A COMPARATIVE INVESTIGATION INTO A PROCESS-BASED APPROACH TO LIGHTING STUDIES USING PHYSICAL AND COMPUTER GENERATED MODELS IN DESIGN STUDIO

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Abstract. This pilot research attempts to investigate differences in process between lighting study using physical model and computational simulation. A Physical modelling team, a computational modelling team, and a monitoring and tracking team were formed to process and monitor the research by a defined workflow of the design process. Using a time schedule technique, the procedures of each of the two methods were tracked. The research reveals that the research team favoured physical modelling for its ease of use and computational simulation for its flexibility. And that the users of physical models were more aware of the need for technical knowledge whilst the users of simulation software are more contended with the virtual results without evaluating them critically. In addition, the experiment also shows that the feedback mechanism of the physical modelling process is instant, continues and intuitive, whereas that of the computational process is discrete. Preliminary results not only confirm the long established view that the computational process lacks the tactile quality required for architectural understanding; worst still, it gives inexperienced users an illusion of knowledge and claims of understanding. Due to limitations of time, the research captures only the feasibility stage of the design process, further works involving a more comprehensive design program should be conducted.

1. Introduction

Natural lighting has always played a dominant role in architecture, both to reveal the architecture of building and to create a particular ambient, and to provide the occupants with visual comfort and functional illumination (P. G. Hopkinson, 1966; N. Baker, 1993). Recently, there has been a revival of interest in daylighting for the energy efficient design of buildings (Bryan H J, 1990). However, daylight can impose some serious negative influences such as glare, solar overheat and unevenly distribution when it is not properly design. Because of its uncontrollability and unpredictability, daylighting poses uncertainties and complications to designers.
Architect and lighting designers have been using physical models for the prediction of daylighting in building for many centuries (Love J A, 1993). Recently, the use of computer aided design technology for daylighting design also attracts great interest from the design professionals with the rapid development of CAAD technologies (Ng E, 1998). Although advancements in using computer simulation have been establishing, the use of computer aided lighting design technology has not been wide spread (Ng E, 1996). Many designers prefer model photometry as a means of testing design (Benton C, 1990), and calculation method provided in IES-RP-5-1078 Recommended Practice of Daylighting (IESNA, 1978) is based on data obtained through model photometry.

While the physical model and computer simulation technology for the study of lighting performance have been used, the comparative evaluation of the process of lighting design under different models has not kept pace. This paper examines, in detail, the work process difference between using physical models and computational models in a design environment. The objective of the research is to identify bottlenecks and mismatches, and to develop strategies to synchronise the computational studies and the design process. The significance of this research is in seeking understanding of the strategies required to integrate scientific visualisation techniques into the design process, both professionally and in design studio.

2. Background

Lighting designers have developed practices and methods for lighting various visual tasks (IESNA, 1993). Photometric systems, model photometry and computer simulation techniques and their inter relationship for daylighting design have been developed and studied (Love J A, 1991).

Architectural model is one of the more popular tools in studying daylighting design. The main purposes were to access subjectively and, since the days of illumination engineering, quantitatively the likely building qualities before the building was built. The advantages of using architectural models have been well documented (Love J A, 1993). In short, they are: it is intuitive, physical model can cope with complicated window systems and spaces, it is validated when properly conducted, and the work process is relatively well defined to cope with the design decision making process.

Great advancements in computing and visualization capabilities have been achieved since the mid-1980s. Software like Micro Lumen, Radiance, Lightscape and Inspirer are available to the designer. Since the early 90s, their accuracy and applicability have been largely validated (Mahdavi A, 1993; Mardaljevic J, 1997; Kevin W, 1999). A number of studies have already been conducted with various degrees of success (Ng E, 1999; Ward G J, 1995) The
advantages of using computational models are: relatively cheap and fast to build the model, the model could be used to conduct other studies and/or for presentation, it is less cumbersome, and it is easier to use for studying large number of options. However, a number of limitations have also been identified. They are: it is not intuitive, it requires skills beyond the traditional training of an architect, it is still expensive and difficult to use, and, most important of all, methods have not been developed to synchronise with the design process (Ng E, 1998).

Researches are beginning to address the limitations of computational lighting simulation by building interfaces and by developing configuration files. In 1996, referring to the process of lighting design, D.L. Roe and R.E. Rowlands wrote, "It is possible that computer visualization programs may eventually help with this process, but currently they are little more than design testing programs which are cumbersome to use. The computer can, however, be used to produce line perspective which can printed out as a basis for developing shaded sketches. Perhaps eventually the computer will be able to turn these sketches into equipment schedules but it is likely to be a very long time before this occurs." (Loe, D.L, 1996).

In 1999, Moeck developed a method in lighting design using computer simulation. He breaks down the lighting design process into physically definable actions and objects, and to automate the selection, placement, and orientation of luminaries according to light pattern (Martin Moeck, 1999). However, the author's approach to develop a taxonomy of lighting techniques could only be used by professional lighting designer. The bottlenecks and mismatches in teaching lighting design using computer techniques need to be further explored.

![Figure 1. The proposed site plan of the church.](image1)

![Figure 2. General view of the proposed site of the church.](image2)

Ultimately, questions had to be answered as to how the computer techniques could be developed as tool which could use heuristic approaches to help
students and young designers. Departments of Architecture are beginning to turn out computer literate graduates. The problem of ‘cost and value’ will be overcome in the next few years as Gigaflop processors are making their ways to the desktop.

This paper describes an experiment which intends to compare and evaluate the daylighting design process by using physical models and digital models in a design environment. The vehicle of the research is a real design problem given to the research team by a professional design practice. The design calls for spaces for a church within a highly complex high rise building in an urban environment (Figure 1). The vehicle is chosen for this research for the following reasons: 1) It is a real design problem. 2) It is a complex problem, it does not naturally and obvious favor either physical modeling or computational modeling, 3) It is a unique problem in that it is situated in a densely populated urban environment (Figure 2).

The workflow of the design process and time limits were defined. Using a time schedule technique, the procedures of each of the two methods are tracked. To ensure inter-dependency and coordination, three teams were formed to process and monitor the research: physical modeling function, computational modeling function, monitoring and tracking function. Two M.Arch students who have the necessary lighting knowledge made up physical modeling team and computer simulation team. For the computer simulation team, good CAD skills were required. For the physical model team, they get used to build up physical model from the early training. The authors conducted the monitoring and tracking function.

Based on past experiences, the contingencies of each of these functions have been identified. Precautions measures, as informed by previous researches, have been applied to ensure that rigour and precision are maintained despite the constraint of time and cost.

3. Experiment and Observation

Lightscape was selected as the simulation software for this experiment. The reasons for selecting Lightscape are because it is reasonable accurate, and it is a user friendly in comparison. This study was not intended to facilitate a comparative evaluation of the simulation software and physical models, but rather to determine the fundamental differences in the work process between the two methods.

There are two stages in this research. The Model Building stage is six days long. Students of the physical modelling and the computer simulation team were required to study the necessary church design information. They were advised to pay attention to and seek ways, on their own, to efficiently build the model and to record down the process and problems encountered during the working
process. The quality and quantity of two different models were kept at the same level. The Design Study stage is six days long. Students were required to conduct design study of daylighting in this church project, which would be focus on the design problems identified in the model building stage. As in the first stage, they were asked to seek, on their own, methods to pursue the best design result and to record the process they encountered in the process. The monitoring team, the researchers, monitored and tracked the work process of the two teams, and provide advises and materials on an as needed basis. The team works 8-10 hours per workday, but the computer simulation team can leave the computer on – for rendering – overnight.

3.1. STAGE ONE: MODEL BUILDING

The following section describes, in chronological order, the activities of the two teams and the problems they encountered and questions they frequently asked.

3.1.1. Physical Model Team:

All the necessary instrument for lighting study and an artificial sky which could simulate the overcast sky conditions was provide to the physical model team. The major questions posed by the physical model team during the first stage of the study can be catalogued in four parts. These include 1) Questions about building the models, 2) About the equipment 3) About measurement methods, and 4) About general lighting knowledge. The questions aggregated generally in this chronological order.

Day 1 & 2: Students began by studying the site conditions and the drawings of the proposed church building. A few simple study models were also made for reference and testing. Afterwards the students were instructed on how to use equipment such as the "artificial sky" and photocells. The major questions raised at this point were mainly concerned with building the models. Students
inquired about the most suitable ratio for the artificial sky and what kind of material should be used to build models and to be used in the lighting study. How complex should the model be for the purposes of this research?

Interestingly, the students began by asking how to introduce adaptability and flexibility into the model for further use. As advised, they began by constructing models of the buildings adjacent to proposed church—one of the essential elements of good lighting design (Figure 3).

Day 3 & 4: The basic physical model was completed on the third day. Students then concentrated on how to use the necessary measuring equipment. They used their model to measure data in the Artificial Sky. The students often asked how to properly use the instruments for lighting measurement, and how to read the measuring data correctly. They realised the constraints of the equipment, and found that the model must be placed in a carefully so as to receive light from every direction. The students quickly realized the differences between standard architectural models and models for lighting study.

Day 5 & 6: The students came to appreciate the difficulty in securing accurate measurements (Figure 4). As a result, their questions focused mainly on how to improve the physical model in order to get better measurement results. Students found that the building model used to study lighting must be well sealed by black adhesive tape in order to avoid light leakage. They learned that materials had to be used carefully in order to simulate accurately the real situation. For example, the students had to alter the colour of the upper surface of the adjacent flyover when they found that excessive daylight was being reflected into the church (the flyover was acting like a light-shelf). The problems were solved immediately after the physical model was properly revised. Once the related accurate data were measured, the students then inquired about the most critical points to measure in the model. At the end of day 6, a 1:50 physical model was constructed and all the necessary measurements were secured and documented on time.

Throughout the whole process of the first stage, students made detailed inquiries about the basic lighting concepts related to the project. Although all the relevant lighting concepts were taught in lecture courses, the students still found them confusing when applied to a real experimental lighting study. They also requested additional material and were given reference books to read. The students found that the study brought together their knowledge of lighting concepts in a new way.

3.1.2. Computer Simulation Team:
Two pentium III, Desktop type personal computer running Window NT, AutoCAD 14 and Lightscape 3.2 were provided for this research. All the parameters used and measured for the physical model such as the reflectance of
material, the illuminance value of daylighting source, sky condition were applied. The major problems met by the computer simulation team within the first stage of the study can be summarized in three categories. These include 1) Problems about file import to Lightscape, 2) About using Lightscape, 3) About AutoCAD file preparation.

Day 1 & 2: A basic demonstration of Lightscape, such as how to import CAD files and assigns material and lighting sources were explained at the beginning. The students of the computer team were excited and impressed by the reality of simulating image of Lightscape. Since most of the commands of Lightscape are quite similar to AutoCAD and 3DMax, and the two students of the computer simulation team had good computer skill in AutoCAD and 3DMax, they thought they could start work immediately.

Students were advised that they would be better off doing a few simple models before building up the complex AutoCAD model (Figure 5). They were warned that there are differences between the standard CAD model and CAD model for studying lighting before they construct their CAD model. However, they were allowed to develop their own work process freely. Students spend most of the time building models in AutoCAD in the first two days. Only a few questions like how to draw complex 3D polygon in AutoCAD were asked. Although they were told that they did not need the furniture and interior fixture in their CAD model in the first day, they still described in their record that some details were difficult to draw in 3D AutoCAD file in the second day. At the end on the second day, a complex AutoCAD 3D model was near to completion.

Day 3 & 4: Students started to work in Lightscape using imported 3D AutoCAD file. The questions they tended to inquire were falling in the first two types within these two days. The major problems about file import to Lightscape include: 1) Scale factor - the scale factor AutoCAD file is in “mm”
while Lightscape is in “Meter”. 2) Material map – the martial in Lightscape file should be assigned and loaded every time when AutoCAD file was imported. 3) For every import process, manual check on surface should be taken since some surfaces might miss without rationale. The major problems about using Lightscape include: 1) Orientation of face, 2) Defining windows and openings, 3) Define the parameters, 4) Daylighting Setting.

As expect by the researchers, the 3D model they built in AutoCAD had many problems in Lightscape. The students had to go back to AutoCAD to modify the 3D model. The students complained that the work of orienting the surface was rather time consuming and they had to spend many hours finding an easy way in Lightscape to solve this problem. Some mistakes, like duplicate copy of same surface which could be ignored in rendering in AutoCAD or 3D Max, were found to cause serious problems in Lightscape. The students began to express that Lightscape is not easy to use at day 4. They requested additional technical help in using Lightscape. They were given Lightscape user manual to read.

Day 5 & 6: The students still struggled with the technical problems they encountered in Lightscape (Figure 6). They found that lighting leakage problems of the 3D model in Lightscape were not easy to solve. When the buildings adjacent to the church were added to the CAD model in Lightscape, students found that daylight source did not work on the external obstruction at all. Although the two students worked very hard during these two days, the CAD model still cannot be properly simulated in Lightscape. However, students began to realise the differences between the normal CAD model and CAD model for studying lighting. They felt proper file preparation was very important. The experiences of the CAD model preparation for lighting simulation software use can be concluded: 1) The CAD model should be simple and the detail of model should be considered carefully. For example, the curve line of balcony would better be changed to a serious of straight lines. 2) Lightscape use different colours to represent different materials. The students found that they can easily assign different materials to the model in Lightscape if they could assign different colour to the surface of the different materials in building 3D model in AutoCAD. 3) The normal wall in Lightscape can be drawn as a single 3D surface in CAD file. However, two surfaces should be drawn if lighting calculation is needed on both sides of walls. 4) Opening does not mean ‘nothing’ in normal CAD file. It should be drawn as a 3D surface which assign the different layer and colour in AutoCAD, and the 3D surface would then be define as opening in Lightscape. 5) Layer set in AutoCAD can be directly read in Lightscape. The students found that the CAD file have layer set in AutoCAD so that the different sets of components such as opening, wall and floor, can be on and off for viewing, simulation and selection in Lightscape.

Day 7 & 8: Two days were extended for the computer simulation team to complete their task of the first stage. The students decided to rebuild the 3D
model in AutoCAD based on the experiences above. A new CAD model was quickly built up on day 7. For solving serious light-leak problems when the external obstructions were introduced to the 3D model, students found that Lightscape could simulate properly when they define each window opening as opening after many attempts. They concluded that the relation between inside and outside was confusing. The computer team produced the required results on day 9.

3.2. STAGE TWO: DESIGN STUDIES

As advised, both teams began by studying the daylighting distribution of the church with maximum opening based on an analysis of results of the lighting conditions of the existing design. They could then propose design options to improve the existing design and conducted tests. The students of the two teams had no technical question to ask during this stage.

3.2.1. Physical Model Team:

The students of the physical team visited the site and took some photographs on the first day of stage two, since they expressed great interest in getting the true measurement of the site under a real sky conditions from stage one. They hoped to feel the real site conditions and to get the real data to compare with the data they measured in lab.

From an analysis of the lighting condition of the original design and an option with the maximum possible opening, students stated that opening on the north-east facade could be a major contribution of light into church and opening on the south-east facade does not contribute much to the lighting quality no matter how big the opening was cut. The students proposed to change three parameters to improve the lighting distribution of existing design. They included 1) The ceiling would be changed to white cardboard to improve the reflectance of interior surface. 2) The window would be modified to 4 meter high with horizontal light-shelves in white colour. 3) Close the opening on south-east
facade. Beside, parameter two -- the horizontal light-shelves was later titled 20 degree, all the design options were kept to the end (Figure 7).

The students spend four days on revising the physical model and measuring the data, and one day on documentation. The physical team completed the whole studied at the end of day 6.

3.2.2. Computer Simulation Team:
Although a site visit was strongly encouraged from begin of this research, the students of computer simulation team expressed less interest in it. They intend to spend all the time in the virtual world.

From an analysis of the original design, the students stated that the interior light distribution was uneven and light mainly comes from one direction. Unlike the physical team, the students of the computer team claimed that opening on south-east facade would make the interior much brighter. Therefore, they kept the south-east opening, and they add one horizontal light-shelves which was the same as the physical team. The students claimed that their proposal was successful because light were redistributed and resulted in a more even light intensity environment from their simulation (Figure 8). They spent another one day on documentation. The students stated that they had completed all the jobs of the stage two at the end of day 4.

4. Analysis and Discussion

Figure 9. Comparison the different methods between the physical model team and computer simulation team to approach goals.
A task list done by the two teams in chronological order (Table 1) revealed the differences of approaches between the physical models and computer models. These differences could be illustrated in Figure 9.

**TABLE 1. A summary of the tasks done by the different team in the different time.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Physical Model</th>
<th>Computer Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage One Model Building</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>Study drawing and understand the site conditions, build the simple model and begin to build 1:50 model.</td>
<td>The basic demonstration of Lightscape and begin to build up CAD model in AutoCAD.</td>
</tr>
<tr>
<td>Day 2</td>
<td>Continue to build 1:50 model.</td>
<td>Continue to build the CAD model in AutoCAD and it was nearly completed at the end of this day.</td>
</tr>
<tr>
<td>Day 3</td>
<td>1:50 model was completed at the end of this day.</td>
<td>Mainly work on Lightscape. There are many problems with AutoCAD model.</td>
</tr>
<tr>
<td>Day 4</td>
<td>Measure data under the Artificial sky.</td>
<td>Solving problems in Lightscape and go back to AutoCAD to modify model.</td>
</tr>
<tr>
<td>Day 5</td>
<td>Meet the problems and revise model.</td>
<td>Solving problems in Lightscape and go back to AutoCAD to modify model.</td>
</tr>
<tr>
<td>Day 6</td>
<td>Measure data and get reasonable results. Job complete.</td>
<td>Solving problems in Lightscape and go back to AutoCAD to modify model.</td>
</tr>
<tr>
<td>Day 7</td>
<td>N.A.</td>
<td>Rebuild 3D model in AutoCAD</td>
</tr>
<tr>
<td>Day 8</td>
<td>N.A.</td>
<td>Solving problems in Lightscape and rendering.</td>
</tr>
<tr>
<td>Day 9 Morning</td>
<td>N.A.</td>
<td>The required results are simulated. Job complete.</td>
</tr>
<tr>
<td><strong>Stage Two Design Studies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>Site visit</td>
<td>Study the drawing, discuss the design option and simulate the maximum condition of model.</td>
</tr>
<tr>
<td>Day 2</td>
<td>Discuss the design options and revise the model</td>
<td>Conduct the test of the design options</td>
</tr>
<tr>
<td>Day 3</td>
<td>Get the results of maximum condition and revise model for the design options.</td>
<td>Get their satisfy results.</td>
</tr>
<tr>
<td>Day 4</td>
<td>Revise model and conduct the test of the design options.</td>
<td>Documentation. Job completed.</td>
</tr>
<tr>
<td>Day 5</td>
<td>Revise model and conduct the test of the design options.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Day 6</td>
<td>Documentation. Job complete.</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
From figure 9, it can be seen that the method used to approach the study using physical model is quite close to the right, or expected way. This is because the physical model is intuitive, and the method for the physical model is direct and straightforward. The experiments also show that the subjects followed the standard sequence from the beginning and realised the problems which they might meet in future very early on. Since it is not easy to make a complex model, they never had intention to build one. That is why the problem could be easy solved once they were found. On the whole, the method of the physical model is well defined.

Compare to the physical team, the method of computer simulation team approaches to their study is deviates a great deal to the right, or expected way. The major reasons could include:

1) The method of the computer model is not direct and straightforward, therefore the subjects could not realised the difference between the standard procedure in build the CAD model and the CAD model for studying lighting design from begin. It can be seen that the students only found their method almost at the end of stage one (day six) in the experiment.

2) The lighting simulation software could be easily confused with other 3D rendering software, like 3D Max etc. It could be supposed that there are certain dreams such as some beautiful renderings in the mind of the subjects, these could tempt the subjects to the wrong decision. This is because they might be able to get such results using the same method in a different software. The experiment show that the students built their AutoCAD model urgently in the beginning without listening to any advises and expressed obstinate in changing their thinking style because they believe they could get that images.

3) Once the certain computer skills are mastered, a complex CAD model could be easily and quickly to build up. Therefore, the subjects always build up the CAD model as complex as they can. They would seldom realise that the complexity of the CAD model would make it difficult in Lighting Simulation Software. The experiment shows that the students still intended to add the furniture and the interior fixture, though they know these are not needed.

4) It is easily make mistake in the CAD models. For example, duplicate copy of the surface in a CAD model could be found, which is impossible in a physical model.

5) Daylight source. When external obstructions are introduced in CAD model, properly applying daylight sources in light simulation software is difficult.

6) The subjects intend to stay in the virtual world and enjoyed the digital science, but ignored the real conditions. The students of the compute model
team would rather to spend more time in front of the computer instead of a site visit.

The research reveals that the research team favoured physical modelling for its ease of use and computational simulation for its flexibly. In addition, the experiment also shows that the feedback mechanism of the physical modelling process is instant, continues and intuitive, whereas that of the computational process is discrete. Preliminary results not only confirm the long established view that the computational process lacks the tactile quality required for architectural understanding; worst still, it gives inexperienced users an illusion of knowledge and claims of understanding.

Computer simulation software indeed provide an convenient tool in lighting study and design because it can quickly and automatically generate photorealistic picture in match with related accurate data analysis. With the improvement of interface of lighting simulation software, more and more people could easily use it with know little lighting knowledge. The new users and the designers would think computer simulation software can do everything according to above reasons. It is therefore that they would seldom concern about why and how to conduct a simulator. The experiment shows that the subjects of the computer team appear less interesting in knowing about normal lighting knowledge and lighting design than the physical team does because it looks like unnecessary to know. The study reveals the subjects always thought the software can automatic process everything. For example, the subjects of computer team expressed very disappoint with software since they still cannot find an automatic way in orientation all the surface of 3D model, though they spend many time on it. However, standard practices or methods are important part in lighting techniques (Martin Moeck, 1999). Martin stated that no computer can be provided without using previous solutions and existing cases, and procedures. The evidences of this study further support this point. The research shows the users of physical models were more aware of the need for technical knowledge whilst the users of simulation software are more contended with the virtual results without evaluating them critically.

5. Conclusion

Perhaps the simplest conclusion that can be draw from this study is that the differences between physical model and computer model do make a difference in the way we study daylight design. In other words, one cannot simply give a "right" method in teaching and designing daylighting by use computer simulation. Instead, a heuristic guide which towards to help the new user to realise the difference between the standard CAD model and CAD model for lighting study could be introduced at the beginning to reduce misunderstanding. This research indicated that it is important to ensure a better understanding of
the lighting knowledge as well as a understanding the procedures of the computer added lighting design, beside to obtain the computer skills.

However, it is important to recognize that the inadequacy of the subjects and the observation inherent in the experimental are potential confounding factors. And the subjects’ responses may different if the experiment was conducted in a real studio or under other conditions, because the experiences get from each other in a studio might easily change user's method during the work process. Due to limitations of time, the research captures only the feasibility stage of the design process, further works involving a more comprehensive design program should be conducted.

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