

TOWARD A TOOL TO OPTIMIZE THE DAYLIGHTING INTO THE PROCESS OF ARCHITECTURAL DESIGN –REVERSE APPROACH–

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ABSTRACT

This paper traces the various steps of reasoning and development of a numerical model of dimensioning opening-elements based on the reverse approach of simulation of natural lighting.

The model was developed by following two steps: firstly the calculation of the external light coming from a sky-element located in the celestial dome. Based on these data, a second numerical calculation was performed to generate the dimensions of an opening-element enabling to realize the daylight intentions of the designer. A method of comparative validation using standard softwares of daylight simulation and daylight optimization was subsequently adopted to test the reliability of the obtained values.

Having regard to the pedagogical destination of the tool, the results of this research showed the opportunities that may offer a prospective integration of the developed model in the students' awareness about the importance of daylight simulation. Therefore optimize the visual comfort and the energy efficiency inside the future buildings.

INTRODUCTION

Natural light is one of the architectural space-components which allows to better see and better do architecture (Donnadieu, 2002). Despite the strong influence of this aspect in the history of architecture, and on the human psychology and physiology, which was oftenly overlooked in favor of the morpich appearance and always treated downstream design steps (Miguët, 2002)(Francioli et al.,2001).

On one hand, it was approved that natural lighting systems can participate in the process of generating ambience inside buildings (Gallas, 2009). Designing buildings while giving importance to daylight will contribute to improve the energy efficiency, at the same time it will ensure a pleasant visual comfort inside its interior spaces (Polingéas, 2004). Several research works have shown that designers draw upon references in order to formalize an intention of light ambience (Phillips, 2004).

The term "reference" means anything that helps designers to articulate their design problems and imagine solutions (Chaabouni et al., 2007).

On this basis, any attempt of instrumenting the design of ambiances in the earliest steps of architectural design with referential procedures can be considered as a possible approach.

On the other hand, the concept of simulation is an integral part of architectural design since its creation (Lebahar, 1983). Among the tools used to optimize the distribution of daylight in an architectural space, there are computer programs (Gunea, 1997). Currently, with their continuous evolution and undeniable contributions, these softwares have become increasingly the main mediator in the relationship between "architect and graphic tools" (Deroisy and Deneyer 2011).

However, the various software generally used by architectural students during their training have a disadvantage: these computer tools are often used to produce digital representations of the designer's propositions with more or less ease in achieving the different graphic documents. This restriction on the concept of assistance is due, to a large part, to the fact that CAD tools require the introduction of accurate data that are usually available only when the project is already sufficiently developed or sometimes completely finished.

In order to deal with these mentioned situations, the recourse to "reverse approach" was the starting point; this method is based on the designer's intention in term of light ambience, then propose solutions that will fulfill his intention (Houpert, 2003). In this framework we suggest a numerical model enabling the dimensioning of the opening-elements from declared intention. During the development of the model "the sky and the sun" were considered as the only components of the external light environment and the "opening-element" as the only source of light inside the space. The combination of calculation-formulas of external and internal lighting luminance permitted to collect data and results into the same file. The evaluation of the developed model along with other softwares allow to verify the accuracy of its results, and to get the degree of its correspondence to the objectives of this research. The aim is to give more importance to the benefits of simulation in the field of lighting, and reach an optimum consideration of the constraint of natural light from the outset of architectural design.

PARADIGMATIC CONTEXT OF THE RESEARCH

The methodology adopted in this paper was based on the paradigm of "declarative approach" proposed by Daniel SIRET, represented by the concept of "inverse simulation" and developed in practical way for specific ambience "daylight" (Siret, 1997).

Problem of the "direct" simulation of daylighting

In order to argue our choice of approach, we began by analyzing the design steps of opening-elements using various software of daylight simulation such as: ADELINÉ®, DIALUX®, ECOTECT®, GENELUX®, INSPIRER®, LIGHTSCAPE®, RADIANCE®, SUPERLITE® and VELUX®.

We then classified these tools according to the calculation algorithm adopted in their database; this has allowed us to conclude that:

- All these various software use one of the two calculation algorithms: Radiosity or Raytracing.
- The operating mode of these two algorithms satisfies the following chart:

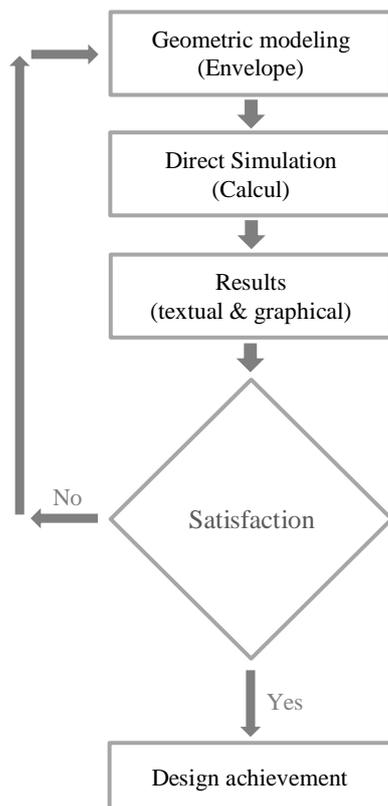


Figure 1 The design steps of opening-elements with daylight simulation software.

The two main disadvantages of this operating scheme are that:

- The "downstream" intervention of the daylight simulation leads to time loss in design in case of the designer's dissatisfaction of the results.
- The end of these tools is thus to enable designers to test the solutions they propose for implementation, but not to suggest a solutions to the students.

The "declarative approach" as a solution

The reverse simulation is a part of a more global approach known as "declarative modelization" which was introduced in the field of design to address the shortcomings of the imperative modelization. The specificity of this implicit and abstract approach is that it creates objects, shapes, images and scenes only by their characteristics and properties (Hegron, 2002) (Houper, 2003) (Gallas, 2009) (Greca, 2005).

The advantages of the declarative modelization can be summarized by the following points:

- It is closer to the designer; it allows him to focus only on the manipulation of non-geometric aspects of the scene he wants to create without caring about its geometric interpretation, which is the mission of the declarative modeler who then determines precisely the scenes with the stated properties.
- It is better suited to the progressive character of modeling; by allowing continuously the modelization of the scene whatever the number and quantity of the stated properties. The user can, at any time, get an early draft of the scene which he can then refine while ensuring the conservation of its initial properties during the modification (Bonnefoi, 1999).

The "reverse" simulation of daylight

Reverse simulation methods of daylight determine the geometric conditions to be met by building components (the morphic composition, orientation, type and location of the opening-elements) to achieve designer's intentions (ensure that a given area of space satisfies a daylight qualification for a specified period) (Siret, 1997).

In the context of the inverse approach proposed by Daniel Siret, the architectural project is considered as a double simultaneous demarcation process of "formes" and "intentions" carried by the intermediate concept of "effect". The actions on these components can be of two kinds (exposure and achievement), each one of them can be associated with one of the problems as shown in the following figure.

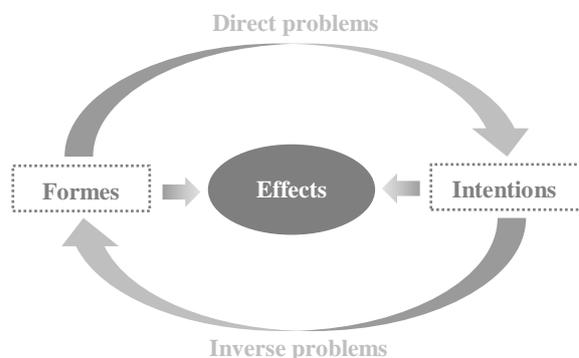


Figure 2 The dynamic of the architectural design process.

N.B: This fact does not mean the nonexistence of software elaborated with this approach such as

TRNSHD©, WINSHADE©, SUSTARC© and CALCSOLAR© (Guedi Capeluto et al., 2005) (Kabre, 1997) (Marion Hiller, 1996) (Yeh and Schiler, 1993). The main drawback of these tools is that they are, in most cases developed in research laboratories and none of them is available on the market. For this, we proceeded to the development of a new tool of daylight simulation and optimization.

REVERSE SIMULATION AND THE DEVELOPMENT OF THE MODEL

Presentation of the adopted space model

The space model used for the calculation is a simple geometrical shape "rectangular" with dimensions corresponding to those frequently adopted for classrooms of schools, colleges and other academic institutions of educational learning.

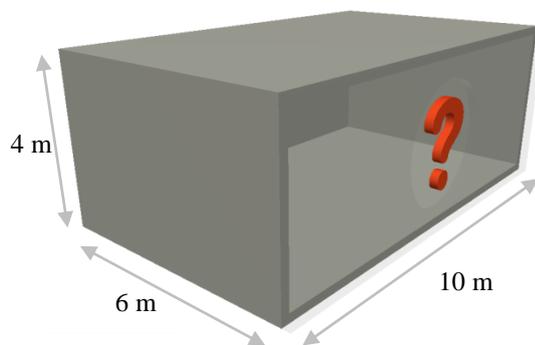


Figure 3 Geometry and dimensions of the adopted space for calculation.

Choice of location of the calculation points

The choice of the calculation points was in order to cover the maximum areas of the space, thus to give an idea about the depth of the lighting system. The three calculation points selected are shown in the following figure:

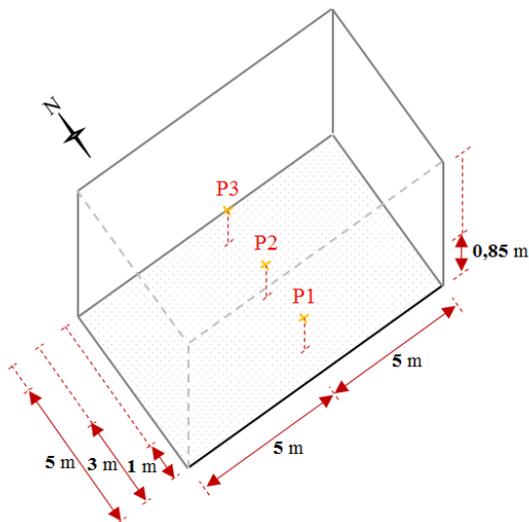


Figure 4 Location of the three points selected for the calculation.

The steps of development

The Calculation of the external luminance

The model used for the calculation of the external light coming from outside (sky + sun) is that of Richard Kittler (Kittler and Darula, 2002). This model was chosen because of the availability of validation work and its ability to include all types of sky and any geographic location.

Table 1

Values of different angles and distances required for the calculation (1).

GIVEN	VALUES (°)	CORRESPONDENCE
α_s	122,28	May 13th 2013 at 11:00 am in Biskra, Algeria
α	120,18	October 6th 1986 at 10:00 am in Constantine, Algeria
γ_s	63,59	May 13th 2013 at 11:00 am in Biskra, Algeria
γ	27,29	October 6th 1986 at 10:00 am in Constantine, Algeria
Z_s	26,41	May 13th 2013 at 11:00 am in Biskra, Algeria
Z	62,71	October 6th 1986 at 10:00 am in Constantine, Algeria

- In order to follow the current CIE Clear Sky Standard, the starting formula was:

$$\frac{L_{y\alpha}}{L_z} = \frac{\Phi(Z) f(\chi)}{\Phi(0^\circ) f(Z_s)} \quad (1)$$

- The formula adopted to calculate the gradation functions Φ for any point in the sky (n) is:

$$\Phi(n) = 1 + a \exp(b/\cos n) \quad (2)$$

The application of the formula (2) for a sky element in view direction :

$$\Phi(Z) = 0,6987$$

The application of the formula (2) for the zenith:

$$\Phi(0^\circ) = 0,4231$$

- The formula adopted to calculate the Indicatrix functions f for any point in the sky (n) is:

$$f(n) = 1 + c[\exp(d \cdot n) - \exp(d\pi \cdot n)] + e \cos^2 n \quad (3)$$

The application of the formula (3) for a sky element in view direction :

$$f(\chi) = 2,6949$$

The application of the formula (3) for the zenith:

$$f(Z_s) = 3,7798$$

- The numeric application to the formula (1) gives:

$$\frac{L\gamma\alpha}{Lz} = 1,1775$$

- The formula adopted to calculate the zenith luminance is:

$$Lz = (1,376 TL - 1,81) \tan \gamma s + 0,38 \quad (4)$$

$$Lz = 11974$$

- The formula adopted to calculate only the luminance of the sky relative to the selected sky element is

$$L\gamma\alpha = Lvz (L\gamma\alpha/Lz) \quad (5)$$

$$L\gamma\alpha = 14100 \text{ cd/m}^2$$

The Calculation of the areas of opening-elements

To calculate the surface must have the opening elements to achieve the desired lighting level, we used the series of formulas created by Vincent TOURRE in his Ph.D thesis (Tourre, 2007).

Table 2

Values of different angles and distances required for the calculation (2).

GIVEN	VALUE	UNIT
α_1	41,00	degrees
α_2	77,00	degrees
α_3	83,00	degrees
β	63,69	degrees
d1	1,15	meter
d2	1,15	meter
d3	1,15	meter
τ	1	/

To resolve the question of obtaining a surface value, we opted for an inversion of the integral function into the formula proposed by Vincent TOURRE :

$$EC = \int s \frac{L\gamma\alpha \cdot \cos^3 \alpha \cdot \cos \beta \cdot t \cdot d\varepsilon}{d^2} \quad (6)$$

The area required for each opening element 500 lx for each calculation point is indicated on the following table:

Table 3

Necessary area for each opening element.

SURFACE	VALUE	UNIT
S1	0,7013	m ²
S2	4,1783	m ²
S3	10,9284	m ²

Configuration of the obtained opening-elements

The dimensions and exact locations of the opening elements are shown in the following figures:

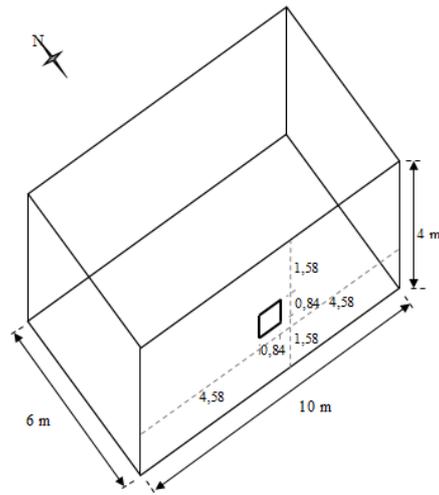


Figure 5 Final dimensions and location of the opening-element for P1.

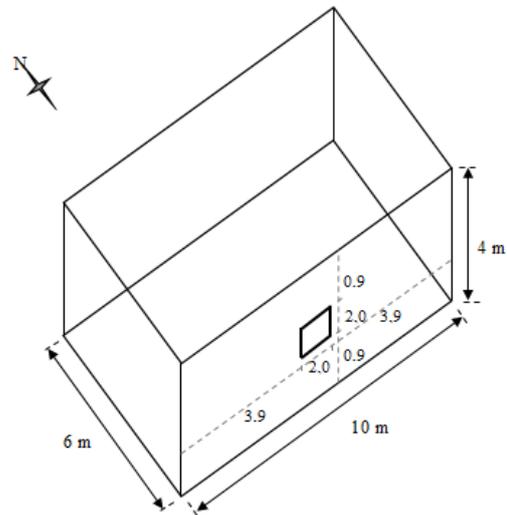


Figure 6 Final dimensions and location of the opening-element for P2.

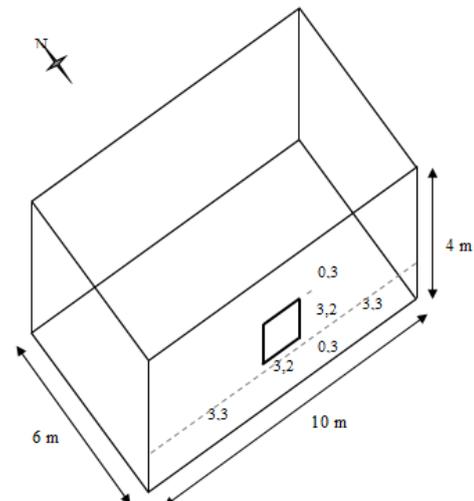


Figure 7 Final dimensions and location of the opening-element for P3.

Overview of the developed model "MNSIEN"¹

The developed model "MNSIEN" is a MATLAB M-file in which appears at its startup, the emplacement of the data to be included by designer:

- The values of angles of the azimuth and altitude of the sun corresponding to the date and time of the calculation; this can be integrated in the calculation page in form of charts.
- The location of the calculation point (its height from the ground and its distance from the wall); this can be measured by the designer from a section including only the calculation point and the designated wall to receive the opening element.

```

1 - clear all
2 - clc
3 %Exterieur:
4 % 1. Calcul de la distribution relative de la luminance
5 % alpha_sun_deg=input('donnes alpha sun =')
6 - alpha_sun_deg=122.28;
7 - alpha_sun=(pi*alpha_sun_deg)/180;
8 - alpha_deg=120.18;
9 - alpha=(pi*alpha_deg)/180;
10 - lampda_sun=1.11;
11 - lampda=0.48;
12 - Z_sun=0.46;
13 - Z=1.09;
14 - AZ=-0.04;
15 - X=acos((cos(Z_sun)*cos(Z))+(sin(Z_sun)*sin(Z)*cos(AZ)));
16

```

Figure 8 Data input fields.

After launching the calculation, the results appear on the same pallet. This allows the designer to visualize these results instantly which helps him to reduce the time of the simulation.

```

Command Window
S_one =
    0.7013

S_two =
    4.1783

S_three =
    10.9284

```

Figure 9 Output fields of results.

¹ MNSIEN is an abbreviation of the French phrase : "Modèle Numérique de Simulation Inverse de l'Eclairage Naturel".

From these results, the designer has an idea on the surface that must have the opening elements. He is now free to choose the shape of both the space and windows. The use of MNSIEN does not affect the morphic configuration of the space but offers a help to optimize the implementation of daylight system.

RESULTS AND DISCUSSIONS

In order to verify the accuracy of the obtained results, we chose the method of "comparative validation".

Validation by direct simulation

- The first chosen software was DIALux 4.11.02 (free software).

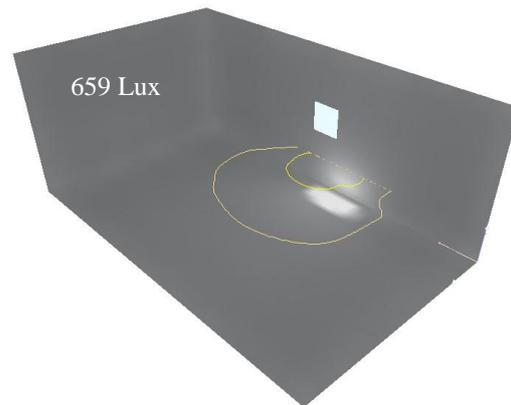


Figure 10 Validation result using DIALux for P1.

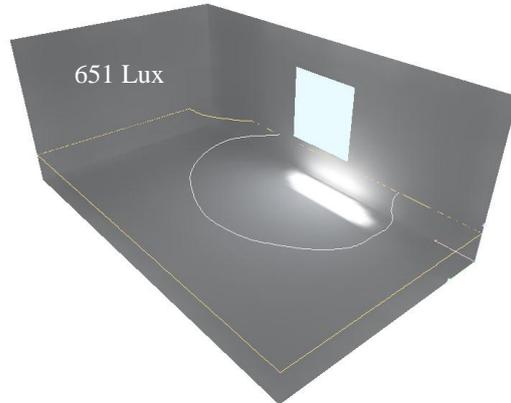


Figure 11 Validation result using DIALux for P2.

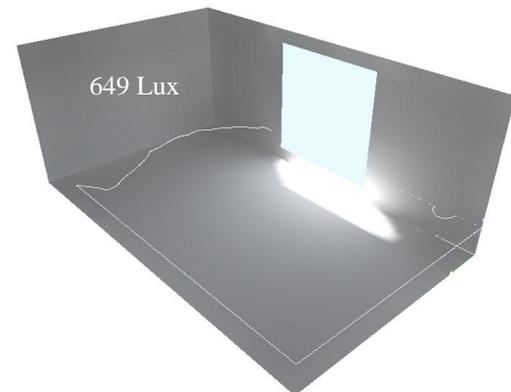


Figure 12 Validation result using DIALux for P3.

- The second software chosen for validation was ECOTECH ANALYSIS 2011 (paid software).

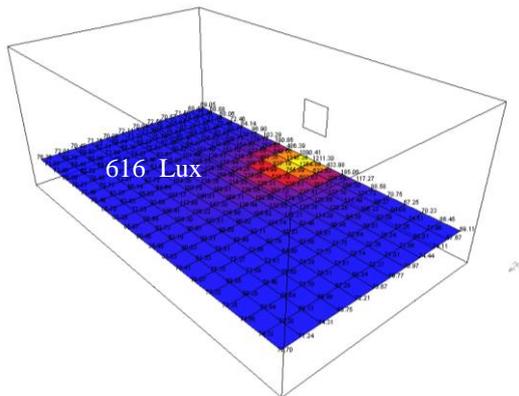


Figure 13 Validation result using ECOTECH for P1.

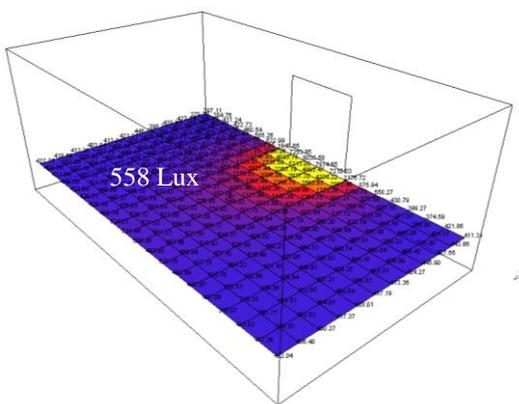


Figure 14 Validation result using ECOTECH for P2.

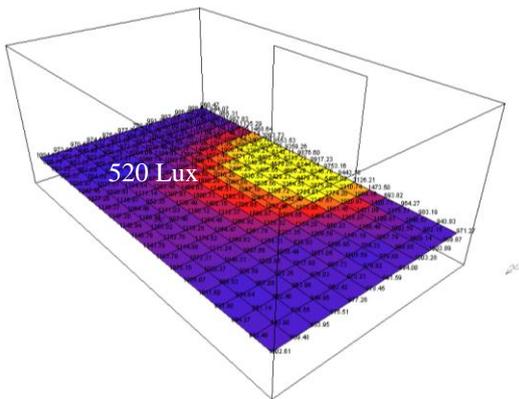


Figure 15 Validation result using ECOTECH for P3.

Validation by optimization

- The second validation part was focused principally on checking the "optimal" character of the obtained results by comparing them with potential solutions derived from tools of daylighting optimization.

For our case, the modeling tool used as working environment was RHONICEROS©: this software was chosen because of its ability to be coupled with other generative algorithms such as GECO©, GALAPAGOS©, GRASSHOPPER© and others (Erlendsson. 2014).

The optimization process, illustrated in the following figures (Figure 15,16,17&18), consisted of four main steps which were repeated for each calculation point:

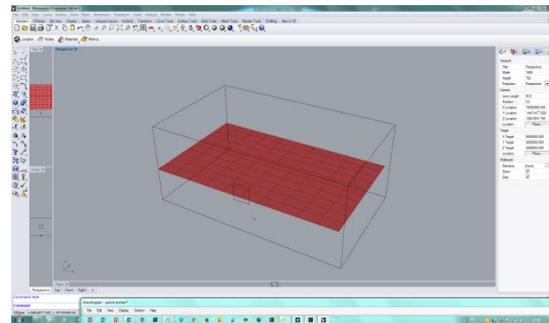


Figure 15 First step: Construction of the volumetry and the calculation data using Rhinoceros.

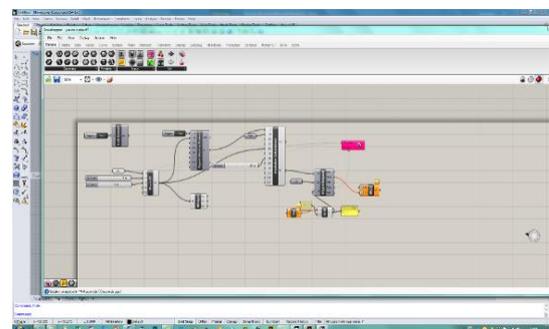


Figure 16 Second step: The use of -Geco- plug-in for export to ECOTECH.

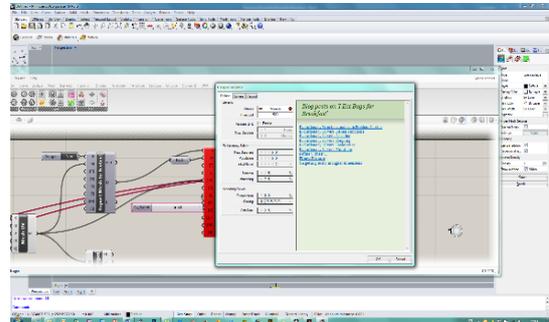


Figure 17 Third step: Statement of the optimization values in Galapagos-Grasshopper-Rhinoceros.

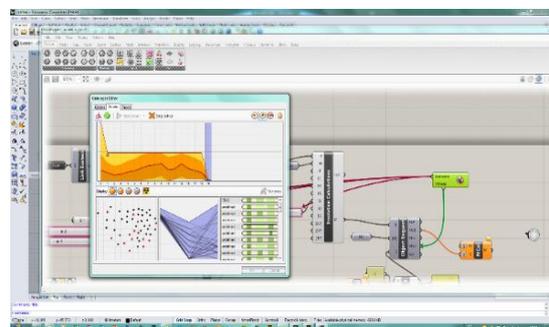


Figure 18 Fourth and final step: Optimization result.

- The solutions were, for each point, identical to those values taken during the development of model (with a margin of 0.01 due to the accuracy of the tool used for optimization).

Statistical evaluation of the differences results

To evaluate the relative differences between the values from the mathematical calculation and those obtained by numerical simulation, we adopted a method developed by Michel Lejeune in the field of statistics. This method use "multiplier coefficient" (CM) to understand precisely and accurately the gap between the several values (Lejeune, 2010).

Table 4
CM values for all calculation points.

POINT	CM	
	DIALUX 4.11.02	ECOTECT 2011
P1	1,32	1,23
P2	1,30	1,12
P3	1,30	1,04

Interpretation

- All values in the multiplier are above 1, which allows us to say that the level of illumination is, in all cases, in proximity of the desired level.
- Values of the Multiplier coefficient are between (CM = 1.04 and CM = 1.32) which reflects the good equality between the desired values and those obtained by simulation.
- The gap between the lowest value and the highest value is (0.02) for DIALux and (0.19) for the results obtained by ECOTECT: therefore, the values are on the same range of variation.
- In both cases (simulation with DIALux and ECOTECT), the CM is at its highest value at the first point; this value decreases to the second point and reaches its lowest value at the third point. This shows that the precision of our calculation reduced near the opening-element and rises slightly and gradually as one moves away from this one.
- Between the various software used, the results obtained by ECOTECT have a smaller gap than those obtained by DIALux, This may be due in large part to the software category (paid) enabling it to have a more accurate than a (free) DIALux.

CONCLUSION

This work could be considered as a link between the conventional and declarative methods of simulation in order to better serve the intentions of the architects for designing of daylight systems. The objective of the reverse approach is therefore to complete and resolve gaps that may occur in exceptional design situations.

During this research, the developed model "MNSIEN" has shown some positive points:

- The first one is a guarantee of an illuminating level that is always higher than desired; thereby this will avoid the inefficiency or the obtained opening element's failure.
- The second positive point is the accuracy of their results, which are closest to those given by paid software; this allows satisfying the destination

(students of architecture in pedagogical institutions) of the model.

- The third positive point for this model is the ease of use that characterizes it, because it is necessary to introduce only the corresponding angles to the sun's position, and that of the sky-element relative to the selected date and time to have the solutions. The designer can therefore proceed to the simulation of his sketches before completing the parametric modeling; this will mitigate the constraints of direct simulation while ensuring his liberty for choosing the morphic configuration.

The evaluation of the pertinence of the developed model allows us to declare that it can be operational, and can be used by students / architects in their first steps of designing new architectural projects. Therefore, it would be a real help in defining the optimal dimensions of the opening-elements. Through this model, we hope to open access to new architectural design tools that address the needs of today's world in terms of ecology, bioclimatic and in terms of environment friendly architecture.

Future research opportunities

In order to push the limits of this work and extend its scope, we propose two kinds of possibilities:

- The main short-term perspective is to expand the database to achieve an annual inverse simulation of daylight for entire space surfaces.
- In the long term, we want to collaborate with other scientific disciplines to integrate other physical phenomena such as thermal, energy, etc... to get more overall solutions.

NAMENCLATURE

α ,	Azimuth angle of the sky-element;
α_s ,	Azimuth angle of the sun;
$\alpha_{1,2,3}$,	Angle between point to illuminate and the center of the opening element (rad);
β ,	Angle between the normal of the opening element and the direction of the opening element to the source side (rad);
$d_{1,2,3}$,	Distance between the height of the calculation point and the height of the middle of the wall receiving the opening element (m);
f ,	Luminance Indicatrix function;
$f(Z)$,	Indicatrix function for sky-element;
$f(Z)$,	Indicatrix function for zenith;
Φ ,	Luminance gradation function;
$\Phi(Z)$,	Gradation functions for sky-element;
$\Phi(0^\circ)$,	Gradation functions for zenith;
γ ,	Elevation of the sky-element;
γ_s ,	Elevation of the sun;
L ,	Luminance;
Lz ,	Luminance at the Zenith (cd/m ²);
$L\gamma\alpha$,	Luminance of sky-element (cd/m ²);
lx ,	Lux;
cd ,	Candela;

m ,	Metre;
n ,	Unknown variable;
P ,	Calculation point;
$S_{1,2,3}$,	Area (m ²);
τ ,	Transmission coefficient;
T_L ,	Turbidity factor of Linke;
CM ,	Multiplication coefficient;
Z_s ,	Angular distance between sun and zenith;
Z ,	Angular distance between a sky-element and the zenith;

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