VIRTUAL REALITY MODELS FOR THE STRUCTURAL ASSESSMENT OF ARCHITECTURAL HERITAGE BUILDINGS

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ABSTRACT

This paper shows the advantage of using virtual reality models in the structural assessment of architectural heritage buildings. Nowadays there are very powerful numerical methods to obtain the structural behaviour of historical buildings, such as discrete and finite element methods. In addition, the continuous improvement of the computer machines has allowed for creating complex numerical models of entire structures. However, the post-processing and interpretation of the numerical results of these models continue to be a hard task. In this context, virtual reality models are powerful tools to simplify the task of post-processing the numerical results. In this way, the numerical results obtained from a 3D model, analyzed with any numerical method can be exported to a VRML file format used to represent 3D interactive vector graphics, and designed particularly for the World Wide Web system. This property will allow upload the virtual model in a tablet, notebook or any device with a web browser and to navigate through the building to observe stresses, strains, damages or any result obtained with the numerical model.

Keywords: *Internet, Virtual Reality, VRML, Structural Assessment, Numerical Models*

1. RESEARCH AIMS

Nowadays there are very powerful numerical methods to obtain the structural behavior of historical buildings, such as discrete and finite element methods [1,2]. In addition, the continuous improvement of the computer machines has allowed for creating complex numerical models of entire and complex structures, such as the architectural heritage buildings (Fig. 1) [3-5]. However, the post-processing and interpretation of the numerical results of these models continue to be a hard task, due to the large amount of information obtained from the numerical models. In this context, virtual reality models are powerful tools, which can help us to simplify the task of post-processing the numerical results. Therefore, the aim of this paper is to show the advantage at using virtual reality models in the structural assessment of architectural heritage buildings.

2. INTRODUCTION

Virtual reality can be defined as a computer-simulated environment that can simulate physical presence in some place. Virtual reality and especially virtual models have received much attention in the last decade as useful tool in the conservation of the architectural heritage [6-10]. Virtual models have been used in the reconstruction of monuments [6], whether in the case of total physical loss of the monument [7] or in case of recreating a loss human environment [8], or in the case of immersion in a computer generated world [9] or in the case of presenting and monitoring the changes through time [10]. The possibilities seem unlimited.

In general, virtual 3D models are developed so that the users have an interactive experience. For example, Figure 2 shows the virtual model of the medieval monastery of Santa Maria de Salzedas, Portugal [11]. This model is part of a document management system developed by the University of Minho [6]. The aim of this document management system is to have an efficient organization and visualization of the data related to the conservation project of the monastery. Thus, the system allows for the interchange of information between different specialists, to prevent the loss of data through time and to promote technical awareness of a general public. With this model is possible to make a “virtual tour”. Thus, the user can freely explore the building. It is also possible to add hotspots on the virtual model at points of interest with additional information.

In spite of these facts, the usefulness of virtual models is not recognize in the structural engineering field. Thus, this paper proposes to use the capabilities of virtual models to make a "structural assessment tour". This means that having the results of a numerical model obtained with any particular method or computational code will be created a virtual model in which the information of stresses, strains, damages or any result are represented (Fig. 3) [12]. This will allow the users to carry out a tour on the virtual model loaded in a tablet, notebook or any device with a web browser, while performing a tour in the real building. In this way, it will be possible to compare in situ the numerical results with the real state of the structure.

3. VIRTUAL MODELS IN THE STRUCTURAL ANALYSIS

Any structural analysis must involves the next three steps: pre-processing, computing process and post-processing.

Pre-processing is the step where the geometry and any data needed for the description of the structure are defined. For example, structural elements, boundary conditions, mechanical properties of the materials, meshing, among others.

The main problem in this step lies in the generation of a numerical model representative of the real structure. Historical constructions seldom have complex geometries. For this reason, defining the geometry and meshing can be complex tasks. This creates the need for some drawing software, that can help us for its realization, as for example CAD codes. Another useful tool is the photogrammetry which allows to obtain three-dimensional digital models from a set of photographs. Laser scanner is another common tool used to obtain complex shapes [13]. This technology help to reduce the complexity of the pre-processing step.

Nowadays, commercial software for structural analysis is very powerful and allows analyzing very sophisticated and complex structures. The numerical model can be created using the graphical environment of the structural programs or by using the common interfaces incorporated in the software with standard drawing programs (e.g. CAD software). This last allows a considerable saving of time during the pre-processing step.

Analysis or computing processes is the second step. At present, all the numerical methods of analysis are performed by computer codes (commercial or “homemade”). Some of these software are very advanced and sophisticated, allowing to perform different types of structural analysis, as: linear, non-linear, static, dynamic, non-linear geometry effects, etc.

The post-processing is the last step. It is the way to visualize the numerical results through graphics or numerical tables. The last step in the structural analysis is the interpretation of results. For doing this, the most widely used commercial codes (e.g. Sap2000, Ansys, Abaqus) allows a graphical display of stress and strain maps and deformed shapes.

The post-processing step continues to be performed in the graphical environment of the structural software. In general, this graphical environment is just enough to obtain a good interpretation of the numerical results. However, for complex structures and models with some thousands of elements, the native graphical environment seldom becomes heavy and slow to be a good tool for numerical interpretation. These native graphical environments mostly do not allow friendly navigation through the numerical model.

There are some specialized software that works as graphical interface where is possible to make easier and faster the pre- and post-processing steps, as for example the software named GiD [14]. These graphical interfaces allow to import and export numerical models and their results. It includes dynamic view tools, pieces of mesh, 3D models and generating image files in different formats (tiff, jpg, eps, etc.). Unfortunately, all these software have the same handicap of the native graphical environments of structural programs: they are not friendly to navigate easy and freely through the numerical model.

In this way, virtual reality is one of the easier ways to perform a friendly navigation through a numerical model. To obtain a virtual reality model, the numerical model must be exported to a standard file format for representing 3D interactive vector graphics, designed particularly for the World Wide Web. This property allows to upload the virtual model in a tablet, notebook or any device with a web browser and to navigate through the building to observe the stresses, strains, damages or any result obtained with the numerical model.

4 METHODOLOGY TO GENERATE VIRTUAL MODELS

Although these facts, neither of structural software nor graphical environments provide the possibility of generating virtual models with structural results. Thus, in this section a methodology to generate virtual models, valid for any numerical integrating and operating commercial, software is described.

The VRML format (Virtual Reality Modelling Language) is one of the current standards for the distribution of three dimensional models. According to W3C [15], VRML allows to create virtual "worlds" networked via the Internet and hyperlinked with the World Wide Web. Aspects of virtual world display, interaction and internetworking can be specified using VRML without being dependent on special gear like head-mounted devices. This gives the advantage of mobility.

Virtual models reflect the geometry of the structure in the detail as the programmer wants. In our case, the structural model is taken as the basic geometry for the virtual model. In addition, the properties and/or structural results as stress and strain maps are assigned to the model in order to be visualized and to navigate through the model (Fig. 3). In this case, the properties that are wanted to be reflected in the virtual model correspond to the obtained numerical values of any analysis generated by the structural software.

Thus, it is necessary to create an interface which can translate the results of the structural software to a virtual model. In this work, the interface was developed in the scripting language Tcl. The conversion process follows the next steps: reading data, restructuring the data, writing the VRML file, writing an HTML page that contains the virtual model.

The input data is taken directly from the output files produced by the structural software. The first needed information is relative to the position of the vertex (nodes) that compose the numerical model. The second information is the definition of the polygon forms of the model (elements). Here, all the required properties or results associated to each one of the vertexes that form the polygon is read. It is clear that as the result files have a lot of information, the reading process involves only the information of interest for the virtual model.

As the format of the output files of the structural software is different than the required format for the VRML files, it is necessary to reorganize the data read in the previous step.

In this context, one of the most important adjustment involves the data of each node of the structural model. In the structural model, the value in a node will depend on the element attached to that node. In order to avoid some discontinuity in the virtual model, it is recommended to average the node results. In this way, each vertex will have associated only one value, independently of the numbers of polygons connected by the vertex.

The virtual model is developed by the standard language VRML, which has a particular syntax. In this work, the last release 2.0 was used. Actually the X3D format is the enhanced successor to VRML [16]. However, the VRML was used in this paper, because it is a very easy, useful and spread tool for virtual reality, as well as, it is open source.

The virtual world consists of several objects, moreover than the geometry and color maps of the results. It is necessary to define a reference plane where the model will be set, the light in the virtual world and the specifications for the user's points of view.

The last step is to write an HTML page that contains the virtual model. However, this step is not strictly necessary for the correct visualization of the virtual model, because the current web browsers can read the VRML files directly without any problem, by installing a free plug-in. Nevertheless, the creation of a web page, writing in HTML, from the VRML file is highly recommended. Since, in this web page it is possible to add extra information to the virtual model, as the scale of values of the stress or strain maps (Fig. 4), some hotspot to display particular information in a particular point, overlay some draw (e.g. cracks, Fig. 5) or photo of the real structure, among other information. It is clear, that the web page can contain all the extra information as one wants.

Finally, the virtual model can be visualized in a web browser, where the user can navigate through the model. The interface allows to the user to rotate the model, make a zoom, go out or inside, up or down. However, sometimes it is necessary to create a video, where the navigation is shown. Web browsers do not allow to record videos. For this case, the 3D Studio Max is used [17]. This software provides powerful, integrated 3D modelling, animation rendering and compositing tools to create a video of the virtual tour.

Thus, the user can decide to generate a virtual tour showing the areas of interest inside or outside the structure. In this way, it is possible to view and show any part of the structure. The proposed interface has an option to generate videos directly from the VRML file. During the creation of the video, it is also possible to define different types and direction of the illumination that it is wanted to assign to each part of the structure (Fig. 5).

5 EXAMPLE OF APPLICATION

The objectives and characteristics of the application are based on the ICOMOS recommendations for recording monuments (ICOMOS, 1996). Therefore, the application was designed in order to fulfill the main principles proposed by ICOMOS (see Section 2).

In this way, the application, as well as the database, is structured on three main aspects, which will define the way as the information can be accessed: a) Spatial units; b) Level of access; c) Thematic areas. Figure 9 depicts the flux diagram of the application.

6 CONCLUSIONS

The new computational tools available for other fields, as for example for CAD design, virtual reality or 3D modeling, can be incorporated in the structural assessment of architectural heritage buildings. These tools can make easier the interpretation of the numerical models. In this way, the numerical results obtained with a 3D model analyzed with any numerical method and computational code can be exported to a standard file format (VRML) for representing 3D interactive vector graphics, designed particularly for the World Wide Web. This property allows to upload the virtual model in a tablet, notebook or any device with a web browser and to navigate through the building to observe the stresses, strains, damages or any result obtained with the numerical model.

Another advantage is that the virtual model is easier to manage and needs lesser hardware resources than the original numerical model. As well as, the software used to visualize the virtual model is mostly freeware, therefore no expensive licenses are needed as some commercial codes used by the structural model. This also allows to the user to do a physical tour in the building with the virtual model and compare in situ the numerical results with the real state of the structure.

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[18]

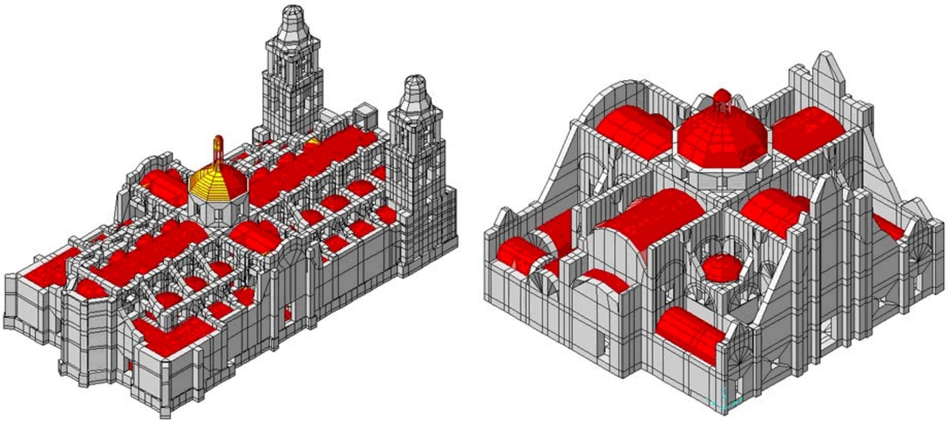
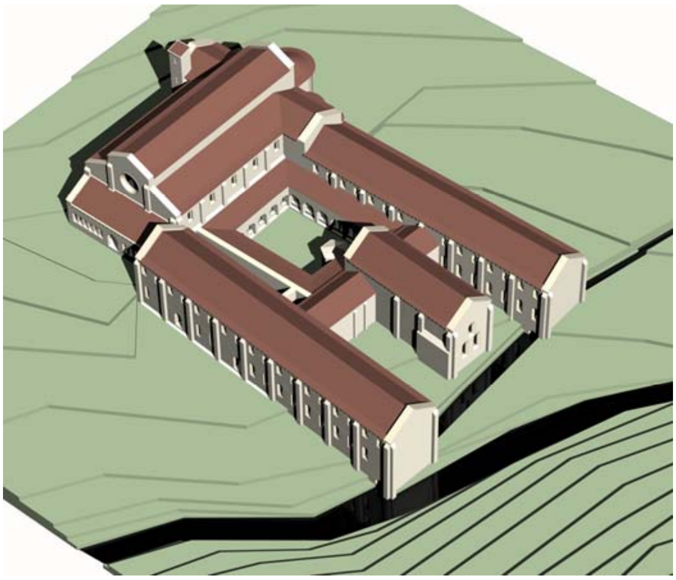
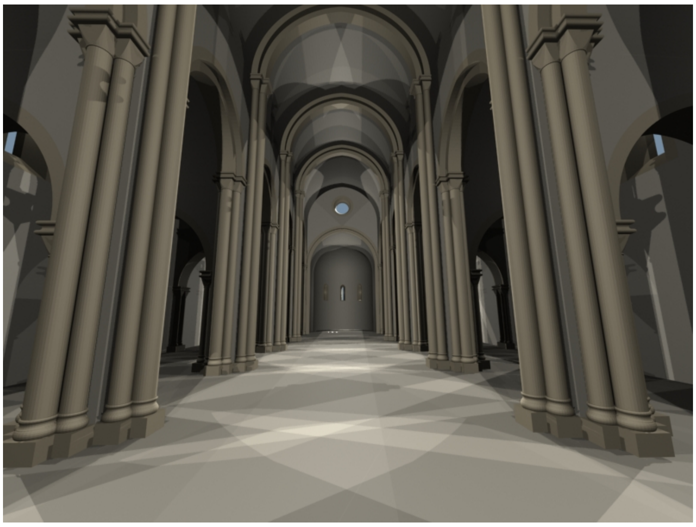


Figure 1. Finite element models of the Cathedral and Sagrario church of Mexico city [3]

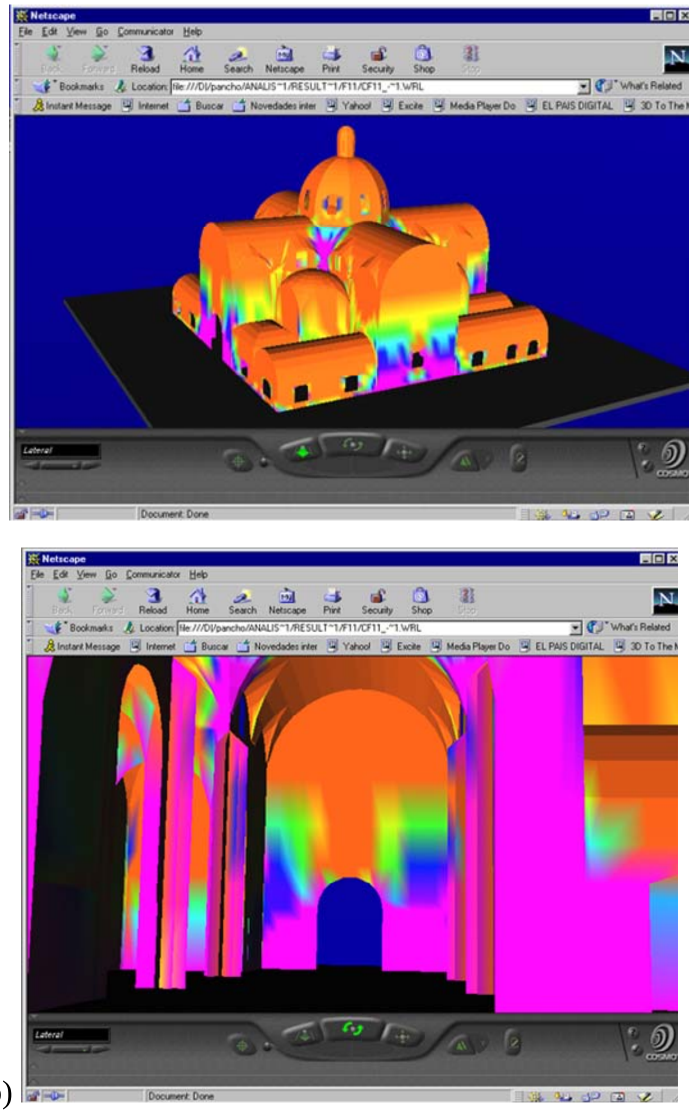


a)



b)

Figure 2. Three-dimensional model of the medieval monastery; a) General view, b) view of the main nave of the church [6].



a)

b)

Figure 3. Example of representation of numerical results (stresses) in a virtual model: a) external view; b) internal view

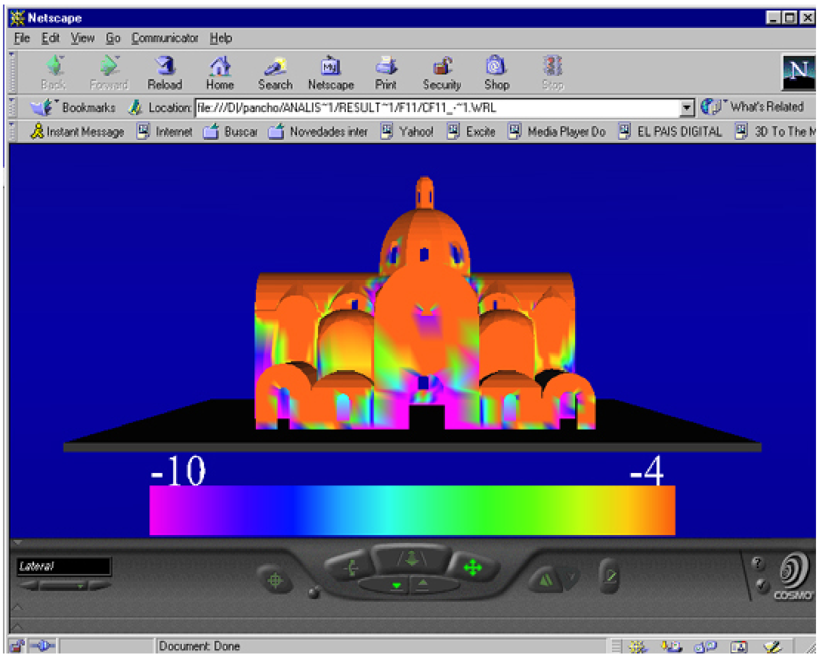


Figure 4. Virtual model displaying extra information (scale of stress map)

a)
b)

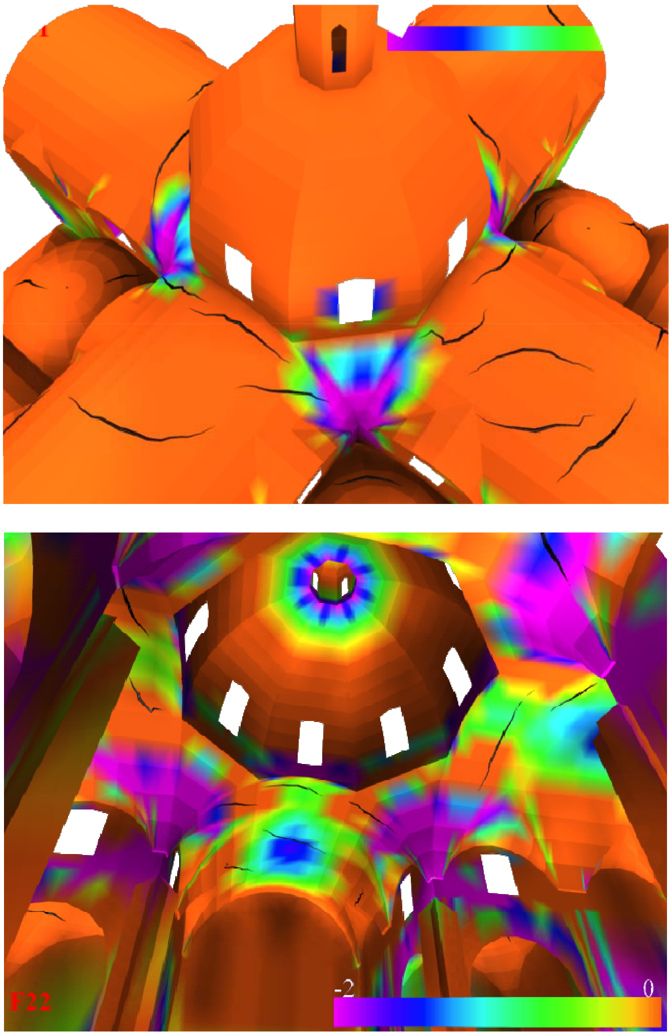
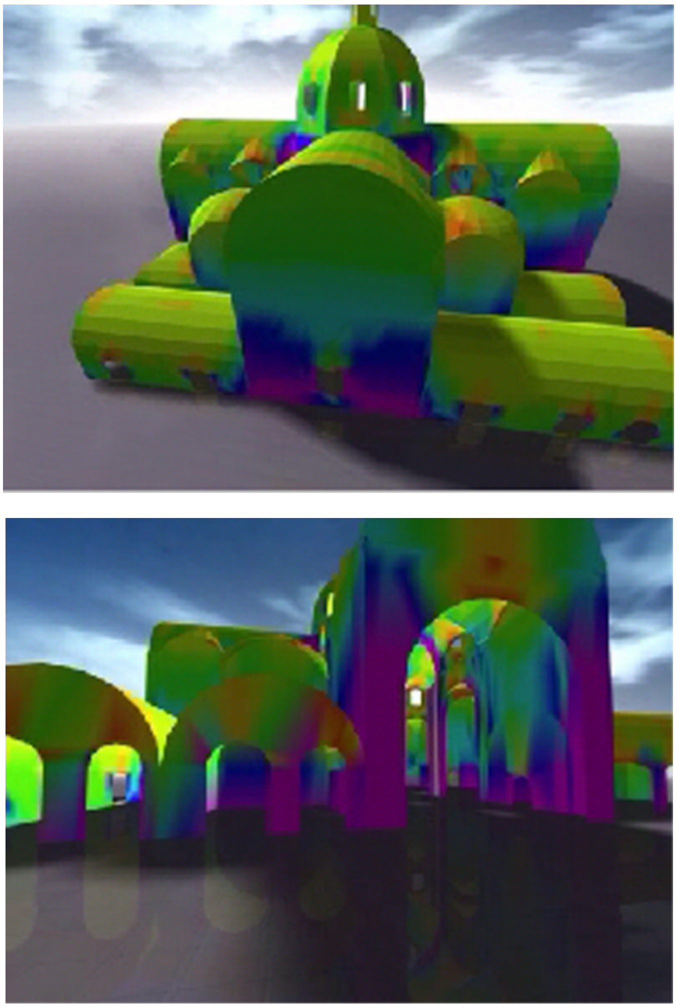


Figure 5. Virtual model with stress map and real crack pattern (black lines): a) external view; b) inside view



a)

b)

Figure 6. Render of the virtual model: a) external view; b) beginning of the tour