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Questa è la Versione finale referata (Post print/Accepted manuscript) della seguente pubblicazione:

*Original Citation:*

3d Modeling of Boccaccio's Hometown through a Multisensor Survey / G. Tucci; F. Algostino; V. Bonora; G. Guidi. - In: INTERNATIONAL ARCHIVES OF THE PHOTOGRAMMETRY, REMOTE SENSING AND SPATIAL INFORMATION SCIENCES. - ISSN 1682-1750. - XXXIV, Part 5/W10:(2003), pp. 1-6. ( ISPRS Commission V Working Group 6 International Workshop on "Visualization and Animation of Reality-based 3D Models"

*Availability:*

The webpage <https://hdl.handle.net/2158/242281> of the repository was last updated on

*Publisher:*

Gruen, A., Murai, Sh., Niederoest, J. , Remondino, F.

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## 3D MODELING OF BOCCACCIO'S HOMETOWN THROUGH A MULTISENSOR SURVEY

G. Tucci<sup>1</sup>, F. Algostino<sup>1</sup>, V. Bonora<sup>1</sup>, G. Guidi<sup>2</sup>

<sup>1</sup> Dept. of Scienze e Tecniche per i Processi di Innesamento, Politecnico di Torino,  
Castello del Valentino, Viale Mattioli, 39 10125 Torino, Italy

<sup>2</sup> Dept. of Electronics and Telecomm., University of Florence, Via S. Marta, 3 – 50139, Florence, Italy

**KEY WORDS:** 3D modelling, CAD model, complex city landscape, urban surveying, orthoimage, texture mapping

### ABSTRACT:

This 3D modeling experience lies in the more general framework of large scale cartography aimed at conservation of an historical city center. The study has been applied to the ancient nucleus of "Certaldo Alto", a medieval village in Tuscany famous as Boccaccio's birthplace. The data acquisition project exploited the synergy of topography, photogrammetry and 3D scanning for generating a cartography at 1:500 scale. The model was built starting from a common aerophotogrammetric survey, suitable for generating a traditional cartographic representation. Instead of dropping the height information, it was employed for building a texturized 3D model, suitable for visualization and virtual visit of the site. Preliminarily to the 3D model creation a critical analysis of the data obtained by photogrammetry has been carried out and different objects have been assigned to different layers. 3D polylines have been then extruded from the vertexes of each building for generating the external walls. Similarly roofs surfaces have been identified. All the elements not deductible by photogrammetry, as stairs, porches and overhangs, have been modeled through the integration of a topographic survey. The altimetry of the area has been obtained from an aerophotogrammetry generated DTM. The model texturization with digital photographs allowed to add visual reality to the model. The final passage to formats for animation (.avi) or interactive exploration (.wrl), allowed finally to dynamically present the town survey.

### 1. INTRODUCTION

This work belongs to an interdisciplinary research about the conservation and monitoring of historical city centers. In 1972 a detailed plan for the restoration of Certaldo Alto was conceived, for which a topographic and photogrammetric survey was achieved. It produced a set of maps at different scales for an accurate analysis both of planimetry and altimetry.

The research objective was to setup a Geographical Information System (GIS) for managing the survey data, for checking the correspondence of restoration works according to the legal provisions, and finally, in presence of allowed restorations, for keeping track of the architectural transformations.

The need of arranging an updated data base, suggested to draw a new large scale cartography according to the more advanced methodologies, involving a detailed 3D modeling of the whole city. Although the metric information was the main objective of the work, the possibility to show interactively the city model thanks to the modern computer graphics techniques, provided additional interests to fulfill the complete 3D modeling.

Omitting to go into the GIS structure, this paper describes the steps followed to obtain an updated mapping of Certaldo Alto, and the processing pipeline for generating the related 3D model. In the last few years several interesting experiences have been carried out in the field of city design, that, on the other hand, is not yet well established, being still tightly related to a two-dimensional vision of the problem. Rapid advances in digital technologies (data surveying, management, storage and visualization) have offered a new impulse for investigating technical and figurative requisites of 3D models. But a growing number of low resolution three-dimensional models have been

created (mainly for multimedia purposes), without giving enough importance to the metric accuracy of the acquired data, and to the tolerances compliance with the specific scale of representation.

Our aim was to integrate numeric cartography (with its own accuracy) with computer graphics technologies, for creating a dynamic 3D model representing urban phenomena and processes for preservation, restoration and city planning.

The model had to combine two different needs. On one hand it had to be accurate in order to guarantee the usability for different technical and administrative purposes such as environmental studies, mapping of energy and telecommunication networks, water pipes, and communication ways. On the other hand it had to be photorealistic and handy for an easy and effective representation, useful in virtual visits and other similar applications. The choice of a representation scale of 1:500 represents a central aspect of the whole work.

In terms of data acquisition it marks an upper limit for cartographic aerophotogrammetry; furthermore data visualization involves several representation problems, since some cartographic details, usually indicated with symbols in smaller scales, might be represented with their true iconographic aspect depending on their actual size.

Nevertheless the 1:500 scale fits both the aforementioned requirements, the advantages are specially evident in modeling complex city centers of medieval towns built over steep hills, such as our case study. Thanks to a metrically accurate 3D model it is possible to describe the volumes of different blocks, to generate sections of building along vertical planes, and to find useful information for Heritage conservation.

The surveying specifications valid in Italy concern the methods for appropriately take metric photos, the flight planning, the generation of orthoimages, the way such data are processed for extracting vector-based maps, the buildings measurement. Standards about non conventional representations (e.g. 3D models or drawings extracted from them) are instead still missing. The same distinction holds for the end-users that easily handle well established outputs such as digital maps, but not always have the same confident approach when dealing with alternative three-dimensional representations. This is also due to the lack of standard software products specifically oriented to this purpose. The possibility to take photographic images and stick them as model texture for a high likelihood representation of the original site, rises new questions about the appropriate measurement accuracy and precision.

The availability of a realistic model stimulates also the end-user to visualize details usually not available with other forms of representation, and usually not compliant with the metric tolerances typical of 1:500 representations.

Finally, the choice of the 1:500 scale involves a demanding on-site reconnaissance, for integrating the aerial measurements with details not available on the aerophotogrammetric takes, as for example the eaves for determining each building base. Therefore the modeling design was tailored to this specific application, and no existing packages for automatically generating a three-dimensional model from photogrammetry were employed.

## 2. URBAN SURVEY

A project was devised for employ a synergy of satellite techniques, topography and photogrammetry, oriented to the accurate digital survey of Certaldo Alto. A stereo couple of aerial photographs acquired in 1980 from the regional authority have been used as starting point. The pictures have been taken from 600 m of height with a 300 mm focal length and 230x230 mm photogram size. The ancient city center resulted therefore fully covered by a single couple of images.

For the images registration six uniformly distributed ground points were selected over the photograms, and their position were measured through a Global Positioning System (GPS) equipment. For coordinate transformation in the Italian Cartographic Reference System (Gauss-Boaga), one IGM95 reference point located in a near village (within 10 km) have been used. It supplies all the 7 parameters needed.

After image registration a set of measurement have been carried out, for generating the following outputs:

- a 1:500 digital vector map (see figure 1a);
- the DTM and orthoimage of the area (see figure 1c);
- the 3D model of the ancient city center (see figure 1b).

### 2.1 Digital Mapping

Part of the research included the definition of the project specifications in agreement with the current legal constrains for the Italian prescriptions. This definition was arranged by the Polytechnic of Milan, which supplied a formally and technically consistent tender, containing provisions for cartography production, structuring of graphic primitives, workflow management and final testing.



(a)



(b)



(c)

Figure 1. Certaldo Alto ancient centre:

- a) Digital ground map at 1:500 scale; b) upper view of the 3d model; c) corresponding digital orthoimage.

In such tender the level of detail is specifically defined through the *Inventory of Entities* and the *Resolution*. The *Inventory of Entities* defines each cartographic item with an univocal code, the geometric primitive describing its shape, and a category which it belongs to. The *Resolution* defines the minimal size of an object that can be represented at its true scale. Such resolution was arranged to be 20 cm. Each element smaller than this value, is represented only as a symbol, when codified in the above mentioned Inventory.

In this map the terrain objects are grouped into three different geometric object types: point, line, surface. For each object

type three *entities* are designed: points, edges and polygons. There are also text labels for toponymy and auxiliary entities to add information and to help interpretation.

The representation with polygon was required only for buildings; the remaining of database has a “spaghetti” structure. Special attention was devoted to validate the geometry of vector entities. Polygons had to be closed and all lines belonging to the same network joined together. Each entity was also represented with the minimal number of vertexes compliant to the planimetric tolerances. Proper connections between neighbour segments was manually enforced for avoiding typical topological incongruences as gaps, dangling segments, or sliver polygons.

As well-known, map at 1:500 scale requires a heavy topographic survey to integrate data not visible in the photograms: porticoes for example, so important from the architectural point of view in urban analysis.

The survey was performed by measuring the main edges of each block of contiguous buildings, with a direct topographic survey to verify the real dimension of buildings. As a matter of facts in Tuscany eaves have normally a considerable dimension: this makes impossible to measure the correct base of buildings in aerial images. At the same stage the street numbers were associated to the corresponding units as well as the toponymy of each area.

The extension of this survey to the street furniture, hydraulic and electric facilities, energy and telecommunication networks, water and gas pipes, involved the introduction of a unambiguous data structuring. Specific classification codes were defined to discriminate for example streets from crossroads, pavements or walkpaths.

The ground elevation was represented through level contours and spot heights associated to well recognizable points.

The height of each polyline node is always referred to the ground level; when not visible in the stereo couple of photograms it was assumed equal at the nearest collimated point. For electrical pylons the basis elevation was reported, while for the corresponding electric lines the actual elevation was shown. In this way the *ground map* was completed.

For generating the *roofs map* perimeters and internal lines of roofs, canopies and terraces have been measured, together with the breaklines constituted by all the volumes emerging from the roofs (e.g. dormer-windows, turrets and arcades).

## 2.2 DTM and digital orthophoto

Even though the flight wasn't specifically designed for producing orthophotos, the stereo images characteristics (80% of superposition between adjacent takes in order to employ only the photogram center), were anyway suitable for appropriately generate an orthophoto of the town.

For this purpose a Triangular Irregular Network (TIN) was measured with a digital stereoplotter (Digicart40). Due to the complex morphology of the town center it was chosen to extract it manually according to the project specifications.

Some features of the previously generated digital map were employed as break-lines for performing constrained TIN triangulation.

In this way the number of wrong connections were effectively limited. Starting from such TIN a matrix DTM was automatically generated, yielding a lateral resolution of 4 m, as required by tender. Finally a digital orthoimage was created with Gcarto Software by Geosoft. For this purpose the image were digitized at 1800 DPI with a photogrammetric scanner involving a pixel size corresponding to 5 cm at ground level. As a final check the digital map was superimposed over the

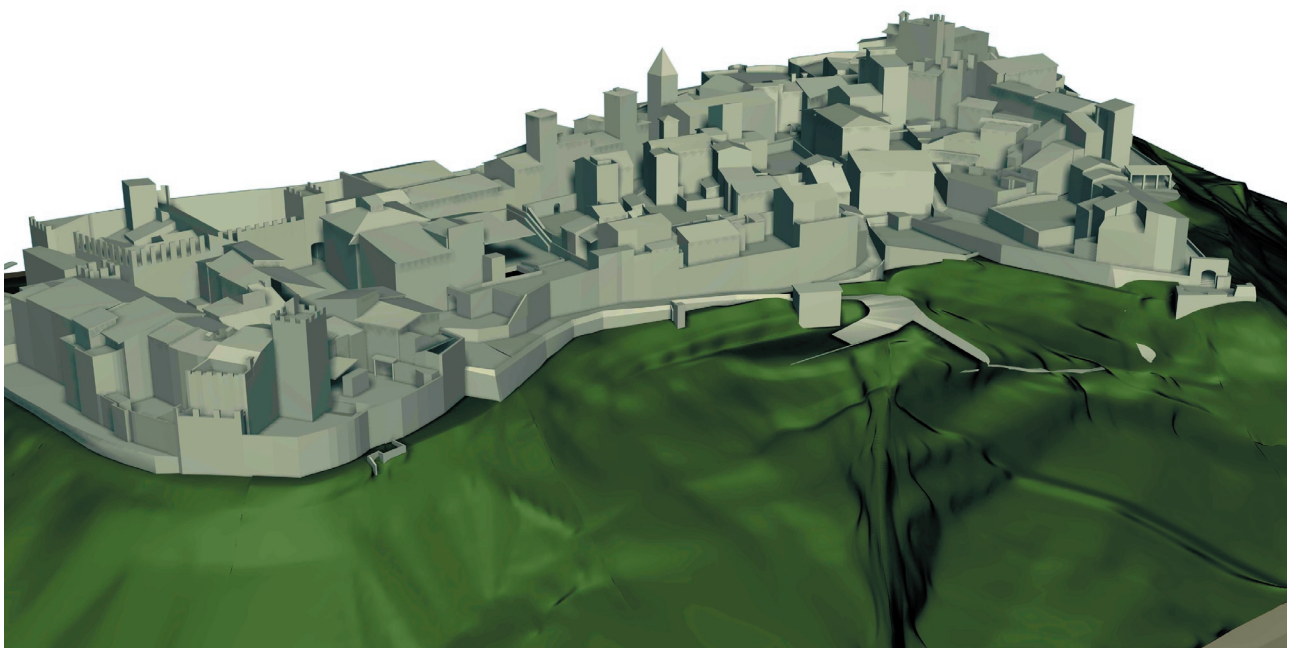


Figure 2. Lateral view of the shaded 3d model.



Figure 3. Thanks to the 3D model it is possible to show the city from specific point of view to study different skylines and the landscape impact of architectural elements.

DTM for manually verifying the correspondences.

### 2.3 Three-dimensional Modeling

Although the acquired data are clearly three-dimensional, their cartographic representation still remain a 2D object. The most recent experiences tend however to take advantage of the available information to give a representation of them in a more realistic fashion. Some researches produced results now available as commercial software packages. There are different semi-automated approaches as, for example, InJECT, a product of INPHO GmbH, Stuttgart; and CyberCity Modeler, marketed by CyberCity AG, Bellikon, a spin-off company of ETH Zurich.

Starting from a digital map, solid models can be rather quickly generated through extrusion, once the eaves elevation of each building are known. However, the unavoidable approximations due to the mapping scale, tend to become evident when the model is enlarged, so that some additional data had to be collected in order to properly model gardens, trees, or other structures fairly defined in the cartography. In some cases protrusions even smaller than the cartographic tolerances may be significant for a proper structures interpretation.

The approach followed in this work was to proceed with a surface modeling starting from the same raw data generated by the photogrammetric processing, which were used to produce the digital map.

The geometrical model (see figure 2) was generated with the well known CAD software package Rhinoceros 2.0 from McNeE which offers a large set of 3D tools; it is also very efficient by using a standard PC with Windows 2000 or NT. For the model texturing stage 3D Studio max, produced by Discreet Software, was employed.

The starting point was represented by the closed polylines representing the buildings planimetric profiles, and the corresponding roofs, integrated by their own internal lines (i.e. ridges and compluvia). It has to be emphasized that in Tuscany roofs have large overhangs so that approximating the roof lines with the buildings perimeters would have created a definitely unrealistic model.

A geometrical congruence verification was then carried out along the vertical direction. Adjacent buildings with

different heights have usually points in common; therefore correspondingly to the same horizontal coordinate, different elevations can be associated and properly connected to other points in the neighborhood. Additional irregularity have been found, partially due to measurement uncertainty, and partially to some asymmetrical geometries, typical of medieval towns, where the geometry deviates from regular pattern: edges are not parallel, intersection not perpendicular, roof faces not planar. This required a final geometrical regularization.

The detail level required to create a 3D model, and in particular the roofs, came out to be higher than the metric tolerance usually accepted for maps.

The available data were therefore more noisy than theoretically required, so they were re-processed and adapted according to formal and technological elements. Some simplifying conditions were imposed to the geometry in order to enhance the visualization, even if in some cases those might involve a less metrically accurate model. For example the roof lines were assumed to be horizontal and parallel in order to impose a single plane defining the roof surface, that increases visualization likelihood.

The same regularization affected house edges. The edges that came out non vertical were singularly checked with a land reconnaissance. Once verified that there were no evident structural deformations they were assumed to be vertical even when the measurements did not give exactly such result. Along these corners the planimetric profile was extruded up to the roofs level. The roof thickness was estimated to be 30 cm for any building. Additional elements such as stairs, tunnels and overhangs - not available on the stereoscopic images - were then added to the model thanks to a topographic integration. During the modeling work, the model was permanently compared with the 2d plans in order to early detect errors or missing parts.

Object reconstruction consisted not only of geometry surfaces determination, but also of texture mapping: images taken with digital camera (Nikon D1, focal length 40mm, calibrated) were used for texturing (see figures 5a, 5b, 5c).

Due to the large amount of data to process the images were corrected taking into account perspective distortions only, rather than all the optical distortions involved (e.g. radial distortions). No horizontal or vertical stretching have been



Figure 4. Two different vertical sections of the town center, automatically generated from the 3D model.

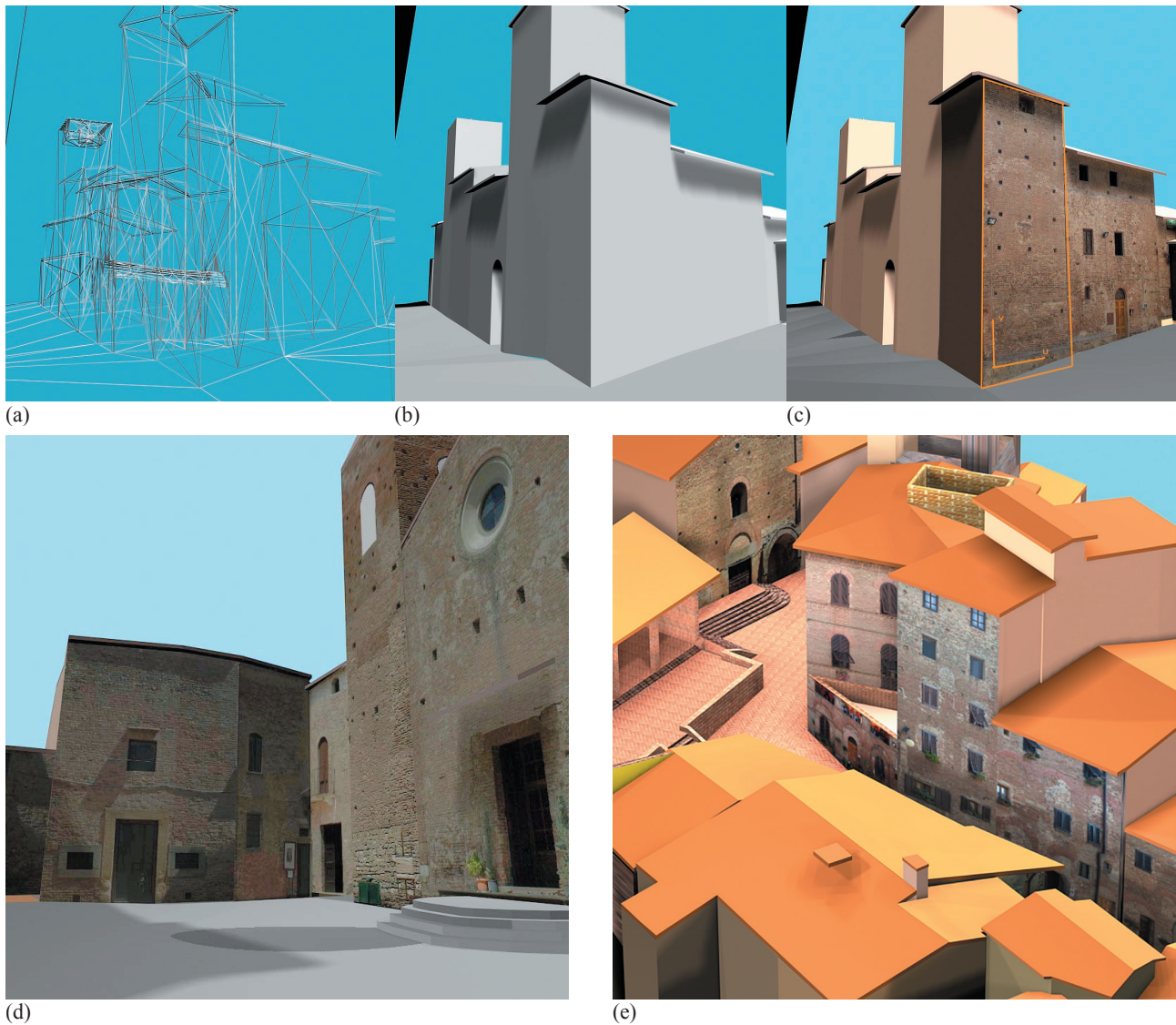


Figure 5. Model texturing: a) wireframe model of a detail; b) corresponding synthetically shaded geometry; c) and with textured facades; d-e) two additional textured views of the main street.

required. After texturing a slight definition loss emerged in the images re-projected over the model due to re-sampling and aliasing. Texture mapping was limited only to the main architectural objects as for example the facades in the main street, or the central square (see figure 5e, 5d). Considering the importance of a likely texture for interpreting the actual conservation state of the modelled architectural elements, for the remaining buildings the use synthetic texturing has been avoided.

An analogous texture mapping was made for the upper view of the model (roofs texturing), by projecting the aerial orthophoto over the whole model. Once the town model was merged with the DTM of the underlying hill geometry, such a projection was extended also to the neighbour area, as shown in figure 6.

A set of conventional outputs as sections and prospects, usually employed by town planners, was automatically generated, once a specific plane of section was defined (see figures 3, 4).

Finally the model was merged and made available in the standard visualisation format.

Although several approaches are currently available for 3D models presentations, the dynamic interaction is the ultimate

objective of three-dimensional modelling. This might still be a critical issue, due to the large amount of memory required to describe the whole set of data contained in the model. Apart from VRML viewers that can be found as freeware, few commercial packages are available for viewing model with real-time rendering, with tools for measuring slicing and post processing it in several way (Polyworks, Innovmetric Soft. Inc., Quebec, Canada; RapidForm, Inus Technology Inc., Seoul, Korea; ). Research are still in progress to enhance memory management in order to make possible to browse a 3D model in real-time, with a standard computer with a reasonable amount of memory, as for example the QSplat viewer developed at Stanford University (see <http://graphics.stanford.edu/software/qsplat/>).

## 2.4 Conclusions and Perspectives

We have presented a high-resolution photorealistic 3D model of Certaldo Alto, produced from photogrammetry integrated with topographic survey. The required quality of the model, which can be used for many purposes, did not allow us to use automated procedures for generating a 3D model of

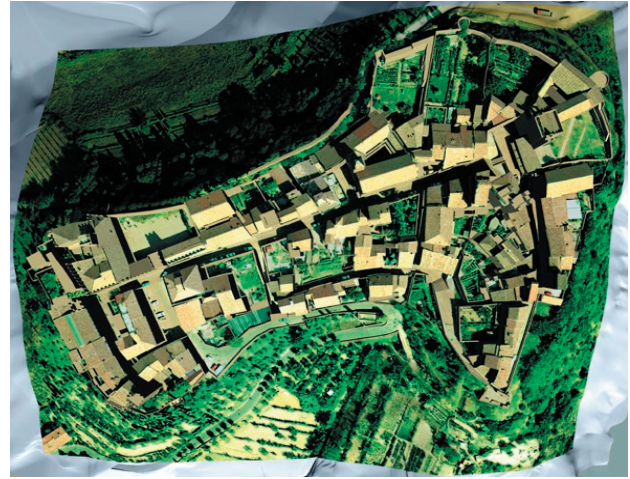
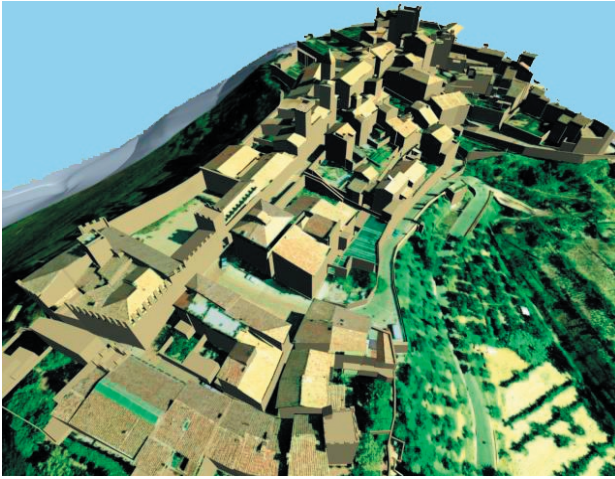


Figure 6. 3D model of Certaldo Alto draped with aerial image.

the ancient town center, therefore a specific surveying and manual modelling procedure was conceived. The focus of the modelling work was on the use of proper geometrical assumptions for guarantee topological coherence to the model, starting from data intrinsically more noisy than needed. Many expectation rely on 3D modelling applied to ancient city centers. In the acquisition stage some groups have proposed preliminary results on alternative techniques for measuring control points for rectification of terrestrial images, by proposing the optimal use of a low-cost Mobile Mapping System to photogrammetrically measure them, with high productivity and sufficient accuracy. Applications of aerial laser scanners are growing, while ground based Time of Flight (TOF) lasers scanners are today becoming rather affordable. This is why possible further integration on the Certaldo's model will be studied, as for example the possibility to integrate geometrical data of complex structures, acquired through a laser scanner, into the existing 3D model.

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### 4. ACKNOWLEDGMENTS

This work was developed with the project "Development of a territorial information system aimed at the design of conservation of historic centres", partly financed by Italian Ministry of University and Research in 1998 as a project of relevant national interest. National coordinator: M. Dezzi Bardeschi. Head of research unit: G. Cruciani Fabozzi. Aerial images have been provided by Region Tuscany. Tender was arranged by F. Guzzetti, Professor at Politechnic of Milan. Photogrammetric measurements were performed by Paolo Mattia (Ril-fo.to s.n.c. in Rozzano (Milano). Vector map, Dtm and digital orthophoto were performed by Geomatica s.r.l. company in Lavis (Trento).