

A framework to use virtual worlds generated from real world 3D models as Work Tool for Architectural & Archaeological Restoration on the Web

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1. Introduction

In this work, we describe a digital framework to record, organize, present, and visually navigate 3D architectural and archaeological data using virtual worlds generated from real world 3D models.

Our system deals with built heritage documentation, visual knowledge representation and our development of a toolkit. It presents two main subsystems:

- a. a basic GIS system architecture that can be operated through a web browser with Internet access. The architecture includes software on the server side that provides access to GIS information and attributes and software on the client side that defines a user interface and provides rendering capabilities. The client side software is implemented using the Virtual Reality Modeling Language (VRML) that provides the rendering and interactive capabilities;
- b. a 3D real-world shape and texture data acquisition and modeling.

The toolkit aims to be a Work Tool for Architectural & Archaeological Restoration on the Web.

Designed for use over the Internet with a VR browser, the system is also intended as a visualization and collaborative design tool and as a study aid. Finally, a demonstrative application is presented based on the authors' experience in 1997, the making of a 3D multimedia Internet system for the Archaeological Superintendence of Rome concerning eight small Roman tombs along the ancient Appian Way, created for restoration and scientific dissemination (see URL: <http://www.archeorm.arti.beniculturali.it/sar2000/>).

2. Background & Previous Works

The main feature of the monuments restoration project is the need of a large amount of data (surveys, analysis, etc.) on which to found the action. A second specification of this kind of intervention is the continuous collaboration between archaeologists, architects and specialists, working together for the solution of the same problem.

Until today those problems did not receive an effective solution. The result is, compared with a growing need of "industrialization" of the restoration process, the completely lack of the use of the whole corpus of the information in the restoration design process or very expensive operations in terms of money and time.

On the other hand collecting, organizing, storing, and conveying knowledge of extant and historical conditions is a challenging problem in architectural preservation. Typical of this problem is a great quantity of heterogeneous data (3D models, images, photos, drawings, texts, written documents, etc.), which does not allow immediate usability and easy transfer and movement. Furthermore, the 3D nature of architecture is such that the use of textual descriptions rapidly degrades the quality of the information.

In the case of digital systems as well, search engines are currently being used to retrieve architectural content over the Internet. While performing well with text, their performance degrades with multimedia and 3D data. Querying words is a much simpler task today than searching images, 3D models, or sounds. The reason is simple: a text is composed of words while a multimedia file is made out of images, models and sounds.

This is a major quantum jump compared to the previous state-of-the-art, since it exploits what Maurice Merleau-Ponty in his *Phénoménologie de la perception* (1945) calls a "theatrical perception" of the world, meaning that all human experience is confined to the perceived world. Our way of taking possession of architectural artifacts, as of all the space surrounding us, is essentially a visual and perceptive way, in which space and times are represented as continuous and iconic systems. Until today the figurative model on which we bring back every real world representation has always been based on three types of analysis:

- a. reduction from 3D to 2D;
- b. starting from few discreet points, construction of the entire continuous system through interpolation, usually linear;
- c. recomposing of the whole world scene through fixed images. (see Gaiani, 2000).

To improve this process it is necessary to find read&write methods capable of preserving the continuous and creating aggregation systems that make data as much unifiable and transferable as possible.

In recent times the cultural heritage field has tried to give a first answer to this problem making large use of computational methods and "metadata" (literally "data about data" or, using a wider picture, "the sum total of what one can say about any information object at any level of aggregation") as description of semantic categories from heterogeneous data, an attempt to describe the essential properties of other discrete computer data objects—specifically, the data objects that make up the information on the World Wide Web (Gilliland-Swetland, 2000, Gill, 2000, Caplan, 2001). However, "metadata" is resulting an increasingly ubiquitous term understood in different ways by the diverse professional communities that design, create, describe, preserve, and use information systems and resources and practically we have seen just a proliferation of the types of metadata without arriving to define true standards. Furthermore, it has been recently envisioned by an expert from the librarian domain that in a close future that concepts of metadata records will be replaced by "borderless network of related entities" (Jorgensen, 2001).

Apart from the possibilities offered us by the visualization of virtual worlds, a powerful tool offering the digital paradigm in this field is the concept of 3D database. For the architect - an operator used to reason first of all in spatial terms - this might be a great improvement: from the making of textual to visual database with hypermedia and multimedia possibilities that allows to collect and integrate huge quantities of heterogeneous architectural data with easy access, to extremely complex data structures and constant user guidance. Main characteristics of a 3D database are:

- a. fully replace physical archives with digital files having the same basic features,
- b. allow the same data to be used and analyzed in a variety of ways,
- c. provide a 3D representation of the architectural complex matching its real-life counterpart,
- d. provide scientific simulation capability for use as a design tool,
- e. furnish both iconic as well as orthogonal visualization,
- f. use of the mode both as representation and as metaphors for navigation (Gaiani and Alessandri, 1999).

Our working group is particular skilful in facing this kind of approach: we have a background as architectural planner, with a specific reference to historical and traditional architecture, a wide know-how as experts and implementors of GIS systems, finally a large experience both in 3D data capture & modeling, and in visual database development. Semantic 3D digital modeling and 3D data acquisition has already been widely used by our group in heritage projects of varying scale. Last year experience in the specific field includes:

- a. 3D scanner survey of the façade of the Hearst Memorial Mining Building, University of California at Berkeley (1997)
- b. 3D scanner survey of parts of the atrium of the 8th century Abbey of St. Mary of Pomposa, near Ferrara, (1998)
- c. 3D scanner survey of Colosseum and Caracalla Thermae in Rome (1999)
- d. Photogrammetry and Topography survey and modeling of Palladio's Basilica in Vicenza, and San Salvatore al Monte in Firenze
- e. 3D models of a Palladio's Villas in Veneto region and of unbuilt Palladio projects for the Centro Internazionale di Studi di Architettura Andrea Palladio in Vicenza (1995-1997)
- f. the CD-ROMs database with full historical citations and detailed multimedia and 3D reconstructions of Andrea Palladio's villas and about Eight Italian Architectures of the Postwar Period (1997-1999)
- g. GIS for the Gruppo Nazionale Difesa Catastrofi Idrogeologiche (National Defence Group for Hydrogeological Catastrophies) and CD-ROM about a GIS interactive map on hydrogeological risks (1997-2001).

To try to give solution to the problem of the documentation and the monument restoration project we have defined as methodological key-point the concept of 3D database, originated from the observation that a 3D model can be seen as a large, ordered database of spatial information, and it can be added to and altered over time. 3D models are, by their nature, highly intuitive interfaces to information, allowing the user to access an object directly via its 3D representation rather than via its name in a traditional text field. A wide range of further information can be obtained by simply clicking on a part of a 3D model.

Finally, the use of 3D real world models instead of 2D black&white drawings is a great improvement to document an operation that is more a cleaning than a construction and for buildings that are not simply a sum of planes and quadratic polynomials (planes, polygons, striped surfaces, portions of spheres and quadrics) as in the new building design. A 3D model offers us a better simulation when we try to replicate the real-life building with its irregularities, out of plumb, curvatures, bulges, hollows, sags and other signs of the passage of time, together with the forms created but never formally included in the classical rules of Vitruvius.

Digital 3D models are a high-potential technique. Although creative, modeling is strongly rooted in knowledge acquisition. The 'creation' must resemble reality even if objective cognitive data are to be put to different use depending the modeling technique adopted. 3D virtual models are a break with the past limits of projection and cross-section, and of the analogy between the sheet of paper and the surface of the wall, since they presents a world more in tune with the world as we perceive it.

3. The system

3.1. From 2D screen to Virtual Theatre

VR desktop techniques in archaeology or in architecture - reconstructions, 3D graphics, immersive imaging - promise an accessible, highly visual, and interactive means of representing difficult-to-see data, opening up new ways of presenting research. VR models allow us to put all of our current knowledge and thoughts about an object into a user-interactive presentation. Such models are important because,

above and beyond their strong popular impact, computer reconstructions allow the presentation of complex information in a visual way that enables it to be used to test and refine the image or model that has been created.

3.2. 3D GIS & VR desktop systems

Extending 3D GIS by the VR interface is a logical consequence of the demand that the tool has to provide vivid visualization. Virtual reality offers new and exiting opportunities to visualize 3D GIS data; in most cases, however, interaction with the data is limited to viewing (Verbree, 1999, Koller, 1995, Raper and McCarthy and Livingstone, 1993). The possibilities to interrogate the GIS database in a more intelligent way and to access more advanced GIS functionality are limited (e.g. to formulate a SQL-query). Even if we introduce a spoken language interface, then we will still miss the spatial references and attributes to formulate these queries. This is not an easy transition, because current real-time systems have been planned for visualization, but not for interaction. To be considered a "3D GIS", a system must be capable of handling data as more than a surface; it must handle geographical feature data supporting query processing, spatial analysis in addition to dynamic user interaction according to three classes:

- a. Orientation and Navigation,
- b. Selection and Query,
- c. Manipulation and Analysis.

There are some approaches for structuring 3D GIS:

- a. raster approach in which voxels serve as the building blocks for geo-objects,
- b. vector data models supporting topological data structure,
- c. object-oriented structuring enabling attribute data access and continuous mapping and querying.

3.3. 3D Web VR GIS

One of the challenges for the 3D GIS development is remote access over the Internet (Zlatanova and Gruber, 1998, Kim and Lee and Lee and Ha, (), Abel and Taylor and Hungerford, 1998, Roher and Swing, 1997). The issue has three central aspects:

- organization of data on the server,
- means to formulate queries,
- visualization of the resulting information (basically 3D graphics, text) on the client station.

To realize 3D interactions in heterogeneous networks a number of requirements have to be fulfilled:

- Suitable client hardware: to make interactive 3D visualization, a dedicated 3D hardware is needed at the client-side (typical a videogames desktop computer).
- Reasonably fast network: 3D environments tend to be very expensive both in term of memory usage and computing resources demand, especially if photo-realistic image quality is to be achieved.
- Geometric object description language: to allow an exchange of 3D data in a heterogeneous environment, a standardized format for object representation is necessary.
- Content information: for most applications, a geometric description of objects is not sufficient. To actually interact with the 3D model, the client has to know what is represented by geometric data, what relations exist between objects, etc. For editing purposes, placement hints are necessary. For simulation applications, additional information about object properties are needed.
- Portable/scaleable visualization and editing software: it would be an enormous effort to write client software (3D visualization, interaction, editing, etc.) for a number of different operating systems. If a heterogeneous environment is to be supported, visualization should based on a standardized system that can be expanded using plug-ins. Until recently,

3D models were not directly accessible on the Web. The Virtual Reality Modeling Language (VRML) was designed to fill the gap (ISO/IEC 14772-1, 1997, Ames, 1997). VRML is basically a language to describe 3D models and to make them accessible on the Internet. It is an open standard and can be used without licensing fees. Visualization/interaction is done by plug-ins for web browsers (Netscape Communicator, Microsoft Internet Explorer). The first version of VRML was developed in 1994 and was nearly identical with the Open Inventor ASCII file format. VRML 1 was sufficient to describe static 3D models and to link their objects with other VRML or HTML documents. In summer 1996, the formal definition of VRML 2 was announced. This version substantially changed the syntax of VRML 1 (causing numerous conversion problems) and added sound, interaction and a scripting interface. VRML 2 was accepted as an ISO standard in late 1997 (VRML'97) and has been called VRML'97 since then. Basic use of VRML is essentially that of dynamic visualizer of pre-formatted files in the browser, without interacting with geo-objects. However, the aim is not only to get a personal view of the 3D model data but also to interact with the geo-objects. This does not satisfy the key requirements of a GIS dynamic query. The language, however, has the potential to describe the behavior of objects, provide links to other documents on the Web, represent interrelations that can be used to retrieve and visualize 3D spatial information and thus serve as an interface to 3D GIS.

In the GIS context, there are two different classes of queries, both requiring interactive specification. The first is focused on getting additional information about a selected object. Using VRML this can be done dynamically by script nodes. An object identifier is used to identify the selected object outside the VRML scene graph such as posing a query to the 3D-GIS kernel. The second kind of data query works in the opposite direction. The user searches objects which meet specific conditions. In this case, the query results in a set of objects (Zlatanova, 1999). On this subject there are two possible approaches. In the first case documents with VRML can be developed with Java applets or Javascripts, which allow interactivity with the computer client. In the second case, changes can be done directly at a DBMS level, using a software that controls data access on the server, such as a Web server side script or Javascripts or Java applets, and a new VRML or HTML document showing the required changes. Dynamically created VRML and HTML documents provide the Graphic User Interface (GUI) to complete queries, visualize results and explore 3D models. As regards this, the use of the External Authoring Interface (EAI), linking Java application to the 3D VRML scene, it can be possible to program Java applications which utilize an interactive user interface using VRML. EAI defines the set of functionality of the VRML browser that the external environment can access. In this way VRML files can be dynamically built and updated via the EAI and, in turn, the applet's data can be also dynamically updated through the VRML interface. Using this property, we can have the web-based 3D GIS engine such as 3D GIS data handling module, and 3D spatial operators built by Java applet which communicate with the 3D geo-spatial data built by VRML files (Kim, 1998, ISO/IEC 14772-2:xxxx, ()). Finally the VRML browser today available, although VRML is an open standard not limited to any operating system, presents restrictions and limitations. Michael Kofler gives us a comprehensive survey of the main problems using different VRML browser (Kofler, 1998). The following are just the main problems we've encountered:

a. Missing/additional features: almost two years after the first public release of the VRML 2 specifications, many browsers still fail to fully comply to these specifications. On the other

hand, many browsers do support additional vendor-specific features.

b. Image quality: as browsers are based on different graphics libraries, lighting, colors, maximum texture sizes etc. vary from one browser to the next. VRML 97 does not specify the image quality browsers should achieve, and many vendors decided to optimize their products for speed rather than for image quality.

c. Scripting: according to the VRML specification, VRML browsers must support the Script node. Unfortunately, the standard does not define any specific scripting language (such as Java, JavaScript or VRMLScript). Thus, different VRML browsers support different languages. Unless VRML authors restrict their users to a certain VRML vendor, they cannot rely on scripting support for any specific language.

d. GIS features missing in VRML specifications (e.g. design limitations).

e. VRML files are very large: VRML lacks a binary (compressed) format. With geometric compression and binary coding, not only could the file size be reduced substantially, but also the time for de-coding.

f. VRML is intended for read-only (visualize-only) single-user applications: Although VRML includes some features to add interaction to 3D models, these features are severely restricted and intended primarily for animation effects. VRML is not intended for real 3D editing; it does not support mechanisms to report changes in the scene back to the server; each time the scene is reloaded, it is displayed again in its original starting state.

g. VRML lacks the scalability needed for very large models: it lacks library mechanisms to locally manage reusable 3D components and to avoid constant reloading/pre-processing. It is however not possible to spatially organize large scenes; VRML browsers are not able to decide which parts of a large model should be loaded and which are currently not within the view frustum anyway.

4. The application

In our case, a 3D Virtual GIS has been implemented to be used in desktop systems. At the basis of this work there are three concepts:

a. The use of 3D digital models as a representation of reality and a metaphor of the surveyed object, for navigating across data. The advantage of virtual computer models in comparison to traditional analysis is evident. The visualizing process resulting from solid modeling can sometimes reveal relationships within an archaeological 'reconstruction' more clearly than any other current methods of display. Consequently, those models permit spatial queries such as "what is next to", what surrounds, what is above, below, to the side of, etc., or the provision of complete physical properties, as well as the ability to generate section views, add full visual physical properties, and detect interferences between adjacent components.

b. A model as an architectural knowledge system. An 'architectural knowledge representation' is one which describes a series of structured objects using a specific architectural lexicon (Gaiani, 2000). Creating digital models as a "cognitive system" allows to easily extend the concept of 2D GIS to that of a 3D GIS, because it generates a more appropriate semantic system to which the GIS data management and retrieval can be referred to (a Geographical Information System is a computer-based system consisting of hardware, software, data and applications. The system serves to capture and update spatial data, to store and maintain, to analyze and present these data in an alphanumeric and graphic form).

c. Web system providing multi-user access using remote networks and heterogeneous hardware (clients with different

operating systems). The development of Internet has a great effect upon GIS. It is a trend to combine GIS with Internet, but there are many restrictions to practice the basic GIS functions (combination of spatial and attribute data) on WWW. For this reason, if a 3D GIS could present GIS function completely, it would be more real and clear to describe the space systems.

4.1. System components

The GIS application includes components that reside both on the server and client sides. The architecture features access control, server side session tracking, simple user configuration of user worlds, translation of native GIS data, and simple collaborative capabilities.

On the server side, a web server serves all client requests for static and dynamic content.

The major components of the system are:

- a. the central database engine
- b. the VR central system.

The visualization and query architecture consists primarily of several generic functional modules coupled with an application specific GUI and objects and is a typical client/server architecture based on four key-components:

- open relational database management system (RDBMS)
- Web server
- Web browser, VR browser
- server side web-oriented language and communication software to dynamically retrieve the contents.

Web servers allow to serve content over the Internet using the Hyper Text Markup Language (HTML). The Web server accepts requests from browsers like Netscape and Internet Explorer and then returns the appropriate HTML documents.

Several software technologies and development packages are used in this application. These include a number of server-side technologies to increase the power of the server beyond its ability to deliver standard HTML pages (CGI scripts, server-side includes, SSL security, Javascript and Microsoft Active Server Pages (ASPs), the Microsoft Internet Information Server version 5, Microsoft Access as RDBMS). At level of client side we used the old CosmoPlayer version 2.1.1 browser plug-in (it's the most efficient VRML browser in terms of quality of visualization and memory usage. Cortona from Parallelgraphics presents more script capabilities and support directly EAI but lacks in the visualization of the objects, mainly two sides visualization).

Distributing the application between client and server across the Internet enables remote access to the information in ways not easily possible with conventional applications. Changes in server based information can be made immediately and universally available. Simultaneous collaborative sessions are possible. Access control provides a mechanism for creating multiple user classes having different access rights to the information. The client side application consists three parts. The first part consists of a series of web pages that provide access control and configuration prior to viewing the content. The second consists of the unchanging parts of the client side GIS application including menu controls, displays, and the base visualization. The third part of the client side application includes the dynamic content that is requested by the user. Furthermore, the dynamic content has embedded Asp calls to report user status and updates back to the server.

The user can access data on the server with the help of Graphics User Interface (GUI) built on combinations of HTML forms and 3D VRML worlds. The HTML documents are used for specifying queries and visualizing text, images, movies, and so on, such as information supported by Web browser. The client GUI is one of the key of the whole pro-

ject, because change completely the usual way to show the information in a web browser, with a 2D window that manage the other types of information. The GUI enables the user to control the major operational modes, make specific input selections, to view current status, and to navigate within the application. The GUI is composed of four modules that include 1) the menu and the work zone on the upper of the screen, 2) the whole world view, 3) the locator, and 4) a lot of windows that can be opened inside the whole world view as virtual tables for a virtual avatar. Not including the work zone, the GUI appears to the user in a head's up display, always appearing at the same position and scale throughout the user's session regardless of the current viewpoint.

Figure 4.1-3 gives architecture of the menu for the current application. When a particular option or function is selected in the menu, an encoded message is communicated to relevant modules in the visualization. Depending on the desired functions and flexibility, the menu can be changed to meet pretty much any desired capability. The fundamental building blocks of the menu are two buttons that enables textual or object search.

In addition, the buttons can be configured to suite a variety of purposes through external specification of its geometry, text labels, and textures (images painted on the button surface).

The form of the menu hierarchy presented to the user must change depending on the privilege and requests of the user.

Since navigating through virtual worlds can be disorienting, a navigational aide is provided to help the user pinpoint their position within the world. In addition, a programmed fly-through route is included on the navigator to allow the user to see the course of the fly-through. Furthermore, landmark names appear as each is passed in the fly-through. The same objects enables specified searches.

The process of client-server communication can be described as follows: the client sends a request for information to the http server using the VR or HTML browsers, the Web server processes the request and returns the demanded data statically or dynamically to the client station. Depending on the request and the type of the data received, four fundamental phases can be distinguished: identification, query, visualization and navigation, manipulation. The requested information, in form of HTML or VRML document, e.g. a table with text data or a 3D model of a particular neighborhood, is visualized in HTML or VR browsers at the client station. In the second phase, the user only retrieves information.

4.2. System functionalities

At this stage of the project, the following GIS functionalities are implemented:

- full 3D support for vector data: the system can get 3D data from each CAD software using VRML file format (triangles or NURBS surfaces)
- integration of raster data, such as orthogonal images and photos: it's possible to manage each kind of raster data linking them as a dynamic html page or to use them as part of a partial or whole VRML model
- visualization and navigation: the VRML standard, used as 3D object representation and visualization engine, ensures 3D data photorealistic visualization and navigation
- manipulation: it's possible to combine in the same window different elements or to isolate others
- 2D measuring: a 2D orthogonal projection superimposed onto a mobile measurement grid generated in Javascript gives the metric values of the single objects (see section 4.2.1)
- selection by SQL query: using a text query window, it's possible to search different kind of spatial, object, textual and image information (see section 4.2.2).

4.2.1. Spatial operations

Mainly the 3D query space distinguishes an information system from a visualization system. To build this query space, not only the geometry of the objects is needed but also spatial relationships between them. Managing spatial relationships, three different categories have been established in the GIS context: metric relationships based on Euclidean geometry, topological relationships managing adjacency, connectivity and containment, and partially ordered sets of these structures. These can be represented through a system such as EAI. Nevertheless, the system is not easily usable by operators for interactively representing the distance between two points in space, as they are traditionally used to plane sections. For this reason, a two-dimensional orthogonal projection gives the metric values superimposed onto a mobile measurement grid generated in Javascript. Using the same script other thematic analysis are made possible, for example in the case of study the 2D window that allows the comparison on the same scale of the recent survey, the mid-19th century survey data, the reconstruction proposed by Canina and the original tomb design.

4.2.2. Query methods

In the application two different classes of queries are possible, both requiring interactive specification.

a. A first class focused on getting additional information about a selected object. Using VRML this can be done dynamically through script nodes. An object identifier is used to identify the selected object outside the VRML scene graph such as posing a query to the GIS kernel.

b. The second kind of data query works in the opposite direction. The user searches objects that meet specific conditions. In this case, the query results in a set of objects. On this subject there are used two different approaches:

1. documents with VRML has been developed with Javascripts, which allows interactivity with the computer client,

2. changes has been done directly at RDBMS level on the server, using the server side software, and a new VRML or HTML document shows the required changes.

Data access Graphics User Interface (GUI) are:

a. the whole VRML world by clicking on a anchor node on the VRML model,

b. a text form, by simple SQL query.

Possible queries are:

- whole VRML world query

- database text query

- database object query.

In this way two important interaction tools are obtained:

a. the user has access to environments and objects always inside the same 3D space. In our case, parts of the entire organism have been made accessible starting from the overall model

b. the VRML becomes a tool to select a page containing other information types.

Here we can see in detail the different types of queries. Let's start with whole VRML world query. By simply clicking a anchor node we obtain the requested information (text, images or 3D shape).

The database text query is obtained exploiting the higher part of the interface, then we interrogate the database by text query.

Last, in the database object query the request for information about an object is broken down into two steps: object identification and information specification. For instance the query "find pulvini in the Usia's tomb" will require means to:

1) point to and select the tombs

2) select the attribute "pulvinus" among all the tombs characteristics.

The first step can be formulated either in a VRML or an HTML document. In an HTML document, the object can be specified by typing its identifier (ID). Most likely, the user is not always aware of IDs in advance. A more attractive alternative is the recognition of the object in a VRML document. The VRML file in this case has to be created as a link between the ID in the database and the object on the screen (for instance the VRML *node* in the VRML document). The user points the object of interest, observes its ID and composes the query. The identification of an object activates an ASP script on the server. The script generates a HTML form on fly, where the user further specifies the parameters. The ASP script processes the form parameters, extracts the needed data from the database and creates a document dynamically, which is sent back to the client station by the server.

5. Making the models & shape data

The generation of a high quality 3D model for a real world object or architecture includes several, partially independent steps. Figure xx shows an overview over these steps. First the geometry and the texture of the object are acquired – often using different techniques and acquisition devices which makes it necessary to align both data sets in a separate registration step. However it is also possible to derive geometry information from texture data and vice versa. Once a complete model exists it can be resampled, converted to a different data format, or compressed to make it suitable for transmission over the Internet. Finally, an application running on a client computer should display the model in an interactive and intuitive way without omitting any information.

On the other hand, from the point of view of a GIS application, a geo-object consists of thematic data, geometry, topology and several object views. In order to maintain property between visualized data and data inside the database, the geo-objects have been obtained from CAD models, employed as surveys of the objects.

The generation of a high quality 3D model for a real world object includes several, partially independent steps. The main steps of the 3D object construction pipeline are:

1. shape & color capture
2. forms of representation
3. systematization of LOD.

5.1 Shape capture

These 3D technologies can be divided into two broad categories (Beraldin and Blais, 1999, IEEE Computer Society Press 1997):

a. Contact techniques: as the name suggests, this technique entails physical contact with the surface of the object, either manually or with an instrument. Techniques include ruler and plumb line, sophisticated articulation with touch probes, and touch probes with optical spatial detection devices.

b. Non-contact techniques: these exploit existing energy sources or generate an energy source (i.e. ultrasounds or optical radiation) that is directed onto the surface of the object. The energy rebound is measured in a variety of ways, including special cameras and even the naked eye. Today, lasers, optical and ultrasound techniques can exploit coherent radiation propagation properties and generate realistic models of objects and large structures.

Techniques can be either:

- passive systems deriving the coordinates of a given object from the information provided by intensity images, such as photogrammetric systems, or
- active 3D vision systems, such as laser scanners and structured light systems in which information inputs are external,

i.e. scanning angle, time of flight, or the shape of projected patterns. A 3D active vision system can measure in a matter of minutes vast amounts of 3D data in the form of accurate 3D point clouds without the need for prism or reflectors. 3D range cameras have been built and tested for applications as diverse as space, industry, anthropometry, and finally - more recently - cultural heritage (Beraldin and Blais and Cournoyer and Godin and Rioux, 1998, Levoy et al. 2000). Clouds of points acquisition is a fundamentally new technology. Unlike 2D measuring and drawing which entails extrapolation and interpolation of the few points taken into consideration, every point in 3D clouds of point technology is measured and assessed, with the result that survey accuracy is greatly enhanced.

The most appropriate 3D survey method for this type of architectural object is a combination of non-contact or 'camera' photogrammetric shots and active vision systems using 3D laser scanners (Gaiani and Addison, 1998, Beraldin and Blais and Boulanger and Cournoyer and Domey and El-Hakim and Godin and Rioux and Taylor 2000).

Using photogrammetry our method is based on the orthorectification, which employs the collinearity equation to correct imaging distortion. A-priori camera calibration is not normally required. To offset problems with large surfaces and close-range camera position, we applied: camera calibration, differential straightening on objects presenting deep curvatures, mosaicking over large surfaces.

Using 3D range cameras over large structures we have adopted a number of techniques and different type of scanner (time-of-flight, triangulation) to create accurate 3D digital models and to eliminate the main sources of errors. With open structures, for instance the façade of a building, the result of a data-driven alignment process might show cumulative errors in the final model especially if there are a lot of planar surfaces. When the object can be closed enough images to loop back to the first image, e.g. a sculpture, then a final global optimization can help in fine-tuning the pose of each image in order to reduce the misclosure in the final model. In any case, the model should be compared to control points, present on the structure itself or around it. These control points should be surveyed with techniques that are more accurate than the range sensor being used. More detail you can see in (Gaiani, 2001).

5.2 Color capture

The appearance of an object consists of several surface properties including color, texture, reflection properties, and normal directions (Gaiani and Uccelli and Balzani, 2000, Seidel, 2001). Due to their large number they are difficult to acquire but nevertheless needed to generate a convincing looking representation of an object. It is therefore justifiable to put a lot of effort into this acquisition step. Color processing pipeline consists of correcting the color images geometrically and radiometrically, discarding pixels that were occluded with respect to the camera or light and projecting the remaining pixels onto the 3D model. The output of this pipeline is a RGB color map. The process comprehends:

- a. color acquisition. All photographs were taken under strict temperature control conditions to ensure exact chromatic reproduction of the sample area. In addition, color and reflectance reference samples, such as Kodak color control patches, were used to identify any variations in temperature color.
- b. fitting the 2D textures onto the geometric 3D model. To offset problems with large surfaces and close-range camera position, we applied:
 1. camera calibration;
 2. differential straightening on objects presenting deep curvatures;

3. mosaicking over large surfaces.

c. elimination of all inherent or cast shadows and highlights: the operation consists of compensating for ambient lighting, discarding pixels affected by shadows or specular reflections, or occluded with respect to the camera or light (Dana and Van Ginneken and Nayar and Koenderink, 1997). To discard the highlights and the shadows we arranged a very simple method that computes a color for each pixel by taking the average of a small neighborhood of pixels in the corrected image, starting from a sequence of images. The algorithm to remove highlights and cast shadows relies on two assumptions: that the scene is static and that each pixel in the texture is free of directional illumination effects in most of the frames. We employed a neighborhood as in Bernardini and Rushmeier, 1999, rather than a per-pixel sample, because tiny alignment errors can produce a very large color error, when there are abrupt changes in color between pixels. The algorithm discards the oddest values (very high relative values are not used to exclude specular reflections, and low relative values are not used to exclude shadows), and calculates, for each pixel, the average of its color values along the image sequence, giving us color values that do not deviate much from the median. We calculate the median and the averages separately for R, G, and B. For color value deviation, "much" is 10% of the R,G,B, value as in Ofek (Ofek and Shilat and Rappoport and Werman 1997). Also in our implementation, we employed from five to eight images for each pixel.

5.3 Forms of representation

Virtual reality systems usually support polygonal formats only, which rarely is the most appropriate geometry for representing a monument, better defined by NURBS surfaces. A triangular mesh allows complete generality, ease of representation, visualization, manipulation; it also features uniform geometry and topology, but an approximate representation. On the contrary, a NURBS surface presents a high mathematical complexity, variable geometry, non-standard topology but exact representation (Besl, 1999).

In our case we started constructing NURBS models.

The process pipeline to build the models from the orthophotographs was as follows:

- extraction of 3D profiles
- creation of the surfaces between the profiles
- insertion of the real life deformations by altering isoparameter curves and CV points.

The process pipeline to build the models from 3D range cameras was as follows:

- acquisition of spatial data: to construct a 3D image it is required to scan the laser beam across the scene, either using lightweight scanning mirrors or by directly steering the laser source;
- survey of control points: control points survey (natural features or artificial targets) is required to provide accurate localization, especially for those edges corresponding to surface discontinuities, and to guarantee that edges are correctly classified (i.e. jump, crease);
- detection and resolution of occlusions: If a complete volumetric model is to be achieved, range data acquired from multiple viewpoints is required to solve all the ambiguities due to occlusions;
- registration: the operation consists in aligning the scans taken from different positions. By definition, range map geometry is relative to the current sensor location and has to be transformed into a unique reference space, so that the sections of the range maps that correspond to the same surface zone will be geometrically overlapping;
- merging of multiple range images: a complete model is more than the sum of individual models, should integrate

geometric features from the single views and delete redundant points. Merging is the reconstruction of a single 3D mesh out of a set of registered range maps. The integration approach depends on the final representation (e.g. triangular meshes, surfaces);

- triangulation & mesh editing: mesh triangulation is the construction of triangle mesh from the aligned meshes, editing improve the quality of the reconstructed mesh performing simple editing actions on the mesh (e.g. to fill small holes, to remove non-manifold components of dangling edges/faces, to apply smoothing filters, etc.);

- conversion of triangles to NURBS surfaces.

Detail of those methods can be seen in (Bernardini and Rushmeier, 2000).

Finally, for all the non-CAD use (mainly visualization), we translated the models in a VRML mesh file format.

The translation of the original NURBS models into a triangulated mesh as forced us to apply decimation of polygons and compression of textures to have good real-time performance on a client PC without visualization accuracy loss.

The polygon simplification it's been developed following two different criteria:

a. polygonal simplification. Two typologies of polygons simplification has been employed:

- adaptive subdivision: used for converting NURBS geometry into triangular geometry;

- geometry removal or decimation: it usually consists in either polygon removal, with re-triangulation of the resulting hole, or merging or collapsing of several vertices into one vertex;

b. architectural semantic simplification. We took into consideration the basic elements making up the architectural structure. We defined the architectural levels of detail for each element, so as to bring not only a reduction of the number of polygons with the usual techniques, but a reduction and simplification of elements, according to the encoding methods for architectural items.

5.4 Systematization of Level of Detail (LOD)

Multiresolution geometric models support the representation and processing of geometric entities at different Levels of Detail (LODs) (De Floriani et al. 1999). Such models are useful in several applied fields to handle geometric data efficiently, depending on specific application needs. The main advantages of a multiresolution model are: data reduction, whenever an approximate representation at low resolution is adequate; fast data access, by exploiting spatial indexing; and hierarchical processing, where speedup is achieved by propagating information across different LODs. A major approach to multiresolution modeling is based on a decomposition modeling scheme, where resolution is controlled through the level of refinement of the domain decomposition: the underlying idea is that the accuracy in the representation is somehow proportional to the number of cells in the subdivision. In our case, we created a static LOD system for polygons and textures according to their distance from the observer, following the VRML 97 specifications. This does not increase the performance but improves the quality of the perception. For different visualizations, 3 different Levels of Detail (LOD) were implemented. The LOD system relies on a semantic modeling system that exploits the architectural order as a decomposing matrix.

6. Case of study: the "Ancient Appian Way 3D Web Virtual GIS"

In the mid-nineteenth century, the Italian architect Luigi Canina was given the task of the restoration of a segment of the ancient Roman road, the Appian Way, just outside Rome. His

restoration of a series of small Roman tombs was ingeniously carried out to solve the fundamental problem of this famous site: the stealing of remnants on the grounds. However, Canina went beyond a mere "cleaning" and reconstruction: he also re-arranged pieces at the site, often incongruously, either on still-extant structures or on newly-built walls, creating an early outdoor museum for visiting pilgrims. Most importantly, Canina documented his entire effort in two exceptional and complementary records: a book with plates showing the tombs before and after the restoration, as well as a hypothetical reconstruction of their original state (Canina, 1853), and a series of notebooks spatially classifying all the pieces on the ground in the mid-nineteenth century (Archivio Canina). These documents provide a rare and precious overlook of the condition of a monument almost half a century ago, as well as a report of which objects have disappeared and where the remaining objects, today preserved at the site or in the National Roman Museum in Rome, were positioned in the days of Canina.

These records demonstrate the importance and value of well-organized visual and data information systems in restoration. In 1997 the Archaeological Superintendence of Rome started a new restoration of the Appian sepulchers, using the same successful match of restoration and information communication firstly adopted by Canina more than a hundred years before. Building on the success of a first foray into digital multimedia archaeological documentation and presentation dated 1999 and realized at the University of Ferrara (Gaiani and Uccelli, ()), an advanced second-generation 3D immersive VR, intended as a visualization and collaborative design tool and as a study aid, as well as desktop system, designed for use over the Internet, is currently under development.

About data acquisition the starting point has been the consideration that the architecture of the Appian Way tombs is composed of 3 distinct parts:

- a general masonry, which we measured with a margin of error of about 2 cm. Texture details were of interest only if the masonry was originally ancient Roman;

- some decorative elements of major interest where dimensional and texture restitution had to be more accurate (about 2 mm);

- a series of mouldings, imitation of the originals housed at National Roman Museum, which didn't require particular accuracy.

Digital photogrammetric technology was chosen in order to have 3D "manipulable" models, built with NURBS type surfaces, high quality texture and metric precision, and few geometrical data for processing simplicity; homogeneous geometry. Starting from NURBS CAD models built in Alias-Wavefront Studio the translation of the original NURBS models of each tomb into a triangulated mesh led to models with over 300,000 polygons, files of 20 to 35 Mb and approximately 100 Mb SGI file format textures.

To have good real-time performance of the whole system (more than 9 tombs) in a client low-end PC without visualization accuracy loss we applied:

- decimation of polygons

- compression of textures.

We obtained final models up to 20 to 30,000 polygons, files of 1 to 3 Mb (in VRML file format) and about 3 Mb of textures in JPEG format.

Finally for what concern the query system over 1500 cards and 500 VRML models have been made accessible from both whole 3D world and database query menu.

7. Future works

In the last days of the 2001 the Archaeological Superintendence of Rome received the first prototype of the application

about the Appian Way Tombs to test the system and to compare with the original version. After short time they decided to use our framework in the new archeological and architectural project of the restoration of the Domus Tiberiana under the Palatin Hill, which is now starting. At the same time the Istituto Centrale del Restauro in Rome (the Italian governmental institute for the restoration, in charge of giving the guidelines and standards for the restoring operation) is benchmarking the system with others developed in the last years (i.e. Akira GIS Server developed by Scuola Normale Superiore in Pisa) to choose a unified institution methodology and software to lead the monuments restoration and documentation in Italy.

Our framework to use virtual worlds generated from real world 3D models as Work Tool for Architectural & Archaeological Restoration on the Web is but the first step toward a representation methodology more consistent with architecture, and based upon 3D visualization instead of textual structure. Among our planned enhancements to the system there are:

- a. increase of the 3D Web VR GIS query capabilities using a descriptor system that can automatically describe shape, scale and color distribution of a large set of 3D files (i.e. the Visual Information Technology Group from the National Research Council of Canada has developed a system that can describe automatically the shape, scale and colour distribution of a large set of two-dimensional and three-dimensional files. The information about each object is written in a descriptor which size ranges from 200 to 600 bytes depending on the complexity of the description. The number of object can easily reach 100,000 objects without compromising the system performances. The system can handle local databases and distributed databases like Internet (Paquet and Rioux 2000);
- b. increase of the geo-referencing capabilities, applying the GeoVRML 1.0 standard. GeoVRML 1.0 (an extension of the VRML 97 standard) allows for the modeling of dynamic 3D geographic data that can be distributed over the Web and interactively visualized using a standard browser configuration (GeoVRML working Group 2000), (Reddy and Iverson and Leclerc 2000., Reddy and Leclerc and Iverson and Bletter 1999);
- c. improvement of SQL queries through integration of a true relational database;
- d. improvement in the interaction between “whole world”, “single objects world” and textual database.

8. Acknowledgments & References

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