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Luminaire position optimisation using radiance based simulation: a test case of a senior living room

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Abstract

The design of a lighting environment is a complex task because of the need to satisfy multiple criteria, which are often in conflict with each other, for example, an adequate level of illumination needs to be maintained in a space to satisfy the requirements for various tasks, while not sacrificing illuminance uniformity or introducing glare and discomfort. The position of luminaires can impact on all of these criteria as well as influence energy consumption of the lighting system, therefore, it is necessary to optimise luminaire position for better performance. Application of computer simulation tools can provide an improved evaluation alternative design decisions to support decision making. However, computer simulation integrated with formal optimisation techniques is not well established within traditional lighting design. An optimisation methodology through computer simulation has been demonstrated in this study to identify optimal luminaire positions within a senior living room. Lighting simulation program Radiance integrated with a Genetic Algorithm (GA) based search technique has been used in this study as an optimisation process. A senior living room comprising two compact fluorescent lamp luminaires was considered as the test scenario. Luminaire position design was subject to meet specific horizontal illuminance uniformity and luminance requirements from guides published by professional organisations. The study demonstrated a methodology to apply formal optimisation technique with Radiance based simulation and the ability to support in decision making. Ray-traced Radiance simulations can be very time consuming, however, with controlled simulation parameters and multi-processor hardware it appears reasonable to integrate formal optimisation techniques with Radiance. The GA based optimisation technique proved to be successful in generating design decision. This paper describes the methodology adopted in detail with advantages and drawbacks, and identifies the potential of the methodology within artificial lighting design.

Keywords: lighting design, optimisation, computer simulation

1 Introduction

The design of lighting environments is a complex task due to the number of multiple criteria to satisfy, particularly when considering lighting for the elderly and low vision requirements to ensure safety and comfort. The design of luminaire positions a key lighting design task which plays important role in over all lighting performance and visual appearance of a space. The position of luminaires can: help to ensure the optimum illumination level and distribution over the desired working area; and influence energy consumption of the lighting system, it is thus necessary to optimise luminaire position for better performance. Lighting simulation tools exist to support designers by providing improved evaluation of complex design solutions. However, the application of formal optimisation techniques integrated with computer simulation is not well established within interior lighting design. Previous lighting related optimisations, integrated with computer simulation, can be found in: window design and associated energy performance (Wright and Mourshed, 2009); building components design (Wong et al., 2010); tunnel (Pachamanov and Pachamanova, 2008); and plant lighting design (Ferentinos and Albright, 2005), etc. Search techniques applied in lighting optimisation include Genetic Algorithm (GA), Artificial Nueral Network, and heuristics constraint based approach (Moeck, 2004), etc. However, the most validated program Radiance has not been well integrated with formal optimisation techniques and objectives were mostly based degree of satisfaction of illumination.

A computer simulation based optimisation methodology has been demonstrated to identify the optimal luminaire position of a senior living room. The Radiance lighting simulation program has been coupled with GA based search method to formulate the optimisation process. The luminaire position design was adjusted to meet specific horizontal illuminance and vertical luminance requirements.

2 Optimisation approach

2.1 Problem definition

The problem case selected for this study is a typical senior living room in the UK. The spatial layout of the room is illustrated in Figure 1. The room comprises two compact fluorescent lamp luminaires as part of the lighting design scheme. The ‘primary luminaire’ was located at the central area of the room and the ‘secondary luminaire’ was located near the entrance and the bathroom doors. Design criteria for the elderly and low vision were obtained from the guidance on low vision published by the Illuminating Engineering Society of North America (IESNA, 1998, 2000) and the International Commission on Illumination (CIE, 1997). The Chartered Institution of Building Services Engineers (CIBSE) Code for Lighting (CIBSE/SLL, 2002) was consulted for information pertaining to the general lighting design criteria. Based on a critical review of literature (Shikder et al., 2009) and guidance on general (e.g. CIBSE/SLL, 2002) and low vision (e.g. CIE, 1997; IESNA, 1998, 2000) lighting design, the objectives and design criteria were selected for optimisation. The locations of the luminaire were varied between discreet positions (as illustrated in Figure 1); the objective was to ensure that there is adequate light over working areas and distributed uniformly within the room to affirm visual comfort. This was defined by the average horizontal illuminance level and uniformity of illuminance. A maximum luminance value for wall surfaces was applied as a constraint to limit glare.

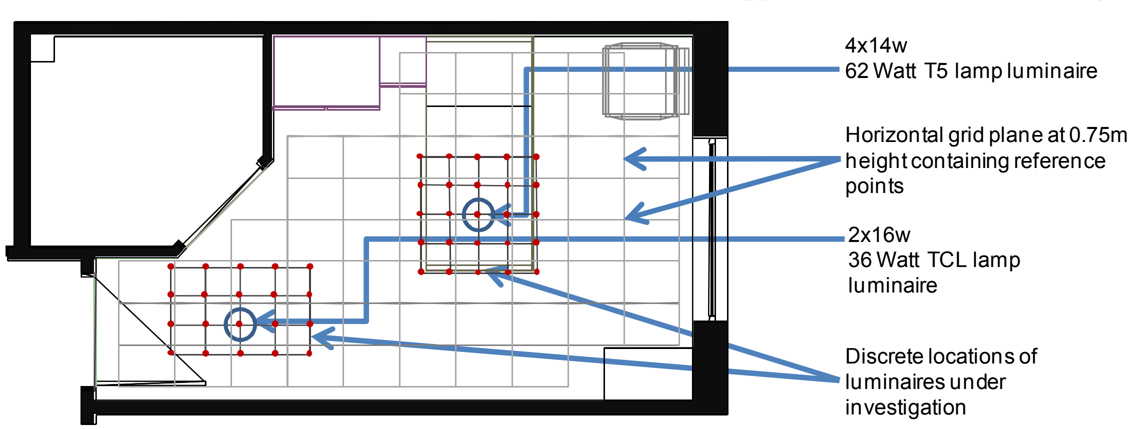


Figure 1. The spatial and lighting layout of the problem case: a senior living room.

2.2 *Visual environment analysis method*

Horizontal illuminance levels on the reference plane (at 0.75 m height from the floor) were obtained by Radiance simulation. The average illuminance in the room was calculated using the Equation (1).

$$I_{avghor} = \sum_{i=1}^{n} I_i \Big/ N \qquad (1)$$

I_{avhor} is the average horizontal illuminance; I_i is the horizontal illuminance of the reference point *I;* and N is the total number of reference points. Illuminance uniformity over the reference plane was calculated using Equation (2).

$$U_{hor} = I_{\min hor} \Big/ I_{avghor} \qquad (2)$$

U_{hor} is the horizontal illuminance uniformity; I_{minhor} is the minimum horizontal illuminance; and I_{avghor} is the average horizontal illuminance.

Apart from maximizing the horizontal illuminance uniformity, the reduction of glare is a significant criterion for lighting design. Glare occurs due to the presence of concentrated and/or high luminance within the visual angle. To avoid glare, a constraint was set for the vertical illuminance levels, values of which were obtained at points on the vertical reference planes with grid points covering all wall areas of the room. The limit for the vertical illuminance level was obtained by identifying the maximum allowable luminance of the wall surfaces (350 cd/m^2) and by calculating the corresponding illuminance using Equation (3).

$$L = (E \times R) / \pi \qquad (3)$$

L being the luminance at the reference point (cd/m^2), E is the illuminance at the reference point (lx) and R is the reflectance of the surface (%).

2.3 *Problem formulation*

The primary objective of the optimisation was to ensure horizontal illuminance uniformity with three constraints. The problem can be explained as lack of uniformity minimization problem. Equation (4) describes the optimisation objective.

minimize: $f(x) = -U_{hor}$ (4)

subject to: $I_{\max hor} \leq 750$ (5)

$I_{\min hor} \geq 100$ (6)

$I_{\max ver} \leq 1500$ (7)

Where: U_{hor} is the horizontal illuminance uniformity; I_{maxhor} is the maximum horizontal illuminance at the reference plane (lx); I_{minhor} is the minimum horizontal illuminance at the reference plane; (lx) and I_{maxver} is the vertical illuminance at the reference plane (lx).

2.4 *Optimisation framework and algorithm*

The framework for the optimisation was proposed to develop a decision making support system using computer simulation. Figure 2 describes the framework by different tools and their various stages during the optimisation process. The process included Genetic Algorithm (GA) based search technique integrated with Radiance based simulation. Environmental geometric modeling for Radiance simulation was conducted using Ecotect software and the GA script was written within the

Ecotect Scripting interface. Radiance generated results of vertical and horizontal illuminance values were stored systematically in American Standard Code for Information Interchange (ASCII) data format and accessed by the integrated optimiser to identify stopping criteria.

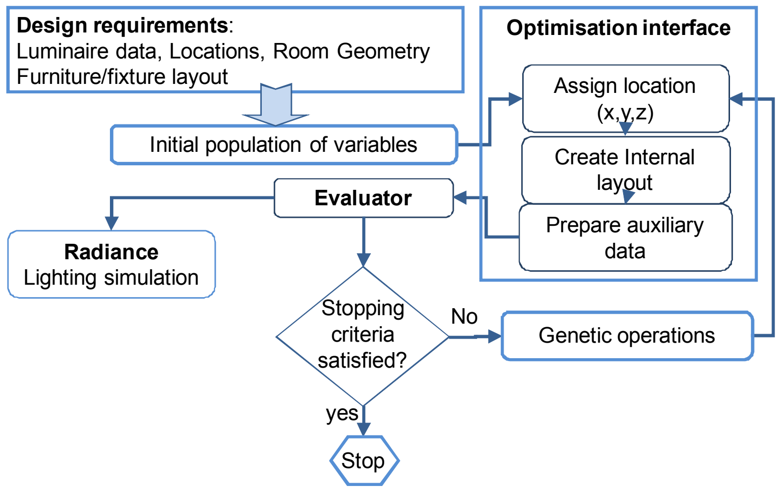


Figure 2. Optimisation components by GA based search process.

3 Example optimisation

The example optimisation was based on a senior living space as described in Figure 1. The space is a purpose built elderly living room with en-suite facility comprised of two compact fluorescent lamp luminaires. The objective was to identify the best position of these two luminaires meeting recommended horizontal and vertical illuminance requirements. The room contained general furniture (e.g. bed, wardrobe, drawers and chair). The detailed modelling and simulation procedure has been described in the following sections.

3.1 Modelling and simulation

Environmental modelling for simulation was conducted by Ecotect software. This included three dimensional geometric definitions of the room with its components, luminaire positions and material properties. The intensity distribution of the luminaires were modelled using photometrics obtained from the manufacturer. Two compact fluorescent lamp luminaires were manufactured by Zumtobel lighting manufacturer. Catalogue reference names of the luminaires are: Lightfields 4x14w - 62 Watt T5 lamp luminaire (primary luminaire); and Panos 2x16w - 36 Watt TCL lamp luminaire (secondary luminaire). IESNA photometrics of these luminaires were downloaded from the manufacturer's website and used as light source definition.

The model contained: 78 horizontal illuminance calculation points located at a height of 75 cm; and 660 vertical illuminance calculation points, which covered all walls and door surfaces. These reference points were defined by x, y, z positions and the direction vector. The Ecotect Scripting interface was used to write the GA script and correlate with the Radiance simulation program.

3.2 Optimisation problem variables

The design variables were position of two luminaire defined by x and y co-ordinates. The primary luminaire had 25 discrete positions and the secondary luminaire had 20 discrete positions (Figure 1). The illuminance values produced by two luminaires within this variable locations were analysed to identify the optimal positions.

4 Results

Figure 4 shows the solution space characteristics for the uniformity of illuminance. Figure 5 describes the genetic search result by best fitness value against generations. Figure 7 shows a comparison of different results (uniformity and maximum vertical illuminance) produced by six randomly selected solutions. The results suggest that different combinations of luminaire positions within the search space result in different uniformity values, which varies from 0.33 to 0.65. The solution space clearly demonstrates variability of results within the small search space. This entails the authenticity of the optimisation in interior luminaire arrangement. The generated solution also filled maximum vertical illuminance criteria, which established the solution as glare free from very high luminance.

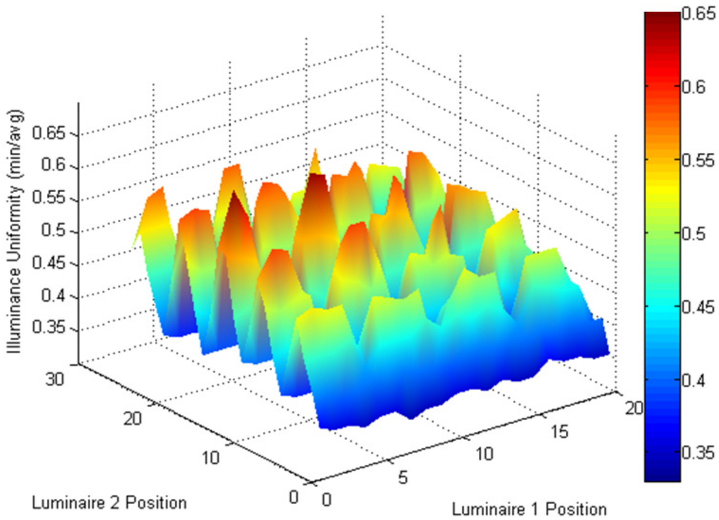


Figure 4: Solution space characteristics.

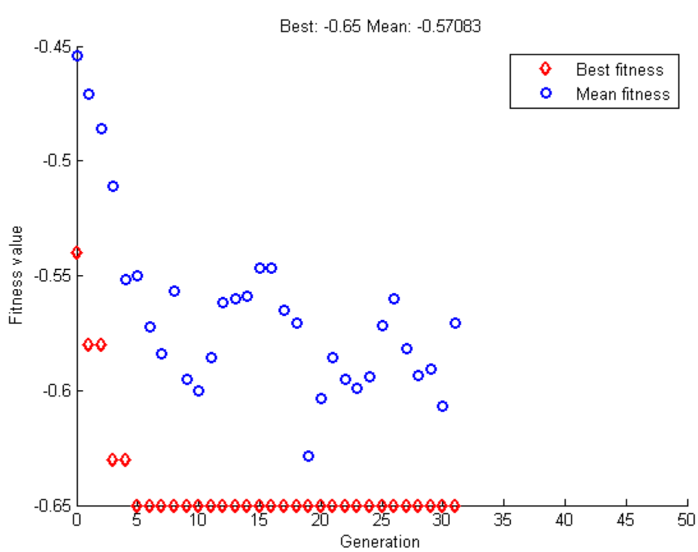


Figure 5. Best function value (fitness) vs. Generation.

UG1 = 0.33
I_{maxver} = 286 lux
Lum1 position: 4800, 2600
Lum2 position: 2850, 2150

UG1 = 0.40
I_{maxver} = 695 lux
Lum1 position: 3800, 2350
Lum2 position: 2850, 1400

UG1 = 0.40
I_{maxver} = 1913 lux
Lum1 position: 4050, 2100
Lum2 position: 1950, 2150

UG1 = 0.39
I_{maxver} = 10449 lux
Lum1 position: 3800, 2850
Lum2 position: 1650, 2150

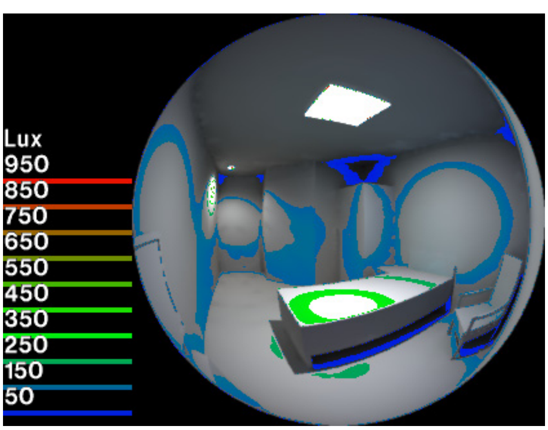
UG1 = 0.45
I_{maxver} = 10407
Lum1 position: 4800, 2100
Lum2 position: 1950, 2150

UG1 = 0.51
I_{maxver} = 609 lux
Lum1 position: 4550, 2850
Lum2 position: 2250, 1400

UG1 = 0.53
I_{maxver} = 622 lux
Lum1 position: 4550, 3100
Lum2 position: 1950, 1400

UG1 = 0.65
I_{maxver} = 591 lux
Lum1 position: 4550, 2600
Lum2 position: 1950, 1400

Figure 6. Comparison of uniformity of illuminance and maximum vertical illuminance values for different luminaire positions (Here Lum1 is 'Primary luminaire' and Lum2 is 'Secondary luminaire'.



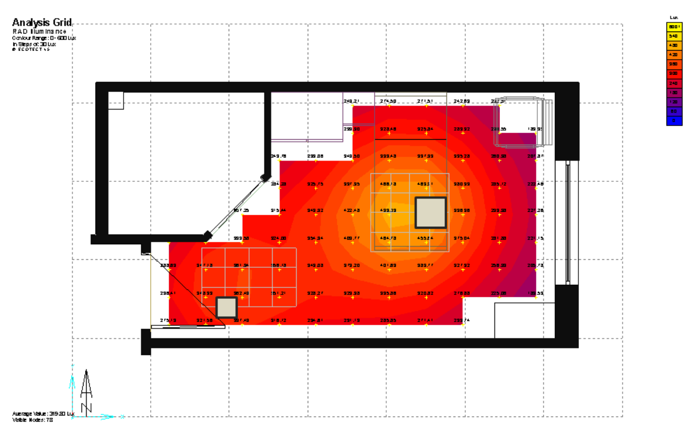


Figure 7. Illuminance image (left), luminaire positions and horizontal illuminance levels over reference plane (right) of the best solution.

5 Discussion and conclusions

This paper demonstrated a methodology of applying a GA based optimisation process within interior luminaire arrangement through Radiance based simulation. The application of Radiance simulation has been validated for interior lighting simulation given the accuracy of its output (Ward, 1994). The proposed methodology has demonstrated novelty in several aspects of lighting optimisation. The methodology is a new approach of applying the Radiance simulation engine coupled with a formal optimisation method based on GA. This procedure with increased evaluation of simulation results has established a new decision support process for lighting design. Architectural design decisions are driven by many factors which includes the design driving force as well as designer's intuition. The proposed methodology is strictly analytical rather than intuitive. However, integration of visualisation and interactivity can make the approach more suitable for creative design process.

The analytical process included two major lighting design criteria, they are illuminacne and luminance analysis. Horizontal illuminance analysis was conducted by calculating values over reference points, which is a well established methodology. Set grid points covered all working area at recommended height. Objective and constraints were taken from recommended guides that ensure compliance of the methodology with the standards.

Luminance values of wall surfaces were analysed by simulating vertical illuminance values over reference points located on to the wall surfaces. This particular methodology shows significant future potential in the design of elderly and low vision lighting. Although not implemented in present optimisation processes, the vertical illuminance values over analysis grid can be further used in evaluating luminance uniformity and ensure adequate illumination level over significant vertical surfaces (e.g. exit door or vertical text labels). Developed vertical illuminance data can further be used for virtual reality (VR) representation of the simulation output. Each grid point value projected onto surface vertex can produce the desired luminance visualisation in VR environment. This will provide the ability to visualise the simulation output in interactive environment.

The proposed methodology also demonstrates a systematic way of evaluating alternative design solutions using computer simulation, which made the decision making process more valid. Though commercial lighting simulation programs provide options to calculate illumination level and uniformity, they do not offer an efficient way of evaluating alternative design solutions without manual reconfiguration for each solution, thus the search process becomes very labour-intensive and limits the number of alternative designs evaluated. The demonstrated methodology is a systematic approach that involves increasing the number of alternative design solutions within the decision making process.

It can be concluded that a formal optimisation method based on GA can be successfully integrated with Radiance based simulation to identify optimal luminaire positions for interior lighting design. The integrated approach was not only successful in evaluating horizontal illuminance but also identified the potentiality for applying the optimisation process in luminance analysis, which is significant for elderly and low vision lighting design. Further research is required to apply the optimisation process in complex problems with multiple objectives including luminance contrast analysis.

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