COMPUTATION IN DAYLIGHT ARCHITECTURE

CHOW KA MING, BENNY
E-mail: kaming@cuhk.edu.hk
The Department of Architecture,
The Chinese University of Hong Kong
Shatin, HONG KONG

Abstract. Daylight phenomena are dynamic, complex and difficult to capture. Students find that they are hard to study and master. Basically, there are three approaches to the problem: physical modeling, graphic techniques and computation. Most of the students make use of all three channels to solve their design problem, but some of them don’t pay enough attention to the third approach - computation.

A lot of people will take for granted every single image rendered by the computer, because they think using computer automatically provides scientific truth. But the story is not that simple. There are different kinds of rendering applications which serve different purposes. Some of them are merely for illustration only. The computer can be used to create any kind of trick to produce so-called “Photo-realistic” images to impress the client, even when they are misleading. On the other hand, there are systems which are primarily for scientific visualization which use photometric data to produce accurate physically-based rendering. The more carefully you input the data, the more accurate will be the results.

The objective of this paper is to report on an experiment that uses a rendering program that uses physically-based environment to help students evaluate their daylight design options in an atrium. “Radiance” from Lawrence Berkeley Laboratory has been selected as the rendering engine and analysis tool. In order to apply Radiance in the architectural design I will discuss the methodology on how to create geometry, convert file format, define sky condition and assign photometric data.

1. INTRODUCTION

A second year Master’s student, Michael Fung1, is designing “A Future Workplace - Headquarters of China Light and Power”. His design is

1 Mr. Fung Chi Ho, Michael. Department of Architecture, The Chinese University of Hong

focussed on designing a workplace which is energy efficient and which can provide a more creative and effective work environment and enhance social interaction. Also, the workplace environment should have good visual and spatial qualities: no glare, good illumination and visual comfort. The building consists of several floors of workplace under an atrium space. He is looking for a way to evaluate his architectural daylight design options.

*Figure 1*: The exterior view of the proposed atrium design

Basically, there are a few different approaches available for the students to evaluate their daylight design options: physical modeling, graphic techniques and computations.
1.1 PHYSICAL MODEL

Exposing the physical model under daylight conditions undoubtedly gives a very good visual picture to students to understand the daylight space, especially with the use of delicate camera which can be inserted into the scaled model. The problem is how to make the model explore under the actual sky conditions in different seasons. Testing the model at different times of day is not a problem. However it will be extremely time consuming to wait for the different seasons of the year. Also, carefully designed artificial sky domes are large, complex and expensive and not easily available.

1.2 GRAPHIC TECHNIQUES

Shading on a design drawing is also helpful for understanding the daylight design. But, it is only meaningful to the experienced designer. Most students can only rely on their intuition and imagination to construct daylight effect in their interior spaces. Carefully built perspective drawings can render detailed reflected light and tonal values on different surfaces. But in any case the output still relies heavily on subjective interpretations and extremely careful hand rendering.

1.3 COMPUTATION

Using computers to perform daylight analysis is the most effective way to obtain meaningful numerical data. One of the advantages is that you can simulate your environment in any configuration under any time conditions and location you desire. You can easily change the exterior obstruction, interior layout and wall finishes. Also, field observation and climate database can be manipulated and fed back to the design system to generate more accurate calculation. Most of the common sky conditions (such as completely overcast sky or average sky) can be simulated under the virtual environment as the standard on CIE and IES algorithms.

But we have to be aware that there are many different levels of the computer rendering. Some students are using the computer in a purely illustrative fashion to show the virtual space, not to predict lighting or true appearance. Also, most of the programs available cannot provide accurate enough results because of the limitation of the machine and the time it takes to finish the picture. So the student can only do a “photo-realistic” picture in which the superficial look becomes their first priority. Most of the time students construct the picture in their mind based on their intuition, and then try to make the rendering match the image by all sorts of faking techniques. An honest visualization of the proposed design is not achieved.
Some of the systems seriously deal with the accurate results. There are many good lighting programs available today, such as MicroLite2, Superlite3, Lumen-micro4 and Radiance5. They will perform fast and accurate calculations. But most of them utilize numbers-based input and numeric representation in the performance criteria. Even after encountering all sorts of difficulties inputting the data and running the simulation, there is still the problem of needing expert knowledge to interpret the simulation results.

The Radiance Synthetic Imaging System6 is chosen to predict the daylight conditions in a proposed atrium design. The reason for using it is mainly as a research tool. It was developed to predict the distribution of visible radiation in illuminated spaces. Also, the simulation uses a light-backwards ray-tracing method technique to build physically-based rendering.

2. LITERATURE REVIEW

Several academic research laboratories have made important contributions to the study of Radiance for lighting analysis in the design studio. The following is an outline of their primary contributions.

2.1 ARIZONA STATE UNIVERSITY

Mr. Lee7 and Miss Hardin's study, Daylight Visual Effects: An Interactive Multimedia Courseware Prototype for Beginning Design Students, describes their experiences with producing prototypes for daylight studies in 1993. The authors constructed an interactive multimedia courseware prototype, Daylight Visual Effects (DVE), based on Authorware. There is a multimedia database that can let students review previous years' student daylight designs, and successful daylight designs by famous architects. The system also provides a non-linear customized learning style to meet students’ needs, including still images and one-day animation to demonstrate daylight conditions in various locations at various times.

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2 Designers Software Exchange (DSE), Graduate School of Design, Harvard University, Cambridge.
3 Originally distributed by J. J. Kim, School of Architecture, Arizona State University, Tempe.
4 Lighting Technologies Frontier, CO.
5 Lawrence Berkeley Laboratory, University of California, Berkeley.
6 Main author: Gregory J. Ward, Lighting Group, Building Technologies Program, Lawrence Berkeley Laboratory.
7 Tsai-Sun Lee, Arizona State University
2.2 AUCKLAND UNIVERSITY

Matthew Carr\(^8\) built a web site to collect Radiance resources for architects. Students began to build models based on ArchiCAD and StrataStudio, and in 1993, Paul Bourke wrote a program to convert these files into Radiance description. A set of "off the rack" materials are available on the web site, such as brushed steel, water and wood flooring. The most useful resource in Auckland's study is the IES Luminaire Descriptions Library. It contains forty-nine artificial lighting fixtures in IES luminaries standards.

Greg Elisara's research on the use of Radiance in architectural lighting design is another important series of studies resulting from the Auckland team's research. In Elisara's paper entitled *The Practical Utilization of Computer Imaging and Visualization Software for the Prediction of Interior Lighting Installations*, Elisara illustrates the accuracy of computer rendering and its limitations in generating realistic images. In his 1995 study entitled *Using the Radiance Synthetic Imaging System as a Tool for Developing Lighting Designs*, Elisara discusses the use of Radiance on lighting design to evaluate artificial lighting options in residential dwellings. In the same year in his report *Computer Aided Analysis of Natural Lighting Conditions for a Proposed Dwelling*, he outlines methods for applying Radiance to evaluate natural lighting and actual architectural plans of a site. He also generated and rendered an animation series based on standard CIE clear day.

2.3 UNIVERSITY OF OREGON

Kevin Matthew's\(^9\) research is outstanding for its ability to link various Macintosh rendering applications to Radiance. His laboratory is fully equipped with Power MachTen (UNIX for Macintosh) and Design Workshop (3D Solid Modeller). Students can easily access and use Radiance on their desktop Macintosh. Matthew has also collected an elaborate materials library containing detailed references on photometric data and an object's optical characteristics. A collection of miscellaneous Radiance hints and tips are also provided to assist the students in solving their particular problems.

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\(^8\) School of Architectural Property and Planning in Auckland University, New Zealand.

\(^9\) Department of Architecture, University of Oregon.
2.4 UNIVERSITY OF KANSAS

Moeck\textsuperscript{10} and Selkowitz\textsuperscript{11} offer an outstanding example of using photo realistic pictures to further assess the quality of a daylight design solution. It states that a powerful accurate simulation tool like Radiance is not widely used, mainly due to its cryptic command line input, which many daylight designers find too difficult to use. Therefore a mouse driven graphic user interface has been developed to allow designers easy and rapid input for all important context variables and design variables. The system can smartly figure out the cryptic command for Radiance from a graphic front-end. The design tool will then generate realistic 'visual task' photos together with numerical daylight factors in a particular design environment for the designer to evaluate his design options.

3. METHODOLOGY

The objective of the project is to compare the lighting quality in the workplace of the atrium using two different options. The first option is the atrium with clear glass only, and the second option is the atrium with clear glass and with 45 degree louver between the glasses as shown in figure 2.

![Figure 2: Roof components including coated glass, louver and I-beam.](image)

3.1 GEOMETRY

The proposed atrium is first modeled in AutoCAD with the same coordinate system used in Radiance as shown in figure 3. (i.e. Z-vector pointing the zenith (up), y-axis aligned with North, and x-axis point to East). After that, the model is rotated and aligned according to the actual site location (figure 4). Finally, Materials were grouped in terms of different layers and different colors. All the photometric properties of the objects will be re-assigned in the Radiance.

\textsuperscript{10} Martin Moeck, Department of Architectural Engineering, The University of Kansas.

\textsuperscript{11} Steven Selkowitz, Lawrence Berkeley Laboratory, Building Technologies Program, Berkeley, CA
3.2 FILE FORMAT CONVERSION

The dimensions are mapped in one unit as one meter. (These units can be applied to any scale as long as all the geometry and lighting fixtures are consistent). The file is then exported as 3DS (3D Studio) format and transferred to the UNIX environment. In the UNIX platform, the file is first converted into MGF (Materials and Geometry Format) and then from MGF to Radiance scene description format. All the materials are group in one single file, separate from its geometry.

3.3 SKY CONDITION

Only daylight condition is considered in this project. Therefore only one light source is needed in the whole simulated environment - global sun. In Radiance, there is a sub-program called “gensky” to generate the description of the sky at a given time, date and location according to the CIE standard sky distribution. The altitude is measured in degrees above the horizon, and the azimuth is measured in degrees west of South. For example, the following parameters will compute the standard CIE sunny sky distribution on September 1st 9:00 am.

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# gensky 9 1 9 -a 22.2 -o 114.2
# Solar altitude and azimuth: 49.8 -75.9
# Ground ambient level: 18.3
```
3.4 MATERIALS

There are basically few kinds of materials used in the atrium. Most of the materials are white concrete (sort of plastic). But the description for the atrium glass is handled with care. First, a glass construction handbook was obtained by the local vendor. All the thermal data are ignored in this stage and only visible light transmittance, reflectance and shading coefficient are considered.

In the Radiance, transmissivity at normal incidence on the glass surface is required. But most of the glass catalogue can only provide transmittance. Therefore, transmittance (Tn) is converted to transmissivity (tn) by the following equation found in the Radiance manual.

\[ \text{tn} = (\text{sqrt}(0.8402528435 + 0.0072522239 \times \text{Tn}^2) - 0.9166530661) / 0.0036261119 / \text{Tn} \]

3.5 REFERENCE VIEWPOINT

A desk and a chair has been put into the scene to simulate the virtual work place under the daylight environment, which is located in figure 5.
3.6 RENDERING

Subsequent to defining the material, two scenarios were simulated. One, the atrium with clear glass only, and the other, the atrium with louver between the glasses. September 1st was selected due to relatively high sun angle in Hong Kong, and three discrete time slots: 9:00 am, 12:00pm and 5:00pm. A series of images has been generated and studied.

All the images are computed and controlled by rfile for rad\textsuperscript{12}, under exactly the same exposure value, camera view parameters, and resolution. After the rendering was done by "rpict", illumination values were checked randomly on the desktop. The finished images were then piped to the sub-program "falsecolor" to compute the extreme points, so that we could use the same maximum values as a scale for the entire analysis. Iso-lux graph was also generated by "falsecolor" with the overlapping of the original image.

\textsuperscript{12} See "rad" on Radiacne User Manuel
4. RESULT

The following images show the result of the physically-based simulation of the atrium. One demonstrates louvers between the glass, and the other is clear glass on the roof.

4.1 ATRIUM WITH LOUVER (SEP 1ST 9:00 AM HK)

*Figure 6*: Illuminance map with values at various position on the desk

*Figure 7*: Iso-lux contours over the scene
4.2 ATRIUM WITHOUT LOUVER (SEP 1ST 9:00 AM HK)

Figure 8: Illuminance map with values at various position on the desk

Figure 9: Iso-lux contours over the scene
5. DISCUSSION

In the beginning, Radiance was difficult to use. People who used it had to be familiar with UNIX environment. The learning curve was therefore quite slow, also because of the complexity of the cryptic input and flexibility on numerous function files. Another reason is the lack of photometric data in the daylight environment.

Although Radiance is equipped with an accurate algorithm in its calculation, the output will not reflect this accuracy nor be realistic until people know how to use it correctly. Most of the common errors are not on the daylight source, but on the incorrect photometric data on the materials. The solar angle can be computed from Radiance without any difficulty. Most of the standard sky conditions have been already supported by the Radiance, like standard CIE clear day, overcast day and intermediate day. The main problem is with the material assignment; there is no way for Radiance to compute the realistic physically-based behavior from inaccurate or non-existent material.

6. FUTURE WORKS

Based on the results of the daylight simulation I would like to explore further the correct photometric data assignment. More work has to be done on comparative studies of the physical environment with simulated environment in Radiance. In order the student to use Radiance effectively, a well organized photometric database is necessary.

Artificial lighting fixtures are not included in this simulation. Although lighting fixtures will not be as dynamic as daylight, there is a wide variety and many combinations available. If students were provided with a lighting fixture library, they could take advantage of the ready made Radiance description. In that case, they could overcome the difficulties of cryptic variables and could explore different lighting strategies for the design. The result would be a physically-based rendering which reflects the actual lumination in the space. As a tool, Radiance can then offer more alternatives and feedback to the design cycle.

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REFERENCE

Carr, Martin. "Lighting Analysis Using Radiance - A simple example". School of Architecture Property and Planning, Auckland University in New Zealand.


