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Multiple uses of 3D scanning for the valorization of an artistic site: the case of Luni

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Abstract

The heritage site of Luni is a very interesting location, which tells the story of an ancient roman colony, and of an area where different cultures left their heritage. In particular, the remains of the pediments of an ancient temple represent a very interesting case and an open field of study for art historians. The scanning of a group of statue belonging to the pediments showed that the produced 3D models could be used in several ways, not only for archival and presentation purposes but also to provide interactive support for the work of the restorers and the scholars. In particular, the use of 3D models to propose and validate hypothesis about the original position of the fragments in the context of the fronton could be an alternative solution to the direct manipulation of them. Moreover, the analysis of the original color of the statues, and the representation different hypothesis about the ancient appearance can be produced through the interactive editing of the 3D models of the statues. In this paper we present the scanning campaign which resulted in the acquisition of five statues,the preliminary results of some of the uses of the models produced with acquired data, and a brief description of other possible future applications of them. This shows how 3D scanning can be considered by now a mature technology for the support of restoration and preservation of Cultural Heritage.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Line and Curve Generation

1. Introduction

Cultural heritage has been one of the main application fields of 3D scanning right from the beginning of the development of this kind of technology. This was due both to the worldwide visibility of a project like Digital Michelangelo, and to the potential application of it to non-contact production of copies. During the last few years, thanks also to the progress in hardware capabilities and software algorithms, 3D scanning proved to be a very powerful technique to bring out the potentials of works of art and to support the activity of art historians and restorers. In this paper we present the very interesting case of the terracotta statues from the Luni great temple, conserved at the National Archeological Museum in Florence, where 3D scanning has been used in several ways for the valorization of the remains and for the support in the creation of a project proposal for a comprehensive valorization of this important roman colony. After a brief overview of related work (Section 2) and the presentation of the story and perspectives of Luni (Section 3), in Section 4 and 5 we present the scanning campaign and some results of the possible uses of the obtained 3D models, together with other future potential applications. Finally in Section 6 we present our conclusions and some indications for future development.

2. Related Work

Since from the seminal project of Digital Michelangelo [LPC*00] Cultural Heritage proved to be a very promising application field for 3D Scanning. Some of the most important monuments in the world [Deb04] were involved in projects where laser scanning was the main technology involved.

3. The Luni statues: the story so far and the perspectives

The roman colony of Luni was founded in 177 BC during the wars between the Romans and the Ligurians. It was the only port of large scale commerce of *Apuan* marble, know in the antiquity as *Lunense* marble. Greeks named the city Selene, the divinity identified by Romans with *Diana-Luna* (the moon divinity). The *Portus Lunae*, already used by Etruscans as naval base, was described in the I century BC by historian Strabone. Nowadays this landing place has disappeared, filled up by the sediments of Magra river, and its key role for marble commerce has been inherited by Carrara-Avenza port.

At the moment of the foundation of city, a goddess *Luna* temple and a *Capitolium* (on the model of the Roma one) were built. The structure of the temple (see Figure 1) and a considerable amount of its terracotta covering are known. In particular, two high-relief group of statues of the pediment distinguish themselves for the qualitative level and the state of conservation (see Figure 2 for an old presentation of them).

One of them, the “Frontone A", has been completely reconstructed. Of the other one, “Frontone B", lots of fragments have been found, but no convincing reconstruction has been proposed yet. The fragments are composed by seven almost complete figures, thirteen large fragments and nearly fifty smaller fragments. Several reconstructions of this pediment have been proposed, but none of them has resulted convincing enough.

An exposition of the two groups is expected in the near future [DDG*06], in order to conclude a project settled by Tuscany and Liguria Cultural Heritage Superintendencies. In the context of this project the production of a scale 1:1 copy of Frontone B has been programmed. This reproduction will possibly be put in Luni archeological site, together with the already existing copy of Frontone A. In order to provide support to the work of archeologists and restorers, a 3D scanning of all the fragments of Frontone B will be put in practice. Acquired data will be used both for presentation and to provide new tools to help experts in their reconstruction work. The scanning campaign, the already exploited uses of 3D models and their possible future applications are shown in next Sections.

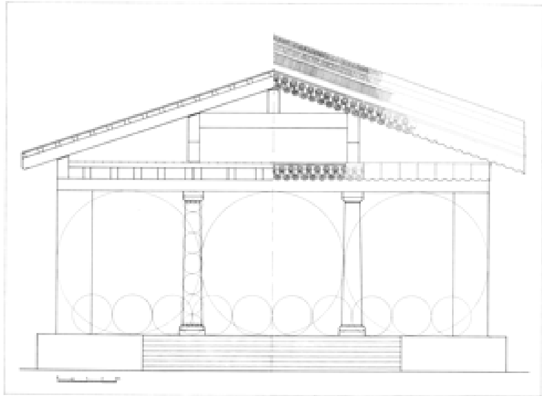

Figure 1: *An hypothetical reconstruction of the Luni Temple from [DSe04].*

Figure 2: *The “Frontone B" group of terracotta from the Luni Temple, according to the old presentation in the National Archeological Museum in Florence (status before the 1966 flood).*

4. 3D scanning campaign

A first scanning campaign was performed in May 2008: the acquisition lasted 4 days. Five statues (shown in Figure 3) plus two important fragments (an arm and a hand) were scanned, for a total number of more than 900 scans.

Some data about each of the acquired objects are shown in Table 1. The range maps were processed using non-commercial tools [CCG*03], producing models at different resolutions. Then groups of images were registered to the models [FDG*05] so that the color information could be projected on the geometry [CCCS08]. Screenshots of the post-processing work are shown in Figure 4.

The post-processing work (alignment of range maps, merging of models, registration of images, color projection) took nearly two weeks to be completed.

The addition of color information resulted in a much more realistic appearance of the models, facilitating for example the distinction between the original parts of the statues and the integration parts.

Some screenshots of the final results are shown in figures illustrating next Section.

Statue Name	Height (cm)	Range maps	Faces for final model	Projected photos
Selene	110	247	5.4 M	13
Cornucopia	105	193	4 M	10
Musa 1	90	153	3.7 M	15
Musa 2	65	140	4 M	8
Apollo	120	185	5.7 M	15

Table 1: *Some data of the statues acquired during the first acquisition campaign (May 2008)*

Figure 3: *The five acquired statues of the "Frontone A" group, displayed in the proposed disposition hypothesis*

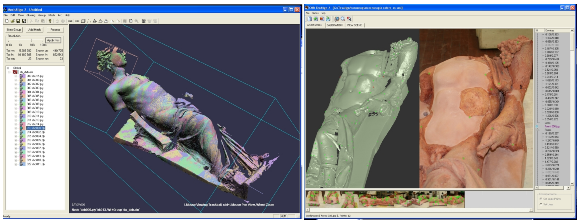

Figure 4: *Screenshots of the tools used for range maps alignment (right) and image registration (left)*

5. Multiple uses of 3D scanned models

The digital models can have various uses in the context of cultural heritage management and restoration: since they are a reliable and complete documentation of the artifact (much more descriptive than a series of photos), it is possible to use them as a way to locate and archive information on the 3D surface, plan restoration action, generate technical drawings and so on. All these usage, however, has been largely addressed in other projects we have been involved in the past, like [CCG*04]. In this section we will present some *specific* use of these digital models which address particular needs of this complex.

5.1. Rendering and presentation

Having the 3D digital models, we were already able to generate high resolution images and in-scale orthographic prints for technical documentation or restoration purpose [CCS*06]. However, what we needed was a way to use the 3D models for a more choreographic presentation of the artifacts. Most of museum nowadays integrates the exhibition with multimedia material that visually illustrates the history and the peculiarities of some important objects. Beside the pure aesthetic value, these multimedia can also be effectively used in order to better present some kind of information that can be hard to show in the exhibition without a large investment in space and material, like the reconstruction of the original setting or appearance of the artifact. Since the large diffusion of computer generated movies, the public is quite familiar with this kind of technology, making this kind of enriched exposition more easily accepted.

In this particular framework, we isolated three main features that could have been effectively exploited in a computer-generated video:

The artifact positioning: even if in the museum the statues will be placed at eye level to enable inspection from the public, in origin the group was placed in the temple pediment. The shape and arrangement of the group heavily depends on the fact that was to be placed high on the building facade, being visible mainly from below. The original position can be easily reconstructed in a computer generated movie, also enabling visitors to see the artifact as it was originally meant to be seen.

The group composition: each statue has been modeled and cooked independently but they have been made in order to closely fit together in a single, very compact group. In a video it is possible to place the user attention on both of these aspects, presenting first each statue independently and then later as a group, while on the real exposition only one of those two aspects can be exploited. Thanks to the freedom of movement of the virtual camera it is also possible to give a better view of the statue details and of the tight fittings.

The original appearance: despite the actual bare appearance, the statues of the two group were painted. Beside providing a physical colored copy, digital media is the best candidate in order to present to the public which was the original appearance of the group.

For the realization of this animated short, we choose to use a free 3D modeler and renderer, Blender [Ble08]. We used Blender to compose the simple scenes, choose surface materials, arrange lighting and generate the camera paths and animations.

The sequences in the short movie has been designed to show the five statues as a series of independent artifacts (with detail close-ups on each statue), then the grouping of the statues in a single decorative element and its positioning high in the temple pediment. All the side elements (objects supports, floor and walls, the temple reconstruction) has been kept as schematic as possible, using simple geometry and shading, in order to focalize the attention of the viewer on the artifacts.

The color used in the short is the one that has been produced with the photographic mapping, as described in the previous section. Regarding the surface material representation, the rough diffuse nature of the terracotta has been well simulated using an Oren-Nayar shading. The properties of the material has been hand-tuned in order to obtain a result that closely matched. Accurate measurements of the surface response have been considered, but we found it excessive for this kind of presentation.

Figure 5: *Three frames of the short movie generated from the digital models. All the frames comes from the sequences that shows the details on each statue*

For the generation of stills and animation, we used an open source rendering engine, YafRay [Yaf08] that integrates quite well in the Blender framework. With this rendering engine we were able to obtain a better image quality, with more appealing shading, but at the price of a longer rendering time with respect to the blender integrated engine. Each frame of the animation required a computation time of approximately 20 minutes; we used multiple PCs to render each scene independently. The final montage, like in real movies, was made at the end, by assembling the various sequences in an video authoring tool.

Each scene was composed by the digitized 3d models, plus very few side elements, in order to keep the attention close on the artifact. We used 3D models of various complexities, from 300k to 2 million triangles depending on the number of the objects and the camera distance in each scene, trying to have in each shot the maximum possible detail. This was not an easy task, since most of the modeling and rendering software are not able to deal with very complex geometry as the one we had to work with. Both Blender and YafRay proved to be excellent at handling such large data.

5.2. Reconstruction of original position

An open issue in the reconstruction of the temple group is the relative placements of the statues and of the fragments. in the course of the years some different arrangements has been proposed, but there is still room for discussion.

The work of finding a proper positioning is quite time-demanding, requiring continuous updates and validations of the arrangement. Since working directly with the actual statues it is both impractical and dangerous for the continuous manipulation of the already fragile artifacts, the experimental work is often carried out using photos or drawing of the objects.

The positioning is guided by two main lines of reasoning: historical and geometrical. the statues in a temple pediment normally depicts one “canonical" scene from the mythological tradition, making it possible to recognize the identity of the statues and deduce some arrangement constrains, based on the events of the scene and similar representation available in literature. The other constrains are of geometrical nature, like the actual matching of the fragments, the dimensions of the figures (taller statues are generally in the center, surrounded by smaller ones) and other more subtle details like the orientation of heads. While the digital models cannot add nothing to the firsts consideration, their geometrical information can be invaluable to validate the positioning.

Beside the obvious advantage of not having to physically interact with the artifacts, the use of digital models for this task also presents some remarkable advantages also over the alternative method of working with photos/drawings of the artifacts:

- working in the 3D space make possible to actually place the objects correctly in the space, rotate them in any possible way and, even more important, to watch the work in progress from any angle.

- when working with photo or drawings, the scale between different objects (or views) is always an issue, while having 3D models guarantees metric precision.
- It is possible to easily work and store many different options, keeping trace of the changes and comparing different solutions.
- The 3D geometry of the parts can be exploited in order to accurately validate the positioning, by checking how good adjacent parts stick together and if there are undesired collision between elements or with the original reconstructed positioning frame.
- Since the work is done in a virtual 3D space, some small parts can be placed in the space without building a support and it is possible to integrate the reconstruction with modeled 3D elements that are easier to build and modify with respect to their physical counterpart.

To work on this problem, we used a tool especially designed for the constrained assembling of a scene from a series of 3D components. The tool works with a schematic description of the scene to be populated; this description contains a representation of the base shape where the objects have to be positioned (in this case the geometry of the upper pediment), plus some basic constrains (maximum extent for working areas, surfaces where the statues can stick, etc.). Additional elements can be loaded and annotated in order to add placement/movement constrains. For example: the flat rear of most statues/fragments can be marked as stick surface, constraining the statue to move only on the sticky plane of the pediment. The imported objects can then be positioned in the scene taking in account the defined constrains.

This positioning problem does not affect the first group of statues (the Frontone A), which we acquired, since the small number of parts and the more clear contact areas made easy to assemble and position the five figures. However, even if there are no positioning uncertainness, the group presents the same geometric characteristics as the other one. It well be than possible to use this 3D data to test the effectiveness of the composition tool, while we wait for the other group to be completely acquired.

5.3. Study and visualization of original color

Our idea of ancient statues is often restricted to objects made of a single-colored material. In reality, most of the statues, ornaments and architectures of the past were painted, gilded or had small details made of a different materials. The modern techniques of chemical analysis, microphotography and multispectral imaging have made apparent this more colorful image of our past. The statues of the Luni temple were certainly painted, to really understand their original appearance, a mere geometrical reconstruction is not enough; it is necessary to render them with the correct coloring.

Unfortunately, almost no color survived on the first group of statues. However, the records of the original finding address the statues as colored, giving a description of the coloring. This alone would not been enough to re-apply paint to the statues due to the lack of measured data int he description but, fortunately, some color remains were present in the other group of statue. Given the common origin of the two groups, it is safe to assume that the artists that made the two groups used the same palette of color pigments.

All color remains have been checked to find suitable samples in order to recover the complete palette used in the group. In order to measure the colors to be used, the color samples has been photographed under stable illumination condition, placing in each photo a small color chart (mini-macbeth REF). The resulting RAW images have been processed using the color reference chart to calibrate the acquired color and obtain the most faithful representation. After the image calibration, for each color sample, we selected an area with uniform color and we calculated the average color in this area, choosing this average color as the color to be used in the painting process. The measure has been repeated for each color on different areas and on different samples in order to have a consensus.

One important question regarding statues coloring was about shading: were the different areas of the statues painted with a single, flat color hue ? Or was there some painted *shades* and *highlights* to make the tridimensionality of the statue more apparent? Given the fragmented and worn condition of the color remains it is really hard to tell. Most of the color remains appear to have a single shade, making the flat option more likely, but for some of the colors it is possible to find 2 or 3 different shades, leaving open also the option of a more complex shading.

To paint the color on the 3D models, we used our primary visualization and editing tool: MeshLab [Vis08]. This tool is an open source project, aimed at creating an extensible platform for interactive mesh visualization and editing. Beside the standard conversion and visualization features, MeshLab can be efficiently used to edit high resolution 3D models. In particular, using the Paint interface, it is possible to assign color to the surface of a mesh using the simple painting paradigm used by most of the image editing programs. MeshLab gives the user the choice of color, transparency and brush and provides the usual color editing tools (color picker, clone brush, hue/saturation/contrast control ...). There are on the market various programs that can be used to apply color to 3d models, however, since they are mostly made for the entertainment industry, it is quite difficult to work with the high-resolution geometries produced by 3D scanning. Using MeshLab, that has been especially tailored to work with complex geometries, we have been able to work directly on the high resolution geometry: in the presented test case we used models of 1 and 2 million faces (depending on the statue complexity).

In a first phase, we started using pure, flat colors, producing the results visible in figure 7. This experimentation is still ongoing: we are trying the different measured shades of the colors and paint areas in order to better match the original color description and similar painted examples in literature. Beside this first objective of re-applying the original color, we are also trying to assess the effectiveness of the MeshLab Paint interface. We hope that we will be able to improve the painting interface trough the interaction with people with a cultural heritage background. Subsequently, if the first results are convincing and when a larger color palette has been obtained by measuring color remains, we will start applying a more complex shading, trying to use painted highlights and shadows in order to accentuate the geometry.

Figure 6: *Main image: an example of one calibrated images of the color samples, in this case, the yellow color used for Apollon hairs. In the Insets: examples of other colors, dark male skin (upper) and grey-green used for vests and background elements(lower)*

A better color measurement would have been done using a spectrocolorimeter, but the device was not available at the moment of the color measurement. If the preliminary reconstruction proves to be effective, it is planned to employ such device. So far, we have only worked on the apparent color reconstruction; a faithful representation of the actual reflectance properties of the painted surface is however still a bit far, since it will be impossible to measure which would have been the BRDF of the color fragments, given their fragmentation and wornness.

5.4. Other possible future uses

The digital model will also enable the museum curators to build very accurate copies of the digitized objects. An interesting, but sometimes underestimated feature, is the possibility to make accurate reproduction at any scale. The full scale reconstruction will be used for the already planned placements of a copy of the second group in the original archeological location. However, also the scaled models could be

Figure 7: *On left: the model of the Apollon statue with its actual color. On right: one of the first results in the reconstruction of the statue original coloring*

used in the setup of the museum exposition in order to show multiple arrangements proposal, give a visual feedback of the color reconstruction or, for example, it will be possible to build a scale model of the reconstruction of the temple and produce accurate in-scale reproduction of the statues to populate its pediment.

One of the big problems of the reconstruction of the second group is the sheer number of pieces to be positioned. there are more than 70 pieces, some of them really small and without clear belonging to any of the large fragments. Try to automatically find correspondence between the various pieces could be an interesting task. Some approaches have been proposed to perform an automatic fragment matching [HFG*06]. However, the very worn state of most of the fracture will probably be a real hard problem to solve.

Finally, a possible usage of the 3d models, still to be fully investigate, is the re-design of the integration parts of the statues. As quite apparent in the images, some of the statues (for example the Apollo) have large reconstructed parts. Those parts has been hand-modeled following the geometry of the remaining pieces and the reference of similar artifacts. As new arrangements are considered, or even just because the restorers are not fully satisfied by the actual positioning of parts inside a single statue, it may be necessary to make changes also on the geometry of these reconstructions: like changing the height of a statue by elongating or shortening the integration (to better match the adjacent statues), or changing the head orientation (to make the statue looking in a different direction). The digital models obtained from the scanning can be easily "cut" to split the statue in its original fragments. It will be then possible to virtually start again from the original elements, re-position them according to the new positioning hypothesis and finally *model* in a 3D program the new integration part. The advantage of this solution will be, again, the possibility to prepare different possible solution to be evaluated without physically work on the real statues.

6. Conclusions

The Luni site is an effective example of the amazing potential of Italian Cultural Heritage. There are several aspects regarding the original appearance of the Luni temple, ranging from original color to the disposition of the statues. In the context of this case of study we were able to indicate at least six different uses of 3D scanned models of the fragments of the temple. This shows that nowadays 3D scanning can be considered a *mature* technology and its must be encouraged, in order to support the art historians, restorers and broad public in understanding and appreciating the art treasures in Italy and in all the world. Moreover, the progress in hardware potential and algorithms effectiveness will probably disclose new sceneries in a short time. Hence, it is necessary to promote the communication between researchers and cultural heritage experts, in order to completely exploit all the potentialities of computer graphics respect to the preservation and valorization of artistic sites.

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