students hearing the same narrative, but presented only with traditional two-dimensional images.

It is our thesis that the students who view the video will demonstrate an increased understanding of the construction process, thus suggesting the further incorporation of this technology into the teaching of that subject. Applications for the teaching of historical construction techniques from more recent periods or the understanding of complex historical structures are numerous. For example, the design complexities and changes over the years of such structures as St. Peters or the United States Capitol could be clearly visualized. The construction of large, complex structures, especially those that have a great deal of modularity like the Crystal Palace or the World Trade Center, could be modeled and visualized. Finally, the reaction of historic structures to physical forces (gravity, wind, earthquakes) could be modeled and studied. We also plan to make the products available for interactive viewing and learning on the Internet. For expanded text and additional illustrations, the interested reader can visit our Web site at <www.viz.tamu.edu/students/sheffler/pantheon/outline.html>.

Notes

1. Kjeld De Fine Licht, *The Rotunda in Rome: A Study of Hadrian's Pantheon* (Copenhagen: Jutland Archaeological Society, 1968).
2. CSG is based upon Boolean operators (union, subtraction, intersection) and volume principles.
3. The coffers in the first four rings have four indentations, in the fifth (uppermost) ring only three.
4. NURBS stands for Non-Uniform Rational B-Spline, a mathematical curve with C3 continuity from which patches/surfaces are generated.

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