TOTAL RECALL: A PLEA FOR REALISM IN MODELS OF THE PAST

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ABSTRACT:

Computer technologies make possible virtual reconstructions of ancient structures. In this paper we give a concise overview of the techniques we have used to build a detailed 3D model of the Antonine nymphaeum at the Sagalassos excavation site. These include techniques for 3D acquisition, texture modelling and synthesis, data clean-up, and visualisation. Our aim has been to build a maximally realistic but also veridical model. The paper is also meant as a plea to include such levels of detail into models where the data allow it. There is an ongoing debate whether high levels of detail, and photo-realistic visualisation for that matter, are desirable in the first place. Indeed, detailed models combined with photo-realistic rendering may convey an impression of reality, whereas they can never represent the situation like it really was. Of course, we agree that filling in completely hypothetical structures may be more misleading than it is informative. On the other hand, often good indications about these structures, or even actual fragments thereof, may be available. Leaving out any structures one is not absolutely sure about, combining basic geometric primitives, or adopting copy-and-paste methods – all aspects regularly found with simple model building – also entail dangers. Such models may fail to generate interest with the public and also if they do, may fail to illustrate ornamental sophistication or shape and pattern irregularities.

1. INTRODUCTION

Virtual 3D models of monuments and constructions that have largely disappeared offer great potential. They are useful to scholars as a basis for discussion and hypothesis verification, and are an effective presentation to the public of their cultural heritage. This said, the level of precision and photo-realism at which one ought to try and produce such reconstructions is disputed. Some warn that the more compelling a reconstruction is, the more the general public may take the correctness of every detail for granted, even if part of the reconstruction is based on not much more than a dedicated guess or one among several hypotheses.

We recognise the relevance of these caveats concerning high visual realism. It should for instance remain possible to visualise the levels of uncertainty in the different aspects of the reconstruction. Rationales behind particular completions and choices should be documented, preferably also as annotations to the model, so that users have direct and easy access. These issues have also been raised by (Forte, 2000), a pioneer in 3D modeling of cultural heritage: 'Noticeable gaps are represented by the fact that the models are not 'transparent' in respect to the initial information (what were the initial data?) and by the use of peremptory single reconstruction without offering alternatives'. Yet, we see at least as big a danger in oversimplified models, and this is what the alternative has often turned out to be in practice. These can be misleading in at least two ways.

On the one hand, copy-and-paste strategies have been popular in the production of such models, but these create unrealistic regularity in shapes or patterns. This may convey a false impression of technological sophistication. Also, such models tend to be produced by starting from a library of predefined, geometric primitives. Perfectly planar walls, precisely cylindrical arches and pillars, repetitions of identical tiles or decoration, etc. tend to be a far cry from actual variations in handcrafted elements.

On the other hand, omissions could have the opposite effect in that they often fail to do justice to the true level of decoration of a structure or to the intentions of its creators. One can leave out colors on Greek buildings, for instance, thereby perpetuating one of the most persistent misconceptions about their original appearance. Even if there may be uncertainty about which color ought to go where, making occasional mistakes in the coloration may well be the lesser evil. Similarly, even if one is not absolutely certain about the ornamentation found in certain parts of a building, it may be better to make a dedicated guess at its original state than to simply leave it out. Quoting (Barcelo, 2000): 'VR is the modern version of the artist that gave a 'possible' reconstruction using water-colours'. One only has to think of the Halicarnassos mausoleum to have a vivid example

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of how widely such hand-drawn reconstructions could be (Müller, 1966).

In this paper, we want to build a case for detailed reconstruction. Often more is possible than building sketchy representations and one can go as far as virtual anastylosis, with additional 'repairs' that are unacceptable if carried out for real. We take a nymphaeum (monumental fountain) at the ancient city of Sagalassos as a case in point. Technology is now available to produce such reconstructions with relative ease and at reasonable cost. Huge costs and efforts involved in producing high quality models may actually have often been the initial reason for not going further in the level of detail and visual realism. Principled objections against such models may sometimes have come rather as an afterthought. Also, in the case of the Sagalassos nymphaeum that we present as a case in point here, it is important to realise that the plan to produce a physical reconstruction has helped greatly in ensuring that as many parts as possible have been retrieved and put into context. Virtual reconstruction technology will make similar care in excavations worthwhile in cases where physical restoration is not attempted.

Moreover, we believe maximally detailed, virtual reconstruction to be well in line with international guidelines, whereas physical reconstruction would only be so in the rarest of cases, when an anastylosis project is possible. Even if the latter is possible, it remains a very time consuming and expensive option.

- Following the ICOMOS (ICOMOS, 1999) 'Managing Tourism at places of heritage significance' (10/99) it is important to make a visitor's experience 'worthwhile, satisfying, and enjoyable' (Principle 3). Realistic reconstructions can greatly increase the level of understanding and involvement. This argument quickly gains importance as new generations are getting used to impressively realistic images in movies and games. How enticing can a simplistic model be to them?

- Detailed reconstructions can also help to realise the Charter's Principle 6, that insists to 'relieve the pressures on more popular places by encouraging visitors to experience the wider cultural and natural heritage characteristics of the region or locality'. By offering virtual reconstructions, sites or monuments with a lower degree of physical reconstruction can be made more attractive. Reconstructions at Knossos may not be among the archaeologists' favourites, but they definitely are a big hit with the general public. How to turn other sites into similar success stories without equally far-reaching physical interventions if not through exciting virtual models?

- Also the Council of Europe Convention (Convention, 1985) for the Safeguarding of European Architectural Heritage (Grenada, 10/85) calls for efforts to make visits enjoyable, and emphasises that information and sensibilisation policies should be based on the latest technologies for communication and animation (Art. 15, Art. 17.3). As we will argue, both computer vision and computer graphics have progressed to a degree that they can provide strong support to such endeavours.

- Such technologies can also help to relieve the tension between making heritage accessible and enjoyable for the visitors on the one hand, and the guideline that physical restoration should be minimal, i.e. only those parts ought to be reconstructed physically for which there is no uncertainty and where sufficient, original components are still available and are not occluded by constructions at a later era. Modern additions should be clearly recognisable as such. The latter principles are stated in the Venice Charter (Venice, 1964) for the Conservation and Restoration of Monuments (Art. 9, 11, 15). These guidelines tend to 'spoil' the experience a visitor may want to have, but virtual reconstruction can make up for this 'loss', and go beyond.

- The Ename charter (Art. 19) possibly yields the strongest support for detailed reconstruction: 'The construction of 3D computer reconstructions and Virtual Reality environments should be based upon a detailed and systematic analysis of the remains, not only from archaeological and historical standpoints but also from close analysis of the building materials, structural engineering criteria and architectural aspects. Together with written sources and iconography, several hypotheses should be checked against the result and data, and 3D models, 'iterated' towards the most probable reconstruction.' (Ename, 2002)

2. THE VIRTUAL ANASTYLOSIS OF A BUILDING

2.1 Overview

In the introduction, we have defended efforts to produce detailed 3D reconstructions. Here we report on the 3D reconstruction of one particular building, which poses a number of interesting challenges. This is the nymphaeum (ornamental fountain) at the upper agora of the ancient city of Sagalassos, about 100 km to the north of modern Antalya.

Figure 1. Sagalassos in southern Turkey

The excavations at Sagalassos are among the largest archaeological projects that are ongoing in the Mediterranean. The site is extremely interesting, as Sagalassos was a prosperous city from early Hellenistic times until it was struck by a devastating earthquake in the 7th century. After having been inhabited for more than thousand years, the city was abandoned and disappeared into oblivion. The nymphaeum was erected during the Roman era of the city, more in particular during the reign of emperor Marcus Aurelius (AD 161-180).

Figure 2: Photographs of the nymphaeum in its current state

Figure 3: Virtual reconstruction of the nymphaeum

Fig. 2 shows images of this building in its current state (result of the ongoing anastylosis project).

Fig. 3 shows images of the overall reconstruction. The goal of this building clearly was to impress. It is a bit atypical in that most nymphaea of this period were two-storied buildings. This building only has one story however, perhaps due to the constant risk of earthquakes. The building stands on a limestone podium rising 1.85 m above the agora which it flanks at the northern side. The total length of the podium is about 28 m.

There are six projecting sections with five recesses. Inside these recesses, the podium is only about 1 m wide, whereas the two outside parts project appr. 4 m, while the width at the four central parts is appr. 2 m. During the course of its history the building has been partly dismantled, repaired, and modified, probably because of an earlier earthquake.

As part of these changes, the socle mouldings in the niches were partly removed to make room for sculptures and pedestals inside, which the original podium width of ca. 0.4 m would not have allowed. The central curved niche, crowned by a fluted concha, had one projecting console in its upper part from which the water fell in a cascade to fill a basin of 81 m^3 capacity. Excess water flowed over the top of the basin, where it could be collected in jars. The larger lateral aediculae each held four columns in two rows, the other aediculae held only a single row of columns. The monolithic columns, about 3.35 m high, had Attic-Ionic bases and Corinthian capitals. They carried an entablature of architrave and frieze blocks, and a cornice. These six aediculae supported richly decorated pediments. The pediments of the lateral aediculae had a double S-shaped outline decorated with opposed volutes, while those on either side of the central niche were curved and decorated with Gorgoneia (Medusa heads). The second and fifth pediment were triangular with a similar decoration. Inside, the aediculae were roofed with large horizontal slabs, with coffers decorated with theatre masks, heads of mythological figures, or floral motifs. The height of the nymphaeum was ca. 7 m in the niches and 7.8 m in the aediculae. A total of 17 different materials (different types of breccia, limestone, and marble) were combined into a splendour of natural colors.

The virtual reconstruction was based on

1. expertise of the archaeological team concerning the architectural style of the period (the determination of which is supported by archaeological evidence) and of the region
2. photographs of the remains of the building
3. architectural drawings of the building, produced as part of the documentation of the excavations and of the preparation of the building's anastylosis. These were made with the help of a total station.
4. 3D reconstructions of parts, using both passive and active techniques
5. textures, synthesised on the basis of sample images of intact material
6. comparison with contemporary monuments elsewhere

The reconstruction intends to reflect the state of the building around the middle of the seventh century AD. Excavations on the nymphaeum started in 1994. More than 90% of the building elements have been found, albeit more often than not in a seriously damaged state. The finds have been documented through a large set of photographs and drawings.

2.2 Shape-from-stills

This already allowed us to build some reconstructions directly from the photographic material based on our 'shape-from-stills' pipeline (Van Gool, 2002). It needs as its input a series of sufficiently overlapping photographs, from which it automatically extracts the camera parameters and positions, as well as the 3D structure of the photographed object. It can be considered to be a generalisation of the self-calibrating structure-from-motion approaches, which tend to use video data. (Pollefeys, 2002) Not only is the acquisition of stills typically easier, the images can have far higher resolution, which then translates into higher 3D model quality. The price that one has to pay is that wide-baseline correspondences need to be found, which is a much harder problem than the usual tracking of features between consecutive video frames. We also found it necessary to systematically take radial distortions into account.

2.3 1-shot, structured light

Apart from this 'passive' 3D extraction technique, we also used Eyetronics' ShapeCam (Eyetronics, 2004). This structured light device was used for some of the highly decorated elements, where the geometry could be quite intricate (e.g. for part of the statuary). This system is shown in fig. 4.

Figure 4: Top: The ShapeCam system consists of a flash projecting a grid and a camera. The camera takes an image from a direction that is slightly different from the direction of projection. Bottom: A regular square pattern is projected on the scene, as seen in this detailed view. 3D co-ordinates are calculated for all the line intersections, resulting in the simultaneous measurement for thousands of points.

An early version of this system had originally been developed in our computer vision lab in Leuven. A grid is projected onto the object by the use of a flash, simultaneously an image is taken, and from the grid's deformation in the image, a complete surface patch is reconstructed in 3D. In both cases – shape-from-stills and the ShapeCam – the apparatus is easy to carry around. As a matter of fact, the camera that is part of the ShapeCam can also be used to take the input for the shape-from-stills technique. From the point of view of the archaeologists, 3D shape extraction only requires taking images with a normal camera.

Figure 5: The scanned Medusa before and after scan post-processing

2.4 Post-processing scans

Several of the extracted models had to be post-processed. On the one hand, damage to the physical elements had to be digitally restored. On the other hand, 3D data coming from the ‘shape-from-video’ and ‘shape-from-still’ pipelines are not always of sufficient quality for close-up shots. The problematic 3D models were manually enhanced using surface editing tools for polygonal objects, which are readily available. We used Alias’ Maya (Alias, 2004), which has excellent edit tools like surface smoothing, sculpting and stitching. Fig. 5 shows on the left raw 3D data, which first have to be stitched together. In the next step, the surface was smoothed to remove noise (resulting from the shape-from-video method) and the effects of erosion.
The damaged snake (= big hair curl) of the Medusa was restored by using Maya's sculpting tool. The resulting surface rendered with its texture is shown in figure 5 on the right.

Some architectural elements of the Nymphaeum (e.g. the decorations on the aediculae) contain so much detail (cavities) that their structured-light scans contain holes and yield enormous polygon counts (see top of fig. 6). In addition, most of the fine elements are damaged. While holes can be filled with cleanup software like Paraform (Paraform, 2004) and high resolution models can be reduced with e.g. Maya, a combination of all three aforementioned unfavourable characteristics makes restoring difficult: the reduce functions imply an unacceptable data loss and editing the cleaned high resolution surfaces is too time-consuming and too complicated. In addition, today's computer hardware is still too slow. Hence, we propose restoring such surfaces via depth map painting. Fig. 6 illustrates the process: in a first step, a depth map is rendered (for non-planar objects, the depth map can be extracted patch-wise with more sophisticated methods like the one proposed by Krishnamurthy and Levoy (Krishnamurthy, 1996). Then the depth map can be easily retouched with image manipulation software like Photoshop (Adobe, 2004) by using the common painting, drawing, and retouching tools. Finally, the restored depth map is converted back into a polygonal surface (or the depth map can be stored as bump/displacement map). For each of these steps several alternative software solutions are available.

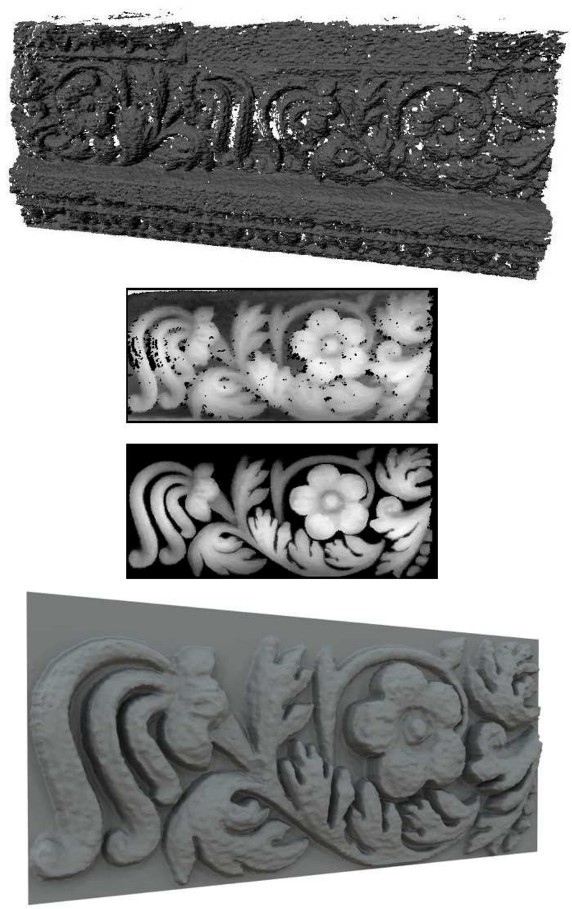


Figure 6. Restoration of the scanned decorations via retouching of the depth map.

2.5 Texture synthesis

As already pointed out, many elements are damaged in the sense that parts have broken off. But the surfaces are also eroded. As a result, the original textures and colours have disappeared. Even if 3D shapes are retrieved and restored, the texture to cover them with in order to restore the full, original appearance cannot be obtained from their available imagery. We have in this case wetted the least eroded parts for some materials to mimic the effect of polishing, and have taken images of undamaged surfaces of the same materials but not found at the site for the remainder. Based on such images, texture models were generated and used to produce arbitrary amounts of similarly looking texture (Zalesny, 2001). A total of 17 different building materials were used in this building. Fig. 7 shows example images for some materials, as well as synthetic texture patches based on these examples. The necessary amounts of synthetic texture were then generated for each type, and with the necessary patch shapes to cover the elements to which they apply.

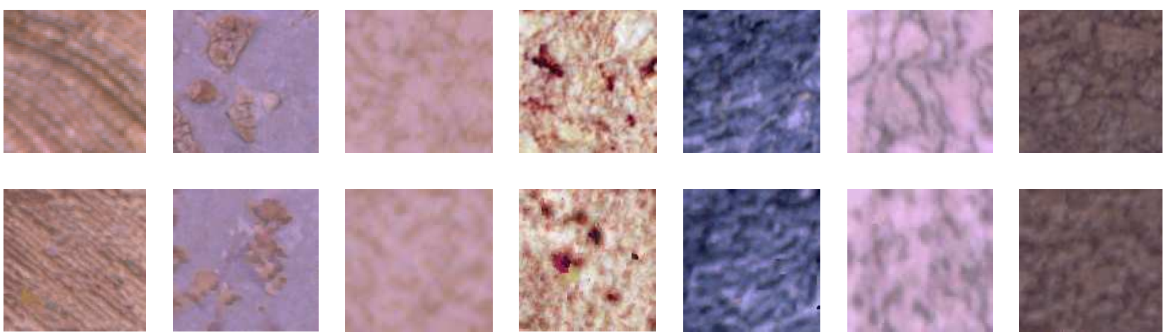
Rather than describing these 3D modeling and texture synthesis techniques any further, we here describe the additional steps needed to put the components together into the final model.

2.6 Assembling the components

With blueprints (figure 8, top and middle left) as guidance, we put all components together within Maya.

Of course, some elements couldn't be scanned, because they are still missing or have been destroyed. Moreover, even if the 3D capture technology is easy to use, scanning every block from all sides is still too expensive (pieces would have had to be moved with a crane). Therefore, the lacking components have to be modeled by hand using common modeling methods like: curve drawing and extrusion (translational sweep), solid modeling and booleans, cutting tools, bevel tools, deformation etc. Further reading on these methods can be found in numerous books (e.g. Mortenson, 1985), software manuals (e.g. Alias, 2004) and papers (e.g. Sederberg, 1986). Fig. 8 shows in the middle on the right the hand-modeled back wall and the basin of the Nymphaeum. The image on the bottom shows the fully assembled monument.

To simplify the manual modeling process, 3D scans can also be used as a shape outline one can constantly refer to. The efficient and cost-effective nature of the ‘shape-from-stills’ pipeline allows for this luxury. In addition, such coarse scans are much easier to make than technical drawings for every construction layer. Fig. 9 shows at the top the aligned scans and in the middle the reconstructed model. Having both models, difference functions can be calculated automatically and visualised on the models, for example fig. 9 on the bottom: the grey areas highlight the parts that had to be extrapolated from other archaeological data, mainly from other pieces of the nymphaeum. Such representation gives an idea of local uncertainty about the model.



travertine deposit	limestone with chert nodules	limestone breccia 1	limestone block with pink stylolths	marble from Dokimeion	“white” crystallized limestone	limestone breccia 2
(type 10)	(type 3)	(type 8)	(type 1c)	(type 6)	(type 5b)	(type 8)

Figure 7: Example images of building materials (top) and synthetic textures (bottom) based on models extracted from these examples.

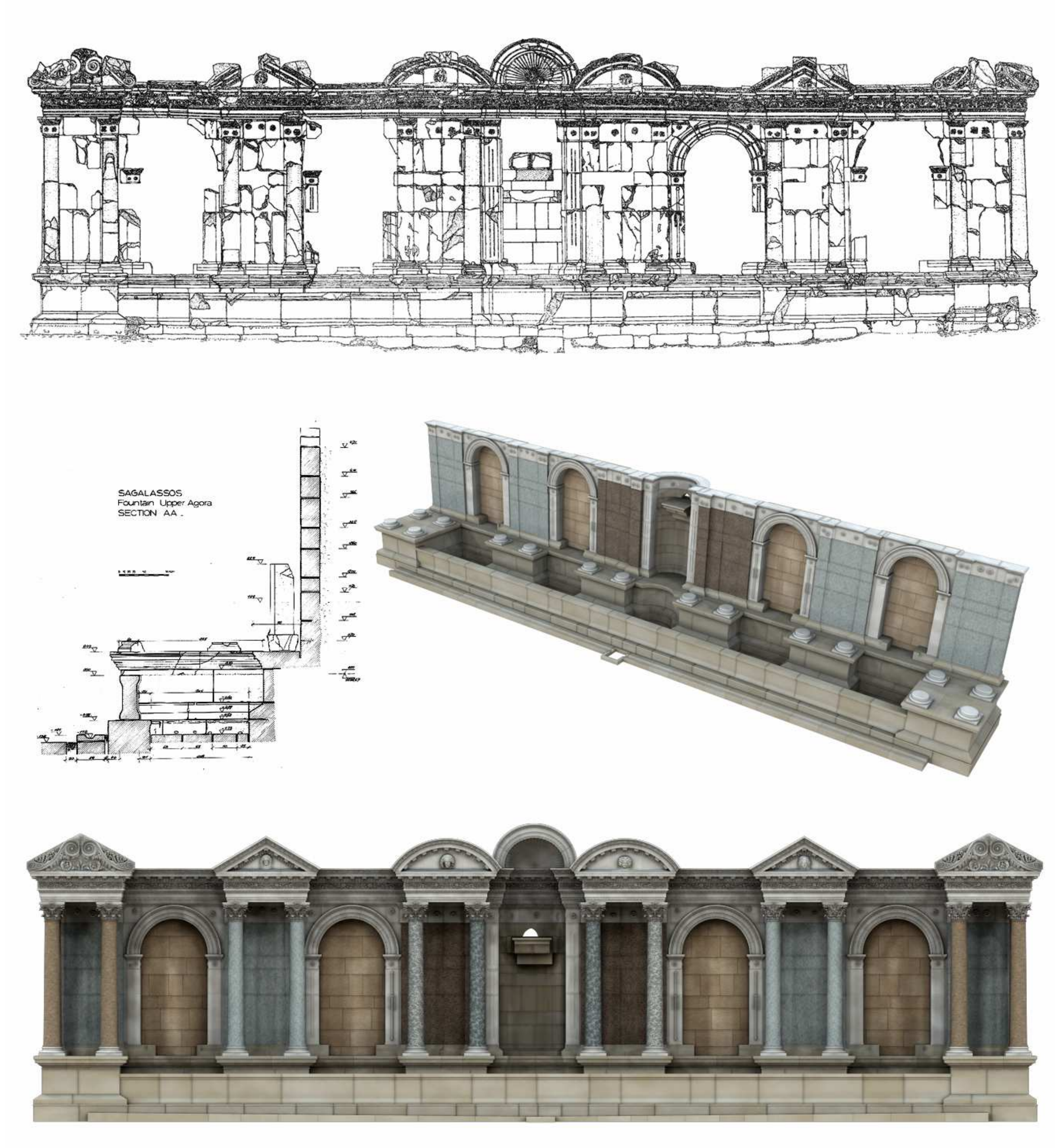


Figure 8. Blueprints have been used to model the missing elements and put all components together.

Figure 9: Comparison of captured 3D data (top) and the reconstructed model (middle) for the aediculae. High intensities in the bottom figure correspond to large differences between these two and hence large uncertainties.

Figure 10. Panoramic image, which has been used for lighting the model

2.7 Rendering

To render the model, we applied the following two methods. The first method, which fakes global illumination, is very popular in the visual effects industry due to its fast render times. The conventional technique to obtain a faked global illumination which approximates atmospheric diffusion, is to use a light rig of spots with shadow maps. The result is interesting, as there is a sensation of light coming from every point of the space and the general feeling is that of a gloomy cloudy day. Fig. 3 was rendered using this method.

The second method we used, is a combination of ambient occlusion with image-based lighting. The image-based lighting was based on the panoramic image of the monument's surrounds (shown in figure 10). The ambient occlusion approach yields extremely realistic shadow effects for outdoor scenes by computing single bounces of indirect light on diffuse surfaces. This makes it a perfect match for image-based lighting. It adds detail in areas of the scene with many edges and sharp light variations (see figs. 11, 12 and 13).

Fig. 14 shows the same shot rendered with the two methods side by side. While the picture on the top took 7 minutes to render on a modern PC, the picture on the bottom took more than 2 hours. Therefore, the first method has been used for the movies that we have produced, whereas the more sophisticated second method was only used for some of the stills.

Figure 11. Fourth pediment from the left. The image shows several of the motifs that are repeated all across the aediculae. Close-ups of these are shown in the bottom two images.

Figure 12. Second pediment from the left. The figure also shows some additional ornamental motifs, including the Corynthian capitals. Close-ups are shown in the bottom two images.

Figure 13. Second niche from the left

3. FOLLOW THE GUIDE…

We hope that the detail in the model makes it interesting for the public to explore this virtual building. It is impossible to show all parts of it in this paper, but we will take the reader on a short guided tour that highlights a few spots where fidelity to detail will be seen to matter.

A first example is the 4 Medusa heads on the 4 middle pediments. When seen from a sufficiently close distance, it becomes immediately clear that their quality is quite different. Facing the monument, quality goes up from left to right. In ancient times, it would have been from the right that one would have entered or left the agora. Hence, it is the Medusa on the right that one would typically have seen most up-close. Fig. 15 shows the first and the third Medusa head. As can be seen, the head at the top is more a bas-relief than a truly 3D head like the one at the bottom, that really sticks out of the back plane and tilts over to have it look down onto the square. The difference in artistic quality is obvious. These differences are most probably not accidental, but may have to be interpreted in relation to their relative visibility for the typical visitor of the square.

Figure 14. Comparison of the two rendering methods: On the top 'faked global illumination', on the bottom 'ambient occlusion'.

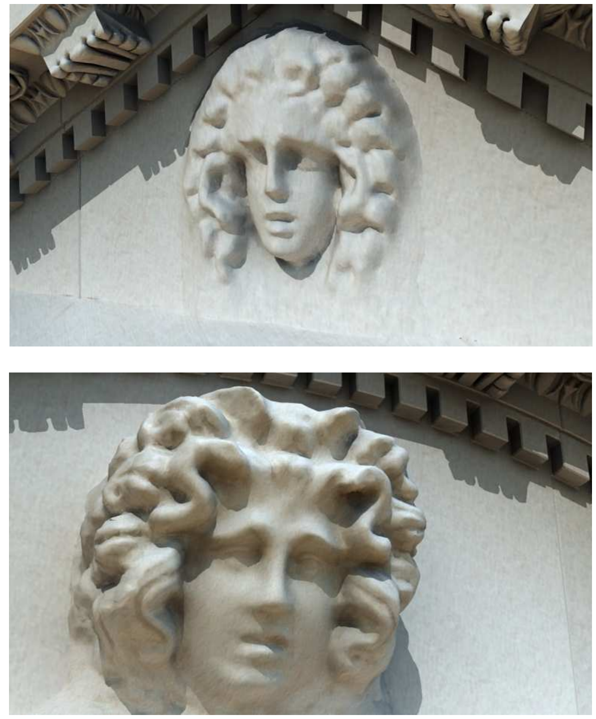


Figure 15. Close-ups of the first (top) and third (bottom) of the Medusa heads, counting from left to right, showing the difference in quality.

We have raised the issue of exaggerated regularity and symmetry that is typical for simplified models. In fig. 14 one can e.g. see that below the head the back plane surface is rounded near the bottom, rather than forming a straight angle with the border of the pediment like everywhere else. To an observer on the agora, this rounding off would not have been visible, however, and thus time and money were saved. At several places in the monument, the lower parts of the gables, not visible from below, were left unfinished in this way.

Again referring to fig. 14, it is interesting to notice the irregularities in the relative placement and the sizes of the dentils on the back plane above the Medusa head. These virtual dentils follow the captured 3D data closely. This is an example of a deviation from expected symmetry and repetition.

Similarly fig. 16 illustrates how the shapes of the arches above the niches show noticeable deviations from a pure semi-circular shape. Again, the actual level of symmetry is lower than one might expect.

Furthermore, several aspects of the building have never been finished. Fig. 17 shows the second niche (from the left). The thyrsus staff on the left has not been carved out completely (compare with the complete pattern on the right). It was merely started.

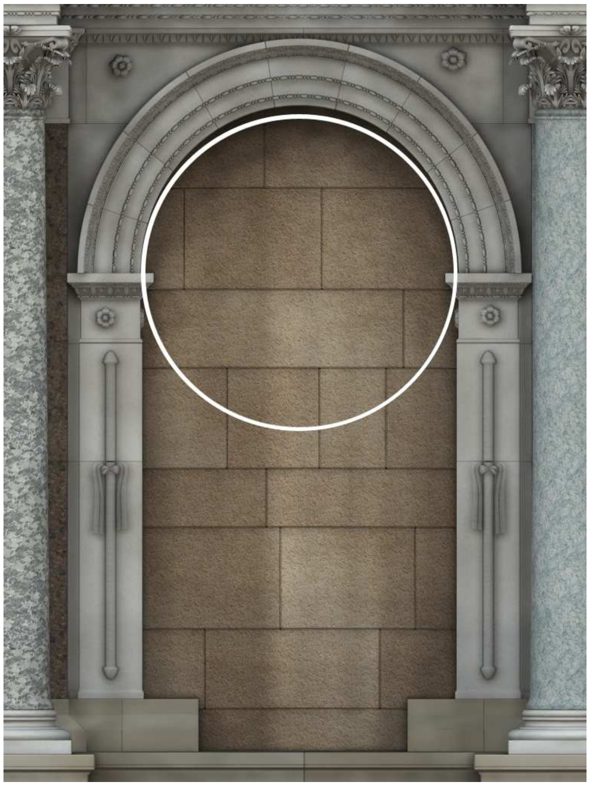


Figure 16. The arch above the third niche (from the left). The deviation from perfect circularity is clear.

Figure 17. Example of ornaments left unfinished. The thyrsus staff pattern on the left never made it beyond the initial stages of carving. Bottom: details of the staff pattern

The style of the ornaments allows an inference for the construction date of the original monument to be made. Their detailed, fully 3D inclusion into the model (e.g. figs. 11 and 12) is therefore not without importance, also for the scholar. At Sagalassos, the closest parallels for the decoration of the nymphaeum can be found in the cornices of the NW shrine, dated to the middle of the second century AD. The motifs on the nymphaeum however have often evolved slightly further. On the one hand, the decoration on some blocks is very plainly executed, an evolution which had begun on the NW shrine (Vandeput, 1997b). On the other hand, the finely dented Acanthus is widespread, and the acanthus, the floridly-carved palmettes and the scrolls are executed following exactly the same method so that the distinction between these motifs is diminishing.

Motifs such as the scroll and the acanthus are more disconnected than corresponding decoration on monuments from around the middle of the century. Both decoration motifs now appear to be built up of several independent parts, a characteristic, which returns on monuments from the second half of the second century AD elsewhere. The lack of natural qualities in the scroll, for example, and the very plain treatment of motifs on the blocks of the nymphaeum, together with the extreme relief of the rosettes on the pilasters and in the coffers, all clearly designed to produce strong patterns of light and shade, seem to indicate a later date than the middle of the second century. The best parallels for acanthus and Corinthian capitals, for example, occur on monuments such as the Faustina Baths at Miletos (AD 160-170) and the Agora Halls at Smyrna, restored after AD 178. Motifs with strongly serrated outlines also seem to occur especially from the Antonine period onward. Some motifs on the nymphaeum, such as the leaf bands on the soffits, even seem to presage Severan decoration. Taken all together, a date in the middle Antonine period (AD 160-180) seems most probable (Vandeput, 1997a).

The building on the whole represents the culmination of a tendency towards polychrome architecture at Sagalassos, with the Temple for Hadrian and Antoninus Pius as a precursor, with its combination of 2 colors. (Waelkens, 2003) Hence, fidelity of the textures in the model is crucial.

4. CONCLUSIONS

In this paper, we have tried to build a case for photo-realistic and detailed 3D modeling. On the one hand, cost-effective technologies are becoming available to make such approach affordable at a larger scale. On the other hand, such models offer a richer experience for the public, and in fact also for the scholar. We have presented a 3D model of the Antonine nymphaeum at Sagalassos as a case in point.

Of course, the creation of such a model still represents a substantial effort. One of the goals of the European Network of Excellence EPOCH (Excellence in Processing Open Cultural Heritage (Epoch, 2004)) is to help streamline the process, in order to further reduce the necessary efforts and to ensure compatibility between and easier access to different technological modules.

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