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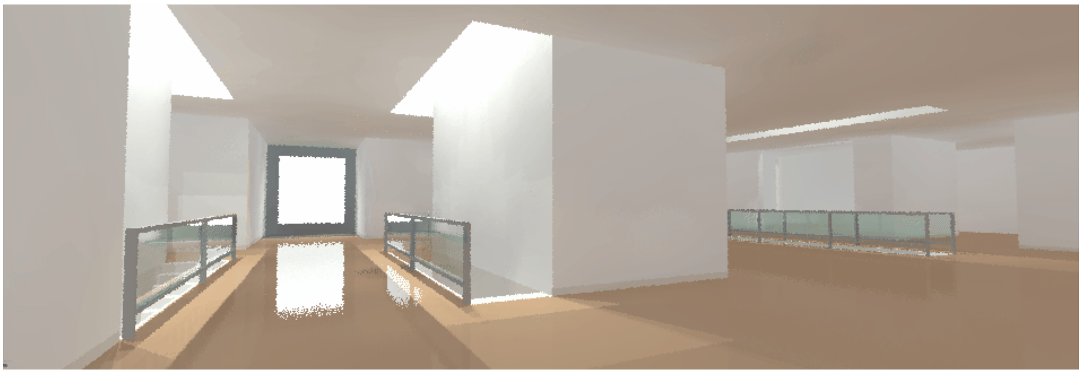

ASSESSMENT OF DAYLIGHT TROUGH SIMULATIONS IN VIRTUAL MODELS

THE CASE STUDY OF RECTORY OF UNIVERSIDADE NOVA DE LISBOA

EXTENDED ABSTRACT

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Introduction and goals

Architecture must provide the conditions for human, physical, psychological and social comfort. The relationship with the surrounding environment depends on the project's supply in conditions of heat, light and sound. Natural light is a great ally to architecture, providing comfort and well-being in users, also being beneficial to health. In addition to that, a new need for the use of natural light has been rising - the importance of reducing energy consumption in buildings.

Thus, control of daylighting aims to meet the functional needs of the space, the human needs at the level of visual comfort, environmental needs and energy efficiency of the building. These criteria are especially applied when the values of natural light possible to capture on an open space, during the day, exceed the amount of light needed inside that space. This demonstrates the great potential of the sun as a source of natural light with inexhaustible energy. The role of architects is to understand the properties and characteristics of light by learning how to apply the methods and systems of daylight capitation and, thus, explore the contributions of daylight and reduce the use of electricity, while contributing to a better environmental performance.

Light is a natural phenomena that changes all the time, so interior lighting depends on many factors such as geographic location, climate and time of the year or day. The architectural layout of the building, its shape and materials can also be used to design natural light paths and intensity in indoor environment. This study explains, in a summarized form, properties and strategies of daylight in order to emphasize the importance of incorporating them into architectural thinking.

The main objective of this dissertation is the analysis qualitative and quantitative solutions of daylight into virtual models through the use of Desktop Radiance software, combined with the development of alternative solutions that optimize the available systems of daylight. The study also aims to reflect on the viability, advantages and limitations of simulation tools that provide the practice of architectural projects.

Strategies for Daylighting

A good daylighting project begins within the urban project. Planning a good accessibility of sunlight in an early stage, simplifies the project's building later. It also has to be taken into account the type of climate, topography of land and height of buildings in order to determine the most favourable orientation to prevent unwanted solar shading.

Side vents, commonly known as windows, had always a major impact in architecture. Whether small, high, horizontal or consisting on large panels of glass, they allow a link with the outside environment, a very important criterion when designing for humans. The position, shape and size of the window in a particular compartment also have a strong influence on the distribution and level of light.
To avoid excessive glare and heat, shading the window is a good solution. There are several types of systems with different shapes and materials, fixed or mobile that can be oriented horizontally or vertically. The purpose of the redirection light systems is receiving the most light and redirecting it, in depth, into the room and simultaneously providing shade.

Skylighting consists on the illumination of a space through openings located in the roof. One of the main features of this lighting system is the distribution of light in interior space in a uniform way, when these openings are regularly distributed through the roof. This lighting system is widely used in office buildings, as it offers a higher level of illuminance on the work plan and a greater uniformity of light. In underground buildings like Metro Stations, the use of natural light enhances the quality of space and its relationship with the outside environment. The advantage of skylight is the variety of locations that they can take, regardless of orientation and built surroundings of the building. One can adjust to the declination of the opening in order to best capture the sunlight, according to local conditions of climate.

Throughout the history of architecture, the use of atria as a daylight providing system gave way to a monumentalization of the building, due to the large amount and quality of lighting, which considerably enhance the space. The purpose of the atrium is to combine the light side with skylight, lighting a large space by allowing the capture of light laterally by the adjacent floor. However, this is a very complex system, and therefore varies depending on the orientation, the shape of the openings, internal geometry of the atrium and the materials used in revetment.

Not always the common daylight systems are sufficient or can entirely satisfy the functional requirements of a given space. The building may be obstructed or contain deep spaces where the light alone can not reach. There are many advanced lighting systems designed to capture the light and redirect it to where it is needed, control it or reduce the amount that penetrates the space.

METHODS OF ANALYSIS

It is important for the architect to pre-evaluate the solution within the quality and quantity of daylight environment inside of a project. According to SANTOS (2003)[1] the analysis methods for quantifying daylighting available and verify the requirements of visual comfort, can be divided into:

- Assessments *in situ*;
- Measurements on small scale models;
- Analytical methods - manual, graphic, computer generated;
- Evaluations by occupants.

As there is no general methodology, the methods of analysis can differ according the objectives, in order to ensure the effectiveness and appropriateness to the case study. These are here presented some methods of analysis of the daylight behaviour through simulations in virtual or physical models applied to projects that are under development. The main objective is to demonstrate the contribution of this type of evaluation for the optimization of environmental comfort and energy efficiency of the architectural project.

[1] SANTOS, António José Costa dos – *Desenvolvimento de uma metodologia de caracterização das condições de iluminação natural nos edifícios baseada na avaliação "in situ "*, 2003

Quantitative aspects

There are many factors that do vary the amount of daylight within a space. It is important that the light meets the quantitative parameters to properly respond to the functional requirements necessary for a human space. Thus, there are values of illuminance recommended for the work plan, within the activities it will develop.

Given the mutability of light available in outside door, especially in days of cloudy skies, it is difficult to quantify the illuminance in an interior space through absolute values. The most appropriate method to quantify the daylight inside is Daylight Factor (DLF), since it is captured through the worst conditions of exterior natural light.

The CIE[2] defines the Daylight Factor as the ratio (in percentage) between the illuminance, in a specific point within a compartment ($E_{int.}$) and simultaneous exterior illuminance ($E_{ext.}$), from a hemisphere clear of sky. It is assumed that the cloudy sky is standard, approved by CIE and excludes the contribution of direct light of the Sun.

$$FLD = \frac{E_{int.}}{E_{ext.}} \times 100(\%)$$

Eint. - interior illuminance of point on a plane (lux)

Eext. - Simultaneous outside illuminance in an horizontal plane, due to a hemisphere of cloudy sky (lux)

Quantitative aspects

One of the main aspects that affect the quality of the visual environment, and thus the visual performance is the existence of substantially different values of luminances within the field of an observer, says BYOCE (*cit. in* SANTOS 2003).

There is visual comfort when the luminances of the several surfaces of the human visual field are kept within acceptable limits. By setting a specific object or surface, the eyes adapt to this level of luminance, when the gaze shifted to another surface, it will have to adapt to the new level of luminance. A greater time of adjustment corresponds to a worse visual performance.

Physical models – model

The use of scale models is common in architecture to study, perform and display projects. The amount of daylight of a particular interior space can be tested in a small scaled model because the light behaves in a similar way, regardless of scale. This is possible because the light waves are very short in comparison to the difference between the real space and the models. But to ensure the similarity in the amount and distribution of light on the scale model, its representation must be as likely as possible to real space. It is necessary to ensure the exact proportions of the space and the optical properties of materials in the surrounding surfaces.

[2] CIE - Commission Internationale de l' Éclairage

Virtual models – 3D

There is also another method of simulation, using a virtual model, through computer programs. Although this tool has great potential, its use in architecture has not been adequately exploited, mainly due to its complexity, since their interfaces are not intuitive and the manuals, incomplete.

With regard to issues of energy efficiency by the natural light, the use of virtual models can simplify the task of adjusting the various alternatives in the project, while being more complicated when done through models. With the help of three-dimensional simulations, it is possible to test and choose the best solution of daylighting and quickly achieve a balance between functional, human and energy needs.

CASE-STUDY

The reasons for the choice of the building of the Rectory of Universidade Nova de Lisboa as a case study focused on the great potential in the development of daylighting systems of the building. Although there is a general concern in this project in terms of daylight, in a preliminary analysis, the light is insufficient in some of the interior spaces. These spaces appeared to be sufficiently rich in terms of daylighting systems, but simple and practical enough for three-dimensional reconstruction, necessary for this research.

The first analysis was to assess areas of work, with different locations of windows, to check the comfort and adaptation to functional requirements and recommended values. The rectory granted access to two meeting rooms, one located on the third floor near the south façade, and the second room on the fourth floor near the north façade. The atrium, which was one of the areas in which the use of daylight was revealed to be insufficient, was also chosen to study. Given the great potential of the location and shape of the atrium space, the compartment was reference to study alternative solutions to improve the use of natural light.

Method

The software selected to conduct this study was the Desktop Radiance, having as basis the Radiance, the software with better performance at the level of analysis of natural light and working as plug-in of AutoCAD.

To calibrate and validate the three-dimensional model it is necessary to compare the values of DLF simulated with measured values *in situ*. It is also necessary to make measurements of illuminance in the spaces under study and registration of the properties of the interior opaque and transparent surfaces, through the calculation of reflectance and transmittance.

Simulations and analysis

A quantitative assessment through the DLF calculation is made to determine the level of daylight and check the recommended minimum values. For this assessment, the calculation of DLF of the simulated environments is performed under the same conditions of measurements *in situ*: through a mesh of points, cloudy sky (CIE - Overcast), date and time. The analysis is done using DLF graphs on schematic sections according to the defined points, matching the values measured both *in situ* and simulated. Tables are also presented with the interior and exterior illuminance measured *in situ*, and the DLF calculation is compared with the value obtained by the DLF of the simulated model. In conclusion, there are presented synthesized and analytical images of the interior environment in order to complete the quantitative evaluation of the spaces.

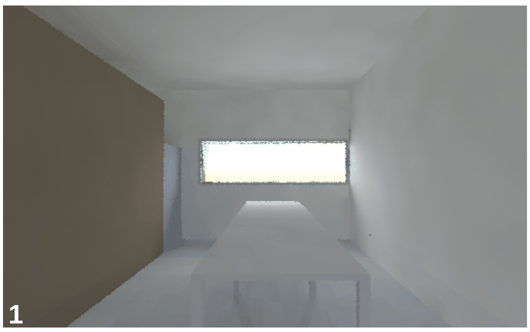
The qualitative assessment aims to examine the evolution of light in space throughout the day, in the main months of the year. The analysis is based on synthesized and analytical images of indoor environments, in conditions of clear sky (CIE - Clear) on the following dates:

- June 21: 9 AM, 12 AM and 5 PM (summer solstice)
- March 21 / September: 9 AM, 12 AM and 5 PM (equinox of spring and autumn).
- December 21: 9 AM, 12 AM and 3 PM (winter solstice)

CONCLUSIONS

<u>Room 1</u>

This room displays the typical curve of side illumination, and can be observed the level of lighting drastically decrease with the increase of distance from the window. There is clearly a lack of daylight, only the first point is within the recommended minimum of 2% of DLF. The room has very low values of DLF to a workspace.



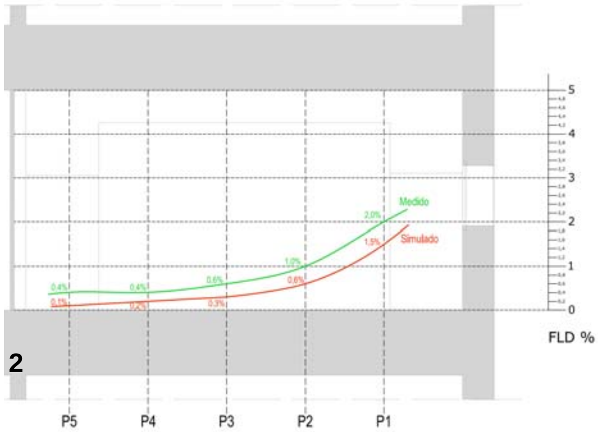


Image 1 – Synthesized image in Desktop Radiance, under the same conditions of measurements *in situ*
Image 2 – Graphic distribution of Daylight Factor in room 1, on schematic sections

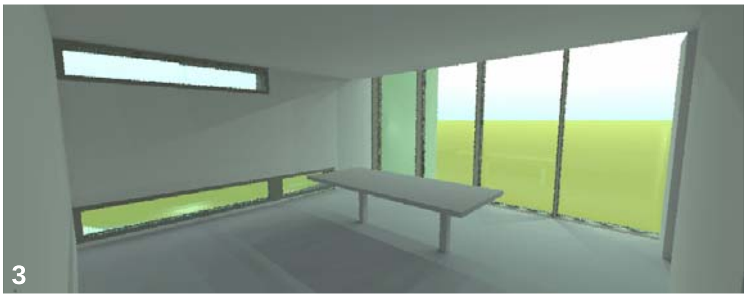
Regarding the performance of the three-dimensional model it is concluded, by examining the graph and table, that the values of the simulation are very close to the measured values, but lower than those measured *in situ*. The analysis of illuminance shows that although the lighting is uniform, the light levels are far beyond the values of comfort and quality that an area of work requires, as the recommended values for the work plan go between 500 lux and 1000 lux.

Through the evolution of light in the room throughout the day, it can be concluded that the area receives direct light at 3 PM of December and 5 PM in June and March / September, causing discomfort and glare, since the light focuses directly on the work table. Finally, it is concluded that this room has no sufficient natural light or quality for a workspace.

Room 2

Analyzing the values obtained *in situ* is possible to see that despite the glazed window receive a large amount of lighting, the first point reached 8.2% of DLF. However, this situation is not verified through the remaining points, since they decrease sharply to values in order of 3%. However, this fact can provide the room a comfortable uniform ambient light.

In a general situation, the level of light in this area of the room is quite uniform. The horizontal windows allow a better distribution of light, and thus a more uniform level of light in space. We can therefore conclude that the entire room has light within the minimum recommended values (2% of the DLF), reaching a satisfactory level of lighting.



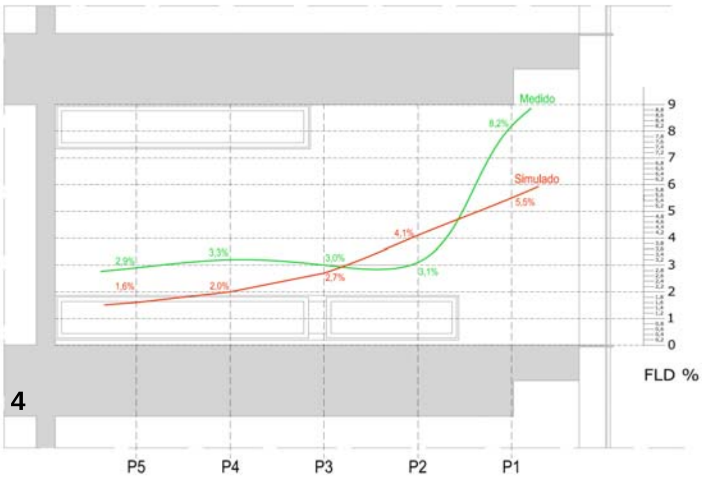


Image 3 – Synthesized image in Desktop Radiance, under the same conditions of measurements *in situ*
Image 4 – Graphic distribution of Daylight Factor in room 2, on schematic sections

As to the values obtained by simulation, it is possible to see in graph a softer decrease in the level of lighting. The first measured point has a lower level of illumination with 5.5% and the other simulated DLF decrease gradually and is always lower, but close to values measured *in situ*. In the second section, differences between simulated and measured values are higher, and the values are below the recommended level of illumination. The simulated values prove, once again, to be lower than those measured.

Through the analysis of the simulated image of the levels of illuminance inside the room, it is shown that the work plan has illuminance values higher than 500 lux, just within the recommended values. The qualitative analysis shows that only occurs incidence of light directly on the work plan in December at 13 PM, from the window near the ceiling. In the simulation at 9 AM of December, the level of illuminance in the work plan is below the minimum recommended, while in the other two simulation months, the values are still within limits. In the remaining hours, the level of illumination is superior to 500 lux, so it is possible to conclude that this room has a good quality and quantity of natural light.

<u>Atrium</u>

This area clearly shows a lack of natural light. Only two points reach acceptable values, with 2.5% and 1.9%. The first point is located near the larger opening side and, as expected, receives a greater amount of light. The second point located on a skylight corresponding to the larger opening, and since it is not above any vertical access, receives a greater amount of light.

The other points have values of DLF between 0.5% and 0.0%, corresponding to very low values. The points with values of DLF different from 0% are the points located immediately below the skylight openings. It is concluded that openings in the lobby do not receive large quantities of light, and the lighting systems are not able to distribute that light into the space.

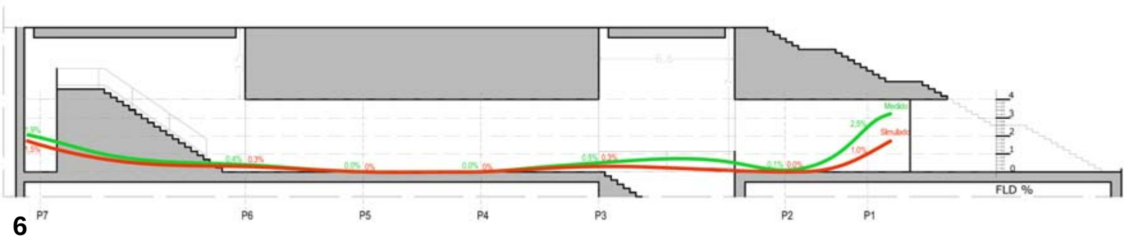


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Image 5 – Synthesized images in Desktop Radiance, under the same conditions of measurements *in situ*
Image 6 – Graphic distribution of Daylight Factor in atrium, on schematic sections

As to the simulation, the values obtained were very close to the values measured *in situ*. The distribution of light in space occurs in a quite similar manner. Looking in detail to the values obtained by *in situ* measurements and comparing with the schematic plans and sections, we can understand the factors that determine the entry and distribution of light. The windows, in addition to being oriented to the north, are positioned in a back plan in relation to the façade. These two factors determine the amount of light that is reached. To further exacerbate this issue, immediately adjacent to the floor openings lies a carpet which absorbs the light, preventing its distribution into the space. As for skylight, in addition to their small size, the light still have to travel the height of one storey to reach the floor of the atrium. It is good to remember that the openings are located above the vertical access, which makes the light focus in this area and not distribute it to the rest of the space.

By changing the light during the day in the several months simulated, we can conclude that there is entry of direct light at 12 AM, in some skylights. This light is directed to the vertical access, having no direct reflection in the floor that could cause glare on users of the atrium. Yet, there may be some visual discomfort caused by reflections in the ground made by side glass doors that receive diffuse light.

<u>Alternative proposals</u>

After a brief reflection on the results obtained by measurements and simulations of DLF, solutions were developed to improve the level of natural lighting in the atrium. It is important to note that although the values of the DLF obtained by the simulation were lower than those measured *in situ*, the development of alternatives is not compromised, because if they achieve satisfactory levels of lighting in the model, the real solution also can.

The first option seeks to maximize the use of natural light of existing lighting systems by increasing the area of skylight and keeping it in the vertical access, thereby retaining the identity of the space. Subtle changes were also applied in the shape of the box, so that it was possible to redirect the light into the space instead of being concentrated in that area. This alteration consisted on leaning some sides of the walls around the ceiling opening, so the light reflected in greater depth.
However, through the values of the DLF obtained by the simulation, it is concluded that although there is a larger amount of diffuse light, it is not properly distributed to the rest of the interior space, being insufficient to achieve the minimum values recommended.

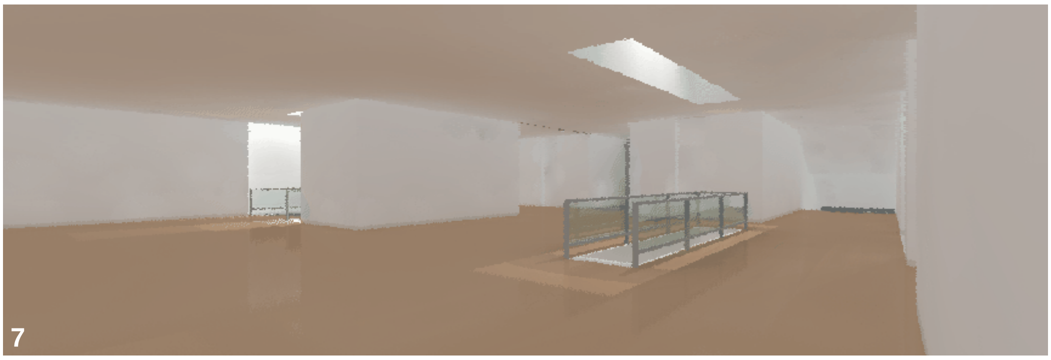

Image 7 – Synthesized image in Desktop Radiance of the alternative 1,
under the same conditions of measurements *in situ*

It was proven necessary to increase the number of skylights, so the second alternative finds new openings in the form of slices through the walls, which also mark different events in the atrium, much like the existing openings, reflecting and redirecting the light. It was also chosen to tilt one side of the skylights in order to lower inter-reflections occurring inside it.

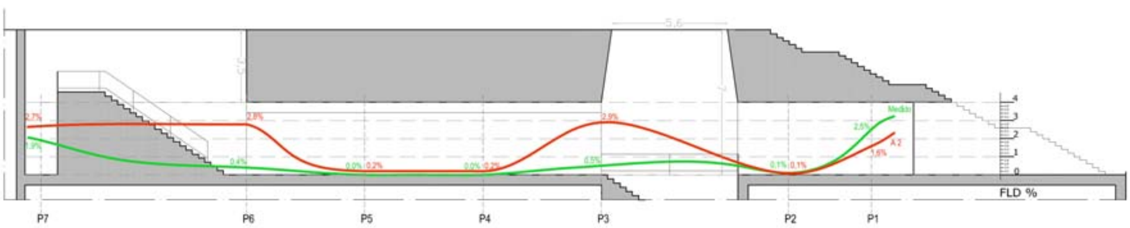

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Image 8 – Graphic distribution of Daylight Factor of the alternative 2, on schematic sections

The values obtained show that it was possible to increase the level of daylighting in almost all points, but not in sufficient quantity to illuminate the deepest and most interior spaces of the atrium. This leads to the conclusion that it would have been necessary to design other systems to the original project that allow natural light and more uniform distribution of it within the space.

General Conclusions

Using the Desktop Radiance software in this dissertation has allowed understanding that these programs are not always easy to handle, require training and experience, not to mention the time needed to perform the simulations. Regarding the Desktop Radiance, the lack of publications and updated information on its capabilities is the biggest obstacle. The most relevant publication is the instructions manual of the program, but this only describes the commands, being of very little teaching and thus, incomplete.

Its interface is complex because it is necessary to properly combine all the available parameters, and the placement of cameras and the application materials shows little interaction because the choices are only perceived after the image is simulated. On the other hand, it has an extensive library of materials, allowing creating customized materials and qualitative and quantitative analysis of daylight. But the simulations generate multiple errors during the process, and cause to restart the whole procedure and sometimes the program itself. There are parameters that are not saved in the programs memory, so the values need to be rewritten to each new simulation. Last but not least, one must spend time to try various alternatives and parameters, to obtain the desired results.

This study concluded that it is very important to incorporate natural light from the beginning of the project, in a proper design, in order to provide the visual comfort for the user of the space. If this assessment is performed using simulations in virtual models, it can explore in a rapid and precise way for architectural solutions, choosing the most appropriate. The use of such tool brings much freedom in choosing and testing of sizes, shapes and materials, and although the necessary acquisition of knowledge and practice in the use of software, is an investment that pays off.