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Multi-objective optimization as a new approach to illumination design of interior spaces

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ABSTRACT

The illumination design is in general oriented towards attaining a prescribed illuminance on a work plane with the most economical lighting configuration. This work presents a new methodology to find the location and the luminous power of the light sources to satisfy a prescribed illuminance on the work plane with the constraint of lowest power consumption. Mathematically, the illumination design is inherently an inverse problem in which the boundary conditions associated to the light sources are unknown. In the proposed methodology, the inverse analysis is formulated as an optimization problem, in which the objective function aims at minimizing the total power of the light sources as well as the deviation between the prescribed and the resulting illuminance. The optimization problem is solved with the generalized extremal optimization (GEO) algorithm. The lighting calculations are based on the radiosity method. The examples discussed in the paper consider the prescription of uniform illuminance at the bottom surface of a rectangular space. The methodology leads to a set of design solutions that are capable of satisfying the problem with different levels of accuracy and energy consumption.

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1. Introduction

Although illumination has long been an inherent part of architectural design, only more recently the art of illuminating spaces has evolved to become a science. The evolution arose from the gained understanding of the nature of light and the establishment of the equations that describe the transport of light in spaces. Due to the complexity of the light transport, the first methods involved various approximations to allow rapid, simple estimations of the illumination of a space from daylight and/or artificial light. Of the first approaches, the lumen method [1] still finds widespread use among illumination designers, but cannot account for many complexities (such as shading, non-uniform distribution of the luminaries in the room, etc.), and at best can satisfy the specified illumination only in the average sense. Other more realistic methods, such as ray tracing, radiosity or hybrid approaches, arose from techniques that were developed by the computer graphics and the radiative heat transfer communities. Those methods can account for the transport of light in fine detail, but on the other hand require computational tools for the solution of the resulting equations. In the last few decades, a number of free and commercial codes have been developed to assist in engineering lighting calculation and photorealistic architectural rendering [2–10]. With the computational techniques, it is possible to perform illumination calculations considering specular, diffuse and directional-diffuse reflection, combined daylight and artificial illumination and complex geometry settings.

In spite of the advances in lighting calculations, the designer can still face considerable difficulty to design an illumination system that satisfies with accuracy the desired illuminance on the work plane. For instance, several applications, including manufacturing processes, plants growth and domestic animals reproduction, require specific illumination intensity [1]; another problem of interest is controlling the luminous environment to meet human satisfaction [11–14]. Employing the conventional techniques, the designer must specify the location and power of the light sources, and run a suitable computational code to find the resulting illuminance on the work plane. If the achieved illuminance is not the one required, it is necessary to redo the calculation until a satisfactory solution is achieved. Due to the complexity of the light transport, it is in general very difficult to make a new guess from a previous attempt. The designer is left to choose the best solution from a collection of trials, which is probably not the best possible one.

A more effective approach would be a direct determination of the location and power of the light sources from the specified illuminance. A similar problem, in both terms of mathematical formulation and specification of the boundary conditions, is the thermal design of

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