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***Abstract*—This paper proposes a Genetic Algorithm to optimize lightning design parameters integrated with a Computer Aided Design (CAD) application. The algorithm offers a search optimization approach to achieve better design solutions when compared to traditional tools. The proposed CAD tool uses innovative concepts of Information Visualization. Complex 3D representation and calculation is established through an intuitive and strategic conjunction.**

I. INTRODUCTION

Lighting design has an extreme importance due to the high cost of implantation and maintenance of the illumination installations. Best illumination dimensioning is indispensable to achieve an adequate lighting and reduced electrical power consumption. CAD tools are very important to the engineer design process to enable alternative simulations before the final solution, improving quality and maturity to the engineering projects. In the electrical installation area, these tools have been proving suitable in several design activities. However, recently studies show that the computational facilities are still dependent to the creativity and experience of the engineer [1], with hinders a better performance from the design to market.

The illumination calculation method, commonly called Point-To-Point, is usually used in Lighting Design and is indicated to external places. Funded in this technique, it is possible to calculate the illumination level in each point of interest in a determinate work surface plan of study [2]. This method in general requires the use of computational applications to calculate a matrix of points in a determinate area plan, providing each point luminance values as result.

The scalar field visualization in 3D is applied to Lighting Design through the graphic representation of the luminance field. Recently, some applications using Virtual Reality has proved to be a useful alternative for this kind of design application [3]. Therefore, it is possible to develop algorithms to process and display fields of illumination in a 3D virtual environment for any required lighting system [4].

An efficient lighting design requires good visibility and color reproduction, power economy, reduce the maintenance costs and must considerate to get lower market expends to the adopted solution.

In luminaire equipment, illumination intensity emitted in a determinate point can be calculated by an algorithm routine using the IES (Illuminating Engineering Society) file format created for the electronic transfer of photometric data. It has been widely used by many lighting manufacturers and is one of the industry standards in photometric data distribution.

Genetic algorithms [5] are a class of search techniques that use the mechanics of natural selection and genetics to conduct a global search of a solution space and constitute in an efficient optimization environment for the Design Optimization procedures [6], [7].

This paper proposes a Genetic Algorithm to optimize lighting design parameters integrated with a Computer Aided Design (CAD) application. Genetic Algorithm offers an optimization approach to perform a search to achieve better design solutions, and proposed CAD tool uses innovative concepts of Information Visualization within virtual environments.

II. METHODS

A. Design Parameters

During the process of lighting design, an engineer needs to evaluate the illumination requirements. These requirements are important to specify the uniformity of illumination levels, glare levels, index of color reproduction, and color temperature.This methodology involves the following items:

a Survey of activities of the local, physical dimensions of the layout, materials used and the characteristics of the grid in place (initial data of the project);
b Determination of the goals of lighting and effects to be achieved;
c Choice of lamp types;
d Choice of fixtures (luminaire);
e Analysis of the factors influencing the quality of enlightenment (IRC and Color Temperature);
f Calculation of general lighting;
g Calculation of control;

h Distribution of light;
i Definition of points of light;
j Calculation of directional lighting;
k Evaluation of energy consumption;
l Assessment of costs;
m Calculation of profitability.

In this paper, we propose to focus only on items [a], [c], [d], [f], and [h] as input parameters for the Genetic Algorithm (GA) application described in section II-D. The GAs fitness function deals with items [j], [k], and [l], automatically. The Genetic Algorithm generates the light source positions and the best pair of lamp type and the corresponding luminaire.

B. Directed Lighting Method

The directed lighting method (or point-to-point method) is the most often used method for illumination calculation in external areas [8] and also recommended by Illuminating Engineering Society of North America (IESNA). With this method, we obtain the luminance performed by one or more light sources, at any desired point or a mesh of dots. A light source is defined by the set of a luminaire and its fixed lamps.

A luminarie distributes, filters or converts the light emitted by one or more lamps. Part of the luminous flux emitted by the lamps is absorbed by the luminaire and does not contribute to the ambient lighting. The flow balance is spent above and below a horizontal plane passing through the center of the luminaire. The beams of light irradiated directly on the work plan are the main contributors to the luminance. For each luminarie, the photometric data used for calculating luminance are obtained by their respective IES files (Illuminating Engineering Society Standard), a international standard used in many existing softwares.

The total luminance, given by adding the contributions of each light source, is represented by (1):

$$E_{total} = \sum_{i=1}^{N} E_i \tag{1}$$

where: E_i = luminance of the source i; N = number of light sources.

The luminance E_i, held by each light source individually, is given by (2) and shown by Figure 1:

$$E_i = \frac{I_{Pi} \cdot cos\gamma}{d^2} \tag{2}$$

where: I_{Pi} = intensity of the light source i toward the point P; γ = angle between normal surface and direction of the considered point P; d = distance between the light source and the point P.

The intensity emitted by a light source in a certain direction is given by the photometric distribution of the light source and varies for each type of luminaire and lamp used. The light distribution of a light source is obtained through laboratory measurements and is usually provided by the manufacturer in different forms: tables, diagrams, graphs or digital files.

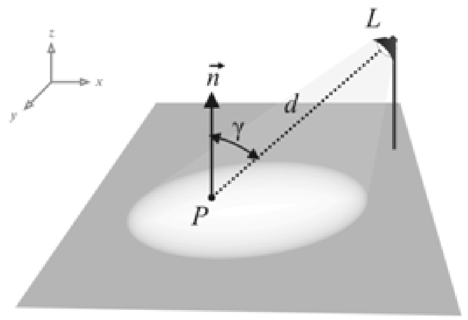


Fig. 1: Arrangement of a lamp: L = installation point, d = distance from the point of light, P = point of interest, $\vec{n}$ = normal to the plane, γ = angle between the vector near straight $\overline{LP}$.

The use of digitized curves and photometric standard (IES) allows automation for consulting the light intensity during calculations, which facilitates the process and makes it faster and more dynamic than when done manually.

The point-to-point method takes as input the initial configuration of lighting (light sources with their position and height inside work plan environment) and provides output results that contain luminance values of each point of the mesh (2D or 3D).

The average level of illumination is given by (3). It is calculated to allow a comparative value.

$$E_{average} = \frac{F_{util} \cdot F_{lux} \cdot N_{lamp} \cdot N_{lum}}{W \cdot D_{plum}} \tag{3}$$

where: $E_{average}$ = luminance average; F_{util} = Utilization Factor of the used luminaries (manufacturer); F_{lux} = Luminous flow emitted by each lamp; N_{lamp} = Number of Lamps per Luminary; N_{lum} = Number of fixtures used in the algorithm; W = Width of the Environment to be Enlightened; D_{plum} = Distance between poles or luminaries

C. Photometric Curve

The IES file allows the creation of photometric curves, as shown in Figure 2, that are polar diagram representations of light energy propagation provided by a lamp/luminary set.

These diagrams usually provide values of light energy in discrete angles increment and, if is necessary, it is possible to calculate a value for an intermediate angle using an interpolation criteria.

D. The Genetic Algorithm Implementation

A genetic algorithm (GA) is a stochastic search technique that, for a given problem, searches a solution space for a near-optimal solution. This search is done in a fashion inspired by Darwinian Evolution. Within a population of possible solutions, they could breed among themselves regarding their respective fitness, forming new solutions that will belong to new generations. There will be evolution of possible solutions for many generations. When the algorithm reaches its end, the best solution found is returned.

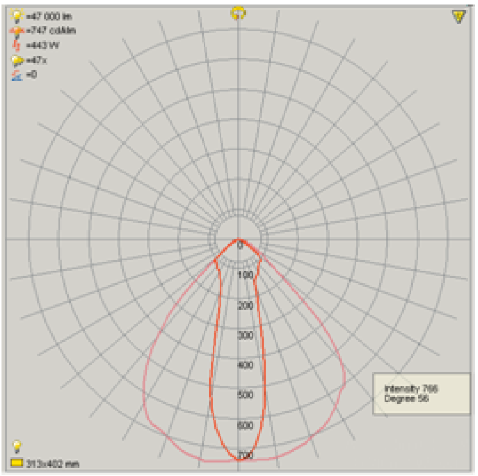


Fig. 2: Photometric curve of the lamp HLF 432 SONT 400W (Phillips)

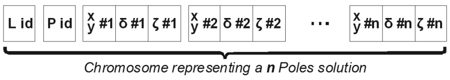


Fig. 3: Chromosome representation

GAs are often applied as a global optimization problem solver. More information about GA can be found at Mitchell, 1999 [5], among other authors. To implement a GA, three main subjects are required: definition of the chromosome structure, definition of a Fitness Function to evaluate possible solutions and to choose strategic genetic operators.

1) Chromosomes: A chromosome is composed by various genes and represents a solution to a problem. Each gene represents a variable of the proposed problem. The value assumed by each gene is called an allele. The best solution is used to the posterior CAD drawing and results.

From the left to right, the first gene is an id that referees to a text file which describes all the information about the type of light associated with a lamp, the power intensity, the market cost and the maintenance cost. The second gene is an id that represents the type of pole (material composition), its height and cost for installation and maintenance.

Each of the next 3 gene sets represents the pole coordinates, the direction of the luminaire focus and its slope, as can be seen in Figure 3. In this chromosome, n poles are represented.

The luminaire direction (δ) varies by 45^o intervals, thus running the cardinal points: 0^o to East, 45^o to Northeast, 90^o North, and so on. The luminaire slope (ζ) varies in 15^o intervals, with the angle of 0^o as the reference that indicates the luminaire is parallel to the work plan, i.e., its focus coincides with a perpendicular line to the plane.When tilted in 45^o, its preconfigured maximum tilt, the luminaire focus will be coincident with a 45^o line to the plane. These angles are shown in Figure 4.It is important to note that in this implementation, the distance between the actual position of the luminaire and the base of the corresponding pole (ΔdL) tends to zero, since

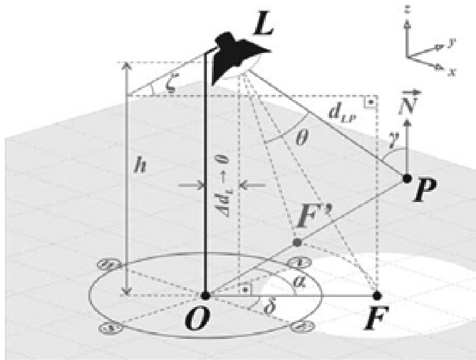


Fig. 4: Schematic of the guidelines: $\vec{N}$ = normal to the plane, γ = angle between the vector $\vec{N}$ and the line $\overline{LP}$, ζ = slope of the light, δ = direction of the light, ΔdL tends to zero, h = height of the lamp(post), θ = vertical angle and α = horizontal angle, both for calculation of illuminance

we consider the fixing point of the luminaire with the same coordinate of the pole in the x-y plane.

2) Fitness function: The fitness function deals with each chromosome of the population evaluating how good is it as a possible solution.

The fitness function evaluates an illuminance matrix to the corresponding horizontal work plan, using the Point-To-Point method applying (2). Using average level of illumination, by applying (3), the function determines the shadow area given by the light source positions presented in each chromossome. Using the illuminance matrix and the average illumination level, the function also determines the over-illuminated area. The energy consumption and assessment of costs given by the chromosome are also calculated.

These four evaluated features (shadow area, over-illuminated area, energy consumption, and assessment of costs) are the output results of the fitness function. A Paretos multi-objective strategy [9], [10] is then applied to optimize these parameters.

3) Genetic Operators : The following operators were implemented in the system:

`Elitism`

New generations will grant 10% of the last generation best individuals to be reproduced.

`Crossover (Recombination)`

The tournament selection method was used with 10% of the population. A canonical crossover was implemented in a way to respect the integrity of a light source entity. For pole coordinates, the Radcliff crossover operator was used.

`Mutation`

If the chosen gene for mutation is the first or the second one, then a different one is randomly chosen to replace it. If the chosen one belongs to a light source entity, a Gaussian mutation operator is applied, respecting minimum and maximum respective values.

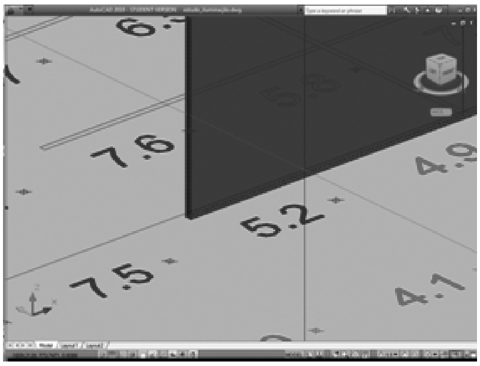


Fig. 5: The figures represent the luminous flux due to impact all the lamp at a given point

Fig. 6: Colors that are used to conceptualize the quantized points in the work plan

E. Information Visualization

With the objective to present the data for calculating illuminance in a simplified context and adequately informative, this work uses Information Visualization techniques [11].

Figure 5 shows one area in which each point is represented by its luminance level quantized and displayed in different colors that indicate comparative intervals with a value previously calculated in (3).

The thematizing colors limits are shown in Figure 6 (Portuguese version, 'Acima' means Above and 'Entre' means Between), where the value E_i is compared to the value $E_{average}$ and colors are presented in accordance with the percentage of tracks comparison.

Thus it is possible that the engineer has total clarity that every point is seen a defined light level and presented by the text.This information presented in colors, provide to the designer the information of light or dark compared to the average expected and recommended by the lighting standard.

This type of presentation intends to apply the concept of Graphic Excellence, i.e., communication of complex ideas clearly to maximize the efficiency of the engineer to the lighting design.

Looking at Figure 7, the yellow dots have a luminance above 200% of recommended average (20 Lux), representing a degree of excess which can be optimized to provide energy savings. The red dots represent the level below 50% of recommended average, which can mean points of sub dimensioning.

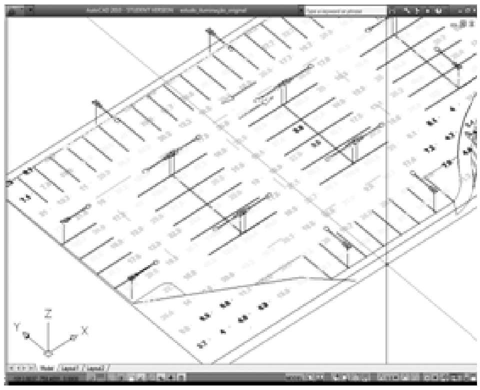


Fig. 7: Proposal Lighting poles calculated to 3 meters in height and Pressure Sodium Lamps 70 w viewed in 3D

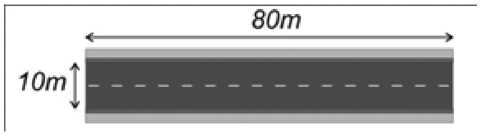


Fig. 8: Parking lot 80x10m street, the red area (1x80m each one) indicates where you can have poles

Below, it is highlighted the following features found in the application for a proposed future work for feature comparison with other similar applications:

- Allows the use of 3D meshes;
- Allows simultaneous viewing of 3D CAD models and field luminance in a single environment;
- Allows navigation and iteration;
- Views by different techniques of scientific Visualization (or Information Visualization).

Due to these aspects, the program proved effective in planning the lighting to provide a method of viewing information in a simplified and intuitive design engineers allowing for the reduction process and also facilitating the decision-making to design better projects. Besides, by exploring Virtual Reality techniques, the system allows an engineer to immerse and navigate in the virtual environment with the feeling that he is actually in the field with different views. This helps the user to configurate and to test different design alternatives.

III. Results

To understand the feasibility of this project, were used a traffic street, in a parking lot [12], as it can be seen in Figure 8. To this street, we consider a minimum illumination of 20 lux and only 1% of acceptable shadow area (less than 20 lux incident).

To set up the Genetic Algorithm, we use a population of 300 individuals and 50 generations by each number of poles. We considered only 6 models of luminaries & lamps:

- HLF432 — SONT400W;
- HLF432 — HPLN250W;

TABLE I: Processing time comparison

	Parking Lot street	Handball block
Variables database	6 light sources 4 highs of poles positioning area: 160m^2 lighting area: 800m^2	14 light sources 4 highs of poles positioning area: 256m^2 lighting area: 1056m^2
Generations by each number of poles	50	10
Total time demanded for solution	$2\frac{1}{2}$ hours	4 hours

- MWF230/150A/47.5 — MHN-TD150W;
- SWF23570SY — SON-T70W;
- MRP822POS.16/19 — HPI/T250W;
- SRC612 — HPI/T400W.

The poles used were those of 3m, 5m, 10m and 15m-high.The implemented application run on a PC with 3Gb DDR2 of RAM and Intel Core 2 Quad Q8200 processor. It took about $2\frac{1}{2}$ hours to reach the solution we can see in Table I.

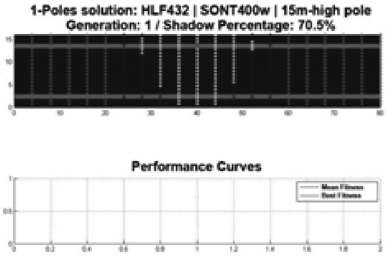
To designing our hypothetical street problem, there are at least 5 variables to be exchanged in searching efforts (meaning a 1-pole solution). This will increase by 3 for each new pole. So, a 3-pole solution will require from GA implementation to search inside an 11-dimensional solution space. The number of individuals and generations adopted were really insufficient to reach a near-by optimum solution. So, the algorithm moves on, adding a new pole to the probable solution.

In this way, a 3-pole solution should be expected for our problem, instead the 6-pole solution reached by GA. Figure 9a presents one of the early generations and figure 9b the results after 300 generations (50 for each new pole added to solution). As we can see, the best solution tended to be found among the first randomly chosen individual generation. Genetic operators are insufficient to alter this behavior, as we can see in Mean Fitness curve (figure 9), due to the small range of generations presented.

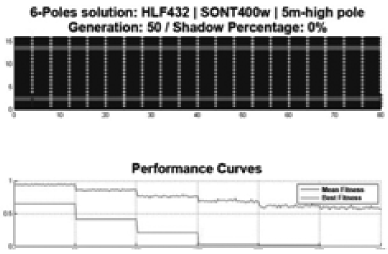
Another experiment was done, with a handball block chosen the same one used by Baade [13]. This time, we used a database with 14 sets of luminaire & lamps and 4 different highs for poles. The run of 10 generations for each number of poles exceeded 4 hours of processing. Because of this huge dimensionality, the GA parameters used were not enough for its conversion to an acceptable solution, as expected.

To emphasize the necessity of faster processing alternatives, a processing time comparison of reported experiments can be found at Table I.

It is necessary to improve the fitness function calculation and speed up the processing to enable larger number of individuals and generations.



(a) One of the early generations



(b) Result after 300 generations

Fig. 9: Experiment with a parking lot street: 10m wide, 80m long, sidewalk with 1m of service width and 2m passage width

IV. Conclusion

A Genetic algorithm shows itself as a powerful tool to general design optimization. One of its main issues is to carefully project a fitness function that covers all aspects of the problem and enables the finding of a near-optimum solution. Another main issue is the correct representation of a solution, here represented by the chromosome.

Whereas this initial work revealed possibilities of GA to handle lighting design problems, there are many improvements to be made. Computational costs reduction for these high dimensionality types of problem is our main quest, and is still under development. Already previewed solutions include the use of faster computers on processing phase, and the determination of better heuristics to cover all the nuances of lighting design problem, including complexities inherent to required calculations.

For future works are proposed:

- Implement new genetic operators or reformulate used ones, to increase the ability to search within the solution space of high dimensionality.
- Understand the feasibility of other programming languages to enable this application for a high performance computer cluster.
- Feasibility study for incorporation of this application to the one developed for AutoCAD that uses Information Visualization technology.

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