Using digital 3D technology for documenting and studying the Griffin

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Abstract
The digitization of the Pisa Griffin took place in the preliminary phase of a much larger research project; it was part of the extensive scientific investigations that were planned to build a complete corpus of evidence data on the object. The digitization of the Griffin aimed at producing a very high-resolution and accurate sampling of its shape and of its surface decoration and colour, thus touching the spheres of both the 2D and 3D representation. The Griffin is a remarkable object that imposed a number of constraints in the planning and implementation of its digitization. The constraints were both in the complex shape of the Griffin (since the representation of the overall shape should be paired by an accurate sampling of the very thin decorations carved on the surface of the statue) and the dark and often reflective bronze surface.
We describe here the procedure implemented to perform the 3D scanning of the object and to process the raw data produced by the sampling instrument. The digitization of the shape was not enough to provide a digital model suitable for the study of this artefact. For this reason, we also planned a photographic campaign, in order to use the photos, back-projected onto the surface of the 3D digital model, and produce a very dense representation that encodes geometry and surface colour detail.
The Griffin project has been also an ideal context for experimenting and assessing different visualization modalities and tools, where the digital model was created not just to support documentation but also to become a working instrument in the day by day work of the Cultural Heritage (CH) experts involved in the project [Scopigno et al 2011]. We have experimented with interactive rendering solutions, working both locally and on the web, as well as a new approach that is able to navigate the 3D model and the set of 2D photographs in a common context.

1. Introduction

3D digitization has been adopted in many CH research projects, since the pioneering effort of the Digital Michelangelo project in 2000 [Levoy et al. 2000]. However, many projects do not present clearly and in detail the strategy, tools and techniques adopted for the acquisition of the digital 3D models, and the available results. Provenance data, i.e. an exact and scientific documentation on the used tools and the data processing, are often unknown or very hard to find.
To avoid this issue, this chapter has been designed to present in detail the technologies adopted for the digitization (3D and photographic) of the Griffin. The same digitization

strategy has been adopted in a coordinated manner to acquire the digital models of the Mari-Cha Lion (even though this digitization was not performed by CNR-ISTI, but by the Centre for Digital Documentation and Visualization CCDV in Glasgow, UK) and the Lucca Falcon, all of them objects casted in bronze. 3D scanning of bronze objects has already been done in the recent past (e.g. see the examples of the 3D digitization of the Minerva of Arezzo [Fontana et al. 2002] or the Arringatore, both conserved at the Florence National Archaeological Museum; Donatello's David [Cioci et al. 2005]; or Riace's bronzes [Muzzupappa et al. 2012]). The definition of common guidelines and procedures for 3D digitization and the open dissemination of those data, both for the sake of the specific research project and for further use of external scholars, allows the production of digital models of "known origin" (where the measurement and data processing methods is well documented) and that could be jointly used in the research and in the documentation of the project results. We present in detail the constraints of the specific scanning campaign and the consequent technical choices, together with the software used for processing the sampled data.
This chapter also presents the first results of some metric analysis performed directly over the digital model. The contribution concludes with a brief presentation of the several technologies that have been offered to the project partners for supporting the interactive visualization of the digital models produced.

2. 3D digitization

3D scanning is not a single technology, but a family of various measuring techniques (and corresponding devices) able to capture the geometry of real-world objects. The choices of the appropriate measuring method and of the specific sampling device have to be taken considering both the characteristics of the artefact to be digitized, and the objectives of the project, i.e. the planned uses of the digitized model: reproduction, visualization, study. Each of these has specific constraints and requirements.

In the case of the Griffin, the overall shape of the object is not extremely complex, with the exception of the area between the legs and over the wings (due to the hard-to-reach area in between the wings). In terms of the manipulation of the object, since the Griffin cannot be tilted or laid on its side, scanning a complete 3D model requires nevertheless moving the scanner around the object, therefore a scanning system that was easy to move in the area surrounding the object was needed. On the other hand, the bronze surface presented serious difficulties due to its optical characteristics: the surface is oxidized in some areas, quite shiny on other areas, and in some places it also presents traces of paint, wax or patina finish.

The aim of the digitization was to produce an extremely high-resolution model, for the documentation and study of the details of the engraved decoration. The geometric sampling should be able to capture details around 0.1 – 0.2 mm in size.

These two considerations led to the decision of using a Structured Light Triangulation scanner. Triangulation is a measuring principle widely used for object of small-medium size, and certainly able to work at the required resolution on an object of the size of the Griffin. A triangulation scanner projects some kind of light on the surface (a laser line for Laser Triangulation, or a striped pattern in the case of Structured Light Triangulation), and uses an off-set image sensor to capture the illuminated area, determining the geometry.

The structured light approach is much more resilient to the optical problems of the surface of the Griffin (dark and shiny); moreover, when looking at commercial devices, high-quality systems based on structured light generally provide a higher sampling resolution than laser-based systems.
Among the available Structured Light scanners, we chose to employ a Breuckmann SmartSCAN 3D-HE, a device with the required characteristics and capabilities, developed for industrial measurement but of common use also in the field of cultural heritage.

However, even working with a carefully chosen device and using robust scanning parameters, in some areas the surface proved to be extremely difficult to be sampled, producing noisy data. This brought the effective sampling resolution produced in the final master model at 0.2-0.3mm; worse than expected, but still suitable for the intended use.

Figure 1: Moving the Griffin to the laboratory used for the digitization.

2.1 Data acquisition

A triangulation scanner only measures the parcel of the surface directly visible in front of it; in order to cover the entire surface of the object, the scanner has to take multiple "shots" from different positions, covering piece by piece the whole surface.
In the case of the Griffin, the CNR-ISTI team used 177 single scans (range maps), each with a sampling rate of around 0.1mm.
Each single scan required 3-4 minutes, considering the positioning of the scanning device, the setting of the parameters of the scan, the digitization time and the alignment of the obtained range scan to the previous ones (this is a handy feature of the Breuckmann scanner, that allows the operator to produce scan by scan a visualization of the sampled dataset and to detect easily possibly unsampled regions).

Each range map produced is in a different reference space (since the scanner has been moved around the object); therefore, all those different scans have to be aligned in a single reference space. This phase is called *alignment* or *registration* of raw data. Generally, this alignment phase is carried out separately, after all the data has been acquired. In the case of the Breuckmann system, however, each range map is aligned immediately after it is acquired by using the software controlling the scanner.
In total, the 177 scans acquired to sample the surface of the Griffin contain 350 millions of measured 3D points, for a disk size of around 12.6 GB.

Since we had serious time constraints for the geometric digitization (the museum curators allowed us to displace the Griffin from the museum for only three days; Figure 1 shows the displacement of the Griffin from the usual museum room to a different location in the museum surroundings), we decided to use two scanning systems in parallel: the Breuckmann scanner was used to gather 3D data on most of the Griffin surface, focusing on the more decorated area of the artefact; other areas of the artefact, characterized by a much lower richness in detail (like the legs) were sampled with a second scanner, a Minolta Vivid Vi-910. This triangulation laser scanner has been used a lot in the field of Cultural Heritage, and is still able to work on the bronze surface (even if at a slightly lower resolution).

The complete 3D digitization of the Griffin was performed in one day and a half. The rest of the available time, another day and a half, was used for the photographic campaign that had two main aims:

- To produce a set of images usable for the photographic mapping over the 3D model surface, in order to obtain a coloured 3D model;
- To produce a complete photographic dataset, showing the Griffin from all sides, usable for documentation and interactive photo-based exploration (as we will describe in the following sections).

To reach these goals, the bulk of the photos were taken by putting the camera on a tripod, framing the whole Griffin and using a turntable to take photos of the Griffin at regular angles; this operation was done with different incident angles (height and orientation of the camera), thus creating a "circular" series, showing the artefact from all possible directions. These series where then integrated with other photos, framing specific details from camera locations nearer to the surface.

The photographic campaign, carried out with professional photographic equipment and lighting, produced 191 high-resolution images (21 MPixels each).

Figure 2: Scanning the Griffin with the Breuckmann SmartSCAN 3D-HE system.

2.2 Data processing

The actual measurement of the surface geometry is only the first step in a much longer working pipeline. The data produced by the scanning device is "raw" in the sense that it contains measured information, but is still a partial, redundant, noisy and usually incomplete representation of the object geometry.

The first step of the 3D scanning pipeline is the *alignment* of the different scans: all scans are brought into a common reference frame using a semi-manual approach. The Breuckman software used to control the scanner helps in speeding up this process since most of the manual part of alignment is done directly during the on-field 3D digitization.
In our case, it was necessary only to add the scans done with the Minolta system, and to perform a global alignment step. This process (align the Minolta scans, put together the two groups and do the global pass) required two days of work.

The 3D data, now in a common reference frame, was then used to generate a single triangulated surface. This is a completely automatic process, often called *merging*; all the measured points are immersed in a volumetric grid and for each cell containing some measurements, a triangulated surface is reconstructed by blending the input data. This method exploits the data redundancy (most parts of the surface were acquired in more than one shot) to reduce scanning noise, and produces a triangulated surface with extremely good detail.
From the scanning data, two different merging processes were carried out, with two different resolutions chosen, and thus producing two 3D models:

- A merging at a resolution of 0.5mm, producing a 3D model suitable for the inspection, measurement and study of the *whole* Griffin
- A merging at a resolution of 0.25mm, to be used to produce a more accurate 3D model, usually used to support the study or visual presentation of *specific areas of interest* on the surface of the Griffin.

In the case of the **0.5mm** reconstruction, the generated 3D model is composed of **21 millions** triangles, for a disk size of 400MB. From this model, using geometric simplification, some other lower-resolution models have also been extracted for easier interactive visualization.
On the other hand, the **0.25mm** reconstruction produced a 3D model made of **100 millions** triangles, for a disk size of 1.5 GB. This model has been kept at maximum resolution, and used to extract smaller 3D models of areas of interest like the head, the engraved beasts on the shoulders and legs and the inscriptions on the front and sides (see Figure 3).

2.3 Photographic mapping

The photographic campaign produced a large number of high-resolution photos. As already stated, the aim was to use some of the photos to map colour onto the 3D surface, but also to produce a referenced photographic dataset for the entire object.
Once the 3D model(s) of the Griffin has been generated, all the photos were registered (aligned) to the 3D object. This process required five days of semi-manual work.

Aligning a photo to a 3D model means to reconstruct the position, orientation and internal parameters (focal length, distortion) of the camera at the moment of the shot.

This is a semi-manual process, requiring substantial user input. The photo-to-3D alignment was done using the MeshLab tool (http://meshlab.sourceforge.net/): the user places the model more or less in the same position of the object in the photo, and an automatic refinement process is activated to find the data of the best-matching camera [Corsini et al 2009].

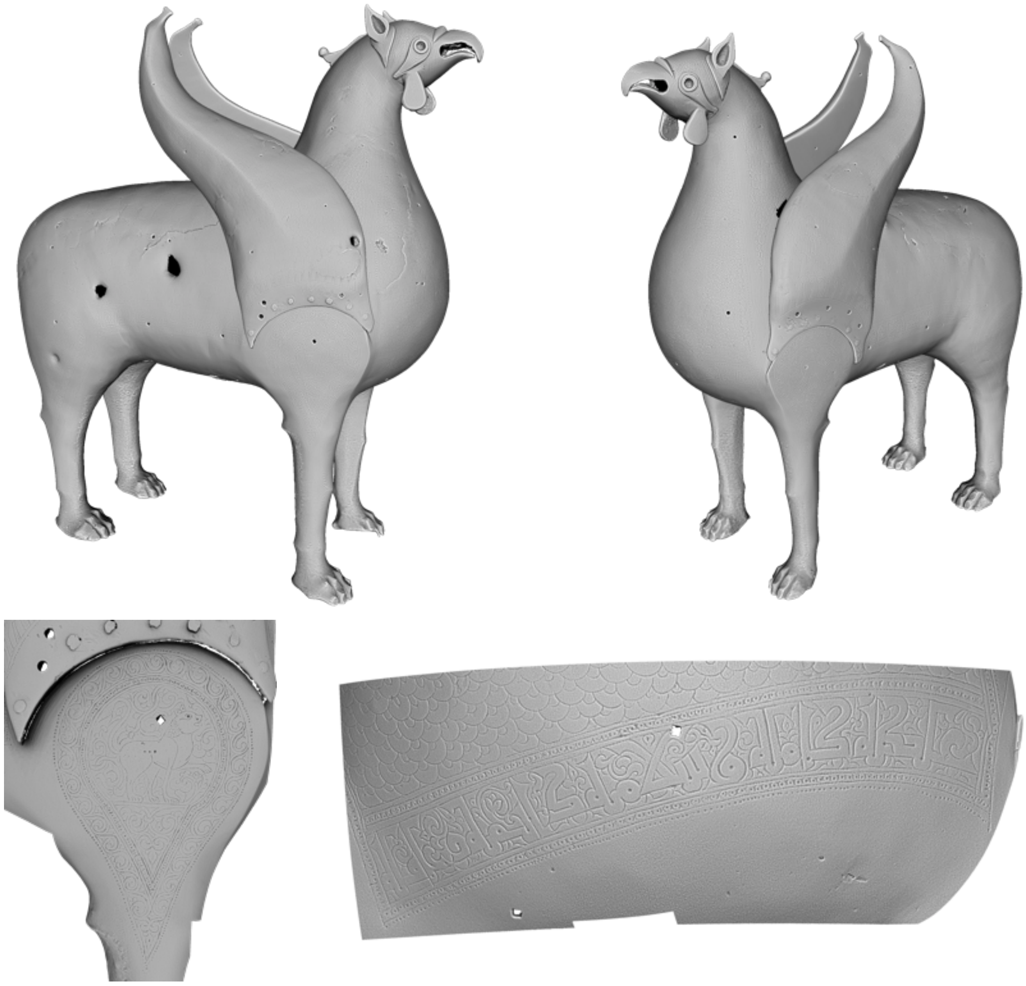


Figure 3: Results of the 3D scan of the Griffin: global model and details.

Once all the camera parameters are recovered with the above-mentioned method, the colour information from the photos may be projected back (using inverse perspective projection) onto the surface of the 3D model [Callieri et al 2008].
Due to the extremely variable optical characteristics of the surface, however, it is almost impossible to obtain a uniform colour mapping on the whole object, without problems such as highlights, colour inconsistencies and blurred areas. For this reason, the colour mapping was done only on specific detail areas.
In order to combine the high-resolution of the 3D model with the high-resolution of the photos, the colour mapping was carried out using a per-vertex encoding instead of a texture. The adoption of a texture mapping approach would have required to work on a lower-resolution geometry, hence losing some of the scanned detail, and also the production of a very large texture space. On the other hand, using the per-vertex colour mapping, it was possible to keep both the geometric and the colour detail at the same resolution level of the master data (master geometry and image resolution).

All the alignments of all the photos enables an innovative "spatial" browsing of the image dataset (see Section 5, the PhotoCloud tool), making it easier to navigate the many photos, renderings, screenshots and drawings.

2.4 Software used

The data acquisition and the initial alignment were carried out using the Breuckman software OptoCAT, which directly drives the 3D scanner.
The Minolta scanner was controlled using Easy3DScan 2, a tool developed by CNR-ISTI.
The MeshLab tool was used to support all the phases of the raw 3D data processing. MeshLab is an open-source tool for the visualization and processing of 3D models coming from 3D digitization (http://meshlab.sourceforge.net/). The software is developed by CNR-ISTI and publicly available from web. This tool implements the state of the art of the algorithms and techniques for the processing of extremely complex 3D models [Cignoni el al 2008].

3. The 3D model of the MARI-CHA Lion

CNR-ISTI was not involved in the scanning of the Mari-Cha Lion, but was in contact with the people in charge of the scanning of the Mari-Cha Lion, discussed with them the technical solution for acquiring the 3D model of this second object and had access to the digital 3D models of the Lion.
The scanning of the Mari-Cha Lion was carried out with a similar technology (structured light triangulation scanner), thus producing a 3D model of resolution and complexity extremely close to the one of the Griffin.
Beside the usefulness of the digital models in the study and documentation of each of the beasts, these two 3D models provide even greater value when used together to study the relationship between these two important artefacts.

4. The 3D model of the Lucca Falcon

CNR-ISTI also worked at the 3D digitization of the Lucca Falcon, another bronze object of Islamic origin with an extremely rich engraved detail. This object, property of the Lucca Parish, is conserved in the National Museum of Villa Guinigi, Lucca.
Following the same procedure used for the Pisa Griffin, the digitization was carried out using the same 3D scanner used for the Pisa Griffin, the Breuckmann SmartSCAN 3D-HE, and the data was processed using Breuckman OptoCAT and MeshLab. As in the case of the Griffin, the digitization reached a detail of around 0.1-0.2 mm, in order to capture the smallest details of the engraved decorations. Also similarly to the Griffin, we produced two 3D models at different resolution (0.1 and 0.2 mm): one for the inspection of the whole object, and one for the study of specific areas of detail.
The 3D digital models obtained in this way, were then colour-mapped using a set of photos provided by the local Superintendency: the photos were firstly aligned to the geometry, and then projected onto the geometry.
The digitization required half day of work, while the data processing and colour mapping took three days.

The resulting 3D digital model, visible in Figure 4, is well suited for a detailed study of the decoration and of the craftsmanship of the object.

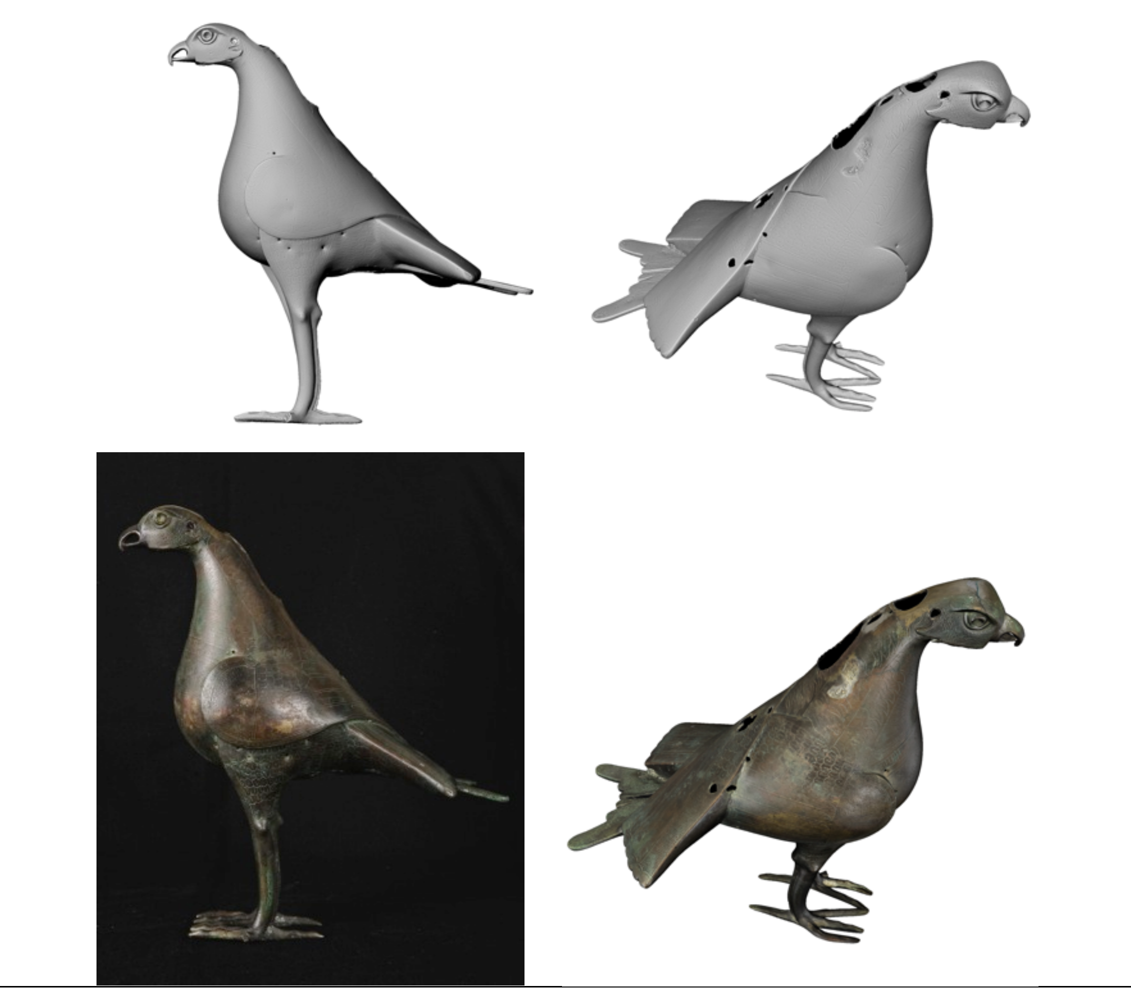
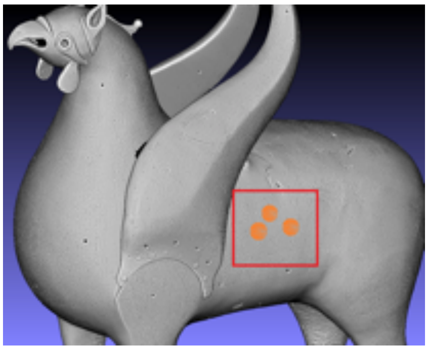


Figure 4: Images of the 3D model of the Lucca Falcon. Top: two views of the digital models. Bottom left: one of the photos used for the colour mapping. Bottom Right: the colour-mapped 3D model.

4. Using 3D models for documentation and measurement

A 3D model is not only useful to support remote visual inspection in study of an artefact, but also because it is generated by geometric measurement, thus representing a fully measurable digital entity.
Measurement that can be taken on the actual object, can also be taken on the 3D model, in most cases in a much simpler way, since working with the 3D model does not require being near to the real object, and since the 3D model can be manipulated and moved without concern for its weight and cumbersomeness.

In the specific case of he Griffin, it is easy, for example, to measure the regularity of the circles on the back of the animal (see Figure 5), supporting the hypothesis that they have been traced with a compass on the surface (rather than transferred from a paper/canvas template [refer to Mirco Bassi's article]). This, however, even if it is made easier by the use of the 3D model, is a kind of measure that can be taken also on the actual object.



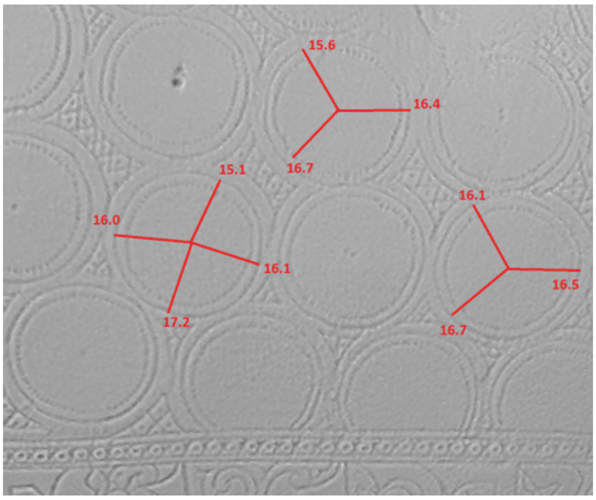


Figure 5: Examples of the images produced to study and measure specific characteristics of the Griffin decoration.

A more complex measure performed was determining the alignment of the different rows of circles. In this case, since the surface of the back of the beasts is not flat, working on the 3D model can provide much more reliable and usable data.
The idea behind this measure was to find if the circles on the back have been laid out in rows, starting from a central dorsal line (from neck to tail); if so, there should be a row of circles extremely regular more or less in the centre of the back, and a series of rows less and less regular the farther from the centre. We tried to confirm this idea on the Griffin and on the Lion. In the case of the Lion, the hypothesis seems true, there is a central regular row, surrounded by less regular ones (see Figure 6). On the Griffin, however, we could not find any "seed" line. While not conclusive, this is still an interesting example of a measurement that exploits the possibilities of the digital 3D models.

An interesting work could be the tracing of all the engravings on the two beasts. This work has surely been done, but probably not in a complete way, and certainly only on images/photos. A vector-based 3D representation of all the engravings could be used to help the study of the decoration, by comparing instances of the same feature, or finding symmetries and alignments between features (to make a hypothesis on how the decorations have been laid out).

Another possible direction is to work at a lower scale, and study the way the inscriptions on the front and sides of the animal have been traced and engraved, e.g. the order in which the lines have been carved, or finding evidence of the "guide lines" used to compose the inscriptions (see Figure 7).

Moreover, it is easy to generate high-resolution images from the 3D models, either in perspective or orthographic views, showing the full object or framing details with specific lighting and visualization parameters. All these images are still references with respect to the 3D models. Similarly, it is possible to create cut-trough sections, exportable as polylines in most CAD-like tools. These are easy ways to effectively create technical documentation.

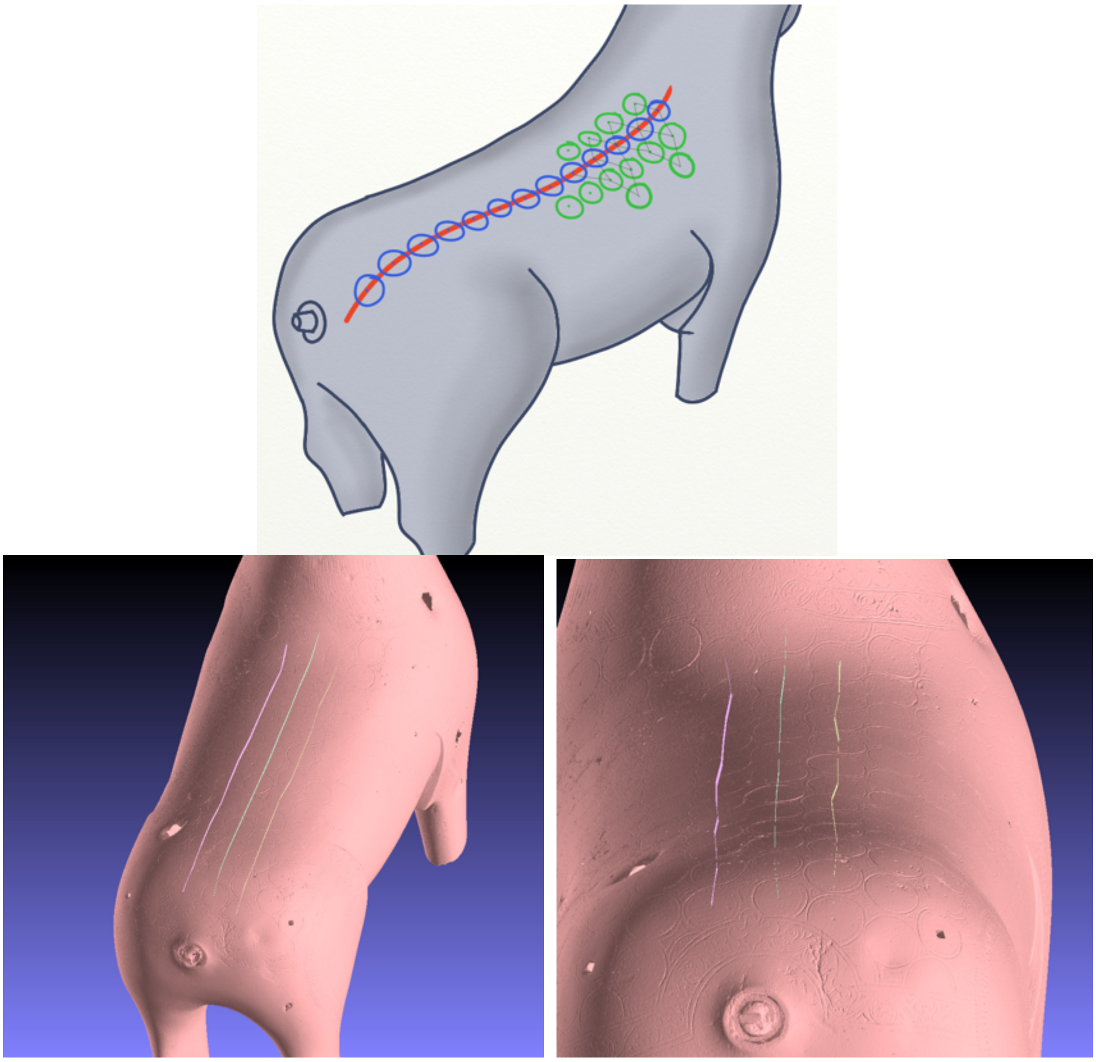


Figure 6: Trying to find the layout method of the circles on the Lion. If the circles have been laid out starting from a central line, it should be possible to find one straight row of circles surrounded by less regular ones, like in this case.

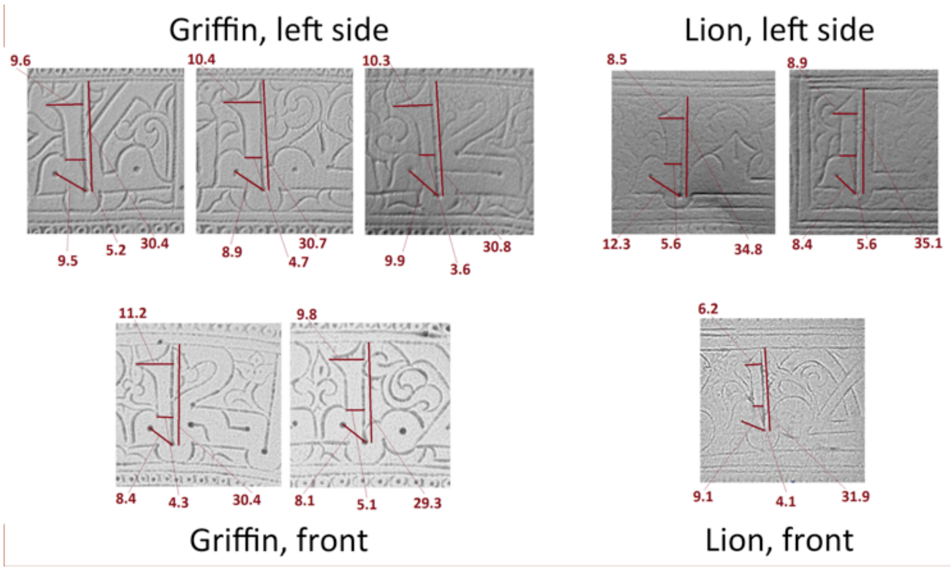


Figure 7: Measurements taken on the writings of the Griffin and the Lion, analysing the occurrences of the same letter in order to find correspondences in size and layout.

5. Interactive visualization

Real-time interactive visualization is also an important tool for the study of this artefact, and its presentation to the public.
Since the Griffin is not a movable artefact, the ability to visualize it remotely and manipulate it with ease is extremely useful for scholars interested in studying it. At the same time, the virtual presentation is an excellent way to present the two Griffin and the Lion in a common environment.

We have provided several different visualization resources to the project team.

MeshLab. The same tool used for the data processing and the measurement is also an effective tool for the visualization of the 3D models. MeshLab can be used to open and visualize all the raw, intermediate and final 3D data, providing an easy access to all the 3D information. The same tool can also be used to export the 3D data in other format, in order to make it interoperable with other 3D software tools.

The MeshLab tool offers a simple but fast rendering and shading of the 3D geometry, ideal to appreciate the geometric and colour detail of the 3D scanned models, and a simple-to-use trackball to manipulate the 3D surface and frame the areas of interest.
An essential tool for the study of the engraved details provide by MeshLab is the movable light, usable to recreate a digital version of the “raking light” used by experts when working with small details (se Figure 8).
Specific shaders may also be used to enhance the visibility of some geometric details, or to visualize numerical data directly on the 3D surface.

The visualization of the 3D models of the Griffin, at a lower resolution, is also possible on mobile devices. A reduced version of the MeshLab tool is also available for iOS (iPhone, iPad, iPod, see at http://www.meshpad.org/) and Android devices (https://play.google.com/store/apps/details?id=it.isticnr.meshlab). Areas of interest have been isolated from the 0.25mm model and are ideal for detail inspection even on this kind of platform.

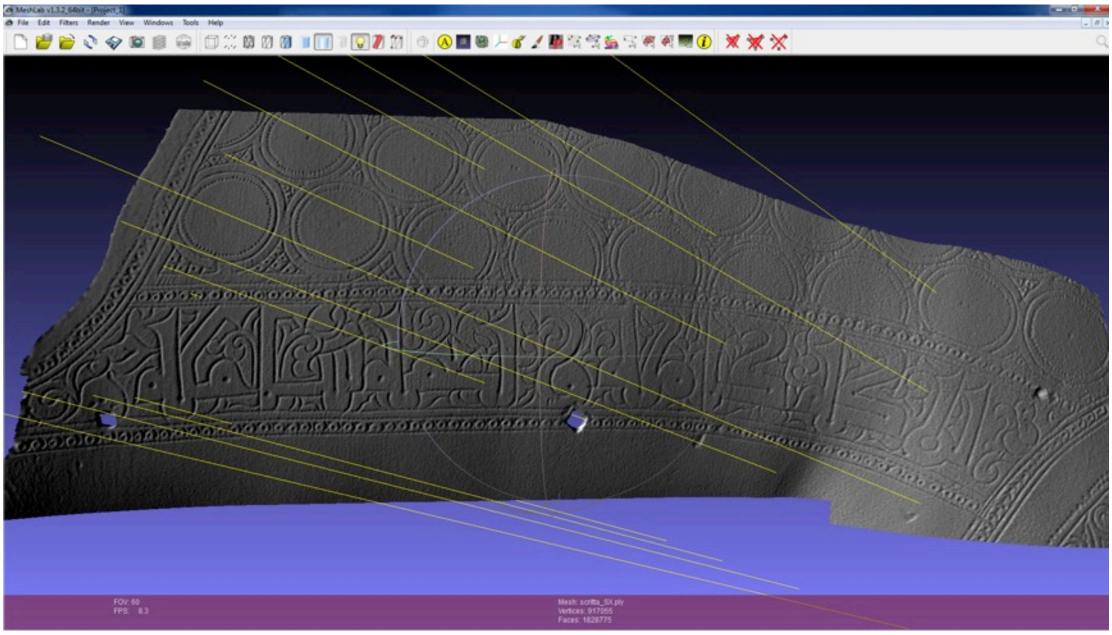


Figure 8: Real-time visualization of the engraved details on the Griffin, using Raking lighting for better perception of the geometry.

Multiresolution visualization. The MeshLab tool unfortunately does not support the visualization of multiresolution models, therefore it has limitation in the maximum size of the mesh to be visualized (this depends on the specific configuration of the PC used; usually interactive visualization becomes very slow on meshes larger than 10-20 Million triangles). In the case of the Griffin, this means that it is possible to visualize just the high-resolution areas of interest or a medium-resolution global model, but not the full accuracy high-resolution model.
The global model at full resolution is too large to be effectively viewed as a whole on most software tools and computing platforms; the visualization would be really slow on high-end computers, and may even be impossible to open these 3D models on notebooks or older PCs.
A solution is to use a Multiresolution approach. The multiresolution schemes generally split the full geometry in chunks; for each chunk, multiple levels of details are available. At rendering time, depending on what the user is seeing, only the needed data is loaded in memory and rendered. Parts that are closer to the viewer are displayed at full resolution, while distant parts are kept at a lower resolution. The visualization is updated as the user changes its point of view.

By using the multiresolution engine developed by CNR-ISTI, **Nexus** (http://vcg.isti.cnr.it/nexus/), it is possible to effectively see in real-time even the higher-resolution 3D model of the whole griffin on normal, off-the-shelf computers but also, as we will see in the next section, online.

Multiresolution visualization on the web. The use of 3D data on the web platform has been, until the last couple of years, really difficult, due to the impossibility to work with high-resolution geometry and the need of using proprietary plugins and additional components. Thanks to the introduction of the WebGL component of HTML5 is now possible to create high-complexity visualization pages that include 3D models.

3DHOP is a tool developed by CNR-ISTI, able to show high-res 3D models inside a web browser with an easy-to-use interface (http://vcg.isti.cnr.it/3dhop/). The multiresolution model of the Griffin can then be easily and effectively seen online inside most modern browsers, without the use of plug-ins or additional tools.

While at the moment the viewer makes it possible to view the different models (global and details) on the web, a useful extension could be use the 3D online viewer as a "spatial index" of the scientific analysis and scholar observations carried out on the Griffin, by linking to specific spots on the object the other data produced by the project.

Integrating 3D models and images. One of the aims of the photographic sampling was to produce a series of photos which should be easily presented in conjunction with the 3D model. While it is true that the geometric 3D model can, even on his own, provide a faithful representation of the artefact, and the colour-mapped 3D model provides an appearance closer to the real-world object, it is also true that a lot of the details are perfectly visible in the photos, and many scholars are much more familiar with working on photos (and not on 3D data).
Following the idea of using the 3D model as a "spatial index", we proposed to the Griffin project another proprietary tool that allows integrating the two kinds of data (3D model and photos) in the same three-dimensional space. The **PhotoCloud** tool enables the user to explore this mixed 2D-3D dataset in a spatial way, making it much easier to navigate a large set of photos (see Figure 9). The user may navigate around the 3D model, and the photos are rearranged in order to present the ones correlated to the area currently visible in the 3D model, conversely, when the user is browsing the set of photos, the model moves to show the area depicted in the currently viewed photos. Using this principle, the user can explore the combined dataset going back and forth between the 3D space and the photos in a simple and accessible way.

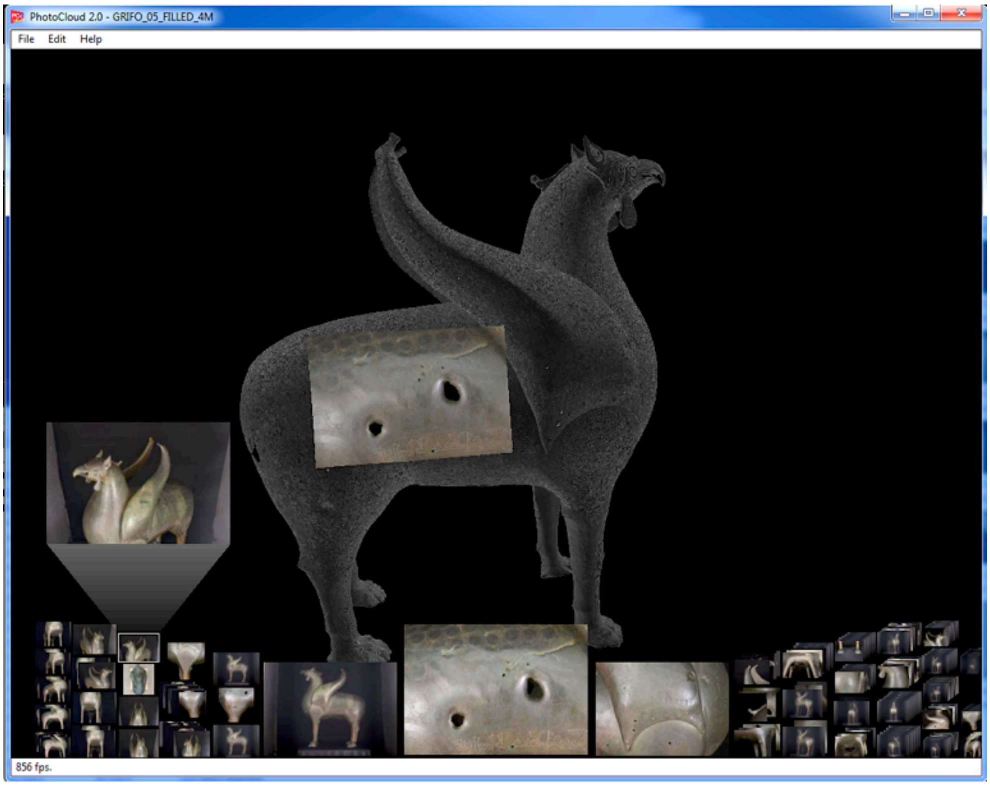


Figure 9: The PhotoCloud tool, showing the photographic dataset in the three-dimensional space of the Griffin model.

6. Conclusions

We have presented the technologies adopted for the digitization (3D and photographic) of the Griffin, to document the digitization strategy and data processing methods of the digital models produced, to ensure the scientific validity of the data. The same digitization methodology has been adopted in a coordinated manner to acquire the digital models of the Mari-Cha Lion and the Lucca Falcon. The definition of common guidelines and procedures for 3D digitization allows the user to produce digital models of known origin and that could be jointly used in the research and in the documentation of the project results.
This chapter has also presented some initial results of metric analysis performed directly over the digital model. The contribution has concluded with a brief presentation of the several technologies that have been offered to the project partners for supporting the interactive visualization of the digital models produced.

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