1st International Conference on
Metrology for Archaeology
Benevento, Italy, October 22-23, 2015

Digital Restoration Using Image-Based 3D Models

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***Abstract* – This article present some results related to different case studies in which it is addressed the problem of digital restoration using digital 3D models exclusively produced by means of image-based technologies. The integrally IB approach is justify by different requirements: the first is linked to the possibility to obtain efficient 3D models complete with texture in easy way. The second is linked to the time of capture of these models and the third on the better management of the workflow due to the excellent performance with low-polygon models generated by IB technologies. Of course the same approach you can get on every type of 3D models, also obtained by laser scanning, but with more problems related to the textures and the management of large amounts of data. The full 3D approach to the problem of the restoration of archaeological finds extremely damaged, raises several points of interest, including sculpting and painting directly on surfaces, as well with the possibility of reintegration of the missing parts using other sculptural elements in similar subjects best preserved. Starting from these premises, we carried out a comparative test on different image-datasets with different ISO and different resolution, to provide a metric comparison of results, as an operational base that allows to know, in advance, the criticality metric in IB surveys.**

I. INTRODUCTION AND AIMS

Facilitating the reading of a monument means making its transformations, identity, origins and *raison d'être* transparent and intelligible. But all these operations, designed to highlight the values contained in the item, can no longer be considered part of restoration: the irreversibility of any reconstruction *in situ* contrasts strongly with the inviolable principles of minimum intervention and respect for an item's historical and aesthetic character. The aim of restoration is, and remains, to conserve and guarantee the temporal continuity of a work of art, while it is the task of virtual archaeology to reconstruct ever more extensive views of our past by means of all types of visual aid. In this sense, the more recent term "virtual restoration" – referring to all operations not directly linked to the repair and recovery of artefacts – would seem to be a contradiction in terms. Forms of virtual restoration are fully admissible where they serve to simulate a hypothetical intervention or the digital restoration of copies of a work, but what should be our approach to the digital reconstruction of an item's original appearance?

Every hypothetical reconstruction that can serve as a vehicle of information – not only on what can be viewed directly, but also and especially on those elements that are difficult to read or decipher – is consistent with the principles expressed in the restoration charters: highlighting the educational value of ruins and making them comprehensible are, as we have seen, objectives common to both restoration and virtual archaeology. Virtual archaeology proceeds by means of a systematic study which is as 'transparent' and intelligible as possible, its evolution being fully logged and therefore 'traceable'. It seeks to provide the public with interpretative information on monuments and works of art whose figurative integrity has been damaged or compromised.

This article starts from these premises to present some results related to different case studies in which it is addressed the problem of digital restoration using digital 3D models exclusively produced by means of image-based technologies. The integrally IB approach is justify by different requirements: the first is linked to the possibility to obtain efficient 3D models complete with texture in easy way. The second is linked to the time of capture of these models and the third on the better management of the workflow due to the excellent performance with low-polygon models generated by IB technologies. Of course the same approach you can get on every type of 3D models, also obtained by laser scanning, but with more problems related to the textures and the management of large amounts of data. The full 3D approach to the problem of the restoration of archaeological finds extremely damaged, raises several points of interest, including sculpting and painting directly on surfaces, as well with the possibility of reintegration of the missing parts using other sculptural elements in similar subjects best preserved.

II. DIGITAL RESTORATION ISSUES

Digital restoration of sculptural elements get significant

ISBN-15: 978-88-940453-3-8

benefits with the use of 3D models. It is well known the benefits derived from 3D models especially in the contextualization of collections located in different places or reintegration of missing parts. As is known, however, the operation of reintegration is possible only in the digital domain, for all those implications referring to the historical-aesthetic instance of the restoration rules. In the past, especially in the eighteenth and nineteenth century, it was often carried out several operations of physical reintegration, with results also striking of juxtaposition of different pieces or stylistic restorations. A clear example of this attitude is given by the Head of Antinous, exhibited in the Farnese Collection in the gallery of the Carracci, placed on a more ancient and extraneous bust. It is an integration of multiple pieces on a single subject.
The head was found in Palazzo Farnese by the end of the '500 and was adapted by Giovan Battista de' Bianchi to a torso of uncertain origin. Carlo Albacini restored this artwork in the eighteenth century, which integrated the arms, the legs and the base with the shore (Fig. 01).

Fig. 1. Farnese Collection, the restored Antinous.

All this, as many other restorations of the same type, have for years argued debates about the authenticity and relevance of the various pieces, but what is most interesting to us is that the same operation, in the digital domain, can be carried out without ambiguity and especially with the use of authentic pieces. We know that many ancient sculptures were made using previous prototypes well known, often work of great artists, that somehow constituted a statuary type replicated and declined in various forms. The discovery of fragments of statues that relate to these well-known prototypes can provide a basis for interested applications in digital restoration. This can give satisfactory results both in terms of style - for the use of original pieces - both for the problems related to the reversibility and to the clear distinction of the intervention.
In digital restoration, in fact, the operation of reintegration can be easily declared and distinct from the original. This can be used for communication purposes, where the re-evocation and description live together, to provide information on the real object - the archaeological find - and its probable original appearance. In this case the material of the work of art is preserved, with the benefit of being able to combine to it a digital reconstruction that reveals those historical and aesthetic values that are illegible today. An effective technique, to that end, is represented by animations where the original object is placed in the reconstructed context. A later dissolve transition shows the same object restored. The transition between the two different stages allows to associate, for example, an object displayed in the museum with the context of origin, or with other original objects exposed in another place. A similar approach was recently used by our laboratory (CNR IBAM ITLab) in different projects. In this way the scientific aspect, linked to interdisciplinary results, has joined the need to deliver to the general public simple and effective communication product. The comparative test just described below has allowed to establish the parameters for 3D image-based survey that have been replicated to all of the fragments used in this work in order to obtain a standard replicable operating procedure.

Fig. 2. original object placed in the reconstructed context

III. COMPARATIVE TEST

Alongside the need to obtain low-cost 3D models on which you can apply the operations of digital restoration, it is necessary to proceed with the operations of survey that give good results in terms of precision and accuracy of measurements. Some experiences about the value of the metric measurements into IB 3D models have already been conducted by different groups and with different objectives. The measurement tests that we report in this article are aimed at defining an operational methodology that, from practices tested, can be useful to identifying those technical parameters necessary for optimal results in SfM/IB survey. What is most interesting in our work is the need to achieve a robust and replicable procedure that can provide parameters useful to obtain repeated measurements with equal error values and the best possible resolution in relation to the number of images captured.

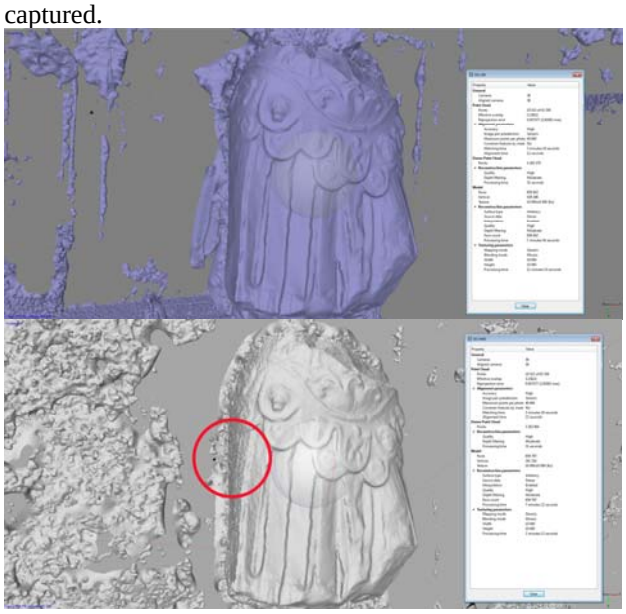

Fig. 3. Comparison of results using different ISO (6400 ISO image below) . In evidence the noise in the dark areas.

Therefore were compared 3D models obtained with photos with ISO values and different resolution of images in order to consider the real difference of accuracy reached in the various datasets. The photographic survey has concerned a fragment of a *loricata* statue of emperor, from the *frons scenae* of the roman theatre of Lecce, actually exposed at the City Historic Museum (MUST). In the same museum are viewable in stereo mode the results of restoration, included in the *scene* of roman theater in Lecce. The shooting, made with full-frame camera Canon 5D Mark II 21.1 Mpix, have produced two different datasets with ISO values of 200 and 6400, in order to create two extreme conditions in relation to the same light conditions, remained unchanged during the acquisition. For each single set of 18 photos, were held constant the focal distance (35mm), the exposure light, the iris opening (f 22) and the sampling step, so as to cover the entire surface of the fragment and ensure sufficient overlapping, an indispensable condition for the identification and the association of homologous points. A third set was prepared by the reduction to 1/4 of pixel resolution using the photo taken to 200 ISO, which satisfying the minimum required by the software, intends to measure the difference in resolution obtained from the model images got with a 21.1 Mpix.

The frames of the three sets were processed with the software PhotoScan of Agisoft. In order to obtain a space of identical processing, the alignment was carried out using all the shots of the different datasets, proceeding subsequently to the creation of the point cloud, the mesh and the processing of the texture for each reference datasets. The software uses flexible algorithms such as to ensure the orientation of photos even in the absence of classic principles of photogrammetry. All operations are automated, leaving to the operator the ability to set the parameters as a function of the desired quality for the definition of polygons number and the texture size.

Specifically, for the creation of dense cloud we were chosen parameters High for Quality and Moderate for Deph filtering; for the mesh Arbitrary in the Surface type, Dense for Source Data; high for polygon count, leaving the average value automatically recommended by the software. For the texturing, Generic for Mapping mode, Mosaic for the Blending mode, 10000x10000 px for Texture size. For the set to ISO 200 was further calculated the option with a value of dense cloud set to 6 million polygons, forcing the average calculation automatically proposed.

Below it's shown the table for comparison of data:

Data set	**Dense Point Cloud**	**Model faces**	**Model vertices**
ISO 200 (21 MPix)	4.285.370	859.062	439.288
ISO 6400 (21 MPix)	3.263.964	654.797	341.316
ISO 200 (5MPix ca)	1.943.435	388.668	199.489

The resulting models were imported into a 3D modelling software; the perfect overlap of different models is guaranteed by the use of the same processing area in PhotoScan. For each 3D model has been isolated a significant element of 15 cm per side in order to compare the subdivision of the polygons and the distribution of points. The comparison between all data set shows that an increase of ISO value, equivalent to 3100% (from 200 to 6400), produces some loss of information, with a less of dense cloud equal to 23.834%. High values of ISO increase global uncertainty in the measurement, that produces - as expected - remarkable 3D noise areas in correspondence of less lighting and less characterized surfaces. The reduction to ¼ of the 200 ISO dataset produce a reduction of approximately ½ of the dense cloud. This results are clearly in accordance with the

recommendations provided by different SFM/IB software houses, but show that the most critical aspect is linked to the amount of images noise, generally due to the high ISO. The lower resolution of the source images, compared to the original ones at full resolution, can give satisfactory results only with the proportional increase of the shooting distance, so as to ensure the capture of a larger number of photographic detail.
Below is a table for comparison relating to the sample of 15x15 cm:

Data set	Area campione	Points	Polygons
ISO 200 (21 MPix)	15x15 cm	653	1049
ISO 6400 (21 MPix)	15x15 cm	526	845
ISO 200 (5 MPix ca)	15x15 cm	215	288

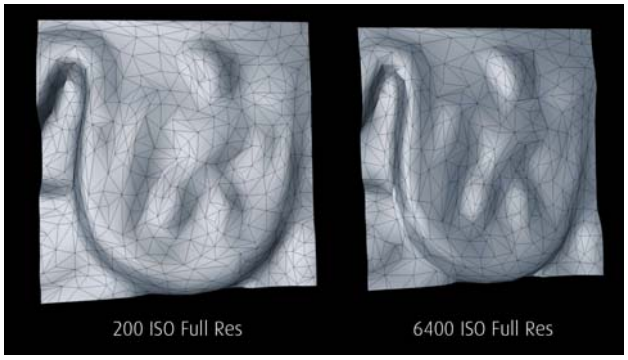

Fig. 4. Comparison between different ISO values

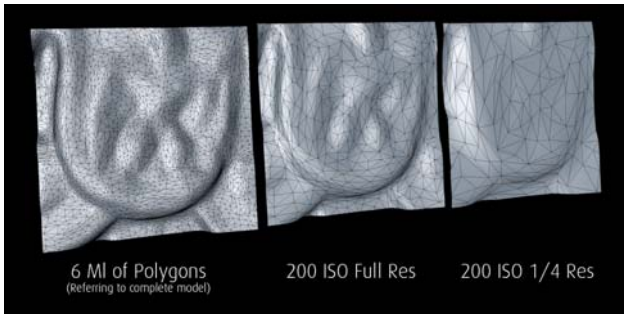

Fig. 5. Comparison between various resolution

IV. CASE STUDIES

The comparative test just described has allowed to establish the acquiring parameters that have been replicated to all the fragments present in the survey work, in order to obtain a standard and replicable procedure. An uniform resolution and excellent quality of the models are the indispensable prerequisite for proceeding to a digital restoration operation which involves the use of different fragments. An example of this technique, as mentioned, has been tested for the three-dimensional reconstruction of the scene of roman theater in Lecce, where several sculptures were placed into niches. The eleven fragments found during the excavations carried out in the Marescalchi alley in Lecce, between 1929 and 1938, are very interesting both for the remarkable stylistic level of the individual pieces and for the variety of types of statues and subjects represented. The group of the ideal statues includes seven *opere nobilia,* replies or reworking of masterpieces of Greek sculpture. They were very appreciated by the Romans. We shows here an example of digital restoration performed according to the methods that have been described. The fragment refers to a statue of a woman, dressed in a chiton with thick folds superimposed with cloak, preserved only in the lower body. Digital restoration follows the guidelines of the archaeologists, with additions made from contemporary and similar female statues. Different objects have been scaled and repositioned, giving the appearance that we shown in figure 6. The whole scene of the theatre was rebuilt incorporating 14 fragments, making possible a comprehensive approach that takes into account both the architectural values and sculptural elements, how he could appear in ancient. Any decorations and colours were excluded from this study. They certainly had strongly characterize the appearance, but we have no archaeological evidence at the current time.

Fig. 6. Virtual restoration of dressed woman.

Fig. 7. The complete scene of theatre with 14 reconstructed statues.

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Fig. 8. Complete reconstruction of theatre