A SIMULATION SYSTEM FOR ARCHITECTURAL PROJECTS

Christine Chevrier, Didier Bur, Jean-Pierre Perrin
Centre de Recherche en Architecture et Ingenierie
CRAI - UMR MAP 694 (CNRS)
Ecole d'Architecture de Nancy
Nancy 54000 France

ABSTRACT

Within the research context relating to the modeling process of architectural buildings and landscape planning, the CRAI particularly works on the simulation of day-light and artificial illumination. The purpose of this research is to develop a software platform dedicated to project design, since there are no overall tools integrating all the answers to our needs. Our concern with the illumination simulation or built spaces leads us to deal with large databases and to take great care of the accuracy of the results. Finally the communication of these results requires several types of output, including an illuminated 3D model. We developed our own modules: 3D reconstruction, converters, geometrical simplification, project lighting design, photometrical tests, animation pre-computation, augmented reality, image computation. We explain the successive steps of the simulation process with the help of an example.

INTRODUCTION

Context:

One of the two research topics of our laboratory is devoted to computer graphics tools and their applications to the architectural heritage. Several sub-topics are investigated, among them rough 3D reconstruction, augmented reality, accurate geometric modeling and building simulation. The software platform presented in this paper is the result of our works undertaken in this domain: it aims at providing a complete tool for simulation, taking architecture as a field of application.

Objectives:

Difficulties encountered by lighting project designers in imagining, formalizing and communicating their concepts are due to the ineffectiveness of the traditional media. Technical plans, sketches and illustrations represent only a part of the character and characteristics of their lighting project, for themselves as well as for the jury of a contest.

Urban planners usually use scale-models and plans to study town transformations and extensions. Their studies are exposed in 2D documents. With the use of 3D tools they should get another thought medium as well as new communication possibilities. Our purpose is to provide a set of tools to the designer, helping him firstly to conceive his project, thanks to the real-time vizualisation, secondly offering various output media: computer generated images, real-time fly-through in the illuminated 3D model.

Why ?

The original idea of such a system was initialy based on two observations: commercial software hardly ever models correctly light behaviour. Furthermore it cannot deal with complex geometrical models, lightened by dozens or hundreds of light sources. Their functions are often limited and their methodology is hardly compatible with the designer's way of working.

Overview of this paper:

The two following parts present the usefulness of our system (part 2) and the interest of such a system (part 3). Next the main modules of the platform are exposed (part 4). With a recent and concrete example, the particularities of a simulation project are introduced in part 5. This example is re-used to explain the progress of a project, including results (part 6). Finally part 7 concludes and exposes future works.

USEFULNESS OF OUR SIMULATION SYSTEM

Goal:

The need of such a system appeared several years ago when "Electricité de France[1]" showed its intention to modernize and enhance the way lighting designers present their projects. It was a matter of assisting decision-makers to better understand the lighting projects with the help of computer-generated images.
Beyond this first objective, the idea of an implementation of a more conception-oriented software appeared to be essential to complete the first simulation tool. Another part of the system aims at quickly reconstructing 3D existing environments. Such simple models are useful for handling interactions between real and virtual worlds in an augmented reality context. Another use is for virtual walkthroughs in real environments to study town planning and existing heritage.

Who can use this system ?

Rough 3D reconstructed models are useful for urban designers when they do not need an accurate 3D reconstruction (town planning, sunshine and aerodynamics simulation for 3D urban-planning documents [PEN91]…). Initially intended to be used by researchers, this platform is directed to any person wishing to simulate luminous environments, by day or night, and applies to any architectural or urban environment, internal or external. Thus the architect and the urban planner, the lighting project designer, the civil-engineer, can use this software to easily adjust their projects.

INTERESTS

Our needs:

In the architectural field, we often have to deal with very large geometrical databases. For example, the data for the Louvre Museum in Paris is composed of more than 400,000 polygonal surfaces. Furthermore we need accurate simulation for the illumination computation (luminous exchanges between surfaces) in order to appreciate the visual impact of the project before its realization. For the visualization of the results, we are often asked for images, sequences of images that can be inserted in photographs or movies (in an augmented reality context) or 3D illuminated model for real time walkthrough. A specialized software is thus not convenient enough and we need a multi-purpose platform to answer all these applications.

Existing systems:

Some products exist to answer the problem of illumination computation. However none of them corresponds exactly to our needs. Main commercial software programs are Maya and Lightscape. Maya computes images with the ray casting method [WHI80]. This is a very costly viewpoint dependent simulation when lots of images are required. In addition it can not provide a 3D illuminated model. Furthermore illumination computation is approximative (computation is not based on an accurate model of the real phenomemon) and uses rough models of light sources and materials.
On the other hand, Lightscape uses the radiosity method [LIG98] [GOR84] for the computation of the luminous exchanges. This means the simulation is viewpoint independent, allowing quick computation of images and walkthrough in the 3D illuminated model. Models of materials and lightsources are accurate though the simulation computations are rough. Unfortunately this software can not deal with large databases: some tests were made with parts of the Quito cloister.

Among other software, Lumen Micro and Photopia (by Lighting Tech.) can be used only to design lighting devices or with small data-bases. Helios (by Ledalite) uses its own format and the Ledalite company's lamps for the simulations.
In the academic domain, there are also lots of prototypes. For instance, Radiance is a public domain radiosity-based renderer, but not very user-friendly and for instance, a light color is described as a simple RGB value. MultiGen (UCLA) [LIG95] is a 3D reconstruction system but cannot generate as much details as we need.

Our choices:

Starting from this observation, we were able to make some choices for our own use. We utilize some existing commercial or academic products such as: standard modelers (Autocad, Arc+, Ipsos [MEN99]), Candela (computation of luminous exchanges, see part 4), Quick-time, Mpeg players, Open Inventor viewers.
However, these types of software do not cover all our needs and don't have links between themselves (between their inputs and outputs). We thus have to develop our own software to have an entire platform answering our needs. Our development context is as follows:

- Object oriented language for a better conception (C++)

[1] *Mécénat Technologique et Scientique – Electricite de France 42 rue de Lisbonne 75008 Paris - France*

- Open Inventor library (graphical objects, visualization and handling in real time) [INV95].
- Candela library (developed in C++ based on the Open Inventor library).

MAIN MODULES PRESENTATION

Our system relies on programs modeled from the tasks and steps of the simulation. Each of the three main steps (modeling, simulation and visualization) corresponds to a part of our system (Fig. 1). Each part is independent from the others and communicates only through the scene data; this means data files respecting the Open Inventor file format.

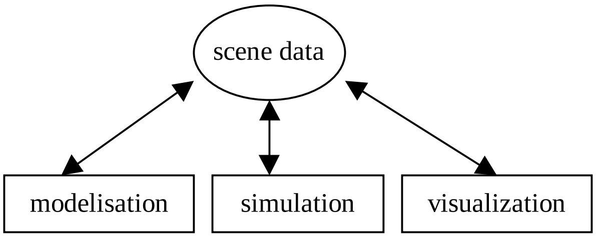

Fig. 1. The different parts of our system

This independence allows easy use of various systems for the following step. For instance, after the simulation we can use either an Open Inventor viewer (ivview), visualize the illuminated scene in a web browser (VRML format) or use our software for the computation of images or movies. Here are the main programs of our system:

Translators

In our case, the three-dimensional geometrical information is a set of polygonal surfaces or simple curved surfaces (spheres, cones, cylinders, or parts of them). These surfaces can be obtained in various ways:

- from architectural plans with commercial modelers using standard file formats such as AutoCAD-DXF or Arc+ GS1 …
- from numerizations with a laser source. We dispose of such a device [MEN99] that allows us to get very accurate models of existing objects (geometrical objects as well as complex statues). The system can provide a model in the dxf format with polygonal surfaces.

Then we have to translate the data file described in an external format into the Open Inventor file format. Some translators exist to translate dxf into Inventor. However, the translation did not correspond exactly to what we expected to (bad organization and translation of extruded polygons and curved objects). We thus developed our own translators. We can also apply treatments to the geometrical data : triangulate polygons, inverse normal vectors, remove trifling surfaces...

Medina

Simplified models of existing objects can be obtained from 2D cadastral plans, or from additional sources of information. For instance the number of storeys in a dxf file format allows us to extrude the polygonal base of buildings. Then from urban regulations and architectural laws for the construction of roofs, we can automatically construct the most appropriate roof for each building [ALL98] (Fig 2).

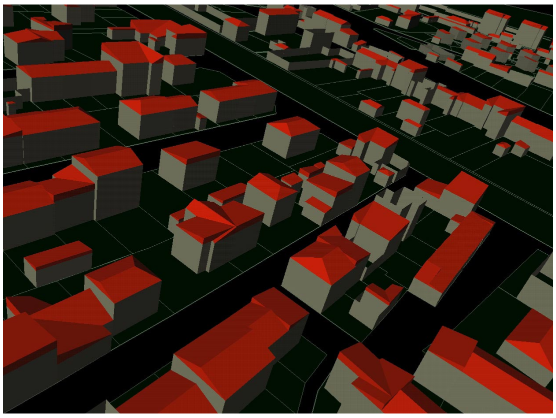

Fig. 2. Automatic 3D reconstruction of a town area.

3Drec

The aim of this program is similar to the previous one except that the 3D reconstruction is interactive. For this, it uses numerized photographs and overlaid 2D cadastral plans displayed from the same point of view as the picture. Simple objects are used : boxes, cones, cylinders, pyramids, spheres, extruded 2D curves.

ModLum[2]

Another important task in a luminous architectural project is the positioning of the light sources in the scene. We found this task very tedious. Most of the time, we put several hundreds of light sources. We wrote values directly in a data file and many tests had to be done to get a satisfying result. We developed a graphical tool which facilitates this task. Thanks to light source networks, repetitive light source placement is greatly simplified (Fig. 3).

[2] This program was developed by E. Viard and L. Martin

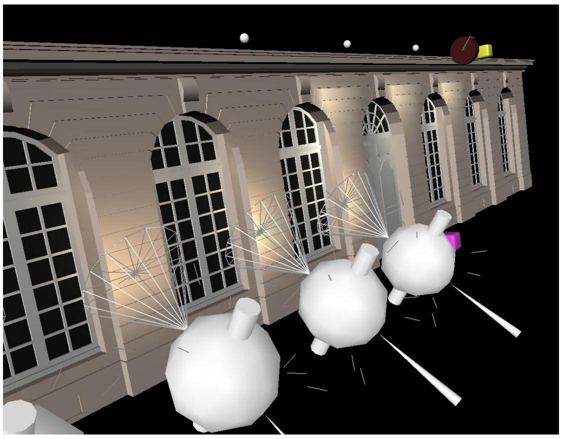

Fig. 3. Light sources positionning with ModLum

LodApp

We have also developed a software [BEL98] adaped to the architectural context and to our needs to generate automatically several levels of detail starting from an accurate unique model (program LodApp). Indeed, the required level of detail depends on the kind of application and on the distance of visualization. A smaller model can be sufficient in some cases and will considerably reduce computation times.

Candela

Candela is a prototype developed by the ISA team[*]. Illumination computation is based on the radiosity method [GOR84] and is therefore viewpoint independent. The meshing is adaptative and the solution is approached with a progressive refinement [MER98]. Candela can deal with very large databases. Various visibility methods can be used according to the expected accuracy versus the computation time. Various mathematical models can be used for the luminous exchange simulation. The closer to the real phenomenon the computation is set to, the longer the computation time will be. A solution can be saved and refined later. A 3D illuminated model can be generated in the Open Inventor file format.

IvTravel[3]

IvTravel is a program that allows the user to define a trajectory into a scene and visualize the result in real time. Commercial products are able to do this and in a more convenient manner. However, none of them can produce a list of camera parameters as an output in order to allow computing images with a higher accuracy with CalImage.

CalImage

CalImage can compute either images or sequences of images, taking Candela illuminated scenes as input, or from non-illuminated standard scenes.

Various kinds of rendering are possible:

- Z-buffer method: very quick rendering by a perspective projection of the scene on the screen,
- 2 pass method: ray-tracing with re-computation of direct light source illumination for better shadows,
- 2 pass method: ray-tracing with computation of secondary reflections (specular and transmitted reflections). These reflections are view dependent and are not simulated with Candela in a view independent manner. This part is in the planning stage.

Various kinds of optical systems were integrated in the program, taken into account for the computation of images with their own characteristics: eye, observer (2 eyes), camera, movie camera, cylindrical, spherical or cubical optical systems.

PROJECT PRESENTATION

We carried out a lot of applications with our system: mpeg sequences, Quicktime VR images and images of two cloisters in Quito (Equator), images of the Monaco palace for the 700th anniversary of the Grimaldi dynasty, images of the visual impact of a new bridge in Nancy, the new school of architecture in Nancy, composed images for the illumination of the great Mosque in Kairouan, etc. We will explain the project progress thanks to this last example.

Distinctive features of this project are principally:

- An illumination project needs a high degree of accuracy in the lighting exchange simulation.
- Objects to encrust already exist in the real scene and are only modified with regard to illumination. We have a geometrical model of these objects and their photographic representation. This makes it easier to determine the viewpoint and the occulting objects.
- In order to appreciate the result of illumination, the pictures needed to be performed at night. As this creates a more difficult camera parameter determination, a compromise was envisaged: pictures were taken at sunset so that we could both see the urban lighting and distinguish relevant elements.

---

[*] *LORIA - Campus Scientifique - BP 239 - 54506 VANDOEUVRE-lès-NANCY Cedex - France*

[3] This program was developed by E. Viard.

Restrictive photometric assumptions were made to render the images:

- The Mosque is assumed to be built with diffuse materials. We assume that we have no specular surfaces.
- The inter-reflections can be neglected between the surfaces of an object if the point of view is far away from the object,
- The influence of the virtual scene on the environment or of a virtual spotlight close to an existing object and vice versa is negligible.

Fig. 4 shows the result of the composition of a computer generated image and photograph for the prayer illumination theme of the Mosque.

Fig. 4. Kairouan Great Mosque illumination.

PROJECT PROGRESS

We shall make clear in this paragraph the progress of a complex simulation. For this we will base our description on our most recent project: the Great Mosque illumination in Kairouan, Tunisia. This technical and scientific sponsorship project was initiated by "Electricité de France".
The Great Mosque is among the four more significant monuments of the Islamic religion and Moslem architecture. For this reason, the simulation before illumination was essential as one of the means of forming around this significant project a consensus of all concerned authorities.

The current illumination of the mosque is limited to the higher building, the minaret, visible from about ten kilometers from the surrounding countryside, as well as the public lighting along the enclosing walls of the court. The new project revalorizes this nightly vision by the illumination of the most important architectural elements of the monument: the dome of the minaret, its facades, the cupolas of the entrances.

A complex simulation requires a succession of mandatory preliminary steps which often take as much time as the simulation itself. In fact, the data preparation needs to be done very strictly, thus avoiding many further problems.

Modeling

The collection of informations (plans and documents of the "Service des Monuments Historiques Tunisiens") as well as a photographic campaign gave us the starting point of the 3D modeling, and of course allowed the lighting designer to elaborate his project. The modeling of such a project consists of the geometrical data creation and the illumination project set up.

- Geometric modeling: the geometrical model is composed of the objects to simulate (called virtual objects) and the existing objects (called real objects) that can influence the virtual ones and vice-versa (the surrounding buildings for instance).

The essential problems to deal with when large data-bases are handled impose the respect of some constraints:

- the hierarchical organization of the geometrical model (for easier automatic simplification for instance),
- the minimization of the number of polygons and the simplicity of their geometry,
- the achievement, with these polygons, of the "skin " of the architectural objects that they represent.

The hierarchical organization of the model, while exploding the building in parts and architectural objects, tends to facilitate all the further tasks: materials and textures settings, partial models handlings, automatic LOD generation, and so on.
The minimization of the number of polygons reduces the computation times. The simplicity of the geometry of the polygons eases their tesselation.
An "ideal" 3D model for the radiosity computation would be the one only made of the envelope of the objects: if this is not the case, a phenomenon called "light escape" occurs due to an erroneous calculation of the radiosity values in points situated "under" or "inside" this envelope.

The geometrical model of the mosque was limited to the two most significant zones of the structure: the North facade and its minaret, the South part with its two cupolas and the interior facade on the courtyard. Each architectural element received a texture, created according to photographic numeric samples, in order to reproduce the visual aspect of the building as faithfully as possible.
Modeled with Arc+ and Autocad software, the geometric model of the mosque is 4 Mb in size

(native format), and 13 Mb once converted to the Open Inventor format. Before the meshing algorithm, the model is made of 41000 polygons.

- Lighting modeling appears in two aspects:

  - the illumination project 3D setup
  - the integration of photometric and spectral data for each light source, as well as for the materials.

The Kairouan lighting project includes many sources that one must position in the 3D model. This positioning and the characterization of each of the light sources are made easier with Modlum: once the geometry has been loaded, it is possible to locate a source near this object or to adjust its position and orientation on a spatial subdivision grid mapped on this object. An approximation of the light source effect on this element is visualized in a specific real-time updated window. The complete set-up of an entire project is thus quick, but only the exact illumination tests will lead to the final tunings.

Besides the ease for positioning the lamps, the interest also lies in the fact that links are created between an architectural object and a light source: if the object (or component) is used elsewhere in the model, then the source that has been linked to it is re-used with the same properties and the same positioning attributes relating to the architectural object.

This module also provides a light source browser and viewer: once loaded, the source can be estimated with its photometric 3D solid and emission spectrum (Fig. 5). The spectrum is displayed as a wavelength histogram; the photometric data is displayed in a 3D interactive viewer. This data set is used for tests in a third window displaying the lamp impact on a uniform white surface.

After positioning lamps in the 3D model, each of them is chosen in a light source library, thus properties concerning spectrum and photometry are assigned to it. The source library has been made up either from measures calculated by the Service d'Eclairage Public d' "Electricité de France" or from data files provided by the lamps manufacturers.

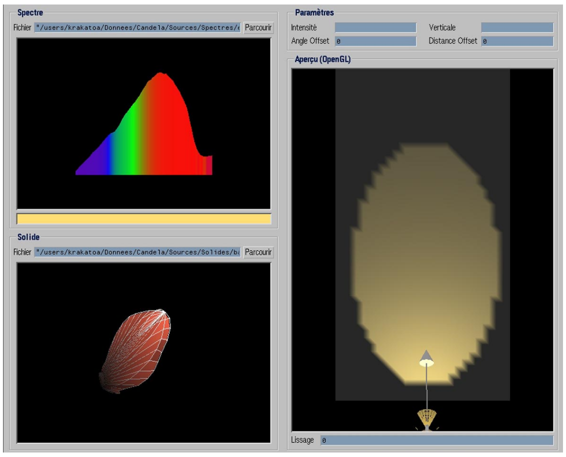

Fig. 5 Light source browser interface.

Development and use of all the modules have been made homogeneous using a standard and unique file format: the 3D model, the lighting project, the source library, the material and texture mapping are all coded with a common Open Inventor description language.

The lighting project of the Great Mosque of Kairouan is dynamic, that's to say that luminous atmospheres may vary from sunset to sunrise just as much as from a season to another. Five illumination themes were established: sunset and sunrise, dim, prayer, Ramadan and celebration. These themes are based on a total of twenty-six electrical circuits composed of 280 light sources of ten various types. The simulation must render these different illuminations. The lighting model hierarchy thus takes up this circuit network, each circuit is represented as a text file describing all the sources in it.
Each lighting theme uses only some of the circuits, and it only takes a call to the corresponding files in the computation script to simulate a particular theme.

Simulation

The next step of the simulation consists in computing luminous effects of the light sources on the architectural elements with Candela. This starts with a command script describing all the actions and all the parameters: which parts of the 3D data-base are used, electrical circuits to light up, geometric and colorimetric accuracy, file saving method, and so on. When testing or adjusting the project, this script permits to select only parts of the hierarchical trees of the 3D data-base and lighting project.

Once each light source has been individually tested, the final computation can be launched with all the surrounding light sources. Obviously it is mandatory

at this stage to load the entire geometric data-base in order not to alter the radiosity results.
Each simulation result (one per lighting theme) was then saved under two Open Inventor formats: a real-time oriented 3D scene and a complete data-base in which radiosity values are stored, allowing a further refinement of the simulation or ray-tracing computations.
A computation for a lighting theme of the mosque required an average of 12 hours on a Silicon Graphics Octane Workstation. A resulting scene was composed of about 6,650,000 illuminated patches (66 Mb Open Iventor file).

Visualization

Despite the large size of the illuminated model, we were able to present it in a real-time viewer to the Tunisian religious and political authorities. This favoured the understanding and the approval of the project.
Lots of images were produced for each theme and from various viewpoints. Some of them were encrusted in photographs. For this we needed a viewpoint reconstruction module (developed by the ISA team). The resulting images (for example see Fig. 4) present the minaret at sunset.

ACKNOWLEDGEMENTS

We would like to thank everyone who took part in this project : E. Viard, S. Belblidia, N. Allani and ISA team.

CONCLUSIONS

With our software we managed to achieve most of our goals. Many architectural and lighting projects have been simulated. Until now the programs have been developed in the Unix environment, but they are planned to be transfered in the PC world, as the Open Inventor library is now available under Windows. The Open Inventor format is close to the VRML format, allowing visualization in a web browser.
Besides this, in order to complete the CalImage module, the specular and transmitted reflections should be taken into account. Future works also include extending the application field to lighting conception and analysis.

REFERENCES

[ALL98] N. Allani-Bouhoula and J.P. Perrin, The Three-dimensional Reconstruction of Urban Fabrics, *Proceedings of the First International Conference on New Information Technologies for Decision Making in Civil Engineering*, Montréal Canada, pages 721-732, Octobre 1998.

[BEL98] S. Belblidia, "Modélisation et visualisation par niveaux de détail de scènes architecturales complexes. ", Thèse de doctorat, Institut National Polytechnique de Lorraine, Nancy, février 1998.

[GOR84] C. M. Goral, K. E. Torrance, D. P. Greenberg and B. Battaile, "Modeling the Interaction of Light Between Diffuse Surfaces, *Computer Graphics 84 (Siggraph'84 proc.)*, H. Christiansen Ed.

[INV95] J. Wernecke, "*The Inventor Mentor: programming object-oriented 3D graphics with Open Inventor*", Addison-Wesley Publishing Compagny

[LIG95] R. S. Ligget and W.H. Jepson, "*Implementing an integrated environment for urban simulation: CAD, visualization and GIS.*", Visual Databases in Architecture, A. Koutamanis Ed., 1995.

[LIG98] http://www.lightscape.com

[MEN99] http://perso.wanadoo.fr/mensi

[MER98] S. Merzouk, "*Architecture logicielle et algorithmes pour la résolution de l'équation de radiance*", Thèse de doctorat. 1998. Institut National Polytechnique de Lorraine.

[PEN91] J.P. Peneau, "Some Problems Relating to the Numerical Simulation of Urban Ambient Environment" in *Environment and Planning B: Planning and Design*, 1991, vol. XVIII, ndeg. 1 p. 107-117.

[WHI80] T. Whitted, "An Improved Illumination Model for Shaded Display", *Communications of the ACM 1980*