Rome Reborn 2.0: A Case Study of Virtual City Reconstruction Using Procedural Modeling Techniques

Kimberly Dylla,[1] Bernard Frischer,[1] Pascal Mueller,[2] Andreas Ulmer,[2] Simon Haegler[2]

[1]University of Virginia.USA
[2]Procedural, Inc., Zurich. Switzerland

Abstract

Rome Reborn is a virtual reconstruction of the entire city of ancient Rome at the height of its urban development in 320 AD. The model consists of two kinds of digital reconstructions: Class I elements (whose position, identification, and design are known with great accuracy); and Class II elements (whose building type and location are known only in a general way). Within the Aurelian walls, there are more than 7000 buildings. Of these, ca. 250 fall into Class I, and the rest into Class II. By their very nature, Class I elements can be digitally modeled with a high level of detail and confidence; Class II elements cannot. The challenge in modeling an entire city such as ancient Rome (and, by extension, many other sites known from incomplete archaeological data) is to harmonize the mode of representation of these two classes of buildings. This paper describes how we utilized procedural and parametric modeling techniques to create visually compelling and detailed models of the Class II elements of the digital model of ancient Rome. Procedural modeling methods made the modeling process very efficient without sacrificing detail or quality. Furthermore, the flexibility of the approach helps to quickly change and regenerate the model as new scholarship or discoveries warrant.

Keywords: *procedural modeling, parametric modeling, 3D modeling, ancient Rome*

1 INTRODUCTION

Rome Reborn (www.romereborn.virginia.edu) is an international initiative based in the Virtual World Heritage Laboratory at the University of Virginia (http://vwhl.clas.virginia.edu). Its goal is to illustrate the urban development of ancient Rome from the first settlements in the late Bronze Age (ca. 1,000 BC) to the depopulation of the city in the early Middle Ages (ca. 552 AD). The first result of the project is a virtual reconstruction of the entire city of ancient Rome at the height of its urban development, in 320 AD.[1] The model is one of the largest scholarly virtual reconstructions made to date, encompassing the entire city within the Aurelian walls. The model has passed through two stages: version 1.0, which had ca. 9 million polygons and was first publicly exhibited by Walter Veltroni, Mayor of Rome, and Rome Reborn Project Director Bernard Frischer on June 11, 2007. Version 2.0 (alpha) is the current version. It has over 400 million polygons and thus represents a dramatic upgrading of the geometric detail of many of the individual elements constituting the model. In this paper, we discuss how and why we created version 2.0 (alpha).[2]

Figure 1. *Rome Reborn 2.0 model rendered with Mental Ray, showcasing both procedural and hand modeled content and showing a major Class I monument (the Circus Maximus in the middle ground) integrated with the filler architecture of Class II.*

The project distinguishes two types of elements in the model. Class I elements are those sites about which we have detailed information about identification, location, and design. Approximately 250 elements fall into this category. Thus far, over 30 sites have been modeled using commercial 3D database authoring software such as 3D Studio Max and Multigen Creator. The second type of element belongs to Class II: they are the ca. 6,750 buildings and monuments (such as single-family houses, apartment buildings, warehouses, etc.) about which we lack precise information. They are primarily known from two late-antique catalogues of the building stock of the city. Known as the "regionary catalogues," these texts report the distribution of buildings by type throughout the 14 wards (or "regions") of the city.[3] In

[1]For the history of the project, see Karen Moltenbrey, "History in the Making. Scholars and Modelers Accurately Re-create Ancient Rome and Make It Accessible Via the Internet," *Computer Graphics World,* December 2008, 16–25.

[2]We denote this version as "2.0 (alpha)" because as of this date (May 30, 2009), the model is in the process of archaeological review. The review is expected to take at least twelve months.

[3]For the catalogues, see *Codice topografico della città di Roma,* edited by Roberto Valentini and Giuseppe Zucchetti, with an introduction by Pietro Fedele, volume 1 (Rome: Tipografia del Senato, 1940).

order to create visually compelling and detailed models of this extensive amount of "Class II" schematic architecture, procedural modeling techniques were employed (see fig. 1).

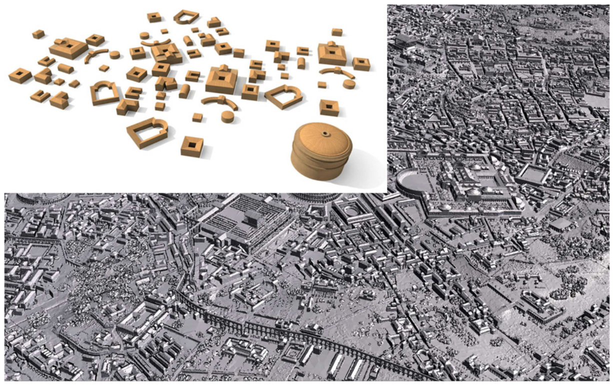

Figure 2. *Laser scan of Plastico di Roma Antica and derived massing model types.*

In the first version of the Rome Reborn model, completed in 2007, the Class II content was modeled and textured by hand, based on positions derived from a laser scan of the large scale physical model of ancient Rome, Gismondi's Plastico di Roma Antica, implemented by a team of engineers from the Politecnico di Milano led by Professor Gabriele Guidi.[1] First, the laser scan data was classified by topology into several simplified mass model types, instanced around the city according to the original molds used by the physical model makers. These simple massing models, created by hand modeling using Maya, were then vertex processed using scripts to derive a footprint from the intersection of the bases with the terrain. This modeling technique, while representing a great improvement over the mesh made directly from the scan data, presented a number of problems.

The resulting Class II models (fig. 2) were very schematic: their architectural detailing (such as windows, doors, balconies, etc.) came from textures, not geometry.
This caused an aesthetic discrepancy with the highly detailed Class I models. Many of the Class II models were not properly placed on the DTM. This could have been fixed, but given the scope of the project, editing the model would have taken an inordinate amount of time and resources. Rome Reborn 2.0 had the goal of solving these problems by replacing all the Class II buildings using novel procedural methods. The improvement to the overall Rome Reborn model was striking (fig. 3).

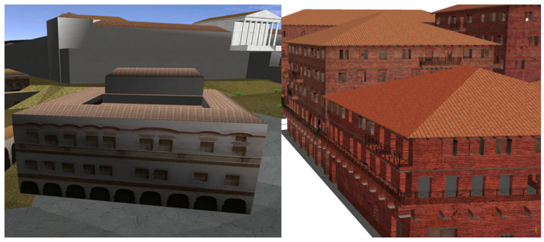

Figure 3. *Juxtaposition of detail present in hand-modeled and procedurally-modeled Class II content. On left is version 1.0 of the model; on right, version 2.0.*

2 PROCEDURAL MODELING

The "CityEngine" software, a procedural modeling solution from Procedural, Inc. in Zurich, Switzerland, employs a shape-grammar-based geometry generation system called "CGA shape" to efficiently create large-scale 3D environments within defined rules and parameter ranges.[2] The scripting language used by CityEngine is an enhancement of the set and shape grammar syntax developed in the last decades and is optimized for architectural content. It makes it possible to control or vary volumes, architectural assets, proportions, rhythms, and materials. The grammar rules (or "rule sets") written with CGA shape are adaptive: they can be applied to 2D shapes from a GIS database as well as to simple 3D shapes. They will automatically adapt to the spatial dimension of the initial shape. The grammar rules for Rome Reborn 2.0 were designed under the careful guidance of archaeological consultants Claudia Angelelli and Bernard Frischer, who provided extensive images, floor plans, statistics, and useful data. The point of departure was the reprocessed scan data of the physical model of the city captured by Prof. Guidi's team at the Politecnico di Milano (fig. 2).

The mass models and footprints of Rome Reborn 1.0 (fig. 4) were imported into CityEngine. Since the mass models are represented as polygon data of arbitrary topology, novel split algorithms were developed to subdivide the mass into its components, such as facades, roofs or interiors. Then, the grammar rules developed based on archaeological data were applied to refine the mass models, generating an entire city of highly detailed 3D building models (fig. 5).

[1]For details, see Gabriele Guidi, Bernard Frischer, and Ignazio Lucenti, "Rome Reborn: Virtualizing Ancient Rome," *International Society of Photogrammetry and Remote Sensing*, Proceedings of the 2nd ISPRS International Workshop 3D-ARCH 2007: "3D Virtual Reconstruction and Visualization of Complex Architectures," ETH Zurich, Switzerland, 12–13 July 2007, available online at: http://www.commission5 .isprs.org/3darch07/ (accessed May 20, 2009).

[2]Pascal Mueller, Peter Wonka, Simon Haegler, Andreas Ulmer and Luc Van Gool, "Procedural Modeling of Buildings," *Proceedings of ACM SIGGRAPH 2006 / ACM Transactions on Graphics,* http://www. procedural.com/company /publications/ procedural-buildings.html.

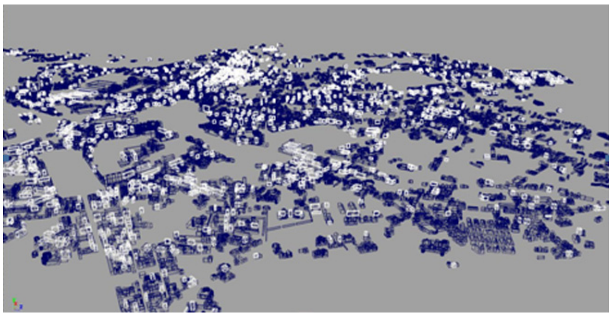

Figure 4. *This screenshot of Autodesk Maya shows in white wireframe one of the several classes of initial shapes which were used as input for the grammar-based modeling system.*

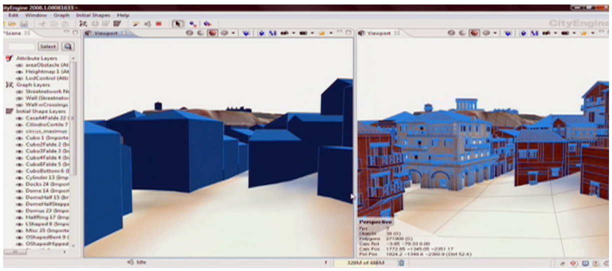

Figure 5. *Multiple CityEngine viewports: on the left side, the initial mass models and footprints of Rome Reborn 1.0 are shown. The right side shows close-ups without* (left) *and with* (right) *the detailed geometry generated by the CGA shape rules.*

3 PARAMETRIC MODELING

Besides the domestic buildings, CityEngine was applied to reconstruct many of the numerous temples in Rome using parametric modeling techniques. Following the well-described rules of Classical architecture, one grammar rule set was written which generates Doric, Ionic and Corinthian temples. The rule set contains almost a hundred attributes which can be modified to control the final appearance of the generated model. Most of the ancient temples have been destroyed or significantly damaged, which limits the possibility of gathering additional geometric information from extant remains. Therefore, the proportions, as described by Vitruvius, were implemented in a rule set and applied to give the best practical approximation of the appearance of the temples. The archaeologist has to enter only the few parameters he knows, and the remaining parameters are then calculated proportional to the known parameters, generating a full temple model with all of the architectural elements automatically aligned (cf. figs. 6, 7).

Since the Rome Reborn project supports different kinds of visualization and publishing platforms, different levels of detail were also integrated into the rule set. Three levels of detail, ranging from approximately 50,000 polygons per building at the top level of detail, to several hundred polygons for the mid level, to simply textured massing models at the low level, were controlled with global image maps (fig. 8). Each level of detail was exported in sections divided according to the 14 regions of the ancient city of Rome, allowing for the complexity of the model to be adjusted according to the specifications of the chosen interface.

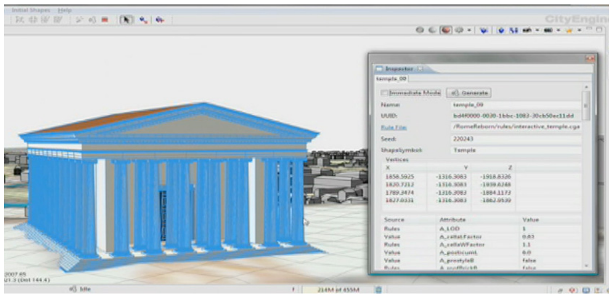

Figure 6. *Temple generated by CityEngine.*

CityEngine has functionalities to export the generated models to any 3D package or visualization software, using the file formats COLLADA, FBX, OBJ, RIB, and Mental Images' MI. This export process runs in batch mode, i.e. the buildings are generated and written to hard disk one by one, as the city model quickly grows too large to be kept in system memory as a whole. In this way, the procedurally generated domestic Class II buildings and the parametrically modeled temples were exported and integrated with the Class I detailed landmarks, which existed in 3D Studio Max format. Because of the use of the same footprint for model generation, the scaling and placement is consistent throughout all of the elements of the city model. Thus, no transforms were needed, allowing for seamless integration of the procedural and hand-modeled content in the platform. In this way, all the models have been exported to the .mi format for direct use with the remote rendering software, Mental Images' "RealityServer", which we describe next.

Figure 7. *An offline rendered scene with temples. Only a single CGA shape rule set describing Classical architecture was used. The different temple variations emerge by adaptation to the initial shape and/or rule input parameter modifications. The rendering was created using Autodesk Maya and Mental Images' Mental Ray.*

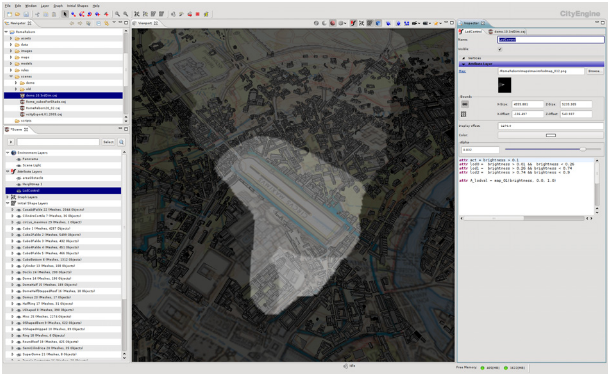

Figure 8. *Level of detail for the procedurally generated building is controlled by image maps. Bright areas designate a high level of detail (up to 50k polygons), whereas dark areas are populated with simple building models. This was done throughout the entire model. In the figure is seen the operation underway for the area around the Circus Maximus.*

4 User Interfaces

The visual improvements to the Rome Reborn 1.0 model by the addition of the geometrically detailed procedural Class II content facilitated by CityEngine in the 2.0 version were substantial. However, they also greatly increased the complexity and polygon count of the model and presented challenges to access and render the model in real time. Thus new interfaces also needed to be explored. The RealityServer[1] remote visualization software package from Mental Images in Berlin, Germany uses a unique server-side progressive rendering technique to allow remote navigation of extremely complex models like the Rome Reborn model, which at its highest level of detail has more than 400 million polygons (see fig. 9). The hardware platform required for real-time rendering of a model this large, especially using realistic environment lighting and shaders, is typically prohibitive in terms of cost and portability. But RealityServer allows the Rome Reborn 2.0 model to be stored and rendered on a large in-house server, and then manipulated and securely accessed remotely over the Internet by clients around the world. The specifically designed FLEX navigation interface requires that the end-user only have a browser and a Flash plug-in to view the model, and allows for various standard camera manipulation techniques, walk navigation, real-world distance measurements, and still image rendering at arbitrarily high resolutions. It also is an advantage in the protection of the intellectual property contained within the scholarly model, as the actual 3D geometry is not being distributed to the users, only 2D imagery. This platform, however, is somewhat limited in frame rate because of network latency. This presented challenges in designing a novel navigation interface to compensate for these issues.

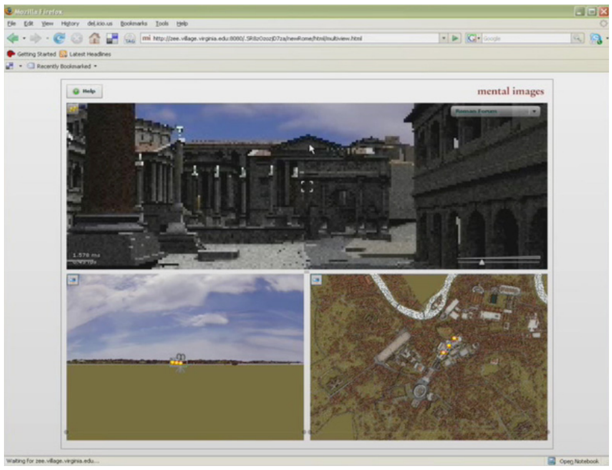

Figure 9. *RealityServer FLEX interface rendering remotely in browser window.*

The Rome Reborn team partnered with IBM to experiment with a second interface solution. This exploited IBM's iRT software for their Cell Broadband Engine architecture (fig. 10). A large server of Cell Blade processors renders the entire Rome Reborn 2.0 model with an interactive and ray-traced lighting solution at 60 frames per second with 1080p output. The model can be accessed via a Playstation 3 console, which provides a smooth and game-engine-like navigation front end for Rome Reborn. The model was easily converted to the iRT binary files via the .OBJ files exported from CityEngine and 3D Studio Max, which were then triangulated using PolyTrans, and converted to IBM's .BVH binary format using a script. Although the fast frame rate, interactive lighting, high-resolution imagery and smooth navigation using a console controller were advantages to this interface, the challenges lay in the prohibitive cost of the hardware, as well as portability and access, as no remote rendering capabilities have thus far been implemented for the Cell iRT package.

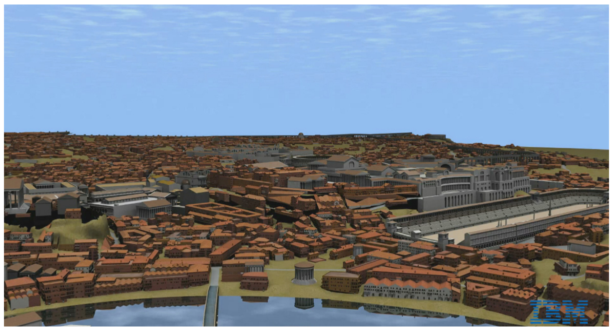

Figure 10. *Image of the Rome Reborn 2.0 model rendered on the IBM Cell Blade Server.*

[1] www.mentalimages.com/products/realityserver. html.

5 Conclusion

In conclusion, for the 2.0 improvements to the Rome Reborn model, procedural modeling methods made the process very efficient without sacrificing detail or quality. Furthermore, the flexibility of the approach helps to quickly change and regenerate the model as new scholarship or discoveries warrant. Procedural techniques as implemented in the CityEngine software provide a robust framework for virtual city reconstruction for scholarly models, accounting for flexibility and change as archaeological uncertainty necessitates, and generating visually compelling 3D reconstructions on a large scale efficiently and accurately.

The remaining challenge for the Rome Reborn team is to combine the high resolution imagery and frame rate of the IBM Cell platform with the secure remote rendering functionality of Mental Image's Reality Server.

Acknowledgements

For their collaboration, support, and donations of hardware and software, we are grateful to Peter Hofstee, Barry Minor, and Joaquin Madruga of IBM; to Ludwig von Reiche, Tom-Michael Thamm, Antonio Salvemini, Cassie Thibodeaux, Anja Kutzner, Brendan Hack, and Lisa Fentner of Mental Images; and to Barton Fiske of Sun. For their contributions of support of our costs to participate in SIGGRAPH 2008 we thank: Mental Images, Past Perfect Productions, Elizabeth Bartman, The Walt Disney Company, and the following units of the University of Virginia: the Department of Art History, the Department of Classics, the School of Architecture, the School of Engineering and Applied Science, and the Office of the Vice President for Research. We also thank Cole Krumbholz for serving as the producer of our booth at SIGGRAPH 2008, where Rome Reborn 2.0 was first publicly presented. We dedicate this article to Joe Marks (The Walt Disney Company), who invited us to present Rome Reborn at SIGGRAPH 2008. Without the incentive of an invitation to exhibit Rome Reborn in a prominent place at SIGGRAPH 2008, it would not have been possible to recruit the various companies and individuals who worked so hard to upgrade our model from version 1.0 to 2.0.

Bibliography

Guidi, Gabriele, Bernard Frischer, and Ignazio Lucenti. "Rome Reborn: Virtualizing Ancient Rome." *International Society of Photogrammetry and Remote Sensing*, *Proceedings of the 2nd ISPRS International Workshop 3D-ARCH 2007*, "3D Virtual Reconstruction and Visualization of Complex Architectures," ETH Zurich, Switzerland, 12–13 July 2007. www.commission5.isprs.org/ 3darch07/ (accessed May 20, 2009).

Moltenbrey, Karen. "History in the Making. Scholars and Modelers Accurately Re-create Ancient Rome and Make It Accessible Via the Internet." *Computer Graphics World*, December 2008: 16–25.

Mueller, Pascal, Gang Zeng, Peter Wonka, and Luc Van Gool. *"Image-based Procedural Modeling of Facades." Proceedings of ACM SIGGRAPH 2007 / ACM Transactions on Graphics*. www.vision. ee.ethz.ch/~pmueller/ wiki/CityEngine/PaperFacades (accessed May 20, 2009).

Mueller, Pascal, Peter Wonka, Simon Haegler, Andreas Ulmer, and Luc Van Gool. "Procedural Modeling of Buildings." *Proceedings of ACM SIGGRAPH 2006 / ACM Transactions on Graphics.* http://www. procedural.com/company /pub lications/ procedural-buildings.html

Valentini, Roberto and Giuseppe Zucchetti, ed. *Codice topografico della città di Roma,* vol. 1 (Rome: Tipografia del Senato, 1940).