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HIGH-QUALITY 3D MODELS AND THEIR USE IN A CULTURAL HERITAGE CONSERVATION PROJECT

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ABSTRACT:

Cultural heritage digitization and 3D modelling processes are mainly based on laser scanning and digital photogrammetry techniques to produce complete, detailed and photorealistic three-dimensional surveys: geometric as well as chromatic aspects, in turn testimony of materials, work techniques, state of preservation, etc., are documented using digitization processes.
The paper explores the topic of 3D documentation for conservation purposes; it analyses how geomatics contributes in different steps of a restoration process and it presents an overview of different uses of 3D models for the conservation and enhancement of the cultural heritage. The paper reports on the project to digitize the earthenware frieze of the Ospedale del Ceppo in Pistoia (Italy) for 3D documentation, restoration work support, and digital and physical reconstruction and integration purposes. The intent to design an exhibition area suggests new ways to take advantage of 3D data originally acquired for documentation and scientific purposes.

1. INTRODUCTION

The in-depth study of a piece of the cultural heritage without doubt demands the investment of a great deal of resources, therefore it is usually done in correspondence to "special events". Even though the current approach favours regular maintenance so as to avoid more radical one-off interventions, documentation projects are frequently undertaken on occasion of restoration operations (Balletti and Guerra 2015). And so it was that during recent restoration of the loggia of the Ospedale del Ceppo in Pistoia (Italy), a survey was commissioned to document the state of the building and to map out the conservation work. The project provided the opportunity to test and also assess other potentials of the acquired 3D data (Tucci et al. 2015a).

2. THE CASE STUDY

The loggia displays one of the greatest decorative friezes made using the glazed terracotta technique known as *robbiana*, after Della Robbia family who invented and spread it throughout Tuscany during the Renaissance.
The loggia was built around 1512 to embellish the façade of the hospital which had been founded in the thirteenth century (Masdea and Tesi 2015). Clay was a cheap material that is easy to model, however the secrets of the firing and glazing used to create great works with bright and lasting colours were jealously guarded.
The reliefs are by various authors: the first works were made by Benedetto Buglioni around 1510-15. Most of the frieze, made by his son Santi around 1526-29, represents the Works of Mercy with many almost life-size figures, showing with realism the life in a XVI century hospital. The medallions in the spandrels of the arches of the portico represent garlands containing scenes from the life of the Virgin Mary and coats of arms and are attributed to Giovanni della Robbia. The last scene was created by the painter Filippo di Lorenzo Paladini towards 1585, when the secrets of this art had been forgotten, with a technically poorer quality result. The dimensions of the frieze are around 45 x 1.5 m, and, also considering the medallions, the overall surface of the ceramic works measures around 75 sq m.

3. MULTI-SCALE APPROACH

A documentation project often requires a multi-scale approach, in order to describe the monument context, the building itself and some of its details (Georgopulos and Ioannidis, 2004). Therefore, accuracy and resolution must be carefully planned and instruments and techniques must be chosen to produce the required data (Guarnieri et al. 2006, Grussenmeyer at al. 2011, Lerma et al. 2011).

Figure 1. Taking photogrammetric imagery from the scaffolding: for close-up images it was not possible to use even the tripod

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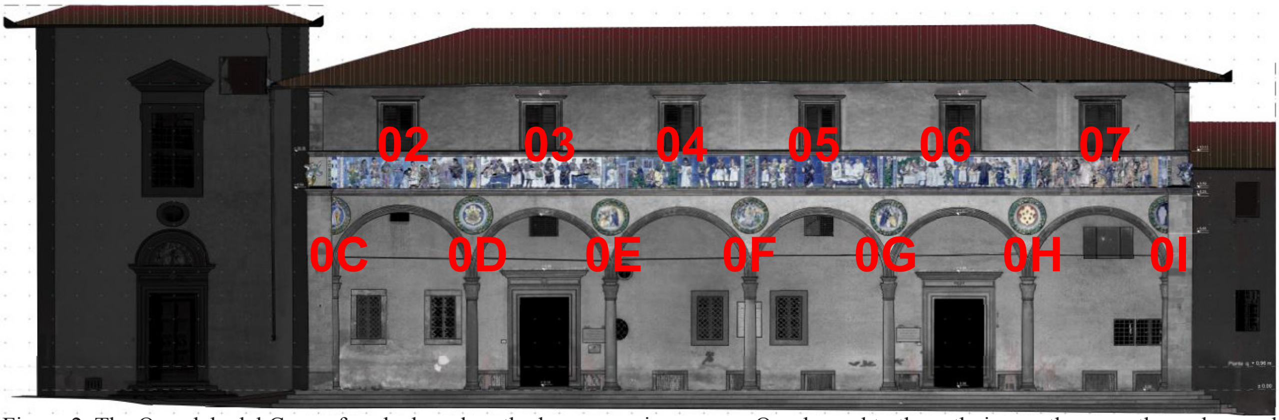

Figure 2. The Ospedale del Ceppo façade, based on the laser scanning survey. Overlapped to the orthoimage there are the codes used for sub-projects identification (see Table 1)

	Before restoration		After restoration	
Sub-project	**Imagery**	**GCP**	**Imagery**	**GCP**
01_Ignudi	315	22	1170	12
Arpia_sx	117	12	276	8
02_Pellegrini_ Prudenza	525	25	935	19
03_Infermi_Fede	407	30	989	21
04_Carcerati_Carità	342	31	981	19
05_Defunti_Spe- ranza	567	38	928	30
06_Affamati_ Giustizia	512	33	1.069	28
07_Assetati	504	31	1.147	24
Arpia_dx	151	12	345	9
08_Ceppo	43	9	133	9
0A_Ceppo_1/2	46	10	103	7
0B_Comune_1/2	68	10	216	8
0C_Ceppo_1/2	107	12	135	8
0D_Arma_Ceppo	126	13	227	11
0E_Annunciazione	163	13	247	9
0F_Assunzione	133	19	240	14
0G_Visitazione	112	16	261	13
0H_Arma_Medicea	133	15	189	11
0I_Arma_ Comune_1/2	143	6	147	10
	4.514	**357**	**9738**	**270**

Table 1. Sub-project organization (see Fig. 2)

3.1. The documentation of the building

The loggia and the façade of the Ospedale was surveyed with scanning systems from the square, with an average resolution on the object of approximately 3 mm, appropriate for documenting the building's dimensions and texture and describing the details typically requested at the architectural scale. The point model has been used to extract slices and orthoimages for architectural drawings as elevations and plans (Fig. 2).

3.2 The documentation of the frieze

As the earthenware decorations are at about 10 m from the ground it was not possible to acquire the frieze and medallions from that distance and position with the requested level of detail. Hence, it was decided to do close-up photogrammetric acquisitions at height during the restoration work (see also Fritsch et al. 2011), taking advantage of the special dual-width scaffolding erected to allow visits to the restoration site (as described below). The camera network was designed considering that it was possible to take normal images up to 1.80 m from the subject and a GSD lower than 0.3 mm.
Even if the scaffolding was specifically designed, somewhere the frame was very close to the object and it was not possible to take photos from all best points of view. Moreover, as in most documentation projects of cultural heritage, survey has to be done in the shortest time and without work interruptions, so it's not possible to wait the best weather condition as cloudy days. So, as most part of the frieze is facing South, a main issue was to shade the survey object, avoiding direct sunlight and sharp shadows of the scaffolding (see also Menna et al. 2016).

Figure 3. Camera network - post-restoration work photogrammetric project

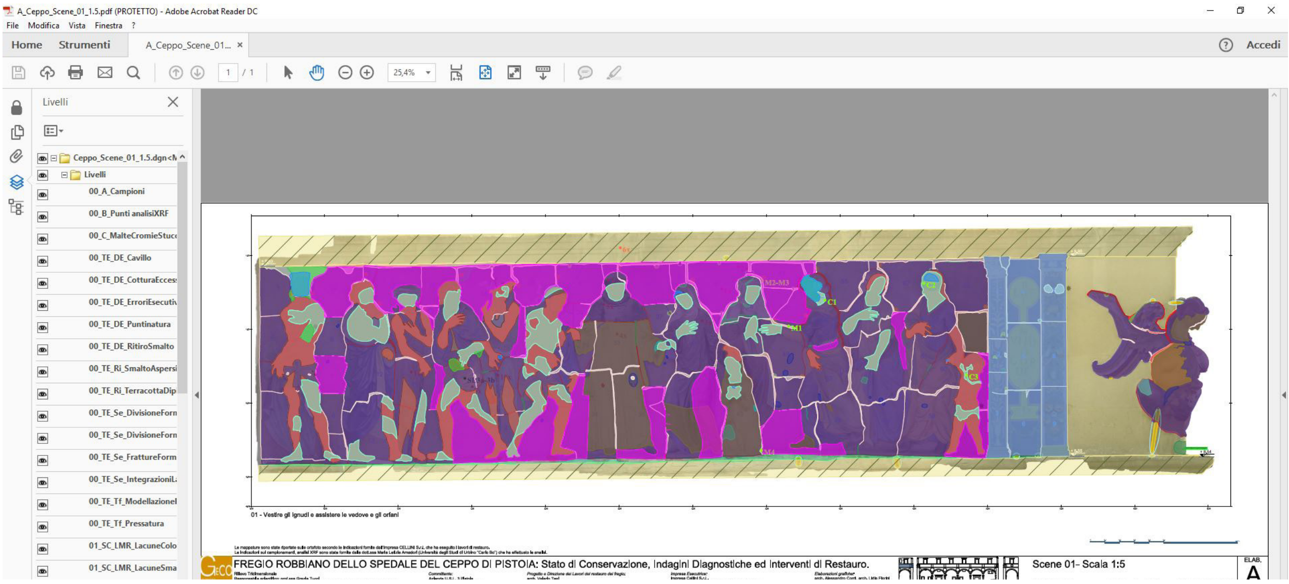

Figure 4. 2D thematic maps related to investigation and conservation work: each theme can be viewed separately or in relation to the others (interactive PDF file)

Figure 5. 3D interactive PDF with thematic maps related to investigation and conservation work

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Figure 6. Mesh model of one of the sub-projects (05 in Table 1)

SUMMARY TABLE	
Acquisition campaigns laser scanner	Febraury 2013 November 2013 December 2014 – January 2015 September 2015
Field personnel	2/3 (scanning – photogram-metry)
3D scans	13
TLS Measured points	419.893.132
Terrestrial Photogrammetric Imagery (before restoration) GCP/CP TPI (after restoration) GCP/CP	4.514 357 9.738 270
GSD	<0.0003m
Hardware	1 laser scanner Leica C10 1 laser scanner Z+F 5010C 1 SLR Nikon D700 Nikkor lens 50mm 1.4G
Software	Cyclone Leica (range maps) Reconstructor (orthoimmages) Bentley Microstation (CAD) Photoshop (editing) Agisoft Photoscan (photo-grammetry) MeshLab (mesh) ZBrush (virtual restoration)

Table 2. Summary of the most relevant data of the project

4. BEFORE AND AFTER RESTORATION WORK DOCUMENTATION

Photogrammetric surveys has been done before restoration works and then repeated at their end. Therefore, two different conservation models have been produced, as well as two orthophoto sets.

A careful study of the building or of the artwork, and as much as possible complete gathering of existing data (images, historic documents, previous surveys, etc.) and a new metric survey are a necessary first step for a correct restoration.

Restoration works must be continuously monitored and documented on an ongoing basis. (Carta del restauro 1972)

As stated by (Sanpaolesi 1973), a complete description of restoration works must be produced, by drawings, photos and updated surveys, also at the end of the works.

4.1 Before restoration photogrammetric survey

The aim of the survey before the restoration work was:

- to attest the state of conservation and decay of the frieze;
- to locate the samplings done by diagnostics specialists;
- as a support to record the restoration work.

The planning of a photogrammetric project can be easily controlled in the case of aerial photogrammetry (even when images are acquired by UAVs) but it is always a challenging task in front of a complex shaped object that requires high resolution digitization. In this case, the camera network included both normal to the object and convergent photos, the latter around most protruding parts (Fig. 3).

It has been not possible to put targets on the artwork, so some clearly visible natural points has been selected on laser scans and

Figue 7. Virtual restoration: mesh model of the female figure whose face has been lost (left), the reconstructiond hypotesis based on surviving elements and antropometric data (centre), the virtual integration of both models (right)

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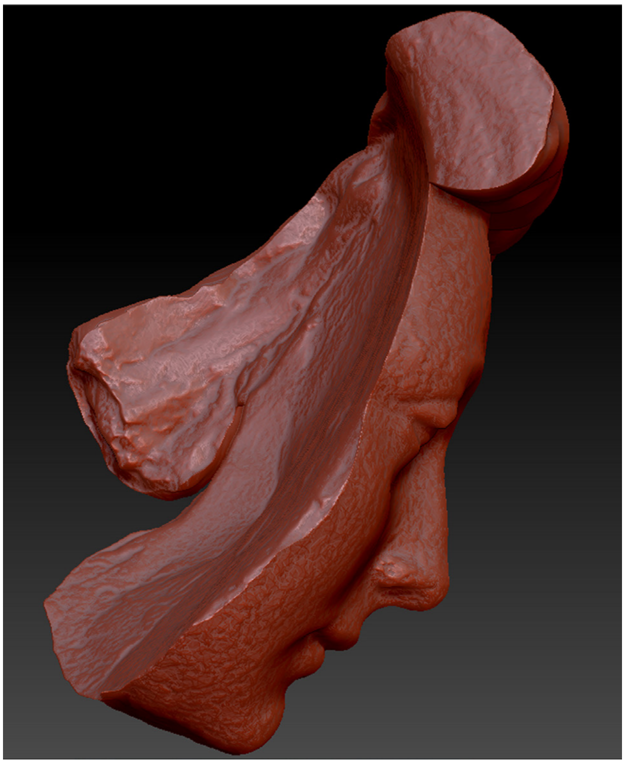

Figure 8. The virtually reconstructed missing part of a female figure: the face and the head cover has been moulded on the surviving surface to obtain a watertight model

used as Ground Control Points and Check Points (Stavropoulou et al. 2014).
The GSD of the resulting orthophotos is lower than expected, due to the amount of close-ups of details. In addition to these, mesh models of the scenes were also made. The investigations and conservation work carried out during the restoration were mapped on this 2D and 3D output, creating high-resolution digital maps on which each theme can be viewed separately or in relation to the others (Tucci et al. 2015b).

4.2 After restoration photogrammetric survey

After the work, a new photogrammetric survey has been done to attest the restoration and to do high resolution orthophotos to

Figure 9. A mesh model displayed on a tablet

show the details of the frieze to the visitors of the new museum that will be opened soon. The gained experience from the project before restoration work has been helpful for improving the camera network and suggested to acquire more images about details. In fact, a lack of data resulted in the upper part and over some heads of the sculptures.

5. THE VIRTUAL RESTORATION MODEL

Restorers still have the difficult and delicate task of achieving a balance between correct restoration and the need to "*to re-establish the potential oneness of the work of art, as long as this is possible without committing artistic or historical forgery, and without erasing every trace of the passage through time of the work of art*", as Cesare Brandi theorized (Brandi 1963).
On the other hand, nowadays digital models allow to study broken or fragmented artworks in many innovative ways. Virtual restoration helps to design a physical reassembling of fragments or to visualize the most likely appearance of a broken artwork for scholars or for a wider public (Arbace et al. 2012).
In the frieze of the Ospedale del Ceppo, small gaps were repaired during the restoration, while the larger ones were plastered to

Figure 10. 3D printing of the surviving surface and of the reconstructed missing part: the models fit perfectly

prevent water infiltration and further damage. In the case of a female figure whose face has long been lost, a virtual restoration was attempted by hypothetically reconstructing the facial features.

5.1 Virtual restoration workflow

The most updated point model has been meshed and, in the lack of certain data about the missing parts, we made the following remarks for the model reconstruction:

- The female figure whose face has been lost wears a partially preserved headdress (called *mazzocchio*) rolled up around her head and with an edge of tissue draped on her shoulder.
- Considering these hints, the headdress has been completed with digital sculpture techniques, starting from a torus surface.
- The face of another female figure from the same scene has been fitted on the anthropometric features of the still standing remains: the face' surface has been duplicated and moved, rotated and scaled, filling the gap in the model.
- Finally, the back part was moulded on the surviving surface so that it would fit perfectly.

5.2 3D printed restored model

This model, ready for 3D printing, makes it possible to envisage a reversible reconstruction of the work.
An FDM 3D printer has been used for printing both the model describing the preserved freeze (the back part) and the model concerning the hypothetical integration (Tucci and Bonora 2011).

6. COMMUNICATION MODEL

Accompanying the restoration project for the frieze was an interesting test project to inform the city and tourists of the work being done. Scaffolding is inevitably seen as an element of disruption and it is not infrequent that restoration work on a monument limits access to it or the public's possibility of visiting it. In the case of Pistoia, it was instead sought to transform the scaffolding into an opportunity to allow the public to "approach" the frieze. Particular attention was paid to access and safety concerns and it was made sure that the scaffolding boards were large enough so that visitors could climb onto it to admire both the frieze itself and the restorers at work. Having a high-resolution 3D model mapping out the restoration work will make it possible to reproduce the close-up observation and educative experience even when the work is finished, with the necessary simplifications for communication to a non-specialist public (Fig. 9, see also Visintini 2011 and Rodrigues et al. 2015).

7. THE TRAINING MODEL

These days, serious games are applied to formal education, corporate training and leisure time; the educational purpose of serious games does not mean that they are not, or should not be, entertaining.
Few experiences have been developed in the cultural heritage field. 3D models and restoration-related data could support innovative digital applications for restorer training and knowledge improvement in such a specialized field as the conservation of earthen materials.
For training a public without specific technical skills, a one-to-one or reduced scale solid print reproduction can effectively illustrate various aspects: iconographic contents of the decorations, production techniques, decay, modern analysis and intervention techniques, and the restoration performed (Balletti et al. 2017). The possibility to explore the model by touch also extends the pool of users to the visually impaired.

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Figure 11. A sub-project mesh model, in wireframe, shaded and textured visualization