An Interactive Installation for the Architectural Analysis of Space and Form in Historical Buildings

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Abstract. This paper describes a methodology for the development of a didactic installation intended to explore the spatial, volumetric and formal relationships that, being present in any architectural work, are basic to understand the compositive and stylistic aspects that define some historical key buildings as paradigms of the history of Architecture. Such an exploration can only be done by providing the user with the ability to inspect the exterior and interior spaces from all angles and distances and perform cross-sections through any meaningful plane.

One of the main challenges of that kind of interactive visualization resides in the geometrical complexity that is present in many historical examples, especially if there is a certain level of detail involved. The use of forms of illumination that reproduce indirect lighting and diffuse reflection, which are needed to properly simulate many interior lighting conditions also increments the difficulty to achieve a fluent simulation. Hence, one of the issues to solve is that of applying a methodology intended to maximize the efficiency of the model in terms of rendering computational cost.

The authors chose the Cathedral of Santiago de Compostela as a case of application. The temple was modeled with a high level of geometrical detail and lit using global illumination, creating a model valid for real-time presentation in order to be examined, explored and manipulated using natural interaction.

Keywords: Real-time architectural visualization, Multitactile interaction, Natural Interfaces, Cross-section, Cathedral of Santiago, Radiosity.

1 Introduction

The techniques used in architectural visualization have always been linked to the historical, technical and cultural moment in which they develop. The great paradigm shift in the techniques of architectural representation which took place in the late eighties was enabled by the development of Computer Aided Design. The development of these new systems allowed an evolution from the classical representation modes based in plans, elevations and cross-sections, perspectives and physical models to a new, more complete, three dimensional form existing in virtual space which can provide almost unlimited views of a design.

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There is little doubt of the excellent visual quality of renderings and animations which can be achieved from a three dimensional model of a building. Rendering algorithms allow the modeler to attain a level of hyperrealism so that the digital image can be indistinguishable from the real.

In recent years, many experiences can be found that make use of visualization software such as Lumión [1], WorldViz [2] and videogame engines such as UDK [3 4, 5, and 6], Unity [7, 8] o CryEngine [9, 10] which provide with high visual quality and the capability of making architectural walkthroughs in the interior space of a building.

On the other hand, several authors have worked on navigation and camera control using multitouch interaction for three-dimensional user interfaces [11, 12, 13, and 14]

Additionally, there are several examples of software that permits users to make single cross-sections interactively on 3D models, such as Sketchup [15, 16] or Constructor SDK [17, 18] inside a CAD editor.

This paper presents a combination of the aforementioned features, in an application suitable to perform the spatial, volumetric, and sectional analysis of any building. Being especially suitable for complex historical buildings such as the case presented of the Cathedral of Santiago de Compostela by means of a natural interaction scheme implemented on a multitouch device that makes use of common gestures to interactively manipulate, examine and cross-section the model.

The analysis of the architectural form is a process that surpasses the simple contemplation of the building since it involves semantic factors which define the composition of the built object. Mass, space and function blend together materializing constructive elements which have relations that have to be understood to obtain an adequate interpretation of the building.

In all times, Architecture has searched for formal solutions that could satisfy the formal requirements of the building, adhering to the structural and constructive limitations of the techniques of its time by means of invention and design. The form of the building and its components then emerge from a mix of the techniques and aesthetics of a precise historical and cultural moment which defines a style.

The Cathedral of Santiago de Compostela constitutes a good example of the concurrence of stylistic features from different epochs living together. The initial Romanesque layout, frequently used as a paradigm to describe the characteristics of this style, was modified throughout the centuries with multiple additions and refurbishments. Those changes transformed parts and added new elements, sometimes in a subtle manner but sometimes in a spectacular way, like in the case of the façade of Obradoiro, designed by architect Casas y Novoa in mid-18th century.

The making of a digital model of a building intended to permit and interactive examination for such a formal analysis requires consequently the recreation of each and every constituent element with a level of detail adequate to a correct and complete visual description.

It is well known that the creation of a digital model for real time interactive visualization needs to fulfill very hard requisites in the making of the model in order to obtain a highly efficient geometry in terms of visual information versus rendering time. In this sense, the presence of geometry very profuse of elements to be represented constitutes a major obstacle for computational efficiency. This is especially true if the model has to display computer costly visual features that are considered important such as projected shadows and diffuse illumination

The following lines will explain the criteria and methodology used in this case.

2 Objectives

The main goal of this work is to obtain a methodology to develop virtual models of complex historical buildings for their architectural analysis using natural interaction techniques. Such models should fulfill the following requirements:

- The model should be manipulated by means of rotation, zoom to any of its elements, and interactive cross-section through any horizontal, transverse or longitudinal plane.
- The virtual reconstruction should reflect faithfully the geometry of the building in its architectonical aspects to preserve the formal accuracy. Simplifications should be avoided in all constructive elements and the use of techniques of emulation of geometry with the use of textures would not be permitted. Only sculptural elements should be allowed to be substituted by a simpler equivalent.
- Visual quality should be high enough to guarantee the presence of cast shadows and diffuse lighting effects.
- The model could be handled using natural interaction criteria.
- Only architectural shapes would be reproduced. Non-architectural elements such as sculptures, furniture, etc. could be simplified or discarded. The reconstruction would be limited to the main temple, excluding the museum, crypt, and the side chapel of Corticela.

3 Methodology

3.1 Project Design

The fulfillment of the aforementioned objectives imposed strong restrictions to obtain a highly efficient model, in spite of its geometrical complexity, that could be interactively manipulated using a common personal computer.

Global illumination was a necessary requisite to visualize adequately both the nuances of the volumes in shadow areas and the diffuse illumination of the interior. As of today, the calculation of global illumination in real time is something out of the capacities of the common computers. Although there are interesting works [19] in this direction, the characteristics of this case made necessary to utilize an approach based on the pre- calculation of the illumination. Current technologies implement this approach assigning a light map to each of the model's surfaces. However, the expected complexity of the model did not permit a solution of this kind due to the high number of texture files needed and the amount of memory required to host them within an acceptable resolution range.

Nevertheless, the high level of polygonalization of the model is just a concept affine to one of the algorithms used to calculate global illumination: the progressive refinement radiosity. This approach, although is not frequently used today in standard visualization software, permits to obtain and store illumination data in the vertices of a secondary mesh which is associated to the model, called energetic mesh. The calculation and further use of distinct energetic meshes on the interior and the exterior would allow combining two very dissimilar lighting states which correspond to the interior, lit with artificial light and the exterior, lit with solar light.

In order to permit the inspection of the spatial structure of the temple and the relations between inner and outer spaces, the application incorporates an interactive cross-sectioning system along three orthogonal axis, allowing the user to obtain any combination of longitudinal, transversal or horizontal section. This system coordinates with a natural interaction model based in the zoom, pan and rotate actions that can be found today in many multitouch device applications.

3.2 Documentation

The information needed to build the digital model was extracted from existing publications related to the planimetry of the temple [20, 21, 22], together with high resolution photographic documentation made specifically for this project. The final application also includes a mechanism to access those images.

3.3 Modelling

The model was made using AutoCAD, praying special attention in the architectural formal syntax for the creation of all of its elements, and attending to the stylistic rules of generation of every shape, that is, considering a column for instance, as the sum of base, shaft and capital, not as the simple replica of a solid volume of given dimensions. This approach permitted the generation of many reusable elements and the enhancement of the regularity, modulation and canonic appearance of the temple.

3.4 Illumination

The calculation of the global illumination was made using Lightscape, a software capable to generate a radiosity energetic mesh where every vertex stores an illumination value. The calculation used the progressive refinement radiosity approach, that is, the subdivision of each and every surface in smaller parts. The quantity of subdivisions is based on the gradient of illumination along the surface. Here is where the complexity of the model played favorably for the calculation, since the presence of the myriad of small elements that constitute every part of the model permitted that, in most cases, the surface subdivision could be very small or null.

The final radiosity mesh finally contained 3.8 million polygons for the exterior model and 2.1 million polygons for the interior, resulting a subdivision ratio with respect to the original meshes of 4.7 and 8.0. That is a result well under the common ratios which result from the application of this technique. Thus, similar visual results are obtained with significantly less computational cost.

Fig. 1. External view: main façade

Fig. 2. External view: Northwest façade

By means of this method, the illumination obtained displays adequately the diffuse reflection of light, both in the interior and in the shadow areas of the exterior. The contour of the shape of the cast shadows is also shown correctly.

Radiosity meshes were imported in 3DS Max and processed to be exported in OSG format using the corresponding plug-in after the application of LSColor, LSMesh and VertexColor modifiers.

3.5 Interactive Application

3.5.1 Engine

The model of the cathedral can be examined using an application developed ad hoc. Real-time rendering is done by means of Open Scene Graph graphic engine [23], based on the OpenGL standard.

Since the radiosity mesh stores the illumination in all of its vertices, there is no need of further lighting calculation during the real-time rendering. Hence, standard lighting can be deactivated with an enormous saving in rendering time, critical for the real-time visualization of a model of this complexity.

Colors among vertices are calculated by bilinear interpolation of the vertices values using Gouraud shading [24], hence avoiding abrupt illumination changes which could produce visual artifacts.

3.5.2 Cross-Section Planes

The cross section effect is done by using two planes in every axis which divide the space of the scene discarding the geometry located in the direction of one of its normal vectors

Since all surfaces in the models are polygons without any topological relation among them, it is extremely complex to obtain the surface of the cross section of the building through a given plane in real time. Instead of calculating this cross section,

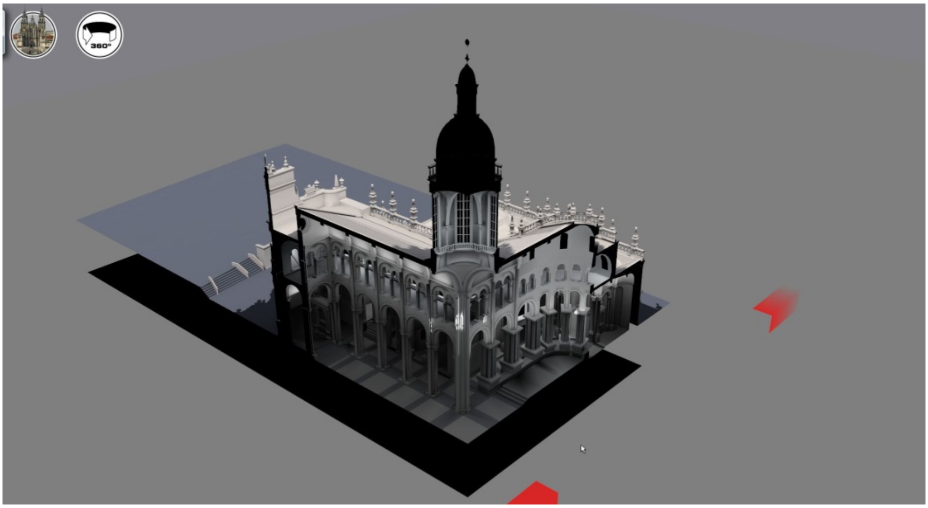

Fig. 3. Combined longitudinal and transversal cross sections with interactor axes in green

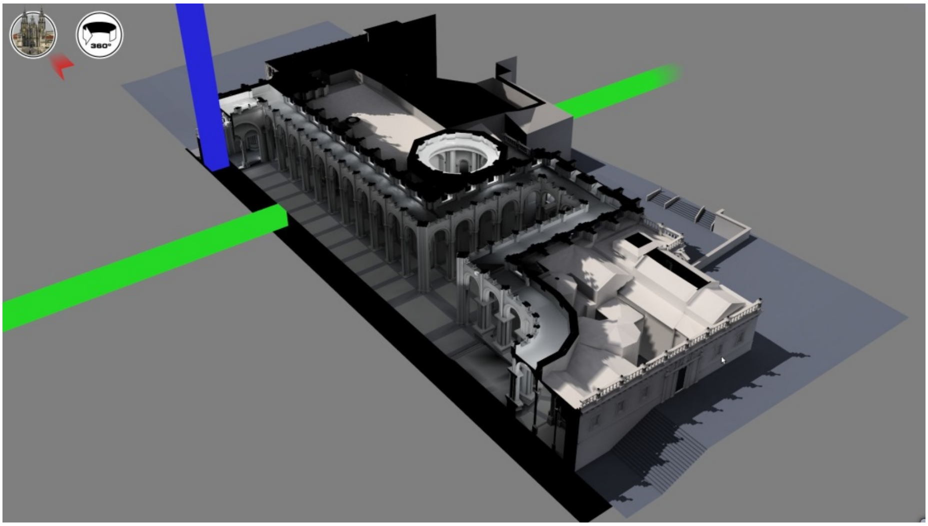

Fig. 4. Combined horizontal and longitudinal sections and interactor axes

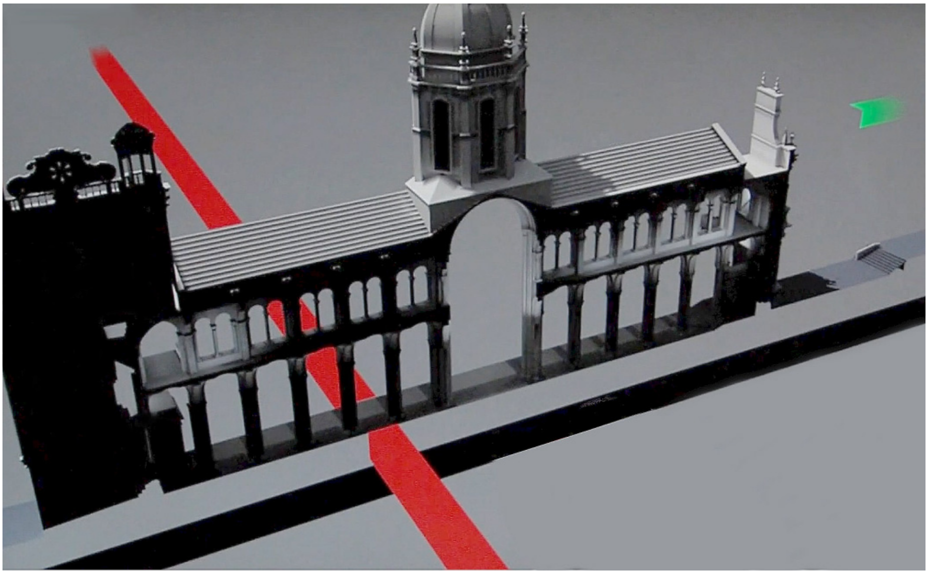

Fig. 5. Double plane transversal cross-section

we used a much simpler approach consisting in applying a flat black color to every visible backface of a polygon. This way, the space between the interior and the exterior models becomes black revealing the shape of cross-section through the desired plane very clearly.

3.5.3 Movement

Architectural visualization requires interfaces with which both common and specialist users can examine every view of the model, from a close detail to a general view.

In order to achieve this goal, the application implements multitactile display technology. It allows exploring the building using a gesture tracking paradigm closely related to that used in smartphones and other devices. One touch gesture controls the panning and two touch gestures control zoom-in, zoom-out, view orientation and pitch. User can also define the location of the section planes by sliding his or her finger along the representation of the XYZ axes.

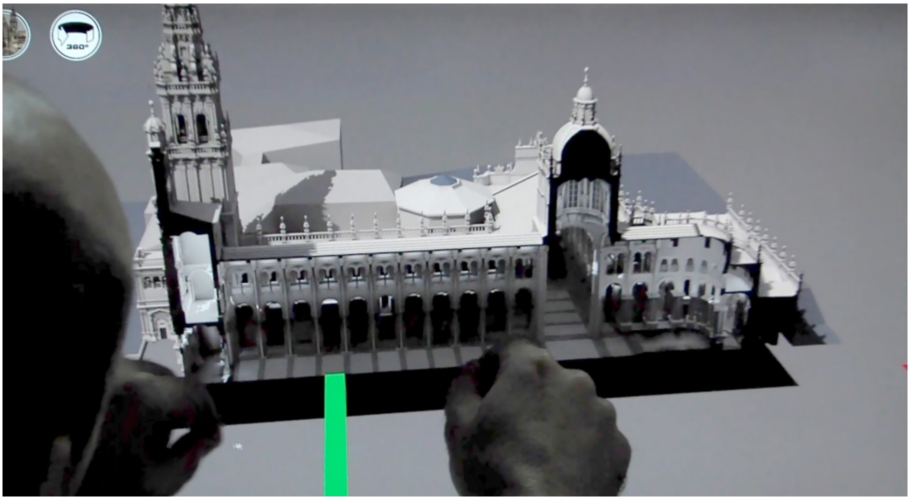

Fig. 6. User interacting with the application using hand-gestures

Fig. 7. Gesture based controls of the application

4 Results

The result of this work was an installation that accomplished all objectives and became part of the *Loci Iacobi* exhibition in Santiago de Compostela.

The resulting model is adequate for the architectural formal analysis both for the non-expert user, who could be only interested in general aspects of the architecture of the cathedral, and for the expert and the specialist, who can analyze the temple using this formally rigorous virtual model.

This digital model also constitutes another new source of documentation of this Romanesque building, which has been developed and can be reused in those CAD working environments that are commonly utilized in the making of architectural planimetric documentation.

5 Conclusions

This paper investigates the use of progressive refinement radiosity, combined with the use of highly geometrically detailed models. The methodology explained here allows obtaining highly efficient models, which can be used in real time with the realism provided by global illumination.

The application of natural interaction and gesture based criteria; combined with such a representation constitutes a very efficient tool for the inspection, and analysis of historical buildings in a fluent and intuitive way.

The use of these types of tools can be of great support in the study of the history of Architecture, and for the comprehension of architectural compositive concepts since it provides a unique experience in the examination of the building, being especially helpful for the volumetrical, spatial and formal analysis.

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