The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2004)
K. Cain, Y. Chrysanthou, F. Niccolucci, N. Silberman (Editors)

Digital representation and multimodal presentation of archeological graffiti at Pompei

M. Balzani[1], M. Callieri[2], M. Fabbri[1], A. Fasano[2], C. Montani[2], P. Pingi[2], N. Santopuoli[1], R. Scopigno[2], F. Uccelli[1], A. Varone[3]

[1] DIAPREM (Centro Dipartimentale per lo Sviluppo di Procedure Automatiche Integrate per il Restauro dei Monumenti), Univ. of Ferrara
[2] Istituto di Scienza e Tecnologie dell'Informazione (ISTI), C.N.R., Pisa, Italy
[3] Soprintendenza Archeologica di Pompei, Italy

Abstract

Graffiti is a special form of art which gives us important knowledge on culture and social life of a lost civilization. Unfortunately, they are usually engraved on soft and non durable materials. The project described here originated from the request for a new approach to the preservation, study and ubiquitous access to Pompei's graffiti. A multidisciplinary team was setup to design a new methodology to support the digital acquisition, the study and the presentation to the public of this peculiar type of Cultural Heritage. We have investigated the use of 3D scanning technologies and graphics modelling to produce accurate digital reconstructions and to enhance them for an improved readability. The specific issues have been considered and ad hoc solutions have been devised. In terms of presentation, we have provided both visual media (interactive visualization) and physical reproduction, obtained by adopting modern rapid reproduction techniques. The work described is a sort of preliminary feasibility study: we are now planning to apply this methodology on a much wider scale at Pompei.

Categories and Subject Descriptors (according to ACM CCS): I.3 [Computer Graphics]: I.3.3 Picture/Image Generation - Digitizing and scanning

1. Introduction

Digital acquisition and presentation of graffiti is a very specific application of modern 3D graphics technologies. Graffiti (i.e. drawings or writings carved on different materials, usually made by ordinary people on buildings walls or even on artworks) are a form of art (e.g. prehistoric art reached us mostly in the form of graffiti) and a very natural way to transmit various type of social or political information. One can try to infer or reconstruct the culture and the way of living of a population from the study and analysis of the graffiti. The study, dissemination and valorization of graffiti is made more complex than other types of documents or forms of art by a number of issues:

- usually, graffiti is produced on soft materials (like plaster or wood) which are easily degraded by the passing of time. It is therefore crucial to preserve them or, at least, to preserve their memory;
- they are usually very synthetic, not easy to read and often need an interpretation by an expert, to locate them in the corresponding temporal and sociological context;
- some sort of reproduction is often needed to show them in a museum context; moreover, non-expert people (e.g. museums visitors) need some form of cultural mediation to understand and appreciate them.

The ruins of Pompei are a wonderful example of an archeological complex containing a huge quantity of graffiti. Thanks to the instant burial due to the Vesuvio eruption, hundreds of walls have been preserved with all their usually transient graffiti decorations. We have some sort of *still image* portraying an incredibly rich font of Pompei's sociological and cultural life.

The aim of the project described here was to design a methodology for the digital 3D acquisition of the graffiti and for their archival, study and presentation both to experts and to the public. 3D scanning technology has been selected as the technology more adequate to obtain a complete sampling (geometry and color) of the graffiti. The accuracy of current 3D scanners is sufficient for this type of application (see Section 5), but scanning graffiti opens some issues in the further 3D processing of the raw scans (see Section 6). Once a dig-

Figure 1: *Some examples of graffiti, from prehistoric age (picture on the left), to Roman age (a portion of one of the graffiti from Pompei), up to the modern era (a graffito probably engraved by a XIX century tourist on the leg of Michelangelo's David).*

ital model is available, many different applications can be designed to support in the most flexible and effective manner either the study or the presentation/dissemination of this knowledge. We have experimented both *interactive visualization*, through the adoption of an easy to use system (Section 7) and *physical reproduction* via rapid prototyping technology (Section 8). The preliminary results of the project have been already presented to the public with a thematic exposition organized in the framework of the *Ferrara Restauro 2004* fair (March 2004, Italy).

2. Previous Work

Even if the adoption of 3D technology either to reconstruct digital models of Cultural Heritage (CH) or to present those models through digital media has a rather recent history, an exhaustive description of previous works goes well beyond the brief overview that we can draw in this section. We prefer to cite here only some seminal papers on the technologies used in the project, i.e. 3D scanning and rapid reproduction, and the few papers that have considered the digital acquisition and presentation of graffiti.
Automatic 3D reconstruction technologies have evolved significantly in the last few years and CH has been a major assessment and application field [LPC*00, BRM*02, BGU00b, FGM*02, PGV*01] [STH*03, GBT*02, BGU00a]. Some exhaustive overview papers or tutorials have been proposed [BR02, CS00].
Real physical models can be reproduced easily from digital 3D models, choosing one out of the different *rapid reproduction* technologies available on the market [SBE95]. The potential of this technology is impressive, since we may produce high-fidelity replicas in any scale with no danger for the reproduced masterpiece. This is a major difference with the standard moulding approach, which is usually highly dangerous for the integrity of the work of art. Not only fragile objects cannot safely be subject to mold, but it has been proven that also stone sculptures lost most of their "patina" after moulding.

Digital management of graffiti is a rather new field of work. Pioneering virtual systems have been designed to provide access to prehistoric sites, in order to give easy access to prehistoric painted caves. In most of these cases, a medium or low accuracy geometric model is sufficient, since most of the detail can be represented through RGB images mapped onto a low-resolution 3D models. This is also true for most projects representing painted architectures, such as crypts [BPGV03] or Egyptian tombs.
A much more complex task is the digital reproduction of carved graffiti, since the accuracy of the geometrical model should be very high and the resulting 3D models tends to be complex (affecting storage and visualization time). Some of the issues arising when we have to manage large surfaces of carved graffiti are described in detail in Section 6. Only a few experiences have been done on this topic so far [BCC*97, CHYM03, Var03]. But the very recent improvement of 3D scanning and 3D graphics technologies makes this problem tractable.

3. Pompei's Graffiti - History and Motivations

The Vesuvius eruption in 79 a.C. buried the city of Pompei, preserving the urban structure as we can see it nowadays, nearly unchanged from the past with the same architectural and town-planning organization preserved by the different strata of lavic materials, that petrified the city during an ordinary day that turned into the tragic moment of the eruption [Var00]. One of the most important aspects that hasn't been emphasized so far is that these peculiar burial conditions have preserved another very important aspect of Pompei: the wall inscriptions placed on many building's fronts known as *Pompeian graffiti* [Var99, Var96].

The graffiti are considered so important because they show everyday life in Pompei as it was two thousand years ago. Unlike stone inscriptions, carved by chisel on hard materials made on purpose to resist at ageing and to be preserved, wall inscriptions were intended either as a temporary form of art or as social and political information. Graffiti were drawn on building's main fronts. The concept can be compared to modern signs for shops and advertisements.

Figure 2: *Left to right: the Lupanare (VII - 12 - 18) entrance; the "cella" (room) of the Lupanare where the survey took place; and a picture of the graffiti found on the wall of the Lupanare's room.*

They were either carved on plaster with a sharp object or painted by brush and charcoal. The inscriptions had the purpose of celebrating somebody's worth and virtues during the annual politic elections and for this reason they also give a good picture of the political situation in Pompei's history. On the other hand the graffiti show different subjects concerning everyday life, from just a signature, rent or lost things notices, acclamations, to a poem or a simple satire. They could be considered as a history book written by common people in the past, far from the big historical events but involving everyday life.

Graffiti interpretation[†] is a very complex matter, that needs to be solved by a specialized archaeologist. The various forms and typologies of Pompeian graffiti, quite often superimposed one on the other or even placed under more recent inscriptions layers, make difficult to standardize the methods of interpretation, that appear incomplete when only traditional research methods are used. The documentation achievable with these conventional means has to be followed by many direct surveys on site. While conventional research methods give a good contribution for listing this heritage and have a complete sampling, the interpretation of the graffiti needs different kind of information: data about the surface, the depth and the section of the engraving helps to understand its meaning and in which age it has been carved.

Understanding and studying the graffiti is more complicated than other forms of art because they are very synthetic and hard to preserve in good conditions. Only a person with a good knowledge of the corresponding temporal and sociological context can give an exact interpretation of the inscriptions that for these reasons need to be explained to visitors and non-experts. Preservation is hard because they are written on soft materials like plaster or wood and usually they can't be removed from the original site. To be exhibited in museums and studied without being damaged they need to be reproduced somehow.

4. Digital management of the graffiti - Project goals

The goal of the project described here is to assess the feasibility of the digital acquisition and processing of the graffiti and their presentation via both visual and physical media. We want to demonstrate on a real case study that new technologies provide better, faster and more flexible methodologies to manage this peculiar type of heritage [Var03]. The section selected for the case study presented here is the *cella* (room) F of a *lupanare* (Regio VII, Insula 12, no.18-20), a building dug out in 1862 and certainly dedicated to the practice of prostitution (see Figure 2). We scanned a large portion of one of its west wall (this action was included in the October 2003 survey). This case study has been chosen as a valid representative of the typologies available in Pompei, and all possible processing and presentation modes have been investigated, to assess feasibility and to test the results with the help of experts.

3D scanning was selected as the ideal modern replacement of the classical mould reproduction. The accuracy of modern scanning systems is superior to the one of standard manual moulding, and the reconstruction of a digital 3D model opens a much wider panorama of possible uses since we are not limited to a single physical replica, as with standard moulding. As we will see in further sections, 3D scanning of reliefs or graffiti opens a number of issues, since we are digitizing peculiar 3D objects having a wide extents (large wall sections, which may span many squared meters) and very thin interesting features (in many cases, sub-millimetric incisions). The ratio between the total size and the mean feature size is in the range 1/1000, or even 1/10,000; this opens a number of problems either in data management and data presentation.

[†] One of the authors, arch. N. Santopuoli, in collaboration with dr. A. Varone and prof. L. Seccia (CIRAM, University of Bologna), started in 1998 a research project concerning the filing and interpretation of the pompeian graffiti, by means of multi-spectral images analysis and development of *image processing* techniques.

The final goal is to increase our ability to disseminate the knowledge on the Pompei's graffiti and, as well, the awareness on the social life, culture and habits of this ancient town. A better dissemination and valorization of the incredibly reach heritage frozen in Pompei by the Vesuvio eruption is a stimulating task, which could gain considerably from an intense use of modern information technologies. The graffiti are a perfect subject to experiment new presentation methods oriented either to the art curators/experts or to the standard tourists or practitioners.

The activities of our project include the following tasks:

- 3D acquisition of the selected graffiti section, by adopting high-accuracy 3D scanning;
- post-processing of the raw scanned data, to build up a complete model and to derive from it optimized 3D representations (different level of details, enhancement of the graffiti readability, etc.) ;
- standard photographic acquisition, both to document the project and to provide color information for subsequent mapping and visualization on the sampled 3D model;
- acquisition of an architectural relief to build up a 3D model of the building of which the graffiti are a component, to support the representation of the graffiti in his architectural context;
- visual presentation via digital media: design and implementation of a interactive visualizer to present the model both to ordinary public (museum presentations) and to the experts (to support study and analysis of the artwork);
- physical reproduction, to allow the standard visual analysis on a concrete physical model on remote locations (museum, remote laboratory);
- design of a multimedia data base to encode all the information gathered on the test case region;
- develop highly customized software tools to aid the experts in the study and analysis of (digital) graffiti.

The technical phases have obviously been preceded by a research on the fonts related to the Pompei's graffiti (bibliographic fonts, archival search, etc.). This was also a phase preliminary to the selection of the specific graffiti section, that was chosen by considering both historical considerations (engraving time, graffiti's subject) and morphological characteristics (depth and section of the incisions, possible instruments used to carve it, etc.). On this test case, an evaluation of the constitutive materials and of the conservation status was performed by the Pompei's restorers (to build up a map of the potential degradation risk). The digital and physical models obtained have been the media for continuing the study of those section of graffiti wall (see Subsection 9).

5. Graffiti's 3D Scanning

Using 3D scanning methods it is possible to obtain a good reproduction of the graffiti surface and morphology that, together with the survey of the space where the graffiti are located, can be used to create an electronic data-base easy to read and consult. A standardized documentation method must be used to achieve a good cataloguing method that provides information also about the preservation condition of the surface where the graffiti are located. 3D scanning allows to create a metric-morphologic model of the surveyed region that gives data dimension, traces and sections of the object (e.g. engraving depth).

The device used for the digital scan of the selected graffiti surface is a Konica Minolta Vivid 910, a triangulation-based laser scanner. This 3D scanner is based on a classical architecture: a light emitter produces a thin laser sheet (swept in space by a galvanometric mirror), a video sensor acquires images of the reflected pattern and computes the geometry of the surface parcels intersected by the laser light sheet. The accuracy of this device is around 50 microns in ideal conditions. The Pompei's graffiti material showed a rather good and cooperative surface reflection characteristics, since the surface reflects light mostly with a diffuse behavior and the color of the surface is usually not very dark. The selected wall portion was 270x330 cm (about 9 squared meters) and it has been sampled with 85 range maps, organized on a semi-regular gridded pattern, in two days of work. The main problem faced while scanning the graffiti was the very limited working space: the graffiti are engraved on the side of a very narrow room (walls are at a distance of around 1 meter). This is a very common conditions, since graffiti were often engraved in passage rooms or corridors interconnecting other rooms. The optimal scanning device orientation is perpendicular to the sampled surface (to get maximal accuracy in sampling) and any scanner has a minimal focusing distance (around 60 cm in the case of the Konica Minolta Vivid 910). The small width of the corridor forced us to sample the graffiti surface with the scanner positioned on a oblique incidence direction; this made planning the set of scan shots slightly more complex, but the accuracy obtained was quite good.

6. Raw scan processing

Scanning any 3D object requires the acquisition of many shots of the artefact taken from different viewpoints, to gather geometry information on all of its shape. In the case of the graffiti test case, we shot 85 range maps (each one covering approximately a region 40*30cm wide); each range map, once converted into a triangle mesh, is composed of 400K-600K triangles. The total number of points sampled by the scanning device is around 25M.

The range maps have to be processed to build up a single, complete, non-redundant and optimal 3D representation. The processing phases (usually supported by standard scanning software tools) are:

- range maps *alignment*, to transform them into a common coordinate space; after alignment, the sections of the

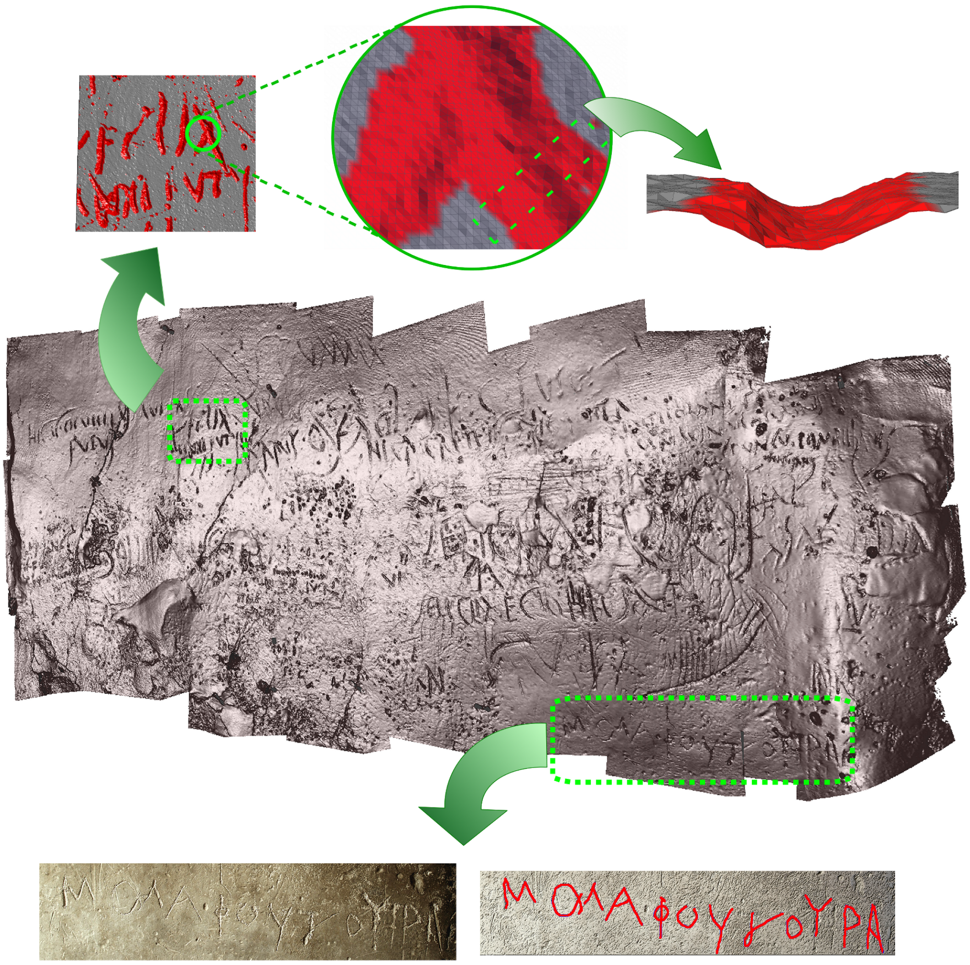

Figure 3: *The figure shows the complete model together with some illustrations of zoomed-in small parcels of the 3D model, with the graffiti engravings enhanced by using color.*

range maps which correspond to the same surface zone will be geometrically overlapping;
- range maps *merge* (or fusion), to build a single, non redundant mesh out of the many, partially overlapping range maps;
- mesh *editing*, to improve (if possible) the quality of the reconstructed mesh;
- mesh *simplification*, to accurately reduce the huge complexity of the model obtained, producing different Level Of Details (LOD) or multiresolution representations;
- and finally, *color mapping*, to map the surface attribute data (e.g. color) to the surface mesh.

The graffiti case introduces a number of constraints on the above phases. A number of problems were raised in a first attempt to manage post-processing with commercial tools. The peculiar aspect of this range map set is the large ratio between the extent of the sampled region and the mean size of the shape features which characterize the artefact (see Figure 5). Processing of the scan set was performed with the ISTI-CNR scanning tools, *MeshAlign*, *MeshMerge*, *MeshSimplify* [CCG*03], a suite of tools developed in the framework of the EU IST "ViHAP3D" project (http://www.vihap3d.org).

In particular, mesh *alignment* is implemented in most systems by searching for corresponding points pairs (initial rough alignment), and then applying ICP [BM92, Pul99, LR01] to reduce the miss-alignment between pairs of range maps.
Since the *Lupanare* dataset mostly consists of planar patches, we faced the problem of the convergence of ICP. Namely, selecting matching points on two planar surfaces is a hard task, since featureless patches can slide one over the

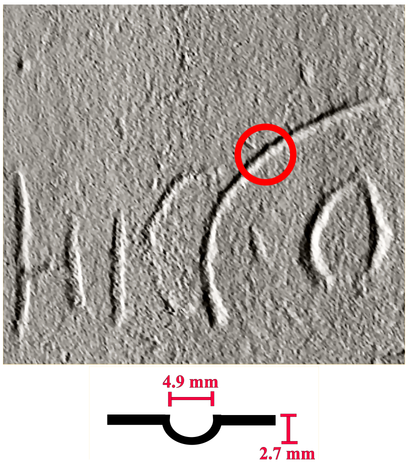

Figure 4: *We show numeric data (computed on the 3D mesh) concerning the width and depth of one of the more visible and macroscopic engravings.*

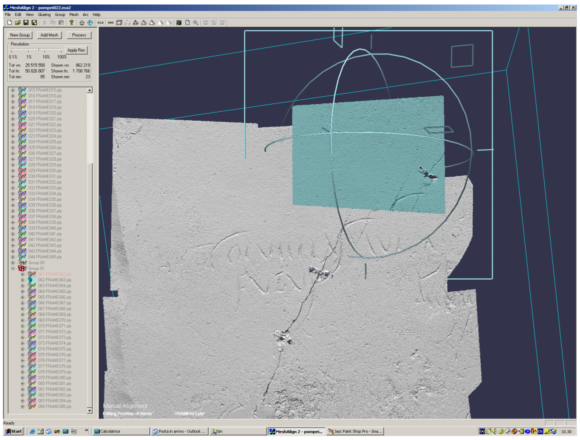

Figure 5: *Aligning a new range map (visualized in light blue) to a group of already aligned ones (visualized in gray) with the MeshAlign tool.*

other and ICP may converge on false minima. Our alignment software allows to select the points used in the ICP iteration by choosing a uniform distribution over the space of the normal vectors (computed on range maps vertices); conversely, other commercial or academic solutions select points performing a spatially uniform distribution. From a geometrical point of view, our solution corresponds to pick up points lying close to high curvature areas.
Moreover, an advantage of *MeshAlign* is the automatic simplification of the set of range maps. All range maps are simplified in a initialization phase by performing an accurate, feature-preserving simplification. This simplification process is used by *MeshAlign* to build a efficient internal multiresolution representation for the range maps. The interactive user-assisted phases are performed using the level of detail selected by the user (to allow interactive performances on any dataset). ICP iteration is executed in two phases: the initial iterations are executed by *MeshAlign* on low-resolution representations, and as soon as ICP convergence is obtained, the same process is refined on the high-resolution representation. This improves the convergence of the method, since the selection of significant points in the ICP iteration is simplified on the more concise representations which preserve by construction all feature points. This approach is more fast and accurate than other solutions like the one used by other academic systems that simply subsample the range maps, and has positive effect in the case of a rather uncommon dataset as the graffiti.
The final alignment has been performed with a maximal error of 0.25 mm (the alignment tool used, *MeshAlign*, returns numerical data on the accuracy of the registration obtained), which is a very good result on this type of dataset.
Moreover it should be also considered that the number of range maps (85 scans and 25M samples) poses strong limitations on the use of most common commercial tools which work well just on a few tens of range maps. As an example of a similar project we could cite the scanning of the walls and ceilings of the Altamira caves, that was reported by a commercial software producer as a "daunting task" even if it was composed by just 6M samples.

The merge of the range map set has been performed with *MeshMerge* [CCG*03], a volumetric reconstruction tool based on a variant of the [CL96] approach. The main technical characteristics of *MeshMerge* are: management of big dataset (many million sample points) on low-cost PC platforms; high efficiency and speed; data fusion performed by the weighted integration of the range maps; optional filling of small holes (region not sampled by the scanner).

Due to the high-density inter-sampling distance used in scanning (0.5 - 0.6 mm), the final model produced after merging at full resolution (i.e. with a voxel grid cell width of 0.4 mm) is very complex (80,266,816 triangles). Most application require this representation to be significantly reduced in order to be able to manage it. Two problems arise when we try to simplify such a model with commercial simplification solutions:

- *data size*: none of the commercial simplification solutions can manage a 80M faces mesh using a PC with a standard RAM size; to give some figures, a standard mesh simplification method based on edge collapse would require around 15 GB of RAM memory to manage an 80M faces mesh. The *MeshSimplify* tool allows to run simplification running on external memory [CMRS03], and therefore has no limits in terms of maximal size of the triangle mesh in input;
- *simplification accuracy*: the simplification of our graffiti mesh is highly challenging. Most of the existing solution

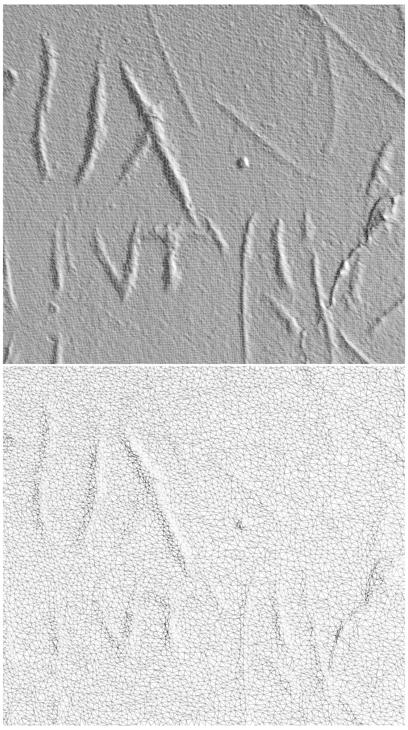

Figure 6: *A portion of the mesh at full resolution (top) and after simplification (bottom).*

will wash out all the detail and features contained in the representation. In fact, even a small error (e.g. 0.5 mm) will remove most of the detail if the simplification is run by taking into account only the shape deformation w.r.t. the original mesh. *MeshSimplify* allows to take into account also the mesh curvature: surface normals are considered while evaluating the effect of each atomic simplification action [Hop99, CMRS03], preserving high curvature regions like the ones on the profiles of the graffiti engravings. This allows *MeshSimplify* to reduce the size of the representation while at the same time preserving most of its shape features.

The initial 80M triangles mesh was simplified to produce a multiresolution model used in visualization (see Section 7) and a 6M faces model to be used in rapid reproduction (see Section 8). The latter simplification required a sufficiently short time (1h:46min on a standard Pentium 4 1.6 GHz equipped with 1GB of RAM). The simplified mesh obtained is shown in Figures 3 and 6.

7. Graffiti's visual reproduction

Two main issues arise from the impressive increase in data complexity (and richness) provided by the evolution of 3D scanning technology: how to manage/visualize those data on commodity computers, and how to improve the ease of use of the visualization tools (as potential users are often not expert with interactive graphics).

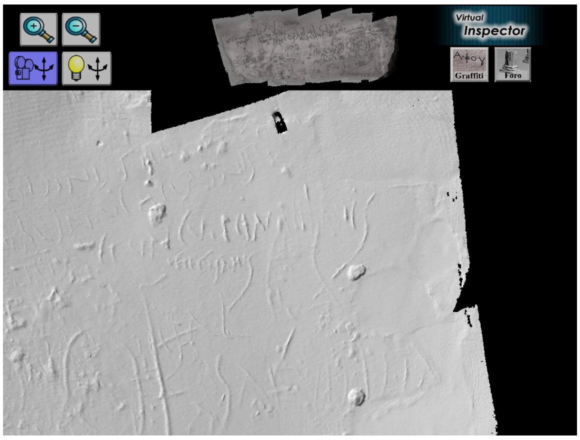

Figure 7: *Virtual Ispector: interactive visualization of the high resolution model; the image shows a zoom-in view.*

Virtual Inspector is a new visualization system that allows naive users to inspect a large complex 3D model at interactive frame rates on off-the-shelf PC's (it evolved considerably from the preliminary version presented in [BCS01]). It is mainly oriented to the visualization of single works of art (sculptures, pottery, etc.), and adopts a very intuitive approach to guide the virtual manipulation and inspection of the digital replica. In fact a main goal in the design of the system was to provide the user with a very easy and natural interaction approach, based on a straightforward "point and click" metaphor: to select any given view the user has just to point with the mouse the corresponding point on the small *dummy* on the top of the screen (Figure 7). Visualization efficiency is obtained by adopting a multiresolution representation; the best-fit level of detail is selected automatically (according to the current view frustum), visibility culling and ready-to-render representation of the geometry further improve rendering efficiency. Another important characteristic of Virtual Inspector is its flexibility: all main parameters of the system can be easily specified via a XML file. XML tags specify the 3D models to be rendered (a single or multiple meshes, encoded in mono or multiresolution), the system layout characteristics (layout of the interaction buttons and how different models will be presented on the screen), the rendering modes (e.g. standard Phong-shading, per vertex colors, RGB textured or BRDF rendering) and the interaction mode (a standard trackball, the "point and click" dummy or both).
A very nice feature of Inspector is the possibility to change interactively the position and direction of the light source, to simulate in real time the "luce radente" (glazing light) effect

that is usually used in real inspection to enhance the visualization and readability of the small graffiti.

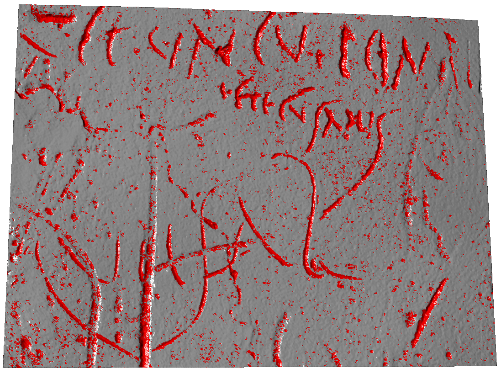

Figure 8: *The visualization of the graffiti can be made more evident with an digital enhancement: the engraving regions are detected and then rendered using a contrasting color (red in this image).*

To enhance the graffiti readability we developed a filter which detects automatically the small engraved regions on the surface. This filter is based on an analysis of the accessibility; given an illumination environment defined by an hemisphere-shaped emitter, it computes the intensity of light which reaches any mesh vertex. A threshold on the level of light received allows us to segment with a sufficient accuracy the regions corresponding to the graffiti (see some results in Figures 3 and 8). Obviously, this automatic segmentation cannot replace the analysis of an expert, but can be very useful if used in interactive visualization to help the expert in the visual recognition.

Figure 10: *The supporting structure, finished and mounted, over which all the tiles have been glued.*

8. Graffiti's physical reproduction

The availability of physical replicas offers to experts or ordinary people a very natural approach to the artifact; it also allows to rehearsal different options for architectonic or pictorial restoration making it possible to apply them to the original object only after an accurate critical evaluation of the final results. In order to create a 3D solid model from a digital surface it is necessary to:

- transform the digital surface into a solid model, possibly with an hollow interior to save reproduction material;
- subdivide the big graffiti model (270x330 cm) in pieces, according to the specification of the rapid reproduction device used;
- reassemble all the pieces together, maintaining the overall shape and curvature of the original graffiti wall.

The digital surface was extruded up to 3 cm thickness with Inus Technology's Rapidform 2004 ©. To complete the task, the original 6M triangles model had to be split into two parts since Rapidform was not able to manage the original (simplified) mesh. Each part was extruded, and then reassembled. Splitting and reassembling was performed with Materialise's Magics 9.1 ©, a rapid prototyping software which supports this type of operations without altering the precision of the model.

The extruded model was then cut in 125 tiles of size 24 x 19 cm (according to the maximal printing size supported by the reproduction system used). An alphanumeric code was printed in relief on the back of each tile to allow easy recognition and correct final positioning. The tiling is shown in Figure 9. The 3D printer used was the Zcorporation Z406 ©; printing speed is around 6 tiles in eight hours. This device produces fragile reproductions, which require to be completely dry up (faster when using a micro wave oven) and then manually injected with an epoxy resin (we applied heated resin with a brush) to assume the stiffness of a plastic material. This requires some manual work, but the positive advantage of the Zcorporation device is the low cost of the reproduction raw material. To obtain a lighter physical reproduction and to reduce the material consumption each tile was made like a hollow solid structure in which each face had a 0.5 cm thickness. To reuse the reproduction powder filling the interior hollow space that hadn't been glued by the 3D printer, all tiles were manually pierced on the contact sides and emptied. The recovered powder has been filtered and refilled to the 3D printer.

The printing and the preparation of the tiles were the longest phase of the project, due to the time needed for the printing and the "stabilization" of the plaster. This work was shared by the DIAPREM in Ferrara and the CMF Marelli in Milano, the Italian distributor of Zcorporation.

Finally, we had to reassemble all tiles to build up the physical wall replica. A complex reassembling procedure was needed, due to the overall size/weight of the tile set and the curved shape of the original wall surface. A wooden base was prepared to host the tiles. The main problem, and the hardest to solve, was to fix a double curvature wall (split in tiles) to the flat surface of the wooden base. A supporting structure was needed, to match the convexity of the real wall

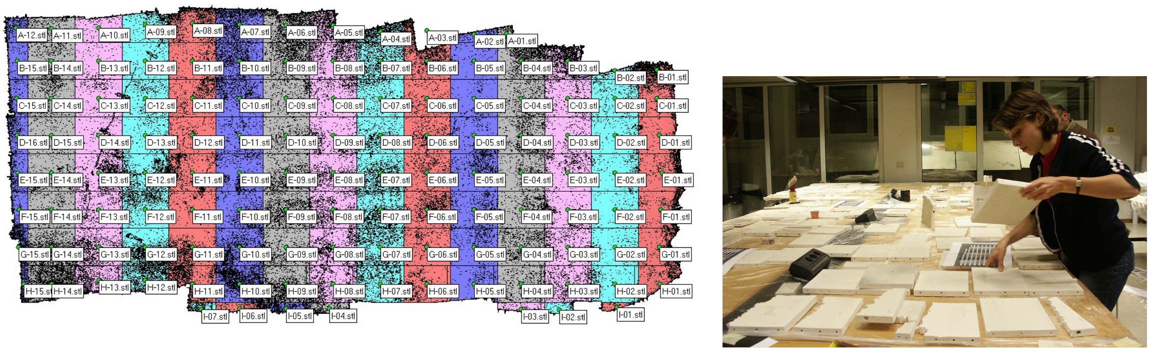

Figure 9: *A map of the partition in 125 tiles of the graffiti surface is shown in the top image; checking and sorting the reproduced tiles (bottom image).*

Figure 11: *The re-assembled physical reproduction (1:1 scale) is hand-painted by a restorer, to make all engravings more evident and increase readability to ordinary public of the Ferrara Restauro 2004 fair.*

and give a proper support to the tiles (see Figure 10). This structure was designed using again the Materialise's Magics software: the digital graffiti surface was positioned at a given distance from a supporting plane and then 15 cross-sections were cut at a distance equal to the length of a tile, exported in DXF format and elaborated with a CAD system. Then, these sections were plotted on paper in full-size scale, glued onto deal boards and cut with a jigsaw. These stiffening ribs were placed on the wooden panel; for a better adherence of the tiles to the supporting structure, a narrow-meshed net was stapled to the stiffening ribs (see Figure 10). After the exact positioning of all the tiles was verified, they were glued onto the supporting structure.

9. Doing graffiti analysis and recognition on the reproductions

To be really used in analysis and recognition, the reproduction (either digital or physical) should fulfill obvious requirements: metrical accuracy, easy accessibility, flexibility of use [Var03]. The two reproductions produced are complementary: the digital representation is very flexible (since different visualization modes and enhancements can be adopted) and easy to transmit/transport to support remote analysis; the physical one allows a very conservative approach in presentation (since it is a 1:1 replica) and allows to apply color enhancements which would have been impossible on the real artifact. Both were used by the experts which studied this wall section; their comments were very positive. In particular, the reproduced wall was exposed with "grazing" light

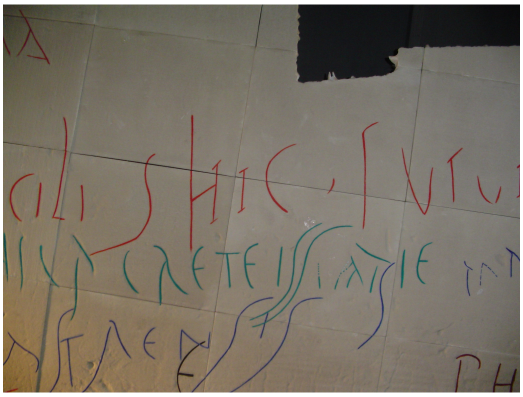

Figure 12: *A small portion of the re-assembled physical reproduction (1:1 scale), which makes evident how painting the engravings augments readability.*

and the archaeologist and two restorers started a second phase of analysis of the inscriptions contained. The inscriptions were subsequently highlighted by brush painting on the reproduced model, using different colors to enhance the different ages to which they were referable (see Figures 11 and 12). This phase took the two experts 2 days and led to new surprising results, thanks to this new method that allows to obtain a perfect copy of elements that couldn't otherwise be reproduced. For example, the frailty of the plaster in the Lupanare makes it impossible to create a mould of it. The possibility of touching, coloring and modifying the angle of exposure were unthinkable on the real artifact. Moreover, the close examination performed led to the discovery of new inscriptions that it wouldn't have been possible to be spot directly on the original wall, due to the restriction in access.

10. Conclusions

We have presented the results of a project concerning the 3D acquisition, processing and presentation of surfaces with graffiti. The specific characteristic of graffiti surfaces open some issues in the selection of the proper approach and instruments, that we have discussed here. The experience was very positive and the comments of the archeologist and restorers were enthusiast. We are planning to apply this methodology to larger extents of graffiti in Pompei.

The results of this first experimentation have been already presented to the public with a thematic exposition organized by DIAPREM at the Ferrara Restauro fair (an international restoration event) held in March 2004. The exposition presented both the digital model and the physical reproduction, together with multimedia material describing the archeological values of the graffiti and the project objectives.

Our experience assessed one more time the potentiality of 3D models for artistic or architectonic heritage; the accurate encoding of the shape and the availability of processing tools makes it possible to better study the artifact and to implement realistic simulations of restoration and maintenance interventions. A second aspect concerns the acknowledgement of the extraordinary informative power that a 3D model can provide. Exploiting the capabilities of multimedia and internet resources, 3D models could improve the accessibility of the archaeological heritage to scholars and specialists of the field, as well as to a large number of art lovers. These methodologies can offer an important contribution to the study, preservation and valorization of the graffiti, that represent an important component of the inestimable value of the Pompei's archaeological heritage.

Our present effort is aimed at: making the utilization of these techniques easier and more profitable by experimenting the use of more efficient instruments; defining suitable standard protocols for the collection, management and remote visualization of collection of graffiti data. Among possible future work, we will evaluate photometric imaging (2D imaging under multiple controlled lighting to reconstruct normal vector fields or 3D geometry) as an alternative to 3D scanning, to evaluate the possibility to use a more cheap acquisition approach and to compare the quality and size of the 3D models obtained w.r.t. the ones of 3D scanned models.

Finally, this project was an example of a successful multidisciplinary cooperation between groups with different backgrounds; most of the interaction and data exchange was through the net between Pisa, Ferrara, Milano and Pompei, since data processing was the result of a coordinated work of many different operators.

Acknowledgements We acknowledge: the financial support of the project EU IST-2001-32641 "ViHAP3D"; the technical support of Konica Minolta Italia Spa, Milano, and CMF Marelli Srl, Milano. The research project described here was directed by DIAPREM (Centre of the Department of Architecture of the University of Ferrara - M. Balzani, N. Santopuoli, F. Uccelli) and the Soprintendenza Archeologica di Pompei (Superintendant: Prof. P.G. Guzzo, Archaeologist: A. Varone). The project was a multidisciplinary activity and a number of people participated to the research, whom we thanks and cite in the following. *Laser Scanner Survey*: M. Balzani, F. Uccelli, V. Savoia. *Metric and photographic survey*: G. Galvani, M. Beltrami, C. Traina, A. Pancaldi. *3D scanned data processing*: ISTI-CNR (see names in authors' list). *Rapid Prototyping*: M. Fabbri, S. Settimo, M. Berti. *Assembly of the wooden base and fixing of the tiles*: M. Fabbri, N. Zaltron, S. Settimo, E. Viaro, N. Brigo, F. Sanmarchi, A. Farinelli, C. Bellan, F. Raco. *Pictorial highlighting of the graffiti*: G. Brunetti e A. Farinelli.

References

[BCC*97] BERTANI D., CAPANNI A., CETICA M., PEZZATI L., PAGLIARA C.: Digitised recording of petroglyphs in poesia cave. *Rock Art Research 14*, 2 (1997), 137–142. 2

[BCS01] BORGO R., CIGNONI P., SCOPIGNO R.: An easy to use visualization system for huge cultural heritage meshes. In *VAST 2001 Conference Proc.* (Athens, Greece, Nov. 28-30 2001), Arnold D., Chalmers A.„ Fellner D., (Eds.), ACM Siggraph, pp. 121–130. 7

[BGU00a] BALZANI M., GAIANI M., UCCELLI F.: 3D survey and modeling for the cultural and architectural heritage. In *High Performance Graphics Systems and Application European Workshop* (2000), Guidazzoli A., (Ed.), CINECA, Bologna (Italy), pp. 39–43. 2

[BGU00b] BALZANI M., GAIANI M., UCCELLI F.: Reshaping the coliseum in rome: an integrated data capture and modeling at heritage sites. *Computer Graphics Forum 19*, 3 (2000), 369–378. 2

[BM92] BESL P. J., MCKAY N. D.: A method for registration of 3-D shapes. *IEEE Transactions on Pattern Analysis and machine Intelligence 14*, 2 (Feb. 1992), 239–258. 5

[BPGV03] BERALDIN J.-A., PICARD M., GODIN S. E.-H. G., VALZANO V.: Virtualizing a byzantine crypt: Challenge and impact. In *Videometrics VIII. Proceedings of the SPIE. Vol. 5013* (January 2003), pp. 148–159. 2

[BR02] BERNARDINI F., RUSHMEIER H. E.: The 3D Model Acquisition Pipeline. *Computer Graphics Forum 21*, 2 (March 2002), 149–172. 2

[BRM*02] BERNARDINI F., RUSHMEIER H. E., MARTIN I., MITTLEMAN J., TAUBIN G.: Building a Digital Model of Michelangelo's Florentine Pieta'. *IEEE Computer Graphics & Applications 22*, 1 (Jan-Febr. 2002), 59–67. 2

[CCG*03] CALLIERI M., CIGNONI P., GANOVELLI F., MONTANI C., PINGI P., SCOPIGNO R.: Vclab's tools for 3d range data processing. In *VAST 2003 and EG Symp. on Graphics and Cultural Heritage* (Bighton, UK, Nov. 5-7 2003), D. Arnold A. C., Niccolucci F., (Eds.), Eurographics, p. (in press). 5, 6

[CHYM03] CAIN K., HE Y., YU M., MARTINEZ P.: Towards digital epigraphy for egyptian hieroglyphics. In *Sketches - VAST 2003 and EG Symp. on Graphics and Cultural Heritage* (Bighton, UK, Nov. 5-7 2003), p. 319. 2

[CL96] CURLESS B., LEVOY M.: A volumetric method for building complex models from range images. In *Comp. Graph. Proc., Annual Conf. Series (SIGGRAPH 96)* (1996), ACM Press, pp. 303–312. 6

[CMRS03] CIGNONI P., MONTANI C., ROCCHINI C., SCOPIGNO R.: External memory management and simplification of huge meshes. *IEEE Transactions on Visualization and Computer Graphics 9*, 4 (2003), 525–537. 6, 7

[CS00] CURLESS B., SEITZ S.: 3D Photography. In *ACM SIGGRAPH 00 Course Notes, Course No. 19* (August 24th 2000). 2

[FGM*02] FONTANA R., GRECO M., MATERAZZI M., PAMPALONI E., PEZZATI L., ROCCHINI C., SCOPIGNO R.: Three-dimensional modelling of statues: the minerva of arezzo. *Journal of Cultural Heritage 3*, 4 (2002), 325–331. 2

[GBT*02] GODIN G., BERALDIN J.-A., TAYLOR J., COURNOYER L., RIOUX M., EL-HAKIM S., BARIBEAU R., BLAIS F., BOULANGER P., DOMEY J., PICARD M.: Active optical 3d imaging for heritage applications. *IEEE Computer Graphics and Applications 22*, 5 (Sept. 2002), 24–36. 2

[Hop99] HOPPE H.: New quadric metric for simplifying meshes with appearance attributes. In *Proceedings of the 10th Annual IEEE Conference on Visualization (VIS-99)* (New York, Oct. 25–28 1999), ACM Press, pp. pages 59–66. 7

[LPC*00] LEVOY M., PULLI K., CURLESS B., RUSINKIEWICZ S., KOLLER D., PEREIRA L., GINZTON M., ANDERSON S., DAVIS J., GINSBERG J., SHADE J., FULK D.: The Digital Michelangelo Project: 3D scanning of large statues. In *SIGGRAPH 2000, Computer Graphics Proceedings* (July 24-28 2000), Annual Conference Series, Addison Wesley, pp. 131–144. 2

[LR01] LEVOY M., RUSINKIEWICZ S.: Efficient variants of the ICP algorithm. In *Third Int. Conf. on 3D Digital Imaging and Modeling (3DIM 2001)* (May 28th - June 1st 2001), IEEE Comp. Soc., pp. 145–152. 5

[PGV*01] POLLEFEYS M., GOOL L. J. V., VERGAUWEN M., VERBIEST F., TOPS J.: Image-based 3d acquisition of archeological heritage and applications. In *VAST 2001 Conference Proc.* (Athens, Greece, Nov. 28-30 2001), Arnold D., Chalmers A.„ Fellner D., (Eds.), ACM Siggraph, pp. 255–261. 2

[Pul99] PULLI K.: Multiview registration for large datasets. In *Proc 2nd Int.l Conf. on 3D Digital Imaging and Modeling* (1999), IEEE, pp. 160–168. 5

[SBE95] STUCKI P., BRESENHAM J., EARNSHAW R.: Computer graphics in rapid prototyping technology. *IEEE Computer Graphics and Applications 15*, 6 (Nov 95), 17–19. 2

[STH*03] STUMPFEL J., TCHOU C., HAWKINS T., DEBEVEC P., COHEN J., JONES A., EMERSON B.: Assembling the sculptures of the parthenon. In *VAST 2003 and EG Symp. on Graphics and Cultural Heritage* (Bighton, UK, Nov. 5-7 2003), D. Arnold A. C., Niccolucci F., (Eds.), Eurographics, p. (in press). 2

[Var96] VARONE A.: Le iscrizioni. In *Pompei. Abitare sotto il Vesuvio* (Ferrara (Italy), 1996), AA.VV., (Ed.), pp. 196–201. 2

[Var99] VARONE A.: Le iscrizioni parietarie pompeiane. indagini preliminari effettuate in vista della redazione di un nuovo fascicolo e degli indici computerizzati di cil iv. In *Atti XI Congresso Internazionale di epigrafia greca e latina* (Rome (Italy), 1999), pp. 609–616. 2

[Var00] VARONE A.: *Pompei. I misteri di una città sepolta*. Newton Compton, Rome (Italy), 2000. 2

[Var03] VARONE A.: Inseguendo un'utopia. l'apporto delle nuove tecnologie informatiche alla lettura obiettiva delle iscrizioni parietali. In *Atti della giornata di studio - Esperienze di studio sui graffiti antichi* (March 7th 2003), p. (in press). 2, 3, 9