Visualization and 3D data processing in David's restoration

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1 Introduction

The David restoration project (started in Florence in 2002) has given several guidelines to the definition and development of innovative solutions to process and visualize 3D data in the framework of Cultural Heritage (CH) applications. Our main goal has been to demonstrate the usefulness of digital 3D models and of visualization tools in the framework of a restoration project. 3D models have been used in CH mostly for still/interactive rendering and for physical reproduction via rapid prototyping technology. *CH restoration* is another field where a large number of proficient uses of accurate 3D models and visualization can be proposed. Restoration is nowadays a very complex task, where multidisciplinary skills and knowledge are required. A complex set of investigations usually precedes the restoration of a valuable artwork: visual inspection, chemical analysis, different type of image-based analysis (RGB or colorimetric, UV light reflection, X-Ray, etc.), structural analysis, historical/archival search, etc. These analysis might also be repeated on time to monitor the status of the artwork and the effects of the restoration actions. An emerging quest is how to manage all the resulting multimedia data (text/annotations, historical documents, 2D/3D images, vectorial reliefs, numeric data coming from the analysis, etc.) in a integrated framework, making all information accessible to the restoration staff (and, possibly, to experts and ordinary people as well). The final goal is to guide the restorer in the choice of the proper restoration procedure by the evidence of the analysis performed, and to assess in a objective manner the results of the restoration (to compare the pre- and post-restoration status of the artwork, to document the restoration process). Since most of the information is directly related to spatial locations on the artwork surface, 3D models can be valuable media to index, store, cross-correlate and obviously visualize all this information. 3D models can also be a valuable instrument in the final assessment phase, supporting the interactive inspection of the multiple digital models (pre- and post-restoration status) to check possible shape and color variations.

We experimented different uses of 3D graphics for the restoration of the David, ranging from the classical *scientific visualization* tasks to more complex *information visualization* applications. According to our experience, the tools available (either commercial or academic systems) do not satisfy all the potential needs of *computer-aided restoration*. While in some cases standard visualization features are sufficient (e.g. to present a scalar field over a 3D surface, see our *surface exposure* investigation), other applications often require more sophisticated tools to map multimedia information to the artwork surface and to present those data visually, e.g. joining the capabilities of a 3D GIS with the ones of a multi-media information visualization system. Moreover, the *frame buffer* cannot be the only communication channel with CH people. They still require paper-based documents, and a screen dump is not a satisfactory answer to users' needs. Visualization instruments should be able to encode information into printable documents; basic features are the accuracy of the printed representation (display resolution is poor when printed on a large paper format), and the capability to easily select a known

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scale factor (see the short description of the *Cavalieri* system in the section on *Physical measures* evaluation).

The David restoration is as an ideal testbed, since a complex set of scientific investigations has been planned both before and after the restoration intervention. This gave us the opportunity of attempting different methodologies to support restorers/scientists with the use of visualization tools based on 3D digital models. In particular, a 3D digital model can be used to support restoration in two different ways: as a tool for the execution of specific *investigations*, or as a *supporting media* for the archival and integration of the restoration-related information, gathered with the different studies and analysis performed on the artwork. Let us describe in the following two sections the work done (a more detailed description of the technology used or developed is available in [10]).

– Start of Proposed Side Bar –

3D graphics (data acquisition and processing) in Cultural Heritage

Modern 3D scanning technologies allow reconstructing 3D digital representations of Cultural Heritage artifacts in a semi-automatic way, with very high accuracy and wealth of details [1, 4]. The requirements of Cultural Heritage (CH) applications (high precision and dense sampling in shape reconstruction, joint management of shape and optical properties of the surface) make 3D scanning a proper technology. Pioneering activities started in Canada and US [5, 12, 6] and many of these efforts focused on Italian artistic masterpieces. An example of what can be obtained is the Michelangelo's David model (56 million triangles, reconstructed from 4000 range maps using a distance field with 1 mm. cell size), produced by the Stanford's Digital Michelangelo Project [6].

The availability of an accurate digital representation opens several possibilities of use to the experts (restorers, archivists, museum curators) or to ordinary people (students, museum visitors). So far, most 3D scanning results have been used just to produce still images, interactive visualization or animations: the classical rendering-oriented applications are still predominant. On the other hand, people working in the CH field are initially fascinated by the beautiful images we can produce, but quite soon they ask for visualization or data processing tools really useful in their day by day work. We agree with them: the use of 3D models should go beyond the creation of synthetic images. Projects proposing 3D graphics as an analytical tool are still rare [7, 11, 12].

An exciting opportunity is to introduce the combined used of 3D digital models together with ad-hoc visualization tools in artworks *restoration*. However, while the cost for acquiring a 3D model of an artwork is progressively reducing - we recently performed a complete scanning of the Minerva of Arezzo [9] (a bronze statue, 1.60 m. tall) in just one week[1], range-maps post-processing included - the main difficulties of the integration rise from the lack of visualization tools specifically designed for this application field.

– End of Proposed Side Bar –

2 3D data as a tool to study an artwork

As stated before, specific *scientific investigations* can be conducted directly on the digital 3D model. In the David restoration, we performed two main "digital" investigations: the characterization of the *surface exposure* with respect to the fall of contaminants, and the computation of a number of *physical measures*. In both cases, ad-hoc codes have been implemented to process data and present the results to the users.

2.1 Surface exposure characterization

We designed and implemented a tool to evaluate the exposure of the David's surface to the *fall of contaminants* (e.g. fall of rain, mist or dust). This phenomenon depends on: the direction of fall of the

[1]See some data on our last Minerva scanning by following the Digital Minerva link on http://vcg.isti.cnr.it/projects/projects.htm

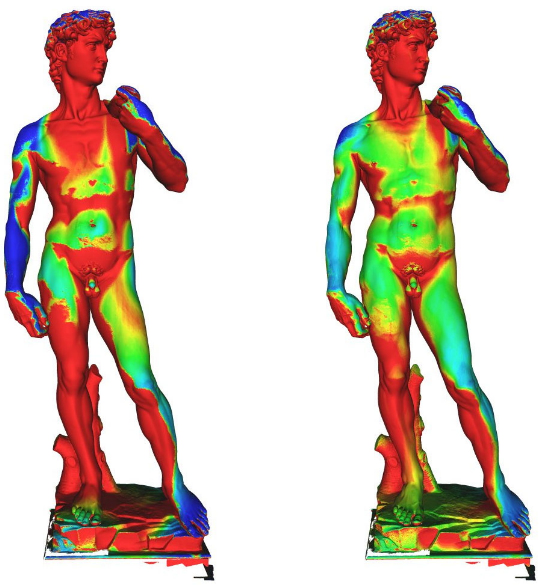

Figure 1: Exposure of David's surface to dust or other contaminations. This visualization shows, using a false-color ramp, the different classes of exposition produced by the simulation (red: absence of fall, blue: high density of fall), under a maximal angle of fall of 5 degrees (on the left) and 15 degrees (on the right).

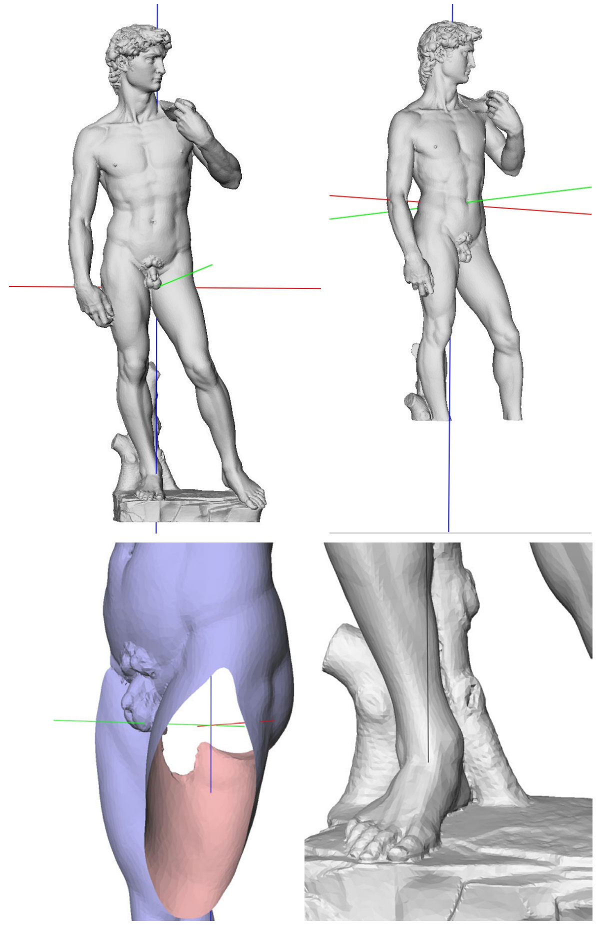

Figure 2: Spatial location of David's barycentre, with and without basement and feet (top); zoomed images of the former.

contaminant, the surface slope, the self-occlusion and the accessibility of the different surface parcels. Our tool produces several qualitative and quantitative results, useful to characterize the artwork surface. The falling directions of the contaminant agents is modelled by assuming a *random fall direction*, uniformly distributed around the vertical axis of the statue within an angle α which defines the maximum fall inclination.

Figure 1 shows some results obtained on the David. The different exposures are visualized using a false-colour ramp; the digital 3D model is therefore used both to compute the simulation and to present visually the results. Numeric data have also been produced (tables and graphs).

2.2 Physical measures

Physical measures can be computed directly on the digital 3D model, e.g.: David's *surface* (19.47 squared meters) or its *volume* (2.098 cubic meters). Known the unit weight of the artwork material, the total *weight* can be immediately computed from the volume measure. *Point-to-point distances* are also often needed, and can be simply computed on the 3D model by adding a *linear measuring* feature to the browser used to visualize the digital model. A linear measuring feature has been included in our visualization tool (*Easy3DView*): the user simply selects two points on David's surface and the tool computes the linear distance between those two

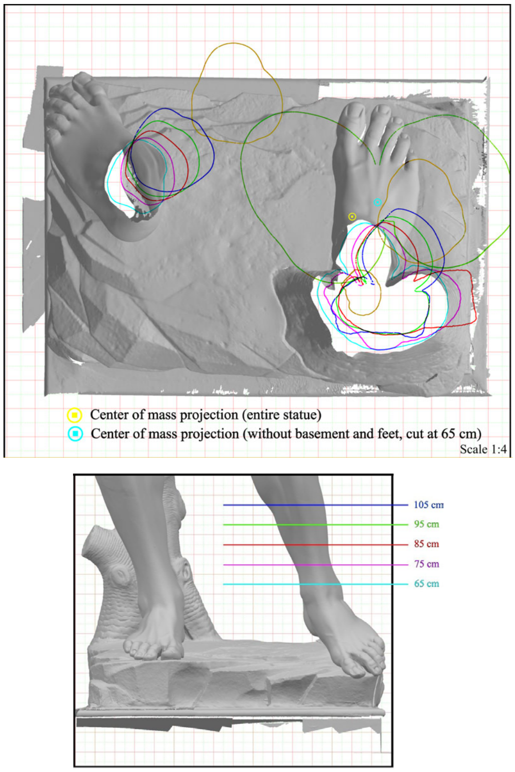

Figure 3: Visualization of the projection of the center of mass (marked by a yellow circle) and of the profiles of some cut-trough sections (ankles, knees and groin; see the respective hight in the right-most image).

points.

One of the issues under evaluation in David's restoration is the *statics* of the statue, since some cracks on the back of the ankles frighten the curators. These cracks could have been generated by a wrong distribution of the mass of the statue (there are historical papers which sustain that the original basement was not properly planar, and the statue was slanting forward). Therefore, an investigation on the statics of the statue was included in the set of investigations to be done before the restoration. The basic data for the static investigation are the mass properties (volume, centre of mass and the moments and products of inertia of the centre of mass), which have been computed directly on the digital 3D model using an algorithm that exploits an integration of the whole volume assuming constant density of the mass [8]. From this computation we obtained that the statue's centre of mass is placed in the interior of the groin, approximately in the pelvis (see a visualization in Fig. 2). The vertical projection of the centre of mass on the base of the statue (i.e. the sculptured rocky base where the David stands) is the blue line, which exits from the marble on the high posterior part of the left thigh and enters again in the marble on the right foot. We estimated also the centre of mass by *removing the basement* (cutting the statue at the height of the main cracks); the new position is again in Figure 2. The projection of the centre of mass on the statue base has been documented with a large size plot (see Fig. 3) produced with a proprietary application called *Cavalieri* [3]. We designed Cavalieri to support the easy production of large format prints (orthographic drawings and cut-through sections, produced according with the user-selected reproduction scale) from the very high resolution 3D models produced with 3D scanning technology.

3 3D models as a media to index, archive and visualize data on the restoration process

A second important use of 3D models is to consider them as an instrument to document, organize and present the restoration data. During the David restoration campaign, a number of *scientific investigations* have been performed; some of them will be repeated periodically, in order to monitor the status of the statue. These investigations include: different chemical analysis (to find evidence of organic and inorganic substances present on the surface of the statue), petrographic and colorimetric characterization of the marble, UV imaging, X-Ray, etc. All the results produced by the scientific investigations are going to be organized and made accessible through a system implemented with web technology. The 3D model of the David is used to build different spatial indexes to those data (see Figure 4), pointing out their location on the surface of the statue and supporting hyperlinks to web pages describing the corresponding investigation and the results obtained.

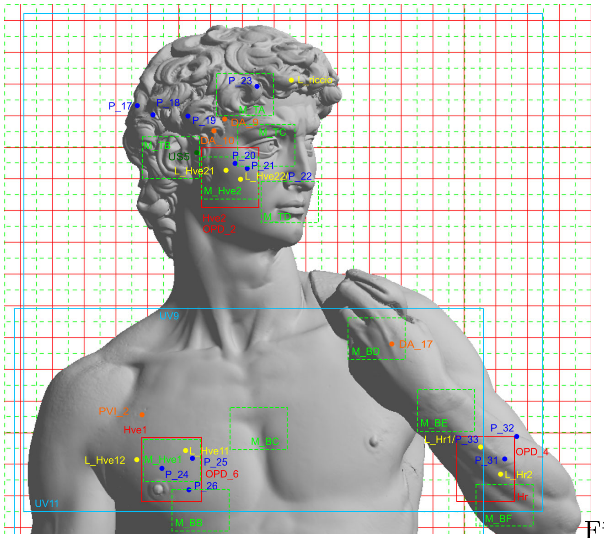

Figure 4: The digital model is used as an index to the scientific investigations performed on selected points or on sub-regions of the statue's surface.

Figure 5: Mapping multiple UV images on the digital 3D model.

Some investigations produced image-based results, which can be directly mapped on the statue surface and presented in an integrated manner. An example is the case of the Ultra-Violet (UV) imaging investigation. Images produced under UV lighting are very important to give visual evidence of organic deposits on the marble surface (e.g. wax), which have to be removed with proper solvents. The UV investigation performed by the *Opificio delle Pietre Dure* (a renowned Italian public restoration institution) produced many 2D images taken from different viewpoints. These images can be mapped onto the 3D surface using an approach which computes the inverse projection and the camera specification from each single photograph and combines all the available photographs in a single texture map which is wrapped around the 3D geometry [2]. Using these visualization processes, we are able to map image-based information on the corresponding location of the 3D object surface and to inspect all of the images at the same time with the help of an interactive browser (Figure 5).

Another important source of data is the high-resolution photographic survey of the David, performed by a professional photographer with digital technology and according to the specifications given by our group. The photographic sampling was planned as shown in Figure 6. The reason for planning these photos is to document the status of the statue before the restoration. These RGB images can be mapped as well to the 3D mesh (see Fig. 7) with the same methodology used for the UV images. Moreover, the restorer Agnese Parronchi has performed a precise graphic survey on the status of David's surface. She drew very accurate annotations on those high resolution photos, covering all the surface of the statue. These annotations describe in a very detailed manner: the imperfections of the marble (small holes or veins); the presence of deposits and strains (e.g. brown spots or the traces of straining rain); the surface consumption; the remaining traces of the Michelangelo's workmanship. Agnese Parronchi drew these annotations on transparent acetate layers positioned onto each printed photo (in A3 format). Therefore, we have 4 different graphic layers for each one of the 68 high-resolution photos. These graphic reliefs have been scanned, registered (roto-translation+scaling) on the corresponding RGB image, and saved at the same resolution of the corresponding RGB image. A web-based system has been implemented to browse the RGB images and to plot in overlay any relief layer selected by the user (see Figure 8). We decided to show the reliefs in overlay onto the RGB images, thus to use a 2D-based visualization

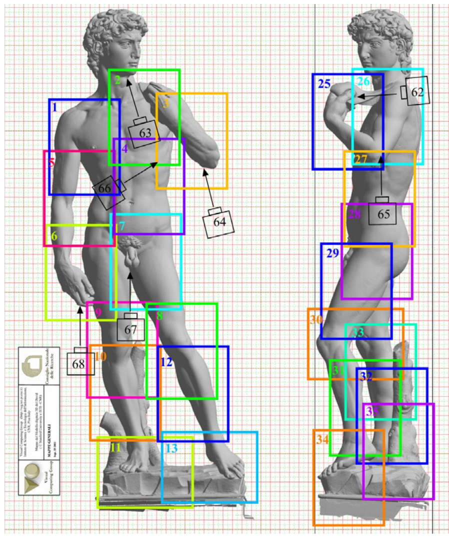

Figure 6: Schema of the photographic campaign, which divides the David surface in 68 photos (only a subset of the images is shown here).

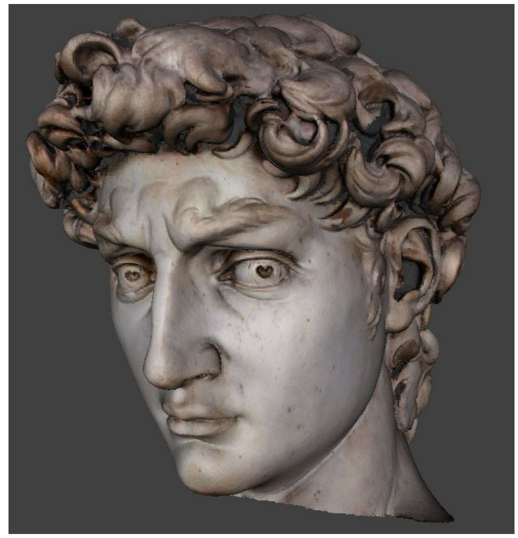

Figure 7: Mapping of a RGB images on a section of the statue's digital model (images rendered from the 3D model).

approach, instead than trying to map reliefs and RGB images on the 3D surface. This choice was justified by the large amount of information contained in those 2D layers (each of them is a 5M pixels image); mapping and rendering interactively such complex data on 3D surface is a very hard work. In this case the 2D space is much more adequate, since the access to those data will be selective (the user will browse over small sub-regions of the David skin). Again, the 3D model is used as a spatial index to the set of images.

4 Concluding remarks

We have presented some examples of how we have used specific visualization tools together with a 3D digital model in the framework of the David restoration. As we have shown, the 3D representation has been used both to execute some particular investigations and as a supporting media for the archival and integration of the restoration-related information. The adoption of a similar approach in a standard restoration project is economically affordable, since the cost for acquiring a 3D model of an artwork is progressively reducing.

However, the main difficulty encountered is the lack of visualization tools and metaphors for the proficient use of 3D graphics in CH domain and, more specifically, in restoration. A clear example is the use of 3D graphics to organize and visualize other data: the tool needed would be very similar to what do we have in the case of geographic data management. In most cases, we need some sort of GIS-like tool which should allow us to easily map data to the 3D geometry, or to segment the digital surface of the artwork according to different categorizations. Unfortunately, the CH domain is still a niche market and does not attract the interest of software companies. Doing research in this domain means that we are often requested to design and implement tools which could have been done by a professional software developer (see for example the Cavalieri system [3]), and this makes the work of a CG research team harder.

Another critical point is the acceptance of digital methodologies by CH people. They usually have a non-technical education and are often very sceptical and reluctant to endorse digital methodologies. Fortunately, our experience is that this initial negative position can be easily overcome when we are able to offer them not just nice images, but tools really usable in their daily work. Usability of the

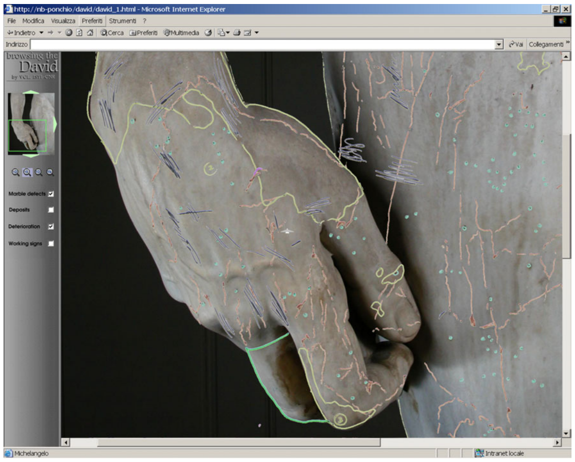

Figure 8: An image of the web-based system to browse the RGB photographs and reliefs database.

tools is another issue: 3D graphics and visualization tools are often rather complex, potential users are in general not expert in IT, and many requests cannot be fulfilled using in naive manner the features of available visualization systems. Therefore, we think that one of the members of a modern CH restoration staff should have a substantial IT/CG education.

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