THE IMPACT OF COMPUTER-BASED DESIGN TOOLS FOR DAYLIGHTING SIMULATION AND PREDICTION FOR A BUILT ENVIRONMENT

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Abstract. This paper investigates the application of computer daylighting simulation to provide qualitative assessment and comparison for designers to improve the built environment especially for non-technical architecture students. A comprehensive study was carried out to evaluate different daylighting design tools and to identify the limitation of current systems in the academic field. The paper will focus mainly on the dynamic information exchange between scientific visualization and the design decision-making process. Both architectural design studio environment and practical design problems in the real world setting were experimented and evaluated. Two case studies are presented: a proposed gallery space for a museum, and a detail architectural design of a community church. Architectural design alterations are proposed, simulated and discussed. The recursive feedback of the designers are studied and documented. Through a combination of qualitative assessment and comparison, designers can evaluate and compare different design options in the computing environment before implementing in the real world situation.

1. Introduction

The objective of this paper is to investigate the application of computer daylighting simulation to provide qualitative assessment and comparison for architectural designers to evaluate daylighting design alterations during the stage of schematic design and design development.

Many people accept any output by a computer as scientific truth. There are different kinds of rendering applications that serve different purposes, and some of them are merely for illustration (Larson and Shakespeare, 1998; Ward, 1994; Tsou, 2000).

Most designers use computer simulation or rendering software purely for illustrative purposes to show geometry and design scheme, not to scientifically predict lighting or the true appearance of the proposed architectural design under actual physical lighting conditions. The computer can be used to create
illusions and to produce so-called “photorealistic” images to impress the client, even they are misleading. The “general-use” computer rendering system itself is designed to help people to create rendering images based on their own preference and not designed to fulfill the special needs of simulating the physical environment. They can easily input any unrealistic values to achieve whatever the designer imagine. That kind of software aims at delivering presentable images to the designer as fast as possible. The algorithms they use are insufficient to represent the actual behavior of light.

2. Scope

The study focuses on how computer daylighting simulation can help architectural designers to further understand and predict the relative performance of proposed design options and daylighting strategies. The simulation itself will not automatically result in the improvement of either the daylighting design quality or the design method, but it will help designers to make design decisions based on available information. Professional daylighting design knowledge is still the core of daylighting design development.

3. Literature Review

A variety of research papers and conference proceedings has been searched and studied. Most of the scientific performance-based simulation tools are far from user-friendly to designers (Wolfe and Sears, 1996). Other major pitfalls in the building simulation environment are the lack of system integration and deficiency in design process. Many CAAD tools have been developed and adopted by different institutes to address specific problems (Moeck and Selkowitz, 1995). Even though similarities could be found among them, it is difficult to find all the components that designers required in a single package. Architects would like to visualize the aesthetic pleasure of an architectural space as well as the performance-based numeric data for daylighting design integration (Elisara, 1994; Martin, 1997).

4. Methodology

Through qualitative visualization and comparison, architectural designer can have a better understanding of the design options for decision-making. In order to enhance Radiance for architectural daylighting design and fill-in the gap between current modeling system and Radiance simulation system, a
collection of in-house software tools was developed and evaluated with studio case study and real world design settings.

Before investigating the application of computer daylighting simulation, there is a need to study and understand the conventional approach to daylighting design. The various daylighting design approaches, such as physical scaled model, graphical techniques and computation are studied. Precedent studies of computer daylighting simulation projects are discussed in the literature. The study of precedent helped to identify the problem domain, the paradigm shift, and the latest development of the daylighting simulation technologies.

Two case studies were completed to evaluate the effectiveness of in-house tools to the integration of Radiance into the design process. The case studies are selected from a graduate design studio project and a professional design project.

5. **Case Study I : Gallery Space of a Museum**

The first case study is focused on the application of computational daylighting simulation on the daylighting design in a design studio setting. “Central California History Museum in Fresno” (Figure1), a master year one studio project is selected for the collaboration and evaluating the project approach. The architectural designer, the student, will cope with computer daylighting simulation in the conventional design development. The research team acted as a computer daylighting simulation consultant to the designer. The proposed design consists of a gallery space in museum. The gallery space should have good visual and spatial qualities: no glare, good illumination and visually comfortable. Although the application of full artificial lighting approach seems to be the easiest and prompt solution to a lighting sensitive space, the designer still would like to make a feasibility study on introducing controlled daylighting into the space in order to further improve the lighting quality. The illumination level and visual comfort glare are the key components that account for the lighting requirement and spatial quality of the environment. The architectural designer finds a match on applying computer technology to provide him an extra information for making design decisions to further improve the lighting condition related to the design of diffuser on skylight structure.
5.1. PROJECT APPROACH

The objective of this project is to make a comprehensive assessment on the lighting quality of the gallery in the proposed museum. Physical scaled model tested in both artificial and natural lighting environments are the traditional method to provide direct and simultaneous feedback to the designer. Nevertheless, the exponential development on the current computing technology seems to generate a paradigm shift to greatly reduce the time spent during the design development stage with a promising accuracy and a new dimension on design alternatives.

5.2. DESIGN STRATEGY

The skylit gallery space is composed of layered roof that consists of external waffle stainless steel diffuser as shading device, a clear glass panel for the pitched roof, and an inner frosted glass false ceiling in order to provide multiple controls on the sunlight before it enters the space.

Based on the study of the sunpath diagram of Fresno and the building orientation, the depth of the diffuser is determined by the highest summer solstice and lowest winter solstice angles. The designer want to make sure there will be no direct sunlight will cast on the wall surface for painting display.

5.3. SIMULATION RESULTS

A series of simulation have been carried out and studying the daylighting intensity of the gallery space in different time of the seasons. The simulation results showed that the natural lighting illumination level, after passing
through the layered roof, is adequate for the time 9:00am to 3:00pm in both summer and winter periods (Figure 2).

Nevertheless, a strong contrast is noticed at the window wall, which may cause visual discomfort. Direct sunlight is observed during summer noontime and it may cause potential damage to the art works. Also, the current lighting diffuser is not good enough to protect the space from low angle direct sunlight during winter. Guth visual comfort probability chart is generated to visualize the lighting contrast in the environment (Figure 3).

5.4. DESIGN ALTERNATIONS AFTER SIMULATION

Based on the preliminary results of the computation daylighting simulation, new shading device is introduced on the exterior of the window to further reduce the possibility of glare. New type of diffuser on the layered roof is suggested on the south to further shade the space from the low angle sun during wintertime. Frosted glass with less transmittance is proposed to further widely diffuse the daylighting into the space.
6. Case Study II: Fairview Church

The second case study is focused on applying computational daylighting simulation in the detail design process in a real world architectural project, the Fairview Park Alliance Church.

Integration of daylighting has been regarded as the major concern of the designer in the church design. The daylighting is a very dynamic element, which is not easy to guarantee certain daylighting design strategy will be functional in all the seasons of the year. The possible combinations of factors and performance matrix are quite far away from pure imagination. Past experience played an important role on making the design decision. Once any factor has been changed such as building orientation, types of glazing or even surrounding environment, the end result may be unexpected compared with the precedent. The architect therefore would like to have a detailed analysis on a number of key design issues, most notably in the areas of daylighting studies.

After the schematic design, the architect would like to carry out an in-depth study concerning design details, such as types of glazing, color scheme, and different combination of glass transmittance and reflectance. Since different types of glass would induce different performance for the interior and exterior in different times of the day, the study is then focused on defining the criteria for glass selection of the Church.

6.1. Design Strategies

The Church has a “Cross”-shaped window on each of the South and the North elevation (Figure 4). The choice of glass for the elevations therefore would have multiple effects on the elevations, spatial quality and the divine character of the church. In order to highlight the "Cross" at North and South elevations, central clear glass, the designer would like to explore different combination of types of glass for the remaining glazing, such as frosted and tinted with various levels of transmittance. The matrix of different combination with different time of the seasons was generated for discussion.

Figure 4. The "cross"-shaped window of the proposed church design.
Apart from the "Cross"-shaped window design, the architect also interested to evaluate the glazing ratio and the illumination level of the church on windows at East and West elevations (Figure 5). He would like the research team to study the effect of illuminance levels if windows at upper level are frosted glass and/or portions of windows at lower level are also frosted.

![Figure 5. The upper and lower level glazing at east elevation of the church](image)

### 6.2. SIMULATION RESULTS

A series of simulation have been carried out to study the visual contrast of the "Cross" and the remaining glazing with different combination using *Radiance* (Figure 6). Matrix of visual effect have been generated and discussed with the architect. A recursive approach is applied to narrow down the research exploration area. At the end, there is no perfect solution for the glazing combination, which will produce good contrast on the "Cross" in both exterior and interior views in all the seasons. Although the computer simulation results could not help the designers to find the "perfect" answer in this case, the possible solutions have been much confined to limited options. A lot of obvious misled results have been avoided. In this case, the architect selected one scheme out of two promising solutions according to the simulation results.
For the study of the illuminance level of the church interior based on different types of glazing at the East and West elevations, the decision making is more straightforward compared to the "Cross" design. The research team based on the suggestions from the architects to simulate the daylighting performance of the church interior in different time of the year (Figure 7). Lux levels are marked along the church floor in the computer simulation results. False color illumination maps are generated to study the intensity distribution pattern and for cross comparisons with other options. The architect was then based on the requirement of the illumination level of the space linked with different church activities to finalize the daylighting strategy of the space with a reasonable support from the computer simulated results.

Figure 7. Computer simulations of the illuminance level of the church interior.

7. Findings and Discussion

Because of previous experience with “general-use” rendering software, the architectural designer in both cases specified excessive geometric detail for the simulation model that adversely affected the speed of the computation. The level of abstraction becomes the bottleneck to optimize the computing performance while guarantee the major contribution components are not missing. The architectural designer highly appreciated the application of
computer technology to provide both qualitative assessment and comparison for evaluating different design strategies, which also helped to facilitate the design thinking and design decision making.

The designers in both cases expressed that they could only rely on theory, experience, and even guessing for making design decisions in the past. Nowadays, the scientific visualization could provide further information to architectural designer the integrated performance for decision-making. Although computer simulation relies on many assumptions, the error margin has been much limited compared to conventional guessing in some cases.

Scientific visualization itself provide a "visual based" platform to facilitate the design communication between architects and engineers. With the assistance by the concrete visual representation of the design problems, the multi-discipline groups can exchange the design alternatives and engineering concerns more effectively.

Even though the design specifications are incomplete during the early design stage, the basic and core configuration are enough to confine the problem and carry out computer simulation to identify potential design deficiency. Hong Kong’s high-density, high-rise urban environment provides a very complex urban daylighting environment. If computer simulation can be done in advance, some major problems could be identified and be avoided.

8. Future Works

Through the continuous interaction between architectural designers and computer daylighting simulation, it is found that the building materials and the corresponding manufactures’ specifications play an important role in the accuracy of the simulation. A carefully defined and comprehensive collection of typical Hong Kong construction materials with photometric data will be very useful for future daylighting simulation development. More works and studies are required to further validate and fine-tune the control parameters of the simulation process for higher accuracy. Better understanding of the professional daylighting design knowledge will help to identify the core of the problem domain and narrow down the study area of a design solution.

Artificial lighting fixtures are not included in the current study. Although lighting fixtures will not be as dynamic as daylighting, there is a wide variety of fixtures and flexible combinations.

Apart from the Radiance simulation system, other systems should also be investigated. Each simulation system may have its own unique strength in a certain specialized area. Expertise is required for the designer to choose the right tools at the right time for the right design problems.

Currently, Radiance is still too cryptic for most designers. The text-based interface is difficult to start with, which results in a very slow learning curve.
Desktop Radiance is now in beta release. It is a port of the simulation system to PC desktop computers with a user-friendly graphic interface whilst equipped with all of its original ability in computing accurate physics-based lighting simulation. More resources should be allocated to explore the potential of the package to architectural design education and professional practice.

Conclusion

Evaluating architectural design options during schematic design as well as design development before implementing in the real world plays an important role to avoid retrofit design which is often costly and time consuming.

No matter how much the architectural designer relies on computer daylighting simulation, all simulation must ultimately be validated by comparisons with measured field data in constructed projects. Although computer simulation and scientific visualization can help a designer to discover design shortcomings and identify deficiencies in a daylighting environment, the domain knowledge of daylighting learned in the theory and practice of design is still the main and necessary component for any design improvement.

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