The atrium of St. Mary Abbey in Pomposa: a hypermedial 3-D network database

Claudio Alessandri, Marco Gaiani

University of Ferrara Via Quartieri, 8 - 44100 - FERRARA Italy phone & fax 39-0532-293601

E-MAIL: mrc@dns.unife.it, ale@dns.unife

Abstract

The analysis carried out on the atrium of the church of Pomposa is an example of a multidisciplinary experience which gathered historians, computer analysts, structural and computer graphics experts on the same project. A 3-D virtual model and the related data base can be considered a common basis for the different approaches attempted and tools indispensable to a correct representation of the complexities characterizing the atrium.

Keywords: 3-D modeling, 3D-database, VRML, virtual cultural heritage, survey, architectural knowledge representation.

1. Introduction

A major problem in dealing with restoration and maintenance of monuments - especially complex constructions - is usually the permanent split between the data defining starting conditions and restoration itself, which seldom takes them as a starting point. There is a large amount of data to draw from: the problem lies in their wide typologic variety (3-D models, images, photos, drawings, texts, documents, etc.), their substantial lack of homogeneity and their need for a high quality visualization in iconic forms. In addition, it is difficult to find user-friendly restitution tools in traditional storage and registration systems, so that, as far as innovative procedures go, digital restitution of the surveyed data is quite a challenge.

The restoration project of the atrium of Pomposa Abbey provided an opportunity to develop a digital data registration and restitution method that would directly support any design process and become integrated in the design itself. This way, resulting data can be enclosed as input files.

A hypermedial 3-D network database was developed for use with a Netscape/Explorer browser for www with the addition of free-plug-ins (Cosmoplayer or Worldview).

The analysis was carried out assuming:

a. Complete replacement of physical archives with digital archives having at least the same characteristics of physical ones.

b. Direct and complementary use of the same data for different analyses and replacement of the physical desktop with a virtual one.

c. Three-dimensional nature of the architectural complex leading to direct physical and virtual model matching.

d. Scientific visualization of various simulations as the starting point for any design process.

2. Historical outline

The Abbey of Pomposa is the oldest monument of an architectural complex including also a bell tower, a Monastery and a separated building called "Palazzo della Ragione". The origin of the Abbey dates back to the VIII-IX century but its growth continued until the XII century with the adjoin of apses, spans and an atrium. The design shows clear architectural influences of the near city of Ravenna, especially in the internal subdivision into three naves, with colonnades and arcades, quite usual in the late Byzantine basilicas. The central nave, more developed than the others in height and width , ends up with a triumphal arch, a crypt and a semicircular apse. Wooden trusses and beams provide the roof structures for central and side naves respectively. External and internal walls are formed from brick and mortar masonries which show no appreciable signs of physical decay but visible out-of-plane deformations and localized cracks due to a process of subsiding started during the construction of the near bell tower in the early XI century and continued also in subsequent times. The present atrium is characterized by a simple geometrical layout: a central triple arch sustained by octagonal pillars, which were replaced to the original marble columns after a collapse not precisely dated in the literature, and full masonry walls on both sides, formed with heterogeneous materials. The façade is enriched with ceramic decorations aligned over the arches,

terracotta strips in yellow and red colors and white marbles. The walls of the atrium, as well as the whole basilica, underwent differential settlements in the course of the centuries and, despite their limited dimensions, exhibit visible out-of-planes, deformations and curvature variations. As a matter of fact, the enormous self-weight of the whole masonry tower, nearly 1,800 tons, distributed on a relatively small square base, produced a vertical settlement of the most compressible soil layers underneath and, consequently, the rotations and the above mentioned out-of-plane deformations of the Abbey walls. In order to prevent a possible, further growth of these structural damages, a set of transverse masonry walls was built in the side naves and in the atrium between the XVI and the XIX century, long time after the occurrence of the first macroscopic subsiding. Although they had to behave as internal buttresses, serious doubts still remain about their statical efficiency; moreover they have altered completely the perception of the internal spaces.

3. The 3-d network database hypermedia system

The 3-D database of Pomposa Abbey is based on a system of 3-D models such as to be the starting point for researches in any branch of architectural interest. The choice of virtual 3-D models is due to the necessity of representing the reality in an easily perceptible way, by simply changing, for instance, the attributes of scenes. Therefore, different images, each one represented with a specific purpose, are easily replaced to a unique final image, usable for any purpose and extremely synthetic. Moreover, according to the prescribed goals, one can chose different output systems in dependence of different solutions: 3-D and 2-D translations, viewers of 2-D images, 3-D viewers and model-coded or image-base coded restitution systems. On the basis of the human behaviors, elements such as orientation, memorization of visited places, recognition of people and situations, movement etc. are absolutely absent in the two-dimensional space of the monitor. The use of three-dimensional metaphors to represent the access to an archive, the consultation of an index by asking for a subject and not for a text field, the navigation inside environments differently characterized, can allow the easy access to extremely complex data structures and a constant guide within them.

The system of navigation and data restitution was developed for various models by using VRML '97, a tool set up to describe scenes and 3-D objects with which it is possible to interact directly in real time.

As the system allows connecting a page HTML to any object present in the scene, according its own URL, or to another VRML model, two important interaction instruments can be obtained:

1. The users can access to environments and objects by navigating always within the same 3-D space.

2. The VRML becomes a tool to select the HTML page containg the information required. In this way a multi-platform system was obtained which allows to visualize a '3-D data base' by means of simple Web browser.

In architecture it is compulsory to analyze, to observe and to design 3-D objects and spaces; also the 2-D data (photos, diagrams etc.) should be referred to them. The VRML language provides new and more useful tools for representation, manipulation and control of strategic fields:

a- restitution of geometric data
b- restitution of morphologic analyses
c- scientific visualization
d- representation of design solutions.

The form used, as any open system, will allow adjustments during the work, integration and monitoring after restoration.

The code is optimized for a PC-client with lowest features: 12x CD ROM drive, RAM 128 Mb, processor Intel Pentium II 350 mhz, OpenGL graphic card 16 Mb, OS Windows 98 or NT 4.0, browser Netscape Navigator 4.05 or later, Cosmoplayer 2.1 plug-in. Interface format: 1024x768 16 bit color.
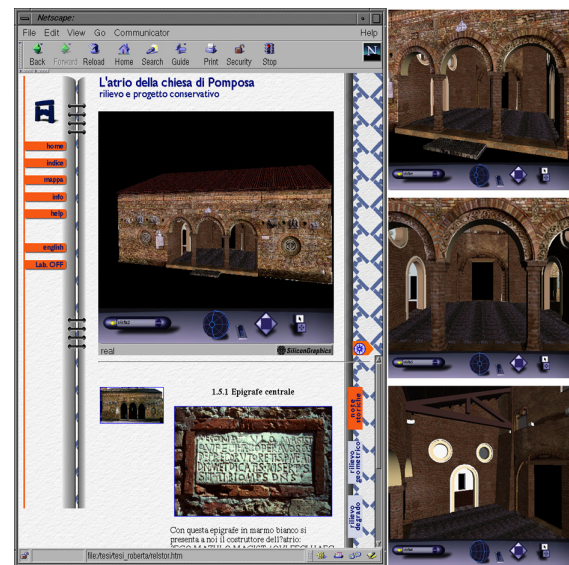

Figure 1: *VRML model of the present state as a navigation tool through the data.*

4. Case Study

4.1. Data acquisition

The façade in particular appears as a sedimentary construction, a patchwork where every anomaly denotes a piece of history; as a consequence, conservation or maintenance programs cannot be referred to traditional methodologies of data acquisition and restitution. Therefore, a joint project involving the Soprintendenza of Ravenna and the Canadian National Research Council was undertaken in order to get a 3-D survey of the atrium surfaces and a 3-D model of the atrium itself. The ac-

quisition of the data referred to portions of the façade was carried out with three different methodologies: direct manual survey, indirect instrumental survey and 3-D survey with 3-D scanner. Subsequently, three different 3-D models were assembled and compared to each other.

A - Direct manual survey.

It consists of the following three main steps:

1 - Data acquisition with traditional instruments.

2 - Reconstruction of "free form" curves by using clouds of points surveyed.

3 - Modeling of surfaces by means of curves.

Therefore, it turns out to be a hybrid operative system where traditional methods for surveying are supported by innovative restitution procedures using bicubic parametric surfaces (NURBS) to be transferred to a 3-D visualization system on a flat screen.

B - Indirect Instrumental survey.

Defining two main sets of significant points carried it out. The first one, consisting of eleven points, is aimed at a global representation of the facade; the latter, consisting of twenty points, gives rise to a refinement of the previous set and it is referred to the portion analyzed with the 3-D scanner. The instrument apparatus consists of a theodolite and an electronic diastimeter. The point co-ordinates were determined with the direct or "forward" intersection method and verified with reference to the polar co-ordinates of the two basic stations. The obtained results show a very high rate of accuracy.

C - Survey of 3-D surfaces by means of a system of structured light and a 3-D Biris scanner.

The goals of the mentioned co-operation have been:

1. Demonstration of a portable 3-D acquisition platform: range image acquisition and model creation.

2. Verification procedure and accuracy of models with large open surfaces.

3. Comparison of the obtained results with a topographic survey.

The error range in surveying the bas-relieves can be estimated in ± 0.2 mm.

The points surveyed were checked with software Polyworks also used to create models Inventor and VRML. These were then textured and completed using Alias/Wavefront Studio, version 8.5.
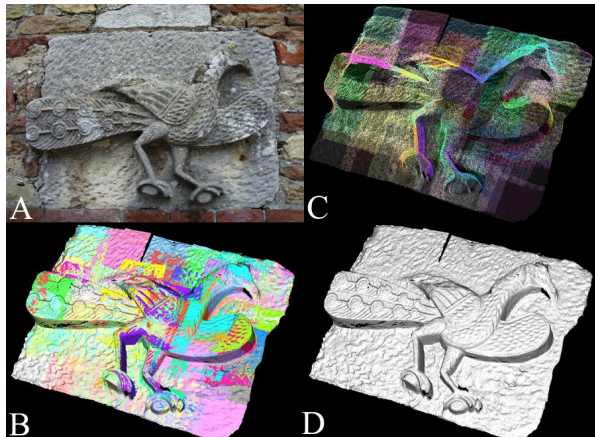

Figure 2: *high relief : a. photo 1998, b. cloud of 3-D points, c. shaded model with multiregistration view, d. the whole shaded model (courtesy NRC)*

4.2. Organization of the hypertext

The hypertext is organized as follows:

Historical notes	the abbey
	the architectural complex
	the church
	the atrium
	decorative element cards
Geometric survey	survey
	plotting
Decay analysis	alteration phenomena and decay
	pathologies and decay cards
	bricks and stones
	material analysis cards
	masonry
Structural analysis	existing state: stress analysis
	strain analysis
	project state: stress analysis
	strain analysis
Project	restoration project
	existing design proposals
	pre-consolidation
	cleaning
	consolidation
	integration
	protection

Each principal item is provided by a VRML model that organizes the others with hyperlinks structured from VRML nodes.
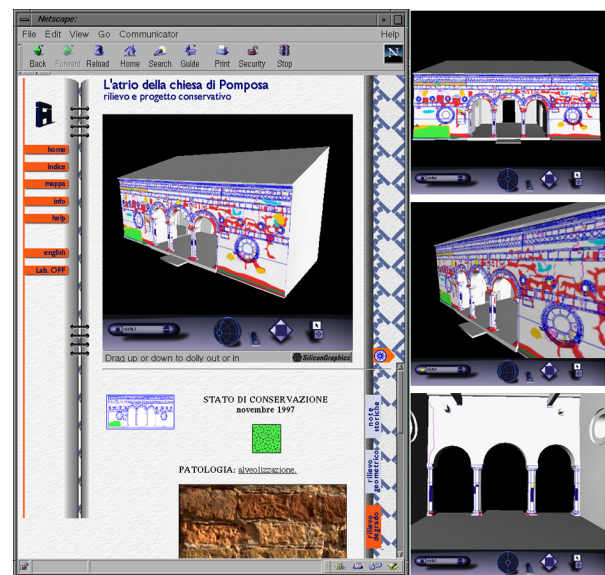
Figure 3: *VRML model representing the conservation and decay state.*

4.3. A subsystem: structural analysis

The 3-D model obtained was then used for the static analysis of the atrium in order to verify the stability of the deformed walls and the present mechanical behavior of the internal buttresses adjoined to the original construction. The analysis was carried out on the deformed model of the atrium by using MARC.Mentat, a F.E.M. code containing a series of integrated programs for the

analysis of engineering problems in the fields of structural mechanics, heat transfer and electromagnetic. Self-weight and live loads are the only external forces applied, whereas no differential settlement was considered for the foundations. In particular, the weight of the roof is transferred to the vertical walls by four trusses, two placed over the main entrance and one for each lateral room. Because of the low tensile resistance assumed for masonry, the analysis is non-linear and the loads are applied by subsequent increments up to their final values. The 3-D model, assembled with A/W Studio, was exported in IGES format in order to be recognized by MARC. In the first place, since the exported model was characterized by a distribution of quite irregular isoparametrics, the atrium surfaces were discretised by a more regular mesh in order to achieve more accurate results. In particular the discretisation was performed by means of 40x40 cm brick elements with a total of 1052 elements for the only façade. One of the major problems was finding on the external surfaces a mesh compatible with the one used for the internal surfaces. The model assumed does not take into account the wall which separates the atrium from the basilica, mainly because the transversal buttresses are not clamped to it. Two distinct analyses were carried, one in the presence of buttresses and tie beams in the whole structure of the atrium, the latter assuming no type of reinforcement. The results show that in both cases vertical displacements and compressive stresses are very small and insignificant, such as to justify the possible choice of eliminating either buttresses and tie beams. As a matter of fact, the tie beams can work only partially because they are inside walls not clamped to the rest of the church. Therefore, the restoration project might consist simply in removing buttresses and tie beams or, at most, in disposing a wooden string course on the top of the external walls and under the roof structure in order allow a more uniform distribution of the vertical loads on the masonry underneath. All the results are shown by means of Quick Time animations or visual simulation single images linked to the VRML model that represents the finite element mesh.

References

1. Salmi M., *L'Abbazia di Pomposa,* Roma, 1936.
2. Russo E., *L'Atrio di Pomposa* in "Analecta Pomposiana", 1990.
3. Di Francesco C., *Pomposa: le fabbriche e i restauri*, Ravenna, 1992.
4. Hartman J., Wernecke J., *VRML 2.0 Handbook*, Addison-Wesley, Reading, Ma., 1996.
5. Gaiani M., Addison A.C., 'Virtualized' Architectural Heritage, *Future Fusion*, IOS Press, Gifu, 1998.
6. Beraldin A., Blais F., *Active 3D sensing*, tutorial NRC 97.

Figure 4: *conservation project: interactive comparison between the VRML model of the present state (left) and the new configuration without buttresses (right).*
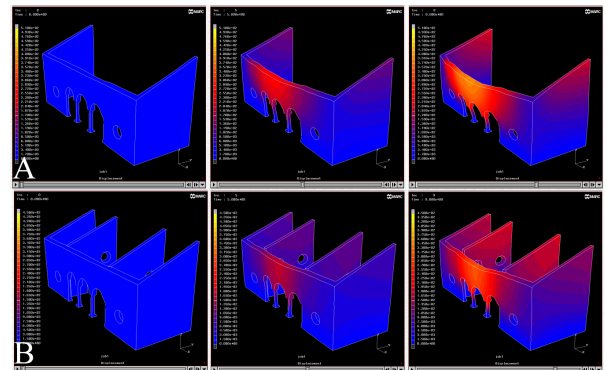
Figure 5: *static analysis: images from the Quick Time animation showing the strain state under increasing loads: a. project state without buttresses; b. present state with buttresses.*