Simulation for Daylighting in the Real World
The art and science of usability

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Abstract. *Technology has been an obvious solution to the increasing complexity of the built environment. As the number and specificity of use requirements increases, designers, clients and managers tend to segment the overall problem to manageable aspects only tentatively linked to each other. As a result, aspects such as ventilation and lighting tend to rely more on mechanical means than on the affordances of the overall design. Ironically this increases the complexity and opacity of the built environment probably to a greater extent than rules, regulations and requirements. The paper presents a review of available computational methods and techniques that aim at a more coherent approach by supporting integration of (day)lighting into architectural designing. It proposes that the two main courses of further action are the improvement and updating building regulations, and the combination of quantitative knowledge of good, existing daylight designs with advanced simulation-based analyses of early design proposals. Improvements in daylighting design and the integration of daylighting in design solutions depend primarily on design guidance based on the coordinated development and thorough understanding of usable measures such as the Daylight Factor, the Daylight Performance Index and function factors. A major prerequisite to both simulation and design guidance are robust and detailed geometrical 3D models that accommodate both the input and the output of design actions and transactions.*

Keywords: *Simulation; daylight; integration.*

Introduction

This article is the result of a decade of practical experience in creating virtual environments, performing lighting simulations and developing related production tools and software additions. It provides a survey of both the technological and practical state of the art in daylight simulation and daylight design, and proposes several key issues for future research. The main purpose of this article is to point out feasible directions to improve (day)light design using computer simulation.

In current architectural design practice there is a lack of intelligent use of computer-based technology. Instead of accusing architects of ignorance, we need to address aspects of usability and necessity. Everyone is familiar with the beauty and relevance of daylight. However, when asked (Dutch)

government officials and architects generally respond in a way that defines the main problem with daylight design: "There is no daylight problem". From a technical point of view we have to realize the truth of this, since every building is fitted with (not always well-designed) artificial lighting that is capable of providing the prescribed lighting conditions, even in a total absence of daylight.

Currently there are two main methods for analysis of daylight performance: physical scale models and full-size digital models. It is noteworthy that unlike thermal, acoustic or structural models, physical models for lighting do not require scaling corrections (Mardaljevic, 1998). However, with the advance of computational speed, the acceptance of digital design tools, the flexibility of geometric, surface and sky models and its potential reliability (estimated at ±10% by Mardaljevic, 1998), computer-based daylight simulation is the rising star. One crucial detail is that it is by no means easy to obtain reliable results from computer simulations. In contrast to scale models, mistakes, errors and inaccuracies can easily remain unobserved in a simulation.

Simulating daylight

It is widely acknowledged that there are currently two tools (and underlying approaches) that qualify for daylight simulation: Radiance and Lightscape. In the past decade Lightscape has become integrated in Autodesk Viz, while 3ds Max in release 7.5 has finally provided the adaptive subdivision that was available in Lightscape ten years ago. Although a case can be made for using Lightscape within its particular strengths (Ng, 2003), we consider Radiance to be superior in daylight modelling (including several CIE sky models as well as Perez and even user data models), and far superior in handling complex geometric models. Because of its extended backward raytracing calculation method, Radiance requires no specific modelling strategy, while Lightscape poses severe

geometric restrictions originating in the radiosity calculation method used. Furthermore, the reliability of the Radiance simulation method has been proved by several validation studies.

Nevertheless, the usability of Radiance suffers from serious drawbacks, especially in the geometric modelling, texturing and surface smoothing capabilities. To cope with this, we have programmed both a translator from 3dsMax to Radiance and additions to the Radiance core so as to provide a flexible, reliable and usable simulation environment. As in many computational areas, "garbage in, garbage out" is a rather adequate description of light simulation conditions. All aspects of geometry, surface reflectance (BDRF), and sky modelling need to be defined with great care. When handled with due care, Radiance is able to provide us with the best of both worlds: visually compelling imagery and reliable lighting calculation.

Case Study: Expansion of Royal Library, The Hague

In the spring of 2003 the board of directors of The Royal Library in The Hague was concerned with the combination of daylight and artificial light in a planned addition to the Library spaces, which would accommodate a variety of functions, ranging from circulation spaces to an exposition area for delicate objects. The owner of the building (the Government Buildings Agency) commissioned the development a digital model for simulation. The main aspect of the simulations would be the visual quality of the spaces involved under varying lighting conditions.

The basic question was whether the simulation could technically perform this complicated task including detailed geometry, daylight, standard artificial lighting, custom lighting and daylight coverage strategies and still produce reliable, usable simulation results. The combination of Radiance and in-house developed tools was deemed sufficient, provided reliable input data was made available.
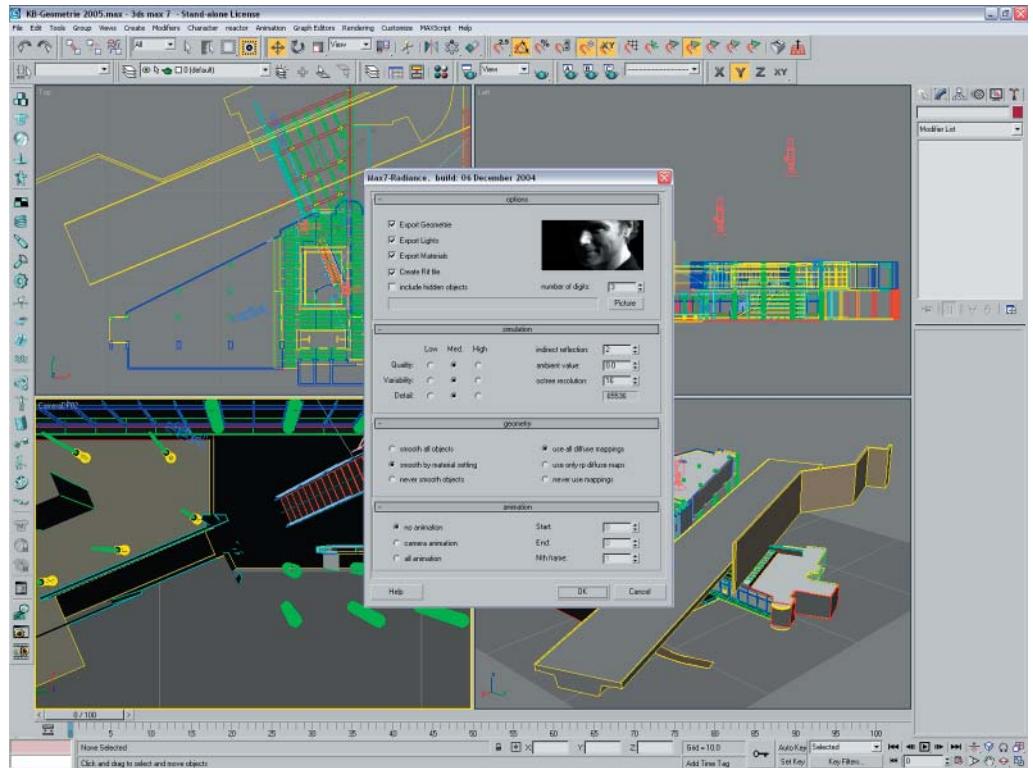
Figure 1. Exporting geometry, calculation setup and viewpoints from 3dsMax

Acquiring the required data for meaningful simulation was a task of varying difficulty. As is common in architectural design, the geometric definition was the clearest task. Based on AutoCAD drawings from the architect's office, the construction of the 3D model proved fairly straightforward (Figure 1).

Since no measured reflectance data was available, reflectance was based on colour description in the RAL-Digital 3.0 software from the Deutsches Institut fur Gutesichering und Kennzeichnung E.V. Most surfaces were considered to be perfectly diffuse, some required additional mirroring settings. For a number of general lighting fixtures, as proposed by a consulting engineering company, the luminance data were available as photometric webs in the IES format. The remaining light sources, including a custom designed lightwall, were individually defined (Figure 2).

A number of simulations were conducted with Radiance, resulting in series of images depicting the variation in visual experience during the day. To account for the non-linearity and accommodation functions of the eye, specific corrections were made to the datasets using pcond.exe, a utility that comes with Radiance (Figure 3).

Other simulated design variations included the introduction of sun screens on several window glazing in the south and west facades (Figure 4).

Furthermore, the central colour-varying lightwall provided great changes in atmosphere, reflected in the colour-bleeding effects on nearby

Figure 2. IES-defined lighting fixtures

Figure 3. Varying daylight conditions combined with artificial light (eye-corrected)

Figure 4. Sun blocking foils on first floor

Figure 5. Custom lighting with changing colours

surfaces (Figure 5).

During the stages of construction, simulation and final presentation, the produced images were immediately used to redefine architectural, material and lighting elements. The spatial visualization capacities of architects and consultants made constructive use of reliable visual impressions. However, even after several discussions about the relevance of trying to predict the future, a common subject emerged: the illuminance levels (in lux) to be expected under daylight conditions. Interesting as it may seem, and bypassing several aspects of material, surroundings and lighting were not set up for this type of analysis.

Evaluating practice

The duality of artistic and engineering elements in architectural design is adequately illustrated by the two faces of lighting simulation: the attractive photorealistic image versus the cold numerical fact. In technical terms, lighting simulation can address both in a coherent manner. However, as in the case of the Royal Library, reality usually complicates matters. The construction of a digital building model can serve many purposes but we should not expect all of them to coincide at every moment.

The analytical representations of the simulation results (Figures 6 and 7) are quite reliable in computational terms. However, the project definition did not include any description of the necessary geometric, reflection or lighting conditions for the analysis. With respect to the relevance of combining the picture with the number, the project needed additional constraints.

In general terms, light simulation needs to stimulate the formulation of good questions that can be answered in a practical and verifiable way. When an answer produced by means of simulation is unusable or unreliable, we must redefine the question in order to achieve better results. This does not imply revolutionary changes in the design process but

a rationalization and optimization of design procedures. Architects do not necessarily need to be instructed in matters of light. Transparent feedback and the ability to create alternatives and variations in an efficient and reliable manner frequently suffice. The main recurring problems are:

• (day)lighting is often considered more as an engineering than a design issue; for

• many architects consider daylighting as a mere result of façade design

• many projects lack an adequate definition of daylighting goals.

The light of tomorrow

Although daylight design is not yet perceived as a crucial issue among the building professions at this moment, we can expect a significant increase in attention to the use of daylight. The main reasons for this change are human physical and mental well-being, building maintenance cost reduction, and environmental costs. CAAD and especially computer simulation have a lot of support to offer in this in both methodical and technical terms. The transparent, reliable and efficient treatment of daylighting analysis requires the development of a logical and expandable framework that includes both numerical and synthetic image analysis.

Reproducible design analysis

In order to be able to compare designs we need global measures of the quality of daylight performance. These include visual comfort issues like glare, functional zoning, light levels variance and speed, but above of all Daylight Factor and Daylight Autonomy ratings.

Of the two, the Daylight Factor is the most significant. It is the percentage of measured illuminance in a space, compared to the unobstructed outside illuminance. Optimizing Daylight Factor distribution for specific functional requirements can have a direct effect on all subjects related to daylight quality. Daylight Factors has to be measured
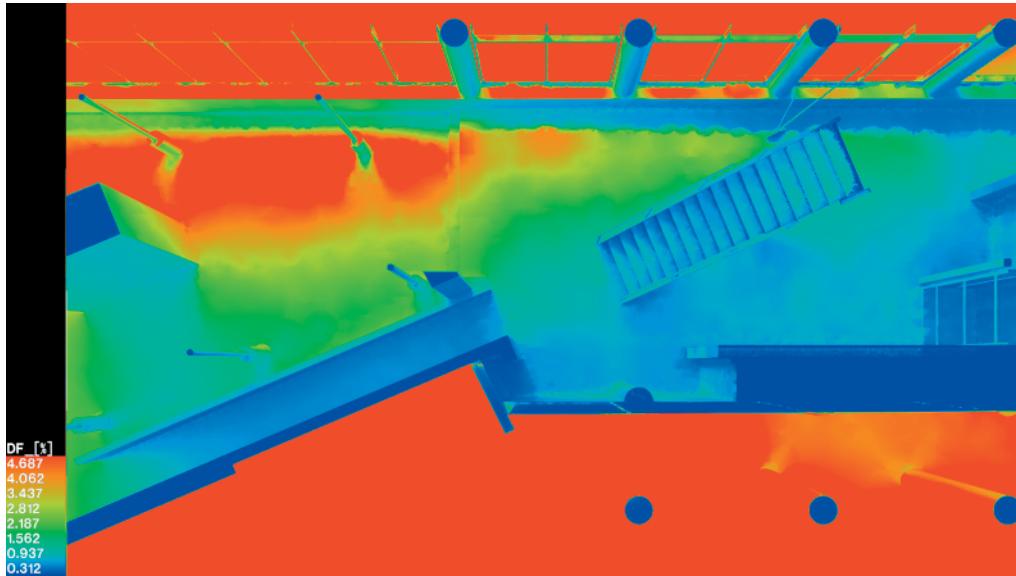
Figure 6. Daylight Factor distribution analysis ground level Royal Library
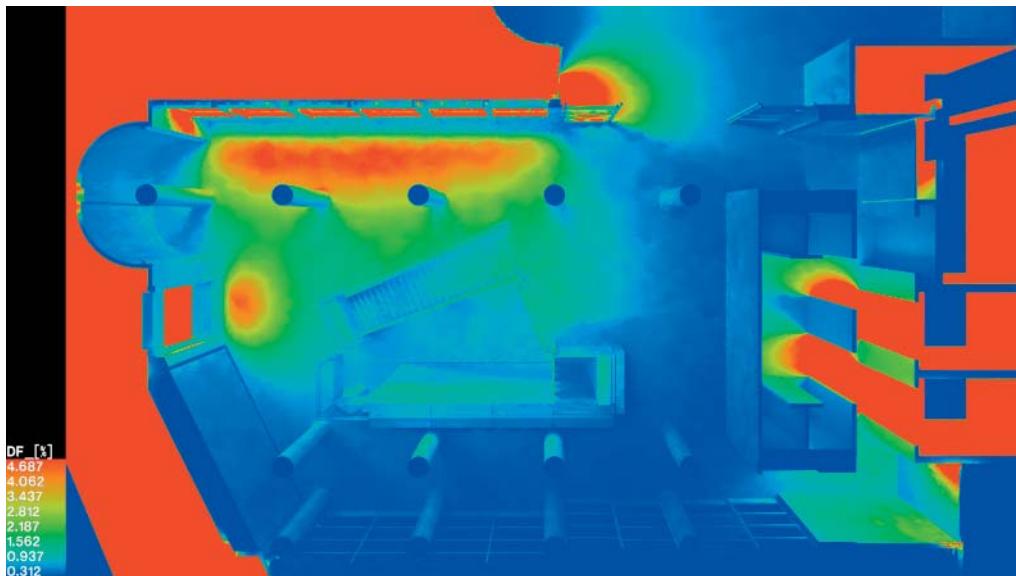

Figure 7. Daylight Factor distribution analysis first floor level Royal Library

and simulated on real surfaces (not on imaginary workplanes) and under CIE cloudy sky conditions. These can be collected in a comparative research database, based on field measurements of existing buildings. Simulating these measured buildings under the same conditions can greatly enhance the practical applicability of daylight simulation

The Daylight Autonomy provides a solid indication for energy consumption and possible maintenance cost reduction. It expresses the fraction of time that a specific use of a space is independent of artificial lighting.

Design guidance

Most architects have more than a passing acquaintance with (day)lighting issues. There are many buildings that demonstrate not only understanding and intelligent use of daylight in building quality and performance but also truly innovative approaches and products. However, good results seem to be restricted to complex design problems with extensive budgets. In many run-of-the-mill projects (e.g. housing, office buildings) there is insufficient time and attention for finer points and designers exhibit the unfortunate tendency to revert to stereotypes that may perform poorly. Even worse, even in prestigious designs where light is a central issue (e.g. museums) there are many cases where (day)light design is separated from architectural design.

There are several possible innovative design strategies for passive solar design, all of which must be developed in close conjunction with the architectural design. For instance, breaking up the spatial connection between daylight openings in the building envelope and façade openings for viewing purposes brings many opportunities for creative daylight design. With such strategies effective daylight design becomes once again the art of carefully balancing the positive and negative aspects of daylight.

Computer simulation, especially if coupled to extensive collections of well-documented cases and precedents, provides the means for effective, efficient and reliable specification, analysis and synthesis. Moreover, intelligent computer simulation can be an unobtrusive, supportive activity in the background of design activities that both identifies potential pitfalls and allows deferment of the solution on the basis of informed opinions (as opposed to unfounded guesses). However, it should be stressed that this presupposes fundamental changes in the current framework of architectural design, including more accurate specifications, awareness of lifecycle aspects and attention to performance, as well as a closer interest in what research has to offer on the methical and practical levels.

References

Chow, Ka-Ming Benny: 1997, Computation in Daylight Architecture, CAADRIA '97 Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia

De Groot, Ellie and Paule, Bernard: 2002, DIAL-Europe: New Functionality's for an Integrated Daylighting Design Tool, in Timmermans, Harry (Ed.), Sixth Design and Decision Support Systems in Architecture and Urban Planning - Part one: Architecture Proceedings

Glaser, Daniel C., Feng, Osbert, Voung, Jan and Xiao, Ling: 2004, Towards an algebra for lighting simulation, Building and Environment, 39, pp. 895-903

Lam, K.P., Mahdavi A. and Pal, V.: 1997, Algorithm and Context: A Case Study of Reliability in Computational Daylight Modeling, CAAD Futures 1997

Larson, Greg Ward and Shakespeare, Rob: 1998, Rendering with Radiance: the art and science of lighting visualization, Morgan Kaufmann Publishers, Inc.

Leslie, R. P.: 2003, Capturing the daylight dividend in buildings: why and how? Building and Environmen,. 38, pp. 381-385.

Moeck, M. and Selkowitz, S.E.: 1996, A computer-based daylight systems design tool, Automation in Construction, 5 (3) pp. 193-209

Ng, Edward and Chan, T.Y.: 2003, Computational simulation based daylight design for urban sites – validation, methodology and legality, Digital Design [21th eCAADe Conference]

Ng, Edward: 2004, Optimise Urban Daylight Design Using Computational Simulations, Architecture in the Network Society [22nd eCAADe Conference Proceedings]