APOLUX - AN INNOVATIVE COMPUTER CODE FOR DAYLIGHT DESIGN AND ANALYSIS IN ARCHITECTURE AND URBANISM

Anderson Claro, Fernando Oscar Ruttkay Pereira and Rafael Zanelato Ledo
Universidade Federal de Santa Catarina, Florianópolis-SC, Brazil
www.labcon.ufsc.br
ander@arq.ufsc.br, feco@arq.ufsc.br, rafael@ecthus.com.br

ABSTRACT

APOLUX 1.0 is a computer code specifically developed for assisting the architect regarding daylighting considerations; it runs in a three-dimensional graphic environment, accepts files from graphic editors and uses models physically consistent for data treatment. It was developed aiming its integration to the architect's design praxis.

INTRODUCTION

The program APOLUX 1.0 was developed having as a conceptual reference the innovative Spherical Vectorial Model proposed by CLARO (1998) in his PhD thesis.

It is a program for calculating and analyzing daylighting in architectural spaces (open or closed) that uses three-dimensional files generated in graphic editors in the DXF format (data exchange file) and it was specifically developed for this task, having as a reference the architect's design praxis.(Fig 1)

In this paper the main capabilities of the program as well as a concrete example of its use in a design context development are presented.

CAPABILITIES OF APOLUX

The program uses the three-dimensional potentialities of the current video cards, (Fig. 2)

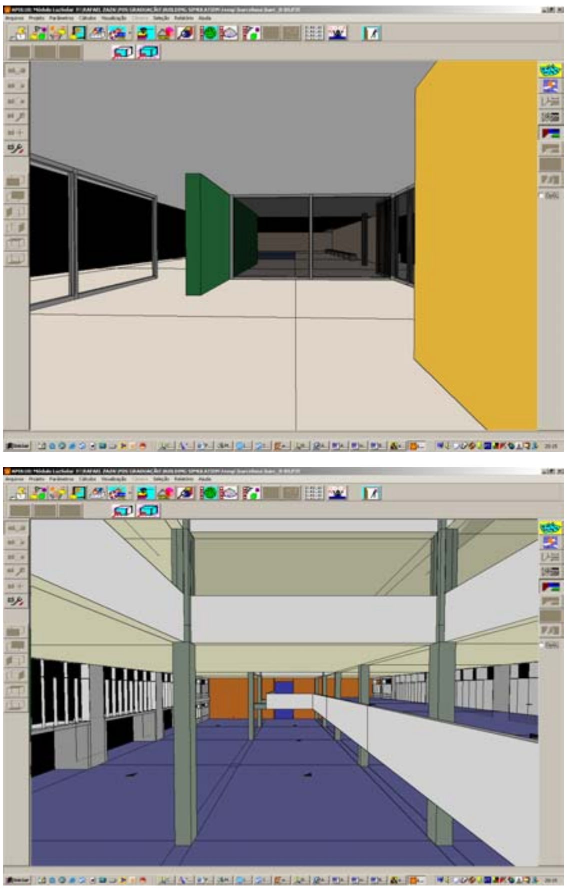

Figure 1: a) Barcelona Pavillion, by Mies Van Der Rohe, modeled in DXF ; b)Building Proposal for Caixa Econômica/SC, modeled in DXF

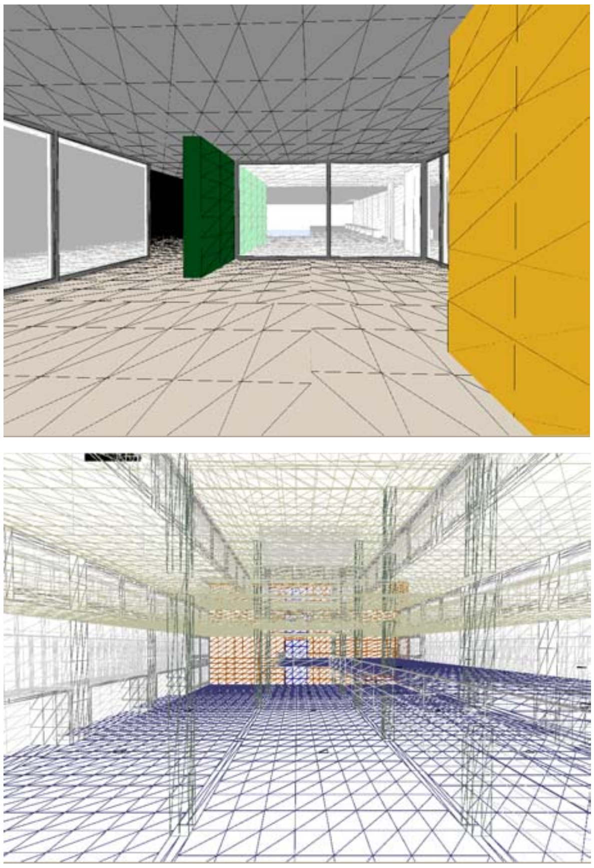

Figure 2: a) Barcelona Pavilion, with 735 plans, fractioned in 12.504 triangles. ; b) Caixa Econômica project, with 3.862 plans, fractioned in 33.228 triangles.

allowing a fast and flexible manipulation of the model in different visualization conditions. Its algorithm for dealing with the physics of light is based on the radiosity method (Goral et al, 1984), representing the surfaces through finite elements divided in small triangular units of area, which are confronted to each other in a full way.

The main calculation involves the determination of the form factors of each triangle in relation to all the others, as well as for all of the visible directions of the sky, according to the modular units of a subdivided globe used as a general system reference, as described by CLARO (1998). Once the calculations are done, the form factors can be used in the determination of different and successive daylighting solutions, under different sky conditions. The properties of the materials can also be modified and the solutions can be recalculated in a very short time, regarding the complexity of this kind of study.

The calculation supports the light energy exchanges that takes place with diffuse opaque surfaces (lambertianas) considering the interference of specularly transmitting surfaces (glazing planes). The program accomplishes the following tasks:

1) Visualization of the luminance distributions of different points of the sky, considering geographical location, air turbidity, meteorological conditions, equation of time, for any day / hour / minute of the year and geographical orientation, with a resolution that varies from 745 to 73.099 positions, according to the equations recommended by CIE for clear sky, sky partially cloudy and cloudy sky. This feature does not depend on the calculation of form factors or the radiosity algorithm(Fig .3).

2) Production of Solar Obstruction Masks for any point of the environment (internal or external), obtained immediately by the coordinates input or by dynamic mouse positioning, with the same resolutions mentioned above. All the opaque surfaces are projected and all of the unobstructed directions are obtained, dependent on the adopted resolution. As the mask does not involve radiosity calculations, high globe resolutions can be used. Besides the projection of the sun path patterns, the luminance distribution of the portions of unobstructed sky are also shown in a colored scale. Through the obstruction masks production, the initial illuminance due to sky and sunlight, besides the direct component of the Daylight Factor and the visible fraction of the sky vault, are given. The possibility of organizing the plans in different levels (groups), that can be activated or not, allows for useful comparative studies of different solutions in a same working environment. (Fig 4)

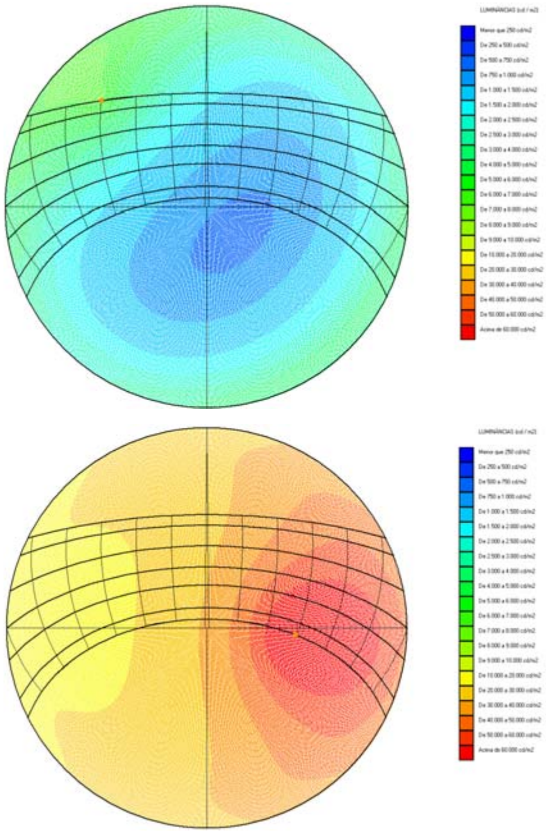

Figure 3: a) Sky luminances in Florianópolis - SC, Summer solstice, 15:00 h, with clean sky, calculated according to 26.335 directions of the hemisphere. ; b)Sky luminances in Florianópolis - SC, Winter solstice, 15:00 h, with partially covered sky.

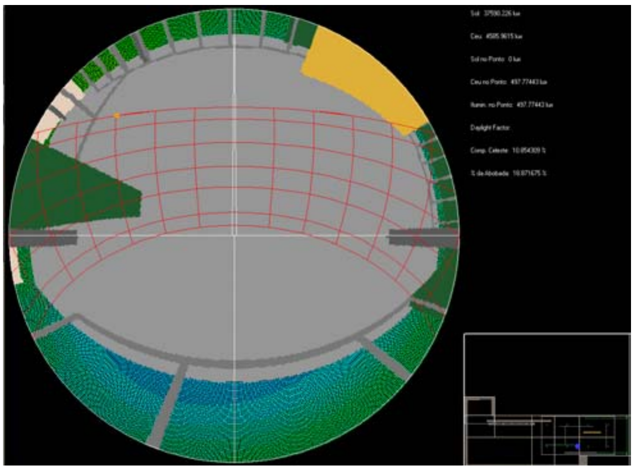

Figure 4a: Inside mask of Barcelona Pavilion, showing the visible sky vault in not masked areas.

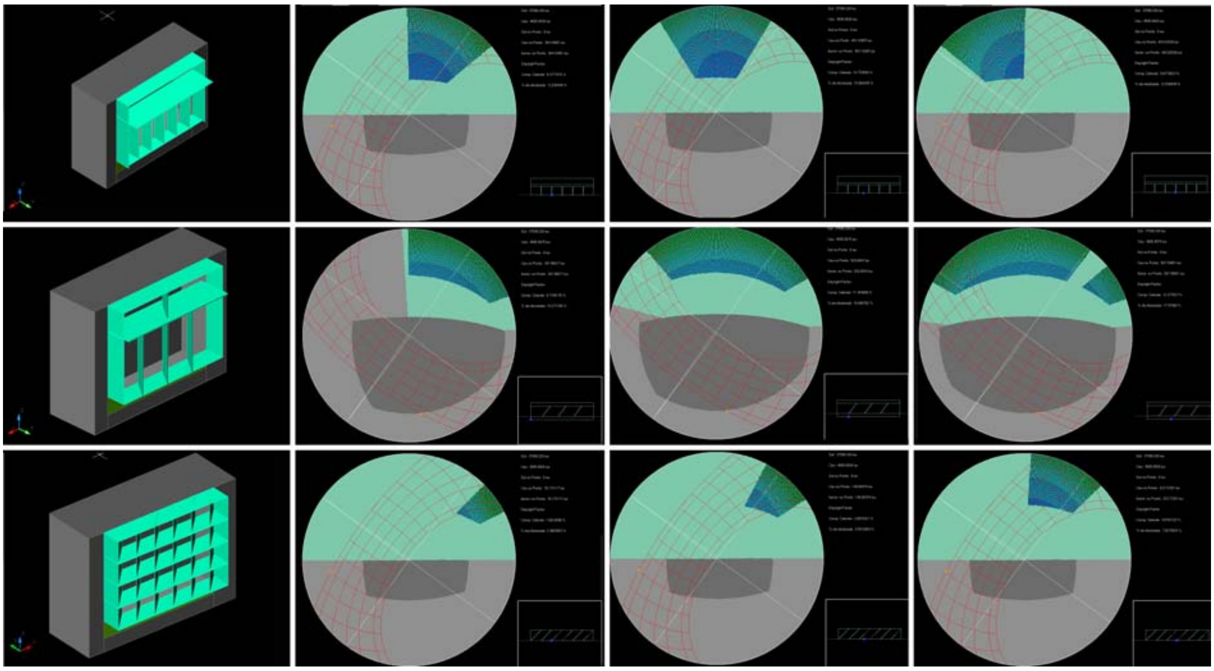

Figure 4b : Parametric study with masks of differents solar protection solutions, Caixa Econômica project

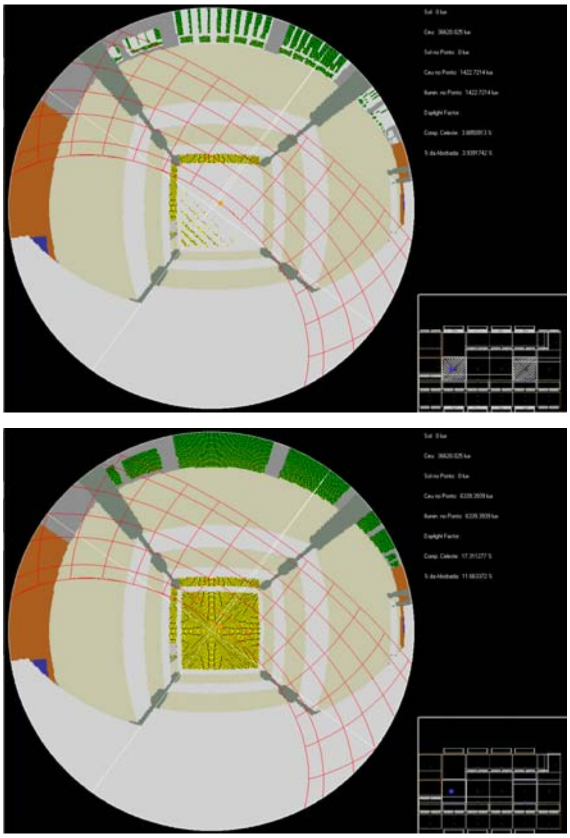

Figure 4: c) Inside mask of Caixa Econômica project, with center well covered by solar protector.
d) Same mask of Caixa Econômica, with center well without protection.

3) Complete calculation of the form factors, through spherical projection, confronting each one of the triangular portions of each surface of the model with all the others. This calculation can be made with several degrees of resolution. Depending on the project, it can be obtained projection units equivalent to a sphere divided into 52.670 solid angles (26.335 for a hemisphere). In this calculation the visible directions of the vault for each one of the triangular portions are determined. The form factors and the directions of the vault are recorded in disk, in order to allow for successive radiosity solutions.

4) Calculation of the illuminance levels: the radiosity equation is applied fully, confronting all surfaces subdivisions against each other. The method of the progressive refinement, as described by (Goral et al, 1984), it is not employed; all the luminous energy exchanges are considered. The method involves the calculation of the initial illuminance produced by the sun and sky, in each triangular patch of each fractional plan, being followed by the calculation of the light exchanges among surfaces in complete cycles, in a number chosen by the user. In this way it is possible to obtain the only initial illuminance due to sky and sunlight, or a more complete solution considering the light exchanges among surfaces. It is also possible to separately calculate the contributions produced by direct sunlight or skylight, in both cases it is possible to find either the initial illuminance or the complete solution. The vault relative parameters can vary, as well as the orientation of the project and the reflectance of opaque surfaces. Therefore, it is possible to obtain successive solutions in a fast way, compensating the extra time for the form factors calculation.

5) Semi-realistic images: The APOLUX program does not aim the production of photographic images, but it allows for the creation of semi-realistic images of good quality, serving as a good assistance in the visual appreciation of different design options. These images complement the graphical and data analysis with a qualitative evaluation of the illuminance distribution for a given spatial solution (Fig 5).

Figure 5: a)Daylighting simulation, Barcelona Pavilion, outside view ; b): Barcelona Pavilion, inside view. ; c) Daylighting simulation, Caixa Econômica project, inside view.

6) Graphs of Illuminance and Luminance: After having calculated a solution, it is possible to visualize images where the surfaces illuminance/luminance distribution are represented through an iso-color map (Fig 6). The program has an equalizer to allow for the control of the numeric limits of each color band, being able to, besides the individual control of each value, the application of different types of mathematical function to adjust the image. The equalizer allows for saving the different configurations, easing comparative studies among different solutions. (Fig 7)

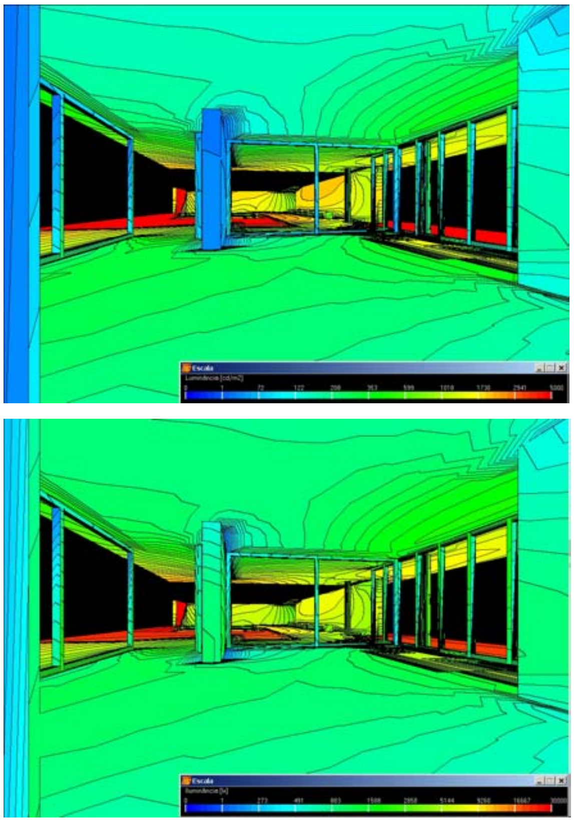

Figure 6: a) Illuminances Graph, Barcelona, inside view. ; b) *Luminances Graph, Barcelona, inside view.*

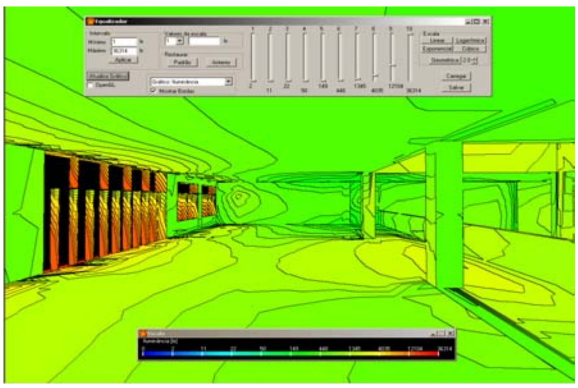

Figure 7: *Screen of APOLUX's Images Equalizer.*

7) Graphics of Daylight Factor: DLF is represented as a rate of the illuminance in a point inside the building to the external illuminance due to the skylight, without considering the direct sunlight. It is calculated in three formulations, as follows: Total format (considering the final illuminance at the point); Direct format (considering only the illuminance produced directly by the skylight); and Contemplated format (considering the illuminance produced by the light reflected from the other surfaces). These resulted are also visualized by colored maps controlled by the equalizer, as in the previous item. (Fig 8)

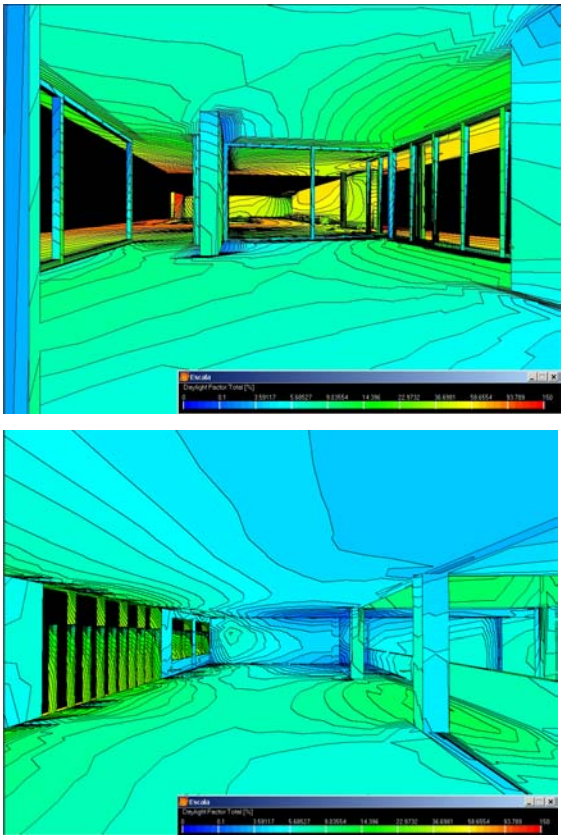

Figure 8: a) Daylight Factor Graph, Barcelona. b) Daylight Factor Graph, Caixa Econômica.

8) Grid of Values: Visualization of the calculated values (illuminance, luminance, and Daylight Factor) in the current image, in selected plans, through a grid defined by the user. The values for each plan can be saved in a text format file, associated to the local coordinates (X,Y) for each of the grid points. It is a very useful feature that eases the interaction with other programs, particularly for the generation of surface graphs (like WinSurfer, p.ex.) or for numeric spreadsheets for subsequent data processing (like Excel, p.ex.). It is also possible to generate a DXF file containing the structure of the triangles patches of each plan, represented by faces, and the calculated values, in text, for each vertex of the triangles, in a fixed reference regarding the design plans, different from the grid points position, which is variable. (Fig 9)

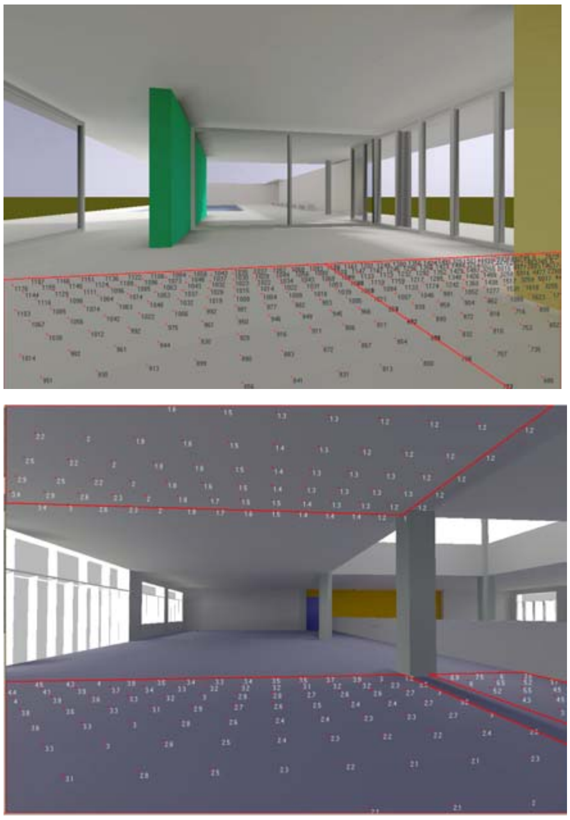

Figure 9 a) Values grid, Barcelona Pavilion. b) Values grid, Caixa Econômica.

9) Photon Vector: this tool constitutes an innovation which was made possible by the Spherical Vectorial Model. It is a circular representation of the observers visibility sphere, obtained according to the resolution of the current globe, just like a picture taken by a fish eye lens camera from the observers position. The Photon Vector contains the representation of the whole luminous sphere, although it just shows the hemisphere centered in the direction of the observers view target.

This feature is dynamically controlled by the mouse movement, allowing for the analysis of the visual field as if the observer had turned his vision towards any direction in the space. This tool gives access to all the necessary information for a complete glare probability analysis, through any of the many proposed methods available in the literature. It is also possible to visualize the visual field either in image mode or in graphic mode (illuminance, luminance, or DLF), as well as fully applying the equalizer features. (Fig 10)

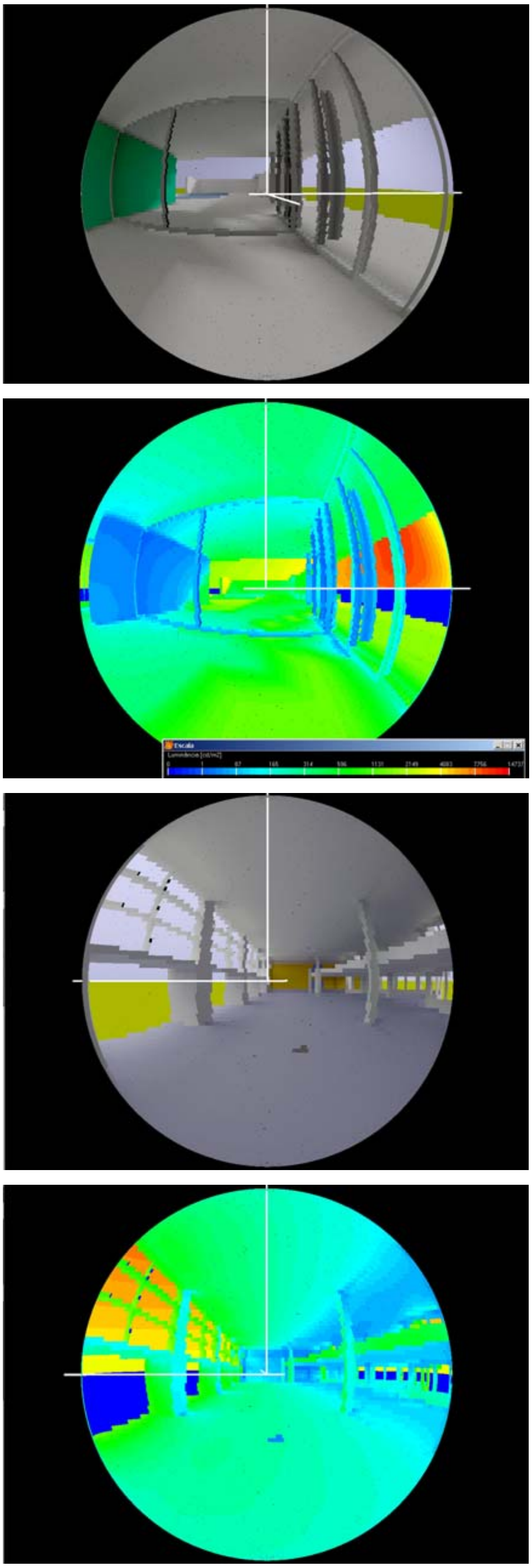

Figure 10 PHOTON VECTOR - a) Inside image of Barcelona; b) Inside luminance graph of Barcelona; c) Inside image of Caixa Econômica; d) Inside luminance graph of Caixa Econômica.

10) Results report: for each radiosity solution it is possible to obtain a complete report, in a specific window, in text format, interchangeable with any text editors and calculation spreadsheets. This report lists all the opaque plans of the project, positioning information, followed by a table describing the order of each plan vertex, their spatial coordinates (x,y,z), the illuminance (lux), luminance (cd/m2), and Daylight Factor Total, Direct and Contemplated (%).

APPLICATION

APOLUX has been used in a real development of the design of an office building in Florianópolis, SC (fig.11), Brazil. Some of the images on the paper were generated during this work.

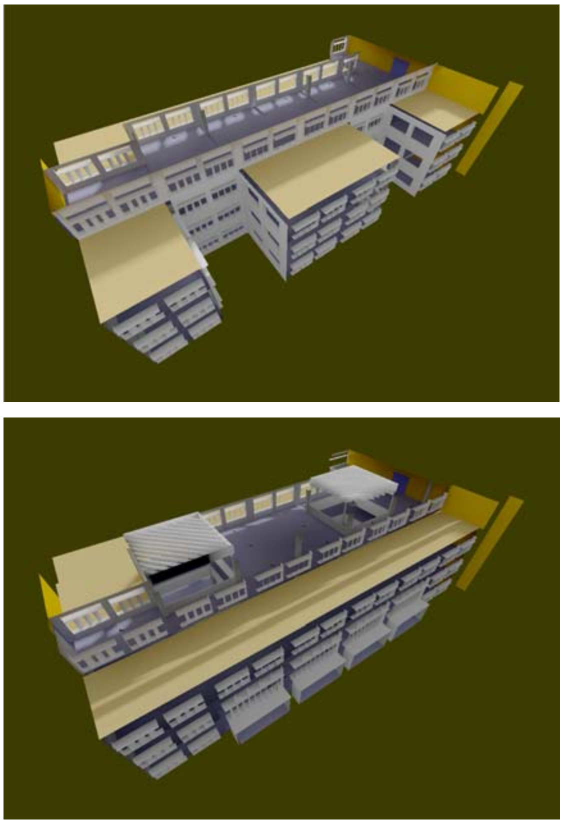

Figure 11: a) Caixa Econômica, proposal with internal well, outside view.
b): Caixa Econômica, proposal with indented facade, outside view.

The application foresees four stages: a) Initial discussion with the architects about the conceptual possibilities of an preliminary architectural proposition; b) Development of a comparative study involving two architectural proposals with different conceptual elements in terms of daylighting exploitation enabling to compare the internal daylighting levels (Fig 12) and distribution of the two options exposed to the same external conditions. At this stage one expects to find the proposal that propitiates the best efficiency, considering other architectural aspects, such as, distribution and integration of activities and circulation; c) Study of solar shading devices for the distinct facades (Fig 13) different types of device models are separately studied through obstruction masks analysis and sunlight penetration. In this phase, in process, one expects to be able to choose for the shading device of best performance, also considering other aspects, such as, façade composition and technical constructive implications; and d) Simulations: a series of complete simulations are currently under development in order to test the performance of different design components.

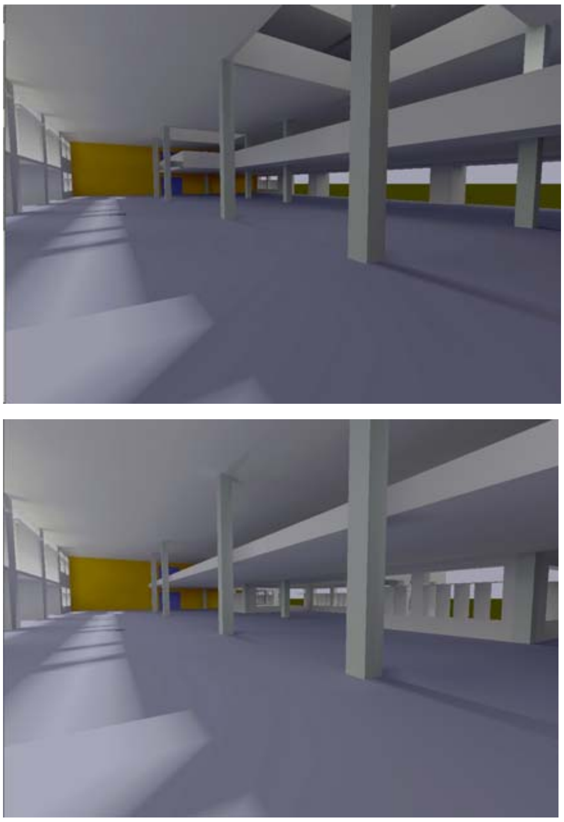

Figure 12: a) Caixa Econômica, proposal with internal well, inside view. b) Caixa Econômica, proposal with indented façade, inside view.

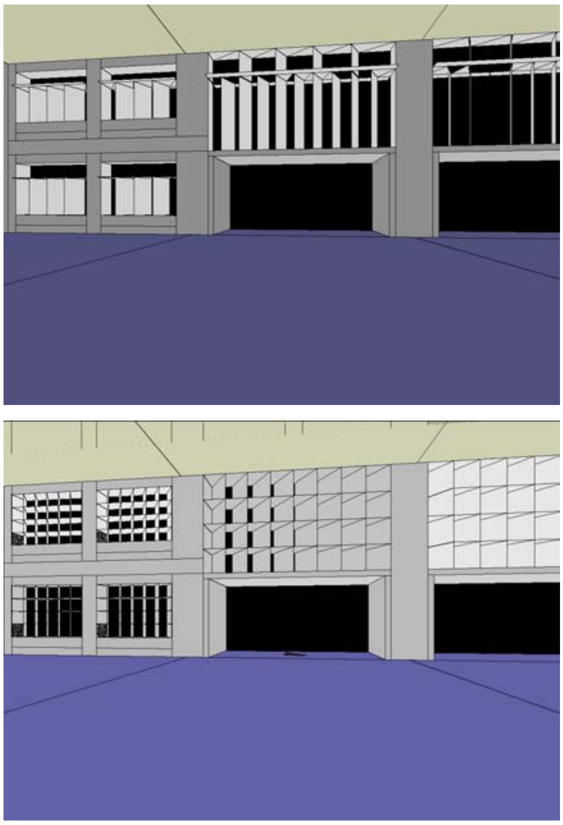

Figure 13:.a) Caixa Econômica, solar shading device 1, inside view.. ; b) Caixa Econômica, solar shading device 2, inside view.

CONCLUSIONS

Besides the laboratory tests and the application described above, the program APOLUX is also being used in several post-graduation studies accomplished at UFSC (Fig 14). Due to a set of original analysis tools and to the fact that it has been developed considering the architects praxis, the program has shown to be quite flexible and with reliable results, as one can see in this paper. In its conceptual basis APOLUX has the possibility, now in development, of incorporating situations of real sky through the input to the Spherical Model of real sky luminance values, measured in-loco. This feature will finally turn possible the validation of the computer code by simultaneous comparison of theoretical and experimental results, ensuring that both theoretical and real model are exposed to exactly the same daylight availability conditions.

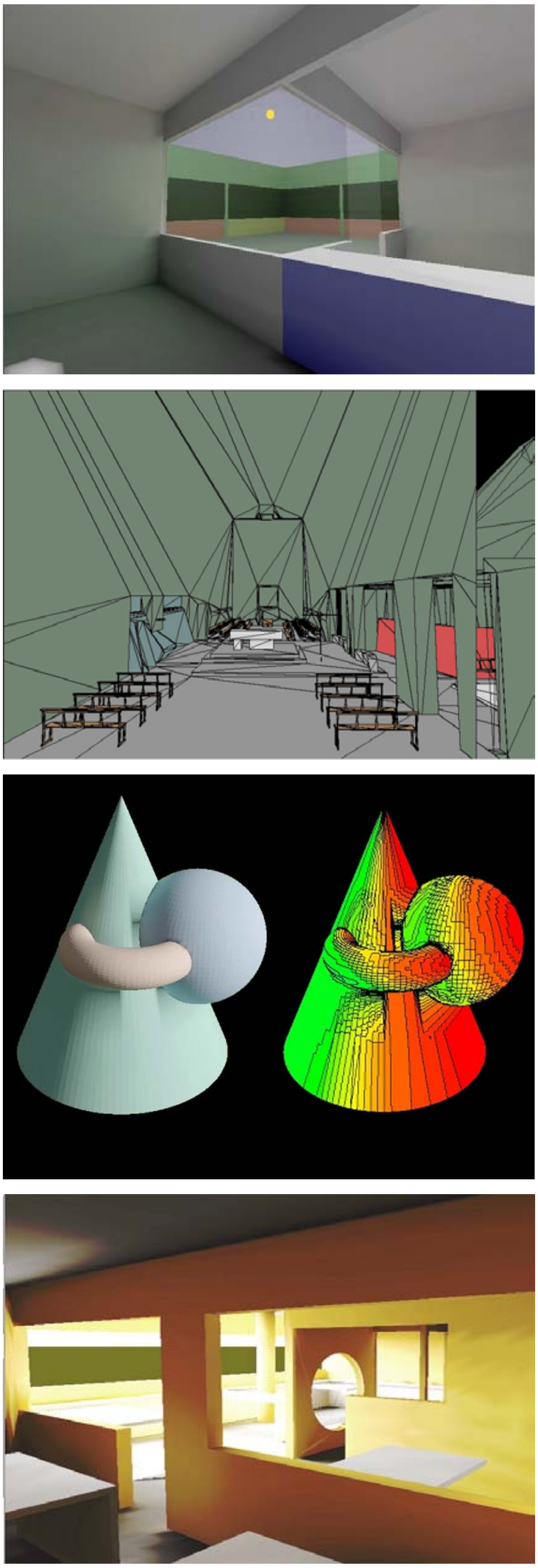

Figure 14: POST-GRADUATION STUDIES USING APOLUX 1.0 - a) Image and Sound Museum- Daylighting simulation; b) La Tourette Chapel- Le Corbusier, modeled in DXF; c) Complex Shapes – lighting simulation; d) Mantovani e Rita Office- Daylighting simulation

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