

CALBaD

Computer Aided Light Based Design

(CAD basado en el modelado y simulación del transporte de luz)

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Abstract

The project consists of a central body (**illumination simulation**) formed by three main blocks, which is oriented to the design (CAD) of active (luminaries, luminaries' distribution) or passive illumination systems and elements (windows, skylights). The results of the three blocks from this central body will be applied to environments, which will be generated in the **Urban modelling** block, and will take advantage of the techniques developed in the **Interactive visualization** block.

- **Urban modelling.** Generation of complex urban and architectural environments with GPU-based solutions.
- **illumination Simulation.** Usage of the light transport simulation and its interaction with the environment in different ways:
 - **Artificial Illumination.** Creation and development of inverse reflector design software tools.
 - **Natural Illumination.** Development of efficient physically based and evaluation techniques of the natural illumination.
 - **Assisted Illumination.** Development of software tools for illumination design from images of the environment to illuminate, or from definitions of desired illumination.
- **Interactive Visualization.** Design and development of solutions, based on the exploitation of the advantages of modern GPUs, for the treatment of complex illumination systems and for obtaining high quality images.

Keywords: Computer Graphics, Light Transport Simulation, Lighting, Urban Design.

1. Project's Objectives

The scientific and technological objectives proposed for the project were:

1. Interactive (and/or real time) generation of realistic images based on the light simulation transport, for a number of specific cases described in section 4 of the proposal (see section 2 of this report).
2. Exploitation of the GPU potential for high quality image generation including surfaces' details as well as for interactive modeling. This was mainly focused to the chosen cases; but it also was a goal of the project to study the fundamental problems in order to get solutions as generic and extensible as possible.
3. Inverse lighting problems resolution for CAD of luminaries (actives and passives), lighting systems and architecture: Reflectors' design, light transporting pipes design and openings design.
4. Human-Computer Interaction based on the specification of the desired result. This actually is an extension of goal 3 to architectural-lighting design.

2. Work Done and Results

In this section we describe the work done up to now, we present the results and we discuss the deviations from the initial work program.

2.1 Development and results.

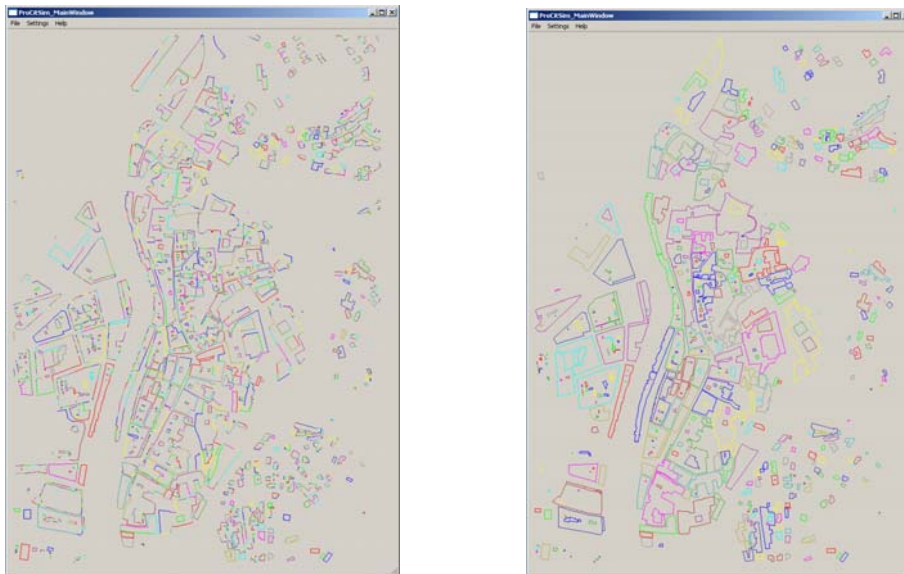
To describe the evolution of the project, we use here the same outline that the one employed in the proposal. In a first stage we studied the main works published in journals and conferences of high relevance, those referenced in the proposal as well as the most recent ones.

Block 1. Urban Modeling

Restructuring of cadastral city data

Our goal has been to create a hierarchic and robust data structure that represents, with the most possible fidelity, a modern city and its blocks of buildings.

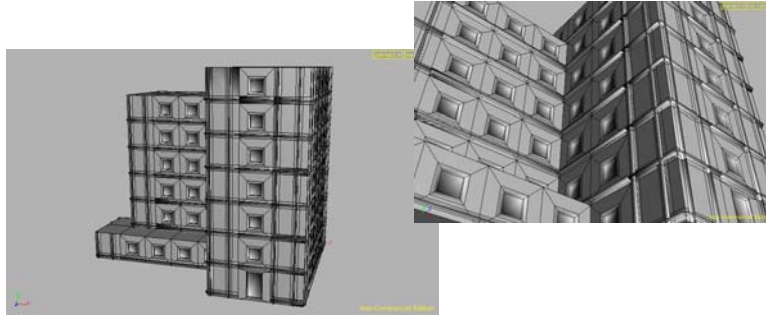
From cadastral data of the city (provided by the local City Council), we process it and correct its errors (frequent mistakes and anomalies) in a uniform way. Consequently, we get structured data able to recognise the blocks and any interesting urban element from this data. This problem is complex because it is necessary to identify not just simple file elements from the input file, but also their connectivity and structure in the real world.



Non structured (left) input data and structured (right) result.

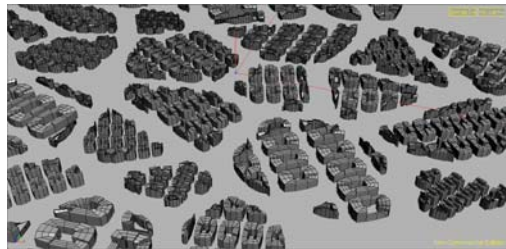
Synthetic Procedural City Modelling

We have done a study of existing solutions for urban landscape modelling. In particular, we have implemented the most effective solutions to date, like, for instance, procedural tools based on rules. We have initially implemented a rule-based building generation system, plus a procedural tool for simulating entire cities.



Initial prototype for procedural building generation
<http://ima.udg.edu/~dagush/projects/skylineEngine/>

Starting from this initial implementation, we have been able to identify the problems and weak points of these techniques, which are enabling us to develop new solutions, more efficient, flexible and user-oriented for urban modelling. In particular, we are currently working on hierarchic urban generation, something which will, in turn, let us employ a precise search system inside the city to localize landmarks and other unique architectural structures, like applying a set of specific rules to create a distinctive urban landmark.



Initial prototype for city generation: we used a pattern-based procedure.

User-Friendly Graph Editing for Procedural Buildings

In this part we propose a simple and elegant interactive visual editing scheme for shape grammars, allowing the creation of rule-bases from scratch without text file editing and in a very user-friendly way [1]. Up to now, there was a disassociation between the rules and their application, resulting in a somewhat unnatural development process. Here we bridge this gap by providing a direct rule-based editing metaphor, which lets artists create new buildings without changing their workflow, in a much more direct and intuitive manner. local controlling operators). This shift also opens the door to a whole series of possibilities, ranging from simple model verifications to full model editing through graph rewriting operations.



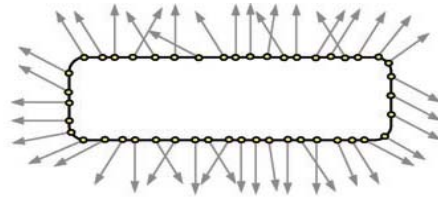
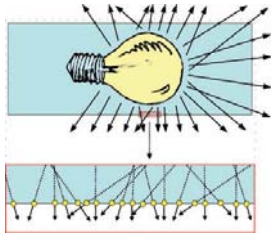
Generation of a variety of buildings (right) from a building template (left)

Block 2. Artificial lighting.

GPU Acceleration techniques for reflector design.

The goal of this block's first task was the use the computing power of the Graphics Processing Units (GPUs) to accelerate the computation of the outgoing lighting distribution of luminaries (reflector + bulb). The goals have been fulfilled and the milestones have been reached:

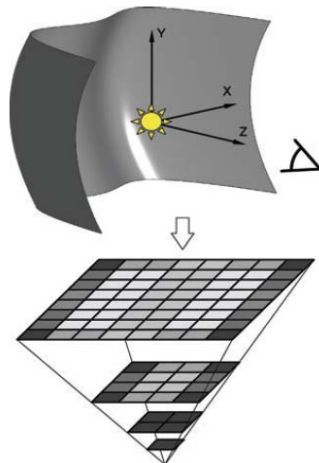
- Implementation of a technique to compute the lighting distribution using near-field light sources.



- Use of the rapid lighting distribution computation technique to guide the optimization process in inverse reflector design.

Both milestones have been accomplished and the results have been published in a international indexed journal [2]. In this paper we present a new technique based in Quad-Tree Relief Mapping to represent the reflector as a mipmap height field (figure bellow) and then trace rays in a efficient way. We have extended the original technique to support multiple reflections and multiple ray orientations. Using this approach the lighting computations per reflector have been reduced to less than 1 second per reflector using 1 million particles to represent the bulb light emission.

Task 2 of this block has their milestones due to the 3rd year. However, since the work has already began,



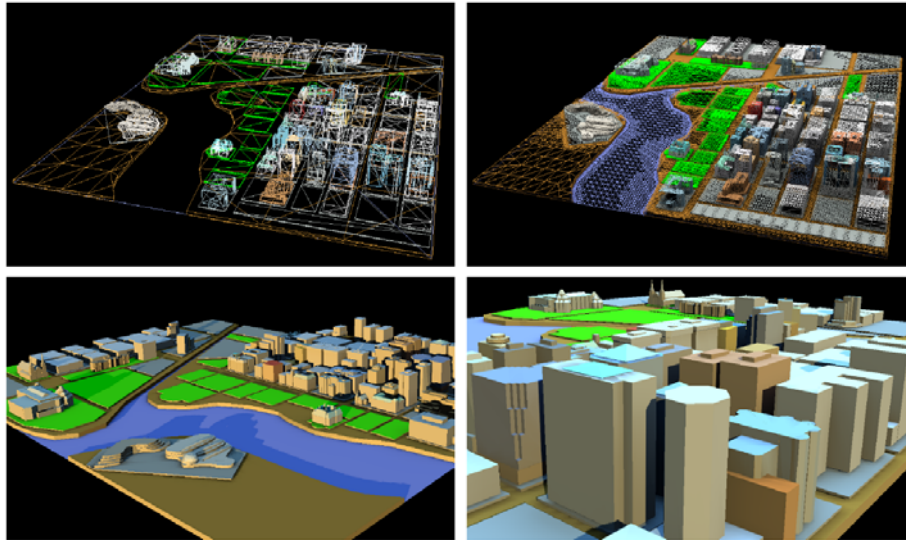
we will to propose a change in its goals due to the results and the experience acquired in Task 1. Despite the acceleration provided by the technique presented in [2], we have realized that there are accuracy problems in certain reflector setups.

Block 3 Daylight

The purpose of this block is the development of advanced simulation of natural lighting to provide tools for analysis and architecture design projects.

Efficient simulation of natural light in generic environments

We developed a new method of interactive simulation that allows direct light to efficiently carry out an adaptive subdivision of the model [3]. The technique is based on the calculation of visibility through parallel projections from a set of directions from the sky, performed by hardware. The method enables interactive lighting visualizations with changing conditions of day and time, and editing the material characteristics of the model.



Results of applying the adaptive subdivision method to a urban model. Input model (8987 triangles, upper left), subdivided model (128309 triangles, top right), displayed with two different natural lighting conditions (bottom)

Simulation though light conductors

We developed a tool to interactively visualize simulation results in light conductors systems under different sunlight date and time conditions. This tool is based on the use of photon mapping techniques and GPU acceleration.

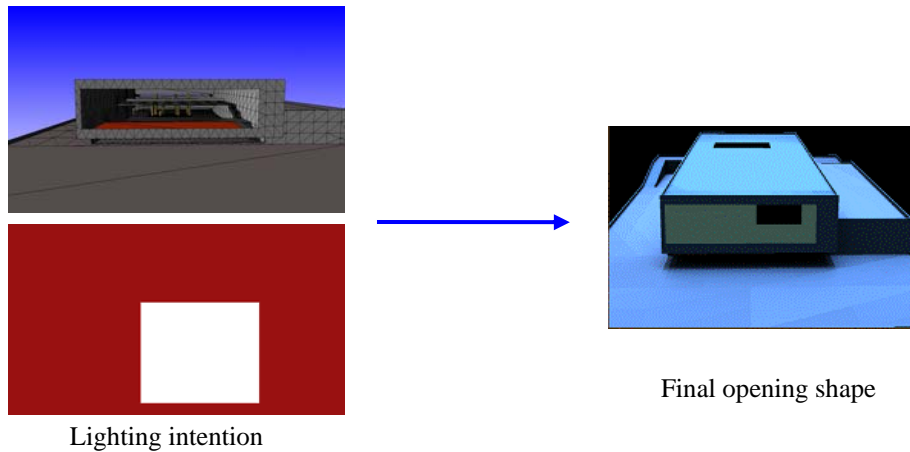
Lighting assessment and analysis

Evaluation and analysis of lighting architectural projects is done from simulations' data results. We have developed the following analysis and visualization tools: Display contour lighting, Calculation of illumination in arbitrary virtual planes, Tone mapping considering perceptual effects and adaptive interactive navigation

Block 4. Assisted Lighting

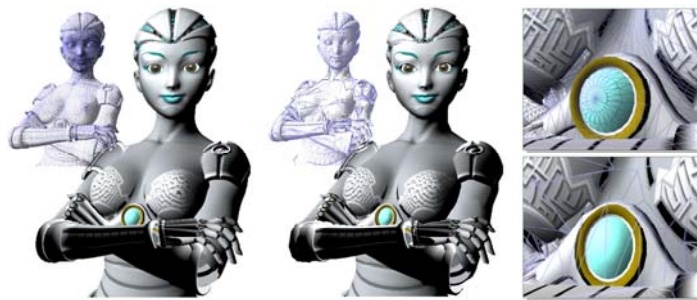
We have developed an inverse daylighting model devoted to the design of building openings. Our objective is to compute opening shape from desired illumination conditions in the early stages of architectural design, using an inverse model [4].

The inverse daylighting model includes sky lighting as well as light reflected by surroundings, and therefore combines near-field and far-field light sources. Input data is a heterogeneous lighting distribution on indoor faces called "lighting intention". Openings are considered as a set of intermediate anisotropic light sources. Therefore the geometric reconstruction problem is seen as a source emittance problem. A pin-hole model generates anisotropic light sources and computes light contribution on each indoor faces. An image metric evaluates the distance between this light contribution and lighting intention. Intermediate light sources which have the smallest distance are selected to be part of opening, and therefore define opening shape. This technique is intended to aid opening design in the early stage of architectural design. Our model is validated from test cases and illustrated by a case study in order to show the opening reconstruction process.



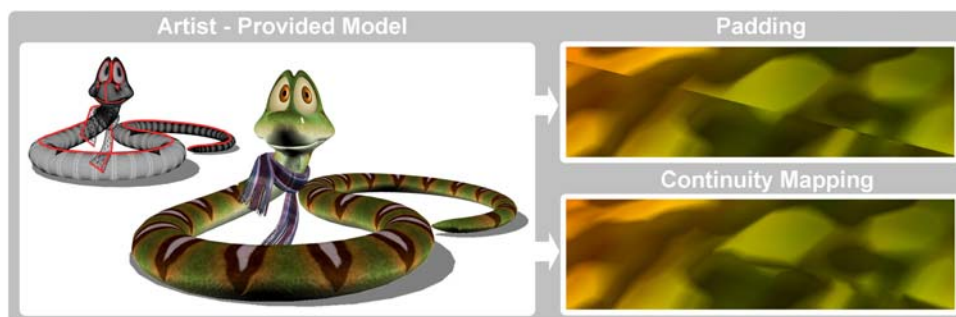
Block 5. Interactive Visualization.

Related to this problem, there is the associated challenge of preserving details from a high resolution reference model onto lower resolution models, where sometimes manual intervention is required to correct texture misplacements. We have developed a technique called “Inverse Geometric Textures” (IGT) [5], which is a parameterization-independent texturing technique that allows preservation of texture details from a high resolution reference model onto lower resolutions, generated with any given simplification method.



IGT example (left and upper inset) onto lower resolution versions of the model (right, lower inset)

On another hand, multi-chart parameterizations introduce seams over meshes, causing serious problems for applications like texture filtering, relief mapping and simulations in the texture domain. We present two techniques (*Continuity Mapping, CM*) that together make any multi-chart parameterization seamless: *Traveler's Map* is used for solving the spatial discontinuities of multi-chart parameterizations in texture



Example of CM application. Comparing the inset on the top (without CM) and the bottom of the figure (With CM).

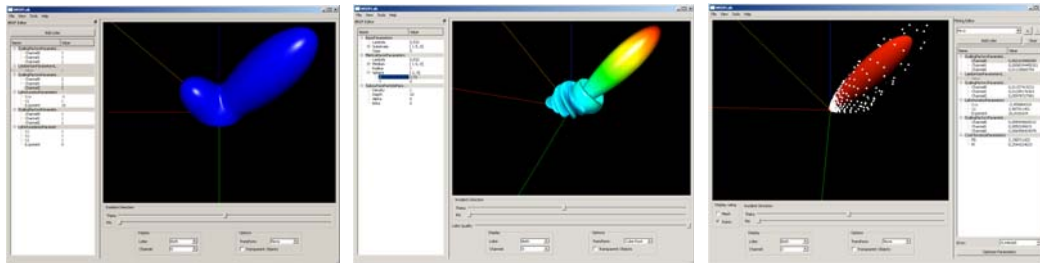
space thanks to a bidirectional mapping between areas outside the charts and the corresponding areas inside; and *Sewing the Seams* addresses the sampling mismatch at chart boundaries using a set of stitching triangles that are not true geometry, but merely evaluated on a per-fragment basis to perform consistent linear interpolation between non-adjacent texel values. *Continuity Mapping* [6] does *not* require any modification of the artist-provided textures or models, it is fully automatic, and achieves continuity with small memory and computational costs.

Finally, we have work on several aspects which are crucial to deal with high quality rendering in many applications including, of course, the one of interest for this project. We have developed several GPU based algorithms:

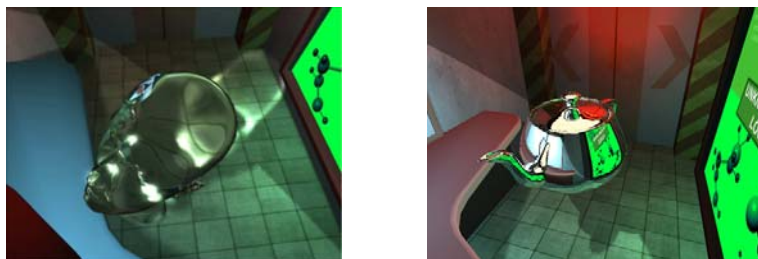
- Rendering path-based 3D surface detail in real-time (groves in the example of the figure bellow. Our method models these features using a vector representation that is efficiently stored in two textures. [7]



- Development of a general system for designing BRDFs. BRDFLab [8] <http://brdflab.sourceforge.net/>



- GPU based reflection and caustic effects solving simultaneously two problems of previous methods: lost of caustic energy and insufficient caustic sampling [9, 10].



2.2 Deviations

There have not been significant deviations in the sense of introducing possible modifications of the global objectives neither in the quantity or quality of the results. Nevertheless some changes have been introduced in the work program due to incidences like the lack of some information and/ the evolution of graphics hardware providing new performances that suggest to change the strategy foreseen in the project's proposal. For example, in the urban modeling we have found that the information provided by city councils includes significant ambiguities and error. So we had to design a technique to clean up this information and make it robust enough. We also had to invest some time to solve unforeseen problems related to the use of GPU. Another important aspect that introduced some additional work is the lack of information on BRDFs and the difficulty of editing/designing them. In any case, we do not foreseen relevant changes in the expected results of the project and we have obtain interesting research and technological results that were not expected.

3. Quantifying results.

- **Reached objectives:** The degree of attainment of the objectives is very close to the foreseen although some non relevant deviations appeared as described in the previous section.
- **Relevance and originality of the results:** We are optimistic given the journals where the results have been published, as well as the interest that several companies have shown for our results.
- **Scientific and technological production:** 10 papers has been produced being some of them been published in high standing journals. Most of them deal with problems of high technological interest.
- **Utility of results and its relationship with the social-economic environment:** We are cooperating with a European company on reflectors design and with a Spanish company interested to use our results on games. We have also been contacted recently by a company interested on the realistic rendering to improve their products.
- **Training:** 2 PhD students will finish in 2010, 1 PhD by the end of 2011 and 4 new students starting their PhD. Several engineering projects and master thesis has been advised.
- **Cooperation with other research groups:** Universitat Politècnica de Catalunya, University of Central Florida, INRIA Nancy, Universidad de Zaragoza, Université de Limoges, University of Bristol are the main ones.
- **Development and management of the project:** The members of the group meet regularly to coordinate the overall and each block is assigned to a responsible researcher who reports in the meetings the advances as well as the eventual topics that require discussion for the projects coordination.

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