Virtual and augmented reality applications for Cultural Heritage

Simone Garagnani
University of Bologna, Italy.
simone.garagnani@unibo.it

Anna Maria Manferdini
University of Bologna, Italy.
am.manferdini@unibo.it

Abstract: *The purpose of this paper is to show the results of a research aimed at investigating the potential of digital technologies in order to provide instruments that allow to share information about the Cultural Heritage, which Museums and Institutions are called to preserve and promote.*
Our project's aim is finding the most suitable procedure to acquire archaeological artefacts, build their digital replica together with 3D printed prototypes and derive simplified models to be visualized through stereoscopic devices, allowing the simultaneous viewing of real and digital 3D data through an augmented reality environment, portable to mobile devices as well.

Palabras clave: 3D recontructions, stereoscopic visualization, augmented reality, virtual museum, rapid prototyping.

Introduction

Digital technologies have become more and more sophisticated in acquiring real data and building faithful copies of them, suggesting interesting applications in the field of Historical, Cultural and Artistic Heritage. In particular, the capability to digitally acquire and restore reality-based models of artefacts allows to improve digital archives by organizing information using 3D models as intuitive graphical interfaces. By restoring the intrinsic 3D characteristics of artefacts, reality-based models:

- provide accurate and detailed information about shape, as well as chromatic and radiometric appearance of what is represented;

preserve 3D information that are fated to change through time, considering acquired data as references during preservation or restoration interventions;
build virtual reconstructions of sites that have significantly changed through time;
share information among scholars who work in different places and times, who can access digital archives through the web.
In addition to these aspects, production of physical replica of finds using digital technologies (i. e. rapid prototyping) provides a significant improvement to reconstructions of archaeological sites allowing, for example, to collect in the same place replica of objects whose original copies are inaccessible because they don't exist anymore or are preserved in different locations.
Despite several technologies and methodologies for 3D digitization have been developed in the last two decades (Bernardini and Rushmeier, 2002; Blais, 2004; Remondino and El-Hakim, 2006; Yin et al., 2009), the lack of a standard procedure and the costs connected to their use still doesn't encourage the systematic acquisition of wide collections.
The purpose of this paper is to show the state of the art of a project whose aim is to provide a methodology in order to create reproductions of small and detailed artefacts for Institutions called to preserve, manage and enhance archaeological finds inside museums or through digital exhibitions.

Methodology

One of the aims of our investigations was to figure out how to effectively exchange information among museum collections, without the need for physical transfer. In order to support and instance our methodology, we selected the case study of the bronze *Situla Arnoaldi*, an archaeological item dated to the full V century B.C. and found together with others funerary goods in 1881 inside an Etruscan tomb in the Arnoaldi necropolis of Bologna. This *situla* is now preserved in the Archaeological Museum of Bologna and consists in an embossed and engraved bronze plate, with one handle cast apart. In three superimposed orders, spaced out from bands with lotus-buds chain, are represented, from top to bottom, athletic scenes of boxing and chariot racing, a military parade of hoplites and horsemen and a deer hunting scene.
These engravings are very detailed and represent topics regarding an aristocratic way of life, probably realized by an Alpine-Veneto artist; it is supposed to be a prestigious wedding present to a high-ranking woman (Macellari, 2003).

Besides its historical-cultural evidence and artistic value, situla Arnoaldi is significant because of the complex micro-scale details of the low marked engravings on its surface and for the dark and reflecting characteristics of its metal material.
Different survey technologies and methodologies have been tested, showing advantages and disadvantages, while the acquisition of radiometric characteristics and the following texture mapping process highlighted some difficulties mainly due to the dark colour of bronze that doesn't ease the recognition of its shallow engravings.
The most accurate information about 3d geometry have been collected in a Master Model, while Simplified Models where derived from this latter aimed at representing different levels of complexities.
One of our main goals was to preserve the geometry of engravings, whose width and depth ranges from 0.3 to 0.5 mm (the situla measures 25 cm high and has a maximum diameter of 20 cm). As a consequence, a Minolta Vivid 900 and a Perceptron ScanWorks V4i with ROMER Omega bracket laser scanners were used in order to compare precision and accuracy of geometric acquisitions and correlate them with time data processing required by both procedures.
Within the artefact, different resin fillers have been used by restorers in order to hold and connect original pieces, fill the lacks of matter and rebuild the whole shape of the find. For this reason, the geometry of the Master Model does not have a homogeneous tessellation of its surface; these smoothed and less detailed areas were acquired using less dense measurements.

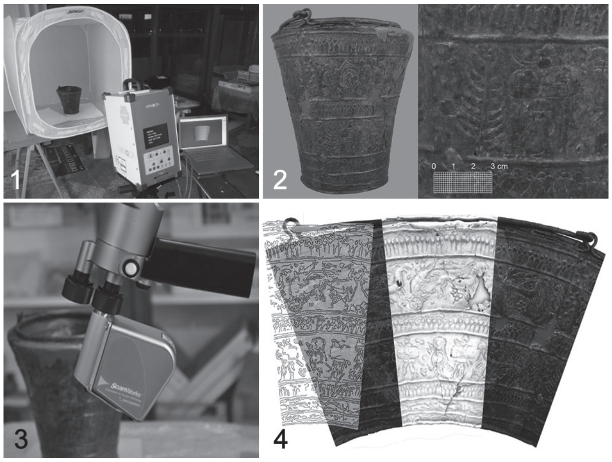

Fig. 1 - Situla Arnoaldi was acquired using Minolta Vivid 900 scanner (1) to document its not homogeneous surface (2). Perceptron ScanWorks V4i was used to collect a more accurate and defined geometry (3) that eased texture mapping. Engravings were highlighted through ambient occlusion techniques, Canny algorithms and binary translation of raster images (4).

Last generation of laser scanners has recently been equipped with high-definition cameras which allow to acquire good quality colour and radiometric information and directly relate them to 3D geometry. Unfortunately, some of the most sophisticated range-technologies in terms of metric accuracy, still do not offer this opportunity, so texture mapping is an important procedure within reality-based modeling even if it still presents some criticalities in case of draping complex shapes with occlusions (Huang, 2010).
Texture mapping consists in the acquisition of high definition images which need to be post-processed in order to correct distortions and to be related to 3D geometry, since planar images are defined through (u, v) parameters while 3D surfaces are defined by (x, y, z) coordinates. These processes usually consists in projections that can be performed following different procedures and using widely spread three-dimensional modeling packages.
The unfolding of a 3D mesh, for example, consists of the projection of polygonal faces on a plane whose (u, v) coordinates range from 0 to 1. This procedure requires the following superimposition of 2D images on the unfolded geometry, in order to connect mesh faces to image pixels. This methods is usually very effective if used on models with no evident geometric complexities, such as deep convexity or intricate shapes.
Another procedure consists in the orthogonal projection of the image plane on the 3D mesh. This method presents evident lacks if used on models with complex shapes and occlusions.
A method which allows a more precise correspondence between the projected image and the 3D model consists in the geo-referencing of geometry with images, through the recognition of homologues points, from which it is possible to derive the bundle adjustment parameters and therefore align cameras within the 3-dimensional reference system (Abdel-Aziz and Karara, 1971; Huttenlocker and Ullman, 1990; Jacobs, 1997; Remondino et al., 2008).
For the situla Arnoaldi, we tested 3DReshaper®, which offered good quality results in terms of precise correspondence between geometry and images, as well as in blending. Aiming at testing widely used software and therefore find a solution that could reduce costs connected to software equipment, we also tested Adobe® Photoshop®, that allows to manage 2d and 3D objects in the same environment.
This procedure highlighted a good quality results in terms of geometric correspondence between image and model. If compared with the previous methodology, one of the main differences is time required for the manual

alignment of images and 3d geometry in the Adobe® Photoshop® environment.
After this procedure, the high definition model was 3d printed in order to obtain scaled and painted components to assemble in a physical replica.

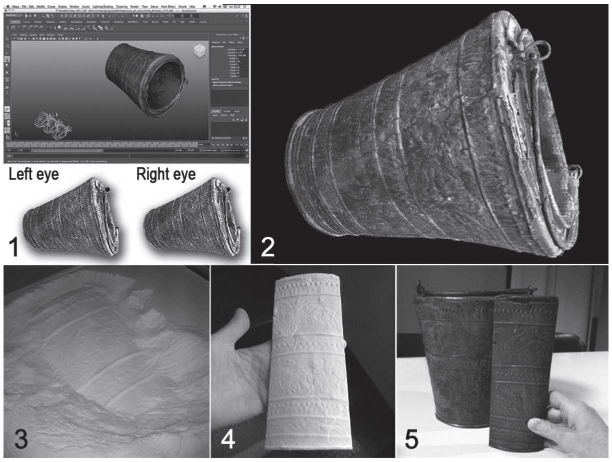

Fig. 2 - Studies on stereoscopic visualization of situla Arnoaldi using the StereoCamera rig option in Autodesk® Maya®; using Nvidia® 3D Vision® active technology, eye-splitted renders were composed in a typical JPS format layout (1). Red-cyan glasses were experimented as well to view anaglyph images through passive techniques (2). The high definition model was 3d printed (3) in order to obtain scaled components (4) to be painted and assembled in a physical replica (5).

Visualization

One of the most important consequences due to the improvements of 3D digitizing technologies is the possibility to use computer graphics as a powerful medium for communication and knowledge sharing aims.
In particular, in order to host and share digital content related to situla Arnoaldi, we selected the Universal 3D (U3D) file format due to its multiplatform operational capabilities and its on-line content sharing easiness.
Originally aimed at becoming a compressed file format standard for 3D computer graphics data, U3D is supported by Portable Document Format, since it can be inserted into PDF documents and visualized using Adobe® Reader® on several platforms, even by different non-proprietary applications. Meanwhile, it provides a high quality viewing experience (Majorov, 2005). Adobe System Incorporated® adopted U3D in 2005, including binary encoding, animation support and extensibility to address evolving visualization needs.
For this reason, 3D PDF files guarantee continuous level of detail and good compression ratio; they are fitted for progressive streaming and therefore allow user interaction during downloading.
Within PDF files, annotations like hypertext links and comments can be added to views by associating them to geometry in form of information layers rendered over 3D models.
3D PDF allows tree structures for model's components so that semantic organization of models is allowed, while it is possible to use measure tools which help to get information about the dimensions of 3D models through sections or ortographic views. As a consequence, the artefact replica becomes expression of a personal experience for every single user, who can customize the access to information independently from its location.

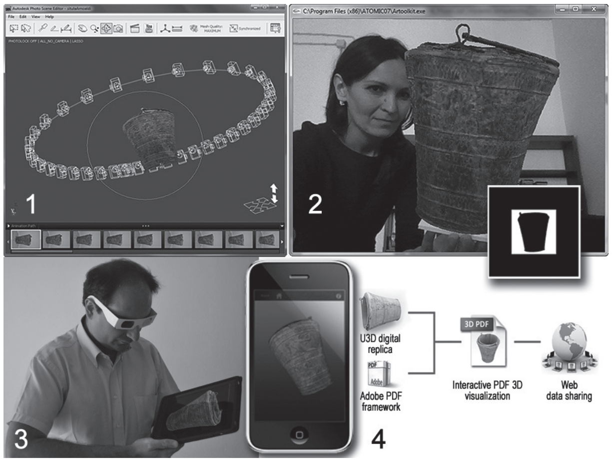

Fig.3 - Digital photogrammetric replica of the Situla (1) with low details can be used in a virtual reality environment (2) where users can interact with the artefact through a marker recognized by the system; light models can be experienced on mobile devices (3) too, or embedded into 3D PDF files destined to web sharing.

Engravings irregularities can be perceived in a more efficient way in a stereoscopic environment: taking advantage of a computer workstation equipped with a suitable card and carrying active glasses which are synchronized with the screen, some situla's images (embedded as a link in 3D PDF with JPS format) were rendered under two different points of view (just like human eyes) and displayed one after the other at 120 Hz frequency (60Hz for each view). Synchronized glasses, which control LCD shutters on lens, make possible for each eye to have its own point of view at a frequency which allows the brain to perceive this spatial phenomenon.
Situla's stereo images (Figure 2) were obtained using the StereoCamera option in Autodesk® Maya®, which automatically creates a proper rigging. Camera's optical axis for both views were almost parallel since this emulates human retinal images (Howard and Rogers, 1995). This configuration, considering a 6.5 cm lens offset, avoids depth pla-

ne curvature and keystone distortion (Woods et al., 1993) when the whole 3D object is visible by both cameras.

Following this procedure, images, movies and interactive models were ported on mobile devices where anaglyph technology can temporarily replace the active one, due to the lack of high frequency screens on PDAs, tablet PCs or cell phones.

In the end, using customized marker recognition software, digital replicas of the Situla were visualized in a virtual reality environment (Figure 3) with the ambition, as a future development, to establish an augmented reality framework destined to Institutions and Museums, where users could easily get information about artefacts interacting with them and their singular components.

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