Reconstructing the Baths of Caracalla

T. Oetelaar[1]
[1]University of Calgary, Calgary, Canada

Abstract
This paper provides an overview of the digital restoration process of Rome's Baths of Caracalla using the parametric CAD package, SolidWorks. It will outline the major hurdles, their solutions, and benefits of the process as well as a brief case study on the reconstruction of the window glazing.

Categories and Subject Descriptors: I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling – Curve, surface, solid, and object representations

1. Introduction

The Baths of Caracalla are a large public bathing complex or thermae built by the Roman Emperor Marcus Aurelius Antoninus (known as Caracalla) between 212 and 216 CE. The building itself, located in the southeast portion of ancient Rome, covers an area of approximately 2.4 hectares and the perimeter wall encloses an area of 10.9 hectares. The initial purpose of this reconstruction was to recreate the *caldarium* – a room similar to a very large modern sauna with hot tubs – for a thermofluid analysis. However, this quickly morphed into an interesting, yet difficult, reconstruction of the entire bathing complex for the Institute for Advanced Technology in the Humanities (IATH) project, *Rome Reborn* – a project designed to rebuild the city of Rome digitally as it existed in the fourth century CE. Its goal is to provide another tool for specialists and non-specialists alike to look at the spatial distribution and urban landscape of ancient Rome. With a 3-D digital model of Rome, scholars can better investigate questions such as the visibility of monuments from different vantage points or how the setting changed under different Imperial building plans. This project has relied on detailed models of strategic complexes, such as the Flavian Amphitheatre (or Colosseum), in a panorama of apartment blocks, shops, and private homes. The details of these key buildings have created a semblance of life in the enormous model of Rome at 320 CE.

As the most intact *thermae* in Rome, the Baths of Caracalla fall into this category. Therefore its reconstruction required careful attention to many different facets, from room dimensions to mosaic patterns. Even though much of the structure still exists, the published, publically available data were surprisingly sparse. Given the complexity of the Baths, the data gaps and the need for an engineering-based geometry, the best option was to use two software suites – one for the geometry and the second for the application of textures, though the latter will not be covered here. To create the appropriate geometry for a thermofluid analysis, the ideal program was a parametric one. Parametric design is the standard in most engineering applications because it allows more flexibility in key stages of the process. The advantages of this type of design include time savings, enhanced ability for collaboration on a particular piece, and easier error correction ([SEL04], [SB08]). Havemann and Fellner [HF04] also use the principles of parametric design, though not 3-D parametric CAD, to analyze and write a code for Gothic window tracery. This paper provides a methodological overview of the software programs used, the overarching issues that arose, and a case study of the intricate insertion of window glazing. In so doing, the major benefits and shortcomings of parametrically modeling the Baths of Caracalla will become apparent.

2. Software

Because of its parametric capabilities, one of the best programs for the geometrical portion of the reconstruction was the engineering CAD program, *SolidWorks*. In parametric design, as the name suggests, the researcher creates features by drawing shapes and defining modifiable parameters to hold the shapes in place. This allows for easy manipulation of pieces of the design if new information becomes available. However, the program is based on mathematical formulae, which limits the creativity of the researcher. Since parametric programs are based on mathematical formulae, forming intricate curves, such as a Corinthian capital, can be time-consuming and frustrating if not impossible. This is why parametric programs are almost always engineering-based. A more useful program for the more artistic finishing details, such as texture application, is Autodesk's *3ds MAX*. However, McNeel's *Rhino 4*, another program, is necessary to ensure a smooth transition between these two programs. Also, because the imported pieces are meshed and not native to *3ds MAX*, the scenes tend to have high memory demands, making the next move to animation and virtual reality cumbersome.

3. General Structure and Broad-Spectrum Assumptions

The creation of the base geometry required a few

underlying adaptations. Even though Appendix D of The Baths of Caracalla by J. DeLaine [DeL97] provided the preliminary data – measurements of wall lengths, door widths and heights, window widths and heights, windowsill heights and niche widths and heights – they were incomplete. In some cases, DeLaine could not provide a particular dimension, either due to access issues or, more often, because it simply did not exist anymore. In these instances, fortunately, the mirror image dimension did exist; and, since the Romans encompassed symmetry in their design, it was appropriate to use the mirror image data. For example, the N window of Room 1E (see figure 1) was missing but DeLaine listed the N window dimensions of Room 1W. In the model both windows used the same dimensions. While she gave many key dimensions, some – most noticeably, the placement of the doors, windows, and niches in the walls – were not in the appendix. Therefore DeLaine's scale drawings provided approximate measurements.
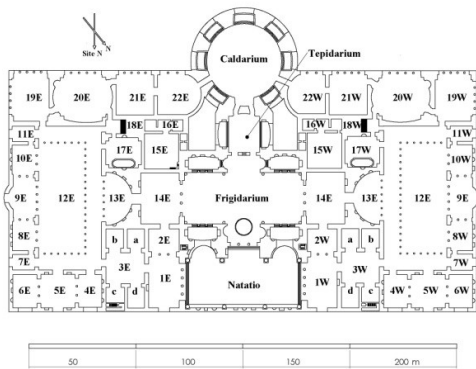

Figure 1: *Plan of the Baths of Caracalla.*

The reconstruction process also involved many assumptions and modifications (Figure 2). The most critical was to make the corners of the rooms square (i.e., 90 degrees). In actuality, opposing walls were not the same length and therefore no room corners were square. In most cases though, the difference was two or three centimetres on a wall measuring up to twenty metres, a relatively insignificant amount. The solution adopted here was to average the lengths of the opposing walls. Parallel walls also allowed a simple extrusion to create the vaults instead of using a complicated, somewhat unpredictable loft. The difference between an extrusion and a loft is that the former converts a 2-D sketch into a 3-D object by expanding it along a straight line perpendicular to the
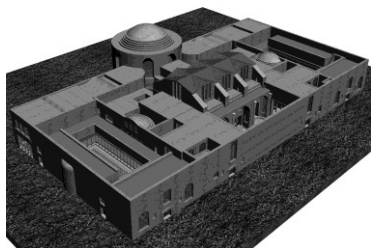

Figure 2: *Isometric view of the completed reconstruction.*

sketch plane, in this case parallel to the walls. The latter, on the other hand, creates a 3-D object by connecting two or more sketches, perhaps following a curve known as a guide path. More importantly, the creation of rooms with square corners simplified the whole process: all walls were either vertical or horizontal.

Heights from the floor to the springing of the vaults also required a similar adjustment. Like the wall lengths, the distance from the floor to the springing of the vault varied by 2-3cm over distances of up to 18 metres. As the finishing piece, structurally speaking, these differences were not as critical and could be incorporated without jeopardizing subsequent components. The vaults themselves were easy to create but their thickness was a concern because of the debate surrounding rooftop terraces. Some reconstructions (including Palladio's [Pal32] and Italo Gismondi's EUR model of Rome) have gabled roofs on many of the major rooms while others (including DeLaine's and Brödner's [Brö51]) have flat roofs. Based on site observations made in 2008, the present reconstruction falls somewhere in the middle. The stairs above Room 11E/W and from Room 18E/W to the roof of the portico above 12E/W indicated the presence of terraces on Rooms 4E/W-11E/W. The well-lit staircases going from the floor of Room 3c to the top of Room 4 were probably designed for public use because light wells likely were not present in stairwells used by maintenance staff. This stairwell is similar to the one inside the Column of Trajan which, as Jones points out, was probably meant to be used by visitors as well as maintenance personnel given the presence of forty windows, ten on each cardinal axis providing adequate lighting throughout the climb [Jon03]. Furthermore, if Jones is confident that the light wells in the Column of Trajan which measured only 0.15m by 0.3m is indicative of public access then in the Baths of Caracalla, where the wells measured at least 0.5m by 1.25m, it is safe to assume that the same principle applies.

The roof of the *frigidarium*, however, may have been gabled because other similar structures were. The most prominent example is the *frigidarium* of the Baths of Diocletian – a sister complex to the Baths of Caracalla in ancient Rome – now, with alterations by Michelangelo, the Basilica di Santa Maria degli Angeli e dei Martiri. The originality of the roof of the church can be established through Karmon [Kar08], who states that Michelangelo took a 'minimalist' approach to his design and was extremely intent on preserving the ancient structure as much as possible. This is echoed by Ackerman who states that "Michelangelo left the elevations untouched" ([Ack61], p123) and through etchings by Palladio in 1550 [Cam72], Dosio in 1564 ([Sie55], p181), and Dupérac in 1575 ([Sie55], p181), which suggest that the vaults were largely intact when construction on the church began. Another comparator is ancient *basilicae*. Both the Basilica Ulpia [Pac01], and the Basilica of Maxentius (similar to the frigidarium in the *Thermae* of Caracalla [Mid05]) – had gabled roofs. When combined, all the evidence suggests the presence of a gabled roof on the *frigidarium*. Interestingly, the gabling on the *frigidarium* did make the room appear visually impressive, especially when the nearby roofs were flat-topped (Figure 3).
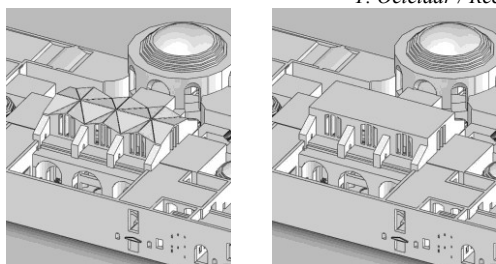
Figure 3: *(left) A pre-rendered version of the Baths showing the gabled roof on the frigidarium. (right) The same view except with a flat roof.*

Considering the size of the complex, it was not necessary to make that many broad-spectrum assumptions. This decreased the amount of introduced uncertainty associated with this reconstruction. The squaring of the rooms and equalling of the springing heights reduced the complexity of the reconstructive process considerably without affecting the overall accuracy.

4. Windows and Window Glazing

One of the more challenging and time-consuming aspects of model construction was the creation of the glazing for the windows, primarily because of the overwhelming number and size of the windows in the complex, and the absence of archaeological evidence. There are 130 windows in DeLaine's reconstruction and the smallest measures 2.5 m wide by 3.25 m high. Considering the state of glass manufacturing practices at the time ([All02]), the Roman designers would most likely have had to make the inserts from compilations of smaller panes. For the purposes of this reconstruction, the process was split into two parts: the glass and the frame. Instead of making the individual panes of glass, it was easier to make one sheet of glass fill the window opening and then overlay the frames.

One major question remained – how big were the panes, muntins, stiles, and rails? For clues one has to turn to sites outside Rome, though, there is limited evidence available. Foy and Fontaine [FF08], Allen [All02], Ortiz and Paz Peralta [OP97], and Charlesworth [Cha77] all provide overviews of Roman window glazing in many different environments. Scholars found glass panes and fragments at a number of bathing sites dated primarily between the 1st and 2nd centuries CE (see [Bas33], p407, p420; [Bar29], p60-61; [Bie85], p17; [OP97], p440, p442; [Bel96], p76; [BT03], p160; [Bou03], p187-188). The finds of Zienkiewicz ([Zie86], p1:337), Nissen ([Nis77], p135), Martini ([Mar84], p199-200), and Formige ([For22], p253-254), though, better indicate the nature of Roman bath window construction where they discovered either putty or frames or even remnants of wooden shutters. None of these studies, however, included complete information of the construction, and so the piecemeal evidence necessitated the use of interpolation. The assumption that the panes of glass were most likely multiples of the Roman foot (1 Roman foot or pes (p) is 0.297m) and that the muntins

were 5 cm established a starting point. To determine the size of the panes, the best alternative was to create a spreadsheet giving the dimensions of each window and try to fit panes of 1p, 1.5p, 2p, 2.5p, and 3p into this space to see if a pattern might emerge. Interestingly, the best fit came from panes 2.5p wide by 2p high arranged in panels with five rows of four panes each and with an adjustable space between the panels (Figure 4). The resultant window design worked for all openings in the building except for those in the top storey of the *frigidarium* and of the *caldarium*.

Figure 4: *(left) Picture of a modern reconstruction of a window in the Constantinian Baths at Arles (credit: J.W. Humphrey). (right) The reconstructed north window of 4W showing the adjustable space between panels.*

The *caldarium* windows were different because the openings were curved. Since curved glass panes were difficult to manufacture and the radius of the curve is so large, the Romans most likely broke these windows down into three equal flat sections and then paned each. Interestingly, though, because of the size differential not all sections had the same number of panes. The northeast and northwest windows of the *caldarium* were the smallest, each section having three panes across the bottom, each 2.5p wide by 2p high; the east, west, southeast, and southwest windows each had four panes 2p wide by 2.5p high; while the largest south windows had six panes 1.5p wide by 2p high (Figure 5).
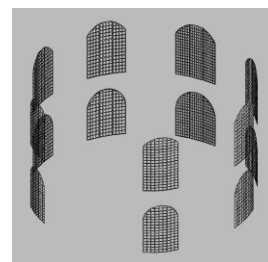

Figure 5: *The windows of the caldarium as seen from the northwest.*

5. Benefits of Parametric Reconstruction

There are many benefits to parametrically reconstructing the Baths of Caracalla. One of these goes against the air of certainty that seems to come with any digital restoration, particularly in the eyes of the public.

Since it is parametric (i.e., the dimensions are parameters instead of hard numbers), *SolidWorks* allows the researcher to make changes easily without having to redo entire pieces. This is particularly helpful when not all the data are available as was the case at the beginning of this project. In the case of Rooms 15E/W, 16E/W, and 18E/W, the initial data suggested one design but after a visit to the site and the discovery of new information the model changed. These changes were easy to incorporate into the recreation.

The other benefit of parametric reconstruction is that one can easily try new ideas that may challenge long-standing beliefs. A perfect example was the south façade of the hot rooms (19E/W-22E/W). Every known model exhibited a columnar veil in the southern openings of these rooms, which, thermodynamically, did not make any sense because any heat generated by the hypocaust would have dissipated outside very quickly. Since the doorways leading into and between these rooms were among the smallest in the complex, the Romans were obviously aware that large doors let heat out faster than small doors. If so, why have a huge opening on one side (two, in the case of 19E/W)? DeLaine recognized this fact but she did not have an answer. The archaeological record and architectural drawings going back to Palladio support the existence of columns. These columnar veils are present in both his drawings [Pal32] of the existing state (ca. mid 1500s) and his reconstructed view. However, this evidence does not preclude the possibility of a secondary paned glass wall. The walls on either side of these openings are intricate, which might support such a design. The problem with this idea, though, is the sheer amount of material that would be necessary to cover these openings. It would have taken approximately 1600 kg of bronze to make the frames and 2000 kg of glass for the south facade of Room 20W. Another possibility is window coverings, such as shades, but this negates the main reason for the southern exposure – solar heating. While these two ideas have their flaws, the point is that one can test these methods digitally.

6. Conclusion

This digital reconstruction of the Baths of Caracalla relied heavily on the work of DeLaine. Her composite of dimensions, along with her scale drawings, provided the baseline data. Even with these data there were perplexing aspects and missing elements, which necessitated some modifications. At the same time, the model is not static and will require modifications as new data come to light. This is where the benefits of parametric modelling become apparent. As new data become available, the reconstruction can easily be adjusted. Although parametric CAD has this flexibility and represents the geometry of a structure accurately for thermofluid analyses, the program does not easily accommodate artistic details or virtual reality without the help of additional software such as Autodesk's *3ds MAX* and McNeel's *Rhino*.

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