AC 2009-378: VIRTUAL-REALITY TECHNOLOGY AND THE TEACHING OF ARCHITECTURAL LIGHTING

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Virtual Reality Technology and the Teaching of Architectural Lighting

Abstract

The study of lighting in architectural and interior design education is diverse. It ranges from energy efficient lighting and daylighting to studies that assess the effect of illuminance upon finish materials and color interaction. This often leads to attempts to squeeze lighting into an already crowded curriculum and is compounded when efforts are made to develop complex study models of interior lighting environments. In short, there is often little time to explore these topics in adequate detail.

This paper explores an alternative to the study of interior lighting environments through use of a Virtual Reality Theater. It discusses the development of one of these highly realistic virtual environments and how it is being used to introduce students to understand and interpret varying lighting scenarios of an interior environment and, as well, how it is generating a series of international research endeavors focused upon subjective impressions of interior environments.

This study is grounded in the seminal work in this field initiated by such scholars as Flynn[1,2,3]. It poses the question of whether or not software-generated images can accurately simulate lighting effects of the physical environment so that subjective impressions are legitimately measured. This research is used as a backdrop to this particular paper that explores the use of the Theater as an educational tool and how it offers up solutions to reducing the time to create complex study models. The use of this technology to alleviate a crowded curriculum, to explore it as an effective teaching tool, and to assess its value and limitations, remains the crux of what will be discussed herein.

1.0 Introduction

This paper introduces an exploratory study into the psychological implications of lighting. It will first discuss the background literature on this topic and then proceed to describe how this historical research was integrated into an undergraduate course in lighting within the Interior Design and Architectural Technology Programs at Indiana University Purdue University Indianapolis (IUPUI). The main focus of the paper will be on an overview of the events that took place in the classroom and the pedagogical methods that were used to introduce students to a 3-D virtual reality theater that utilized highly realistic lit environments. It should also be noted that this study followed upon extensive research that examined whether or not computer images could be used to accurately study the effects of luminance distribution on the subjective impressions of luminous environments. This study will be briefly discussed to set the foundation of the work attempted within the classroom and the virtual reality theater.

2.0 Literature Context

Substantive research on the psychological aspects of lighting was initiated in the 1970's, notably by Flynn[1,2,3]. His investigations explored the effects of luminous environments on subjective impressions of interiors and overt behavior. Results from Flynn's experiments revealed that complex subjective responses to lighting are accurately measured and communicated systematically. Yet it should be noted that these experiments were conducted in full-scale mockup environments with various light settings that utilized combinations of overhead-downlighting and peripheral lighting systems (see Figure 1).

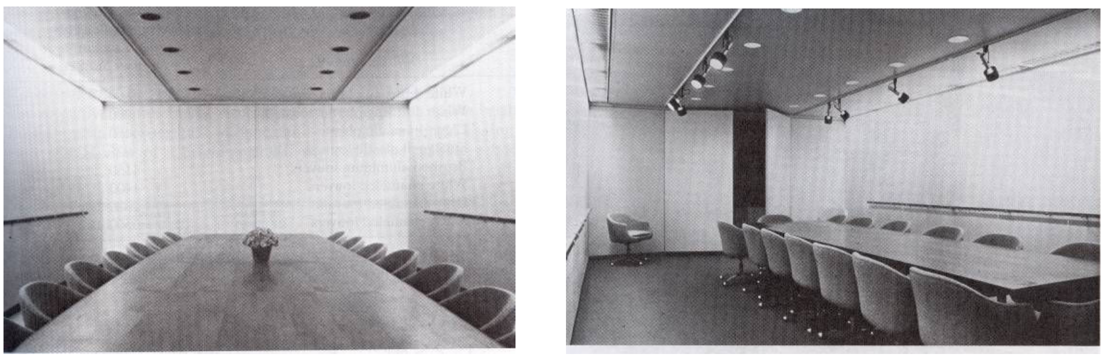

Figure 1. The conference room mockup used in Flynn's experiments[4]

Flynn's research became the basis for several similar experiments, such as those conducted by Hawkes, Loe, and Rowlands[5], Rowlands, Loe, McIntosh, and Mansfield[6], and Loe, Mansfield, and Rowlands[7], with some modification on the configuration of the brightness distributions and interior settings. More recently, Veitch and Newsham[8,9] carried out similar studies to verify the results from previous experiments. However, inconsistency of the results from these studies indicated that this line of experimental research is highly susceptible to individual differences as well as other factors caused by the different settings of mock-up environments.

It has been repeatedly noted that it was the differences in these full scale models that led to the discrepancies in the results from these researchers and that sent others in different directions to resolve the problems. These efforts have been slow and sporadic, given the current focus of lighting research upon energy efficiency and green solutions. This has led the research community onto a quest of studying products (e.g., Desouza[10]) versus the impact of the lighting upon the psychological makeup of the users of various spaces.

However, there is recent research in the area of subjectivity and lighting that follows upon comments made by Totir[11] who noted that the use of digital renderings have supplanted the more tedious mock-up installations that were integral to, yet problematic, in Flynn's work. Her research questions whether computer images will be interpreted and perceived by viewers as realistic. She is also interested in determining if classic lighting studies can be explored in contemporary settings by using computationally rendered images, and identifying to what extent the subjective evaluation of the lighting conditions of an interior space can be reproduced using these images. She makes mention of Flynn, stating that: "Lighting designers have been using the results of his studies since then, but there has been only little additional research done in this area" (p. 14). Totir proceeds to note that little research has been conducted correlating the results of computer graphic simulations with real scenes and that "it is still difficult to create photorealistic computer-generated images, due to the fact that the real-world illumination is highly complex" (p. 30). Her comments lend credence to the necessity of exploring this type of research once again, even though it faces an uphill battle for notoriety in an academic environment centered upon the energy efficiency of lighting.

Results from the recent research of scholars such as Rohrmann and Bishop[12], Eissa and Mahdavi[13], and Newsham, Richardson, Blanchet, and Veitch[14] also indicate that computer images can accurately represent actual visual environments. Their work and results indicate that this area of research is ripe for the reinvestigation of Flynn's conclusions in digital arenas rather than full-scale, model environments. It was these types of results that led this team to explore the notion further and to see if Flynn's mock-up environments could be accurately reproduced in a digital age. It was proposed that this type of experimentation could advance research in this field at a rapid pace as the research studies would not require the labor-intensive building of real, full-scale testing environments.

A literature search of the current research being undertaken in the field of lighting and its psychological impact also uncovered several scholars that are examining the effect of lighting upon worker productivity (e.g., Murphy[15]). This type of research emphasizes that there is an interest in the effects of lighting that has resurfaced and a continued interest in the development of highly realistic virtual environments that can substitute for the finished product. Once developed, these 3-dimensional environments were seen by the authors as an opportunity to test various lighting scenarios and to rapidly expose students to these variances without the time and expense needed to create full scale mockups. However, in reviewing the literature on Virtual Reality Theatres and lighting education, there appeared to be a paucity of articles that address this type of research and thus this area of study was also seen by the authors as both a fertile ground for education as well as research.

3.0 Background Study: From 2-D Computer Monitor Images to the Virtual Reality Theater

As our studies unfolded they began with examining the value of using images on a computer monitor to mimic the environments that Flynn had created. This background study preceded the classroom studies at IUPUI in the Virtual Reality Theater discussed in this paper and was conducted in Indonesia along with the aid of several researchers located in the United States. The images used in the study were rendered using Dialux 4.3 software. The simulated room, interior setting, and light settings closely followed the protocol of Flynn's experiments through the use of the images (and others like it) seen in Figure 1 (Kodrat P, Suryabrata, Pramitasari, Cowan, & Frank, 2008). Twenty computer monitors were carefully calibrated to produce consistent image quality and six images were selected that depicted various lighting settings similar to Flynn's experiments.

Ninety-six participants of the Department of Interior Design, Indonesian Institute of Art, Yogyakarta, Java, Indonesia participated in this experiment. Since specific data from Flynn's original participants was not available for the study, this group was subjected to two new sets of questions about the simulated room in the computer images. The first set utilized a seven-scale differential (e.g., words such as friendly/hostile; pleasant/unpleasant) to come to an understanding of how the students viewed the different environments that were found on the computer screens. The second set of questions measured comparative judgments using closed, ten-scale "similarities and differences" questions, with zero being very similar and ten indicating very different. Nineteen pairs of light settings were presented to the participants. Multidimensional scaling, coupled with multivariate statistics, indicated remarkable similarities of the results between this study and that of Flynn's experiments, concluding that the computer generated images of lighting scenes can be used to represent the real environment. Result similarities between this study and that of Flynn's were especially strong in impressions of spaciousness and of privacy, while there was less congruence in impressions of visual clarity and uniformity preferences. Armed with this knowledge and the access to virtual reality equipment the authors set out to see if students would respond as favorably to lighting environments that were simulated within an immersive, stereoscopic virtual simulation as they did with images projected onto computer screens.

The Virtual Reality Theater at the Advanced Visualization Laboratory at IUPUI consists of three vertical walls and one horizontal floor. High-resolution projectors display a highly realistic lit interior in this environment and enable students to virtually navigate through the space. This display provides a bright, high-resolution, immersive experience using four 10' x 7.5' screens featuring 1400 x 1050 pixels at 6000 lumens. The side screens are motorized to support a variety of display orientations and configurations. The system also features wireless, optical tracking over the entire 30' x 10' space. Our lighting simulations ran on a single workstation PC utilizing an NVIDIA Quadroplex Model IV. The following discussion details the events that are ongoing at IUPUI and that will extend the previous research conducted with 2-D computer monitor images.

4.0 Methodology: Virtual Reality Theater Component

The lighting simulation that we are able to develop in the virtual environment allows students in lighting education the opportunity to view and experience the effects of various lighting settings and equipment. By providing the simulation software with IES-formatted photometric data files associated with a particular fixture/lamp combination, it is able to render the resulting lighting effect in three dimensions. Students are then able to experience a room, for example, with a variety of light fixtures and lamp types installed, in a three-dimensional simulation. They are able to turn on and off each fixture/lamp combination and also vary the output as in a typical dimming application. Without this simulation capability, students would be limited to experiencing physically installed fixture/lamp combinations that are often not current products with literature and calculation data available.

The design, creation, and ultimate rendering of this environment evolved over several months of experimentation. The system needed to provide a reasonably accurate representation of the global illumination in the environment while maintaining a high frame rate, necessary for a realistic virtual reality experience. The system also needed to allow for interactive adjustment of individual light sources and needed to utilize commonly available software to enable fast and easy construction and modification of digital environments. We converged on the use of Autodesk 3ds Max 2008 to model diffuse environments and to pre-compute lighting and occlusion maps for each individual light source. These models and maps could then be combined in real time by custom VR software to simulate a range of lighting combinations. The first step used Autodesk 3ds Max 2008 to create the model with 28,000 polygons and assigned textures and diffuse materials to all room surfaces. We then added seven different light sources that included sixteen wall washers, six recessed downlights, two recessed direct fluorescent luminaires, six indirect fluorescent luminaires, one portable floor fixture, two portable table fixtures, and one television. Light effect properties for the first four sources were defined by IES-formatted photometric data provided by the respective manufacturers.

The 3ds Max model was imported into the 3DVIA Virtools Version 4.0 software package. Virtools is multi-screen aware and handles head tracking and stereo. We implemented the global illumination simulation using OpenGL and pixel shader capabilities within Virtools. Our implementation performs multipass texturing in real time to blend the material texture maps, all enabled light maps, and the ambient occlusion map.

As the implementation evolved over several months, a pilot lab workshop was developed for class instruction. In the procedure shown below for Part I of the lab (see Appendix A), students each spent several minutes deliberately turning on and off a pre-defined sequence of simulated lighting equipment in the virtual simulation, as well as experimenting with real-time dimming in 5% increments. They also viewed a simulated television in the environment for which they selected the most comfortable lighting scenario for viewing. They experienced the effect of TV viewing under bright light and under dim light to see the varying effects of glare and also of high contrast from the TV with no supplemental lighting. When completing their worksheet evaluation, students also experienced light levels for reading.

Continuing with Part II of the lab (see Appendix B) conducted outside of the virtual simulation, students used room dimensions, fixture efficiencies, and lamp lumen data to execute illuminance calculations of the simulation experienced in the Theater. Students made qualitative and quantitative evaluations of lighting effects based on their calculations and viewing experience.

Through this exercise, students experienced various foot-candle levels of light to not only relate the objective data to the simulated environment, but to get a sense of what seemed appropriate for tasks such as television viewing and reading.

Over the course of several semesters, student response has been very positive. Most students commented that they felt reasonably immersed in the simulated environment and subjectively concluded that the digital environment was realistic enough, certainly much better than 2-D pictures or static renderings. The ability to navigate the space was also helpful and convincing. A sample of student responses includes the following[18]:

"It was like you were really there; I didn't realize how effective certain lighting was for different tasks."

"I liked how you could be inside your drawing and see how light affects the space."

"...the control over dimming & turning on different lighting situations; see what works best for TV vs. homework, etc."

"I enjoyed being able to see the differences in lighting so quickly & being able to compare them."

"I liked that you could see how the lighting in a space would look & feel before the installation."

"I liked the design of the room and how you could navigate."

Through the virtual simulation, we are able to provide a much greater variety in lighting effects and illuminance scenarios than students would otherwise be able to experience in the semester-timeframe of each course. A practicing lighting designer relies on years of experience to know what illuminance levels are appropriate and we hope to give students an edge toward this advantage by having early experiences before embarking on their professional careers. By using the virtual simulation and utilizing current products with their available data and literature, students are able to combine the subjective experience with the objective data calculation to support their experience.

(See Appendices A and B for the full extent of Lab questions utilized in the classroom).

5.0 Limitations

Even though similar results were obtained in the previous 2-D lighting simulation research related to Flynn's original work, there were limitations that we plan to address in the future. One is that over the more than 30 years since Flynn's experiments, data on the specific lighting products and lamps used are no longer available. Therefore approximations were included in the simulation research that may influence the general room appearance as well as luminance distribution. The same limitations of available lighting equipment information pertain to other conditions of Flynn's room that may affect the viewing experience; room dimensions, furniture, and finishes. Secondly, since the simulation was viewed on computer monitors in two-dimensions, other variance factors may be introduced such as ambient lighting and luminance conditions in the viewing environment, possible veiling reflections from the monitors, and calibration settings in the equipment. In addition, Flynn's group of research participants generated subjective data more than 30 years prior to the later participants in the lighting simulation. As well, the two groups of participants are distinct from each other and of different cultural backgrounds – Flynn's work was conducted in the U.S. and the simulation research was in Indonesia. Differences in design practice between the two cultures and assessment of impressions may be an influencing difference in results, particularly related to differences in uniformity preferences and visual clarity found between the simulation research and that of Flynn's earlier work.

The current virtual environment has its limitations in the use of a single living room setting with four specific architectural lighting products installed, two portable luminaires, and a television. By refining this scenario for several different student groups, we have refined the user interface and improved its ease of use over the course of several semesters. This has introduced additional limitations, however, where new sample groups from classes each semester have experienced different versions of the simulated environment. In addition, the sample groups each semester are small in size - approximately twenty students experience each revision of the environment, for a total of just over sixty students.

6.0 Future Research Endeavors

In the next phase of research and classroom application we plan to address the limitations found in lighting simulation. To create a simulation as close to realistic as possible, we plan to carefully select an existing physical space that will be modeled and rendered for the Virtual Reality Theater. Criteria for selection will include a varied installation of lighting product types that will also be able to accommodate alternate lamp types in terms of light output, color temperature, and color rendering index. The luminaires in the subject room should also be dimmable. Literature and technical specifications of fixtures will need to be available to create the simulation as closely as possible. Additionally, finish specification of the room's furniture and surfaces, as well as reflectivity data, will be included in the simulation. With this set of criteria the simulation will closely recreate the physical space.

In this next phase of application, we plan to increase the number of participants by controlling the environment across each group. In this way, more students will experience a single instance of the environment. The second factor in extending this research will be to include a control and an experimental group by collecting data in the physical space and in its virtual simulation from the same group of participants. First, we will directly compare each group's experience in the physical environment to their impressions in the virtual simulation. Secondly, by repeating this process with several groups of students, we can compare each group's responses and solidify the comparison of subjective impressions of lighting.

7.0 Conclusions

The classroom strategies incorporating virtual reality technology in lighting education show promise both in pedagogical and professional practice. While objective data and calculations have the potential to predict lighting effects, we strive to convey to future designers the importance of subjective impressions of lighting in the built environment. Until now our educational resources have been limited to pre-selected installations that best address a cross-section of available lighting technology. There is no shortage of installations that represent opportunities for improvement and these provide educational learning experiences. In ideal scenarios, successful design solutions are well-maintained and optimally specified, but these are more difficult to locate for the logistics of classroom instruction.

The research embarked upon and sparked by Flynn's[1,2,3] original work is an opportunity to expand educational resources without physical boundaries. To date, it reveals promising results for the pedagogical use of the digital lighting environment as well as potential use in the design profession. Interior design and architectural technology students at IUPUI are quickly gaining increased understanding of the subjective effects of lighting through simulations in the Virtual Reality Theater. They also foresee the technology's potential in their academic studio work; "It's a much better way to explain lighting." "It's hard to show effects of lighting design on paper"[18].

Through expanded classroom use of advanced virtual reality technology, students will be able to realize the potential of effective lighting design that will supplement the quantitative methods available. We are embarking on the next phase of this tool to address methodological limitations and to substantiate the promise of lighting simulation for educational and professional benefit.

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Appendix A

Lab Workshop - Part I

Lab Workshop - Part I (Frank, 2008a)

Each of you will get a turn at controlling the virtual reality lab scenario with the installed lighting as provided. Following the directions given to operate the equipment, try each of the following scenarios and note your impressions as directed below. Turn in this sheet before you leave.

1. Recessed downlights only

2. Recessed downlights with recessed wall washers

How do you feel in this space with the wall washers on than in the previous setting?

Less preferred More preferred

1 2 3 4 5 6 7 8 9 10

3. Leaving downlights and wall washers on, and adding fluorescent troffers.

How do you feel in this space by adding the troffers than in the previous setting?

Less preferred More preferred

1 2 3 4 5 6 7 8 9 10

4. All on (add indirect cove).

How do you feel in this space with all lights on than in the previous setting?

Less preferred More preferred

1 2 3 4 5 6 7 8 9 10

(check one)

Is this sufficient general light _______, too much light ________, or too little ____________?

5. All off except indirect cove and wall washers

How do you feel in this space with just the cove and wall washers than in the previous setting?

Less preferred More preferred

1 2 3 4 5 6 7 8 9 10

6. All off except indirect cove

For reading in the room, (check one)

Is this sufficient light _______, too much light ________, or too little ____________?

7. With the TV on, select the most comfortable setting of lights using Button 1 (check one).

____Recessed Downlights

____Recessed Downlights & Wall Washers

____Recessed Downlights, Wall Washers, & Fluorescent Troffers

____Recessed Downlights, Wall Washers, Fluorescent Troffers, & Cove

____Wall Washers & Cove

____Cove

Appendix B

Lab Workshop - Part II

Lab Workshop - Part II (Frank, 2008b)

Attached are cut sheets of the products used in the Advanced Visualization Lab (AVL):

Lithonia Indirect Fluorescent Cove

Lithonia Direct Fluorescent Troffer

Juno Recessed Halogen Incandescent Downlight

Iris Recessed Halogen Incandescent Wall Wash

Using the cut sheets, determine the following and include all units where applicable:

1. The Juno downlight lists in its Photometric Report how many possible lumens from a 37W MR16 lamp?

2. How many lumens does the fixture actually allow to be emitted in a downlight distribution of 0-180 degrees?

3. Therefore, what do you determine the efficiency (percentage) of the fixture is by dividing the actual lumens by the possible lumens?

4. What number does the Photometric Report list as the fixture efficiency?

5. Even though the fixture absorbs about 23% of the possible lamp lumens, how did you like the general light effect it emitted in the simulation?

6. With the simulated dropped ceiling's 7'-6" height, according to the cut sheet, how many foot candles at the beam center would there be?

7. Compare that amount to the light level in this room. How much brighter or dimmer is it here and how do you find this light for reading and writing?

8. In the Lithonia fluorescent troffer cut sheet's Photometric listing, how many lamp lumens are estimated from one 32WT8 lamp?

9. Using the simple lumen method and (2) lamps per luminaire, how many footcandles will each luminaire (not lamp) contribute in this 15.5'x15.5' space?

10. Since two fluorescent troffers are used, how many footcandles do they contribute in total?

11. From the Iris wall wash cut sheet, what is the lamp being used and how many lumens can this lamp emit?

12. Given a fixture efficiency of 51.7%, how many lumens will the fixture emit?

13. What does the cut sheet report as the Unit LPW (lumens per watt for *one* fixture)?

14. Therefore, using the lamp's wattage and multiplying it by the LPW, the total lumens available is determined. What is this number?

15. Is this close to the amount found in Question #12?

16. These wall washers are installed 18" from the wall and the ceiling height is 9'-0". If these are spaced 2'-0" apart (on-center), what foot candle level can be obtained directly from the cut sheet?

17. Since this amount is very little for ambient lighting, what is one benefit of using this fixture?

18. In the simulated space, the indirect fluorescent cove fixtures are 18" from the ceiling. While it does create bright spots on the ceiling, one option to help the situation would be to add an asymmetric reflector to the fluorescent strip to "kick" the light directly out into the space. From the Lithonia strip cut sheet, what option would be added to order this accessory?

19. How would this option change the result both quantitatively and qualitatively?