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Computer-Aided Daylight Simulation

A Hybrid Approach to Recording and Exploring Ideas

PARANANDI, Murali
Department of Architecture and Interior Design, Miami University, Oxford, OH 45056
http://www.muohio.edu/~paranam

Accuracy and facility for iterative exploration are two of the most appealing promises of computer use in architectural design. In this paper, we discuss daylighting visualization, a very important aspect of the architectural design process, where computers do not yet fulfill these promises. We initiated a project to understand the reasons for this and to develop methods to deal with it in architectural design education. We report our work in progress, which combines creative thinking with scientific procedures to resolve the bottlenecks in computer graphics technologies making them suitable for design exploration. Our strategy seeks to fill the gaps in the science of photo realistic visualization with time tested physical modeling techniques. We present some of our student work based on this strategy.

Keywords: *photorealism, rendering, daylighting design, visualization, simulation, scale (physical) models, design education.*

Introduction

It is widely acknowledged that predicting the performance of daylighting in a given space is a complex process and that visual information is absolutely imperative to make a sound design judgment about illuminating a space [Matinez, 1996]. Computer scheming, scale physical models, and full-scale mock-up are the most popular design tools of visualization for daylighting design. In terms of effort, time involved, facility for iterative explorations, and amount of design information that can be learned, the physical model approach is still considered to be more useful than anything yet possible from computers [Novitski, 1990]. A recent study comparing the above three methods finds scale (physical) model is the most effective for the creative process [http://lightforum.com/design/daylight1.html: March 2001].

By contrast, we note the major shortcomings of computer graphics as: lack of accuracy, extreme computational expense, and difficult user interfaces [Ramasubramanian et al., 1999; Preetham, 1999; Novitski, 1990]. Why, one may ask, should we still pursue computer-based models if they suffer from such severe problems? We believe Greenberg's [1974] original argument is still a persuasive answer; i.e. computer modeling extends the possibilities of physical scale models because of their: flexibility, walk-through animation capability, and ability to change color. We seek ways to reap these benefits by using our traditional knowledge of design and teaching to work around its limitations.

Previous work

Author initially attempted to use computer graphics rendering techniques to visualize daylighting in Aalto's architecture while working on a Masters thesis project [Paranandi, 1991]. Hardware and software available for the project (IBM-AES system on RT workstations) did not support a visual investigation. Consequently, the analysis was conducted using physical model simulations fairly successfully. Subsequently, in 1997, author revisited the idea of testing the viability of

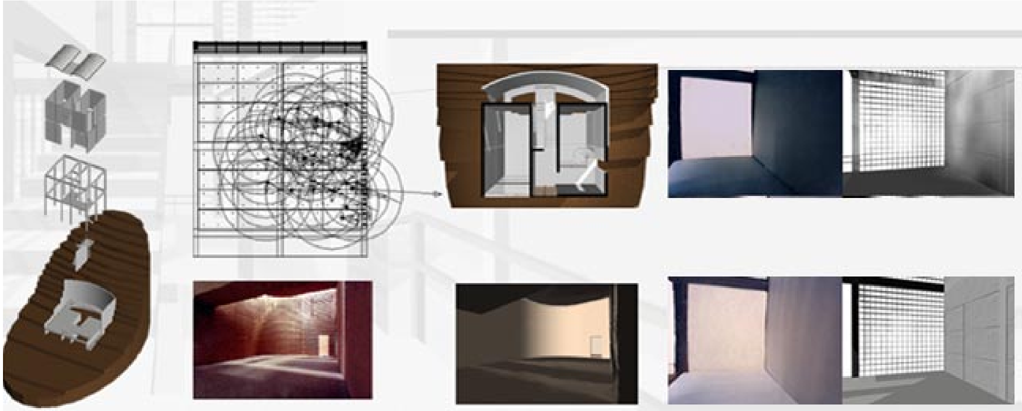

Figure 1. Student project from Fall '97 studio demonstrating the creation of an exhibition space based on daylighting principles of the architect Tadao Ando. form•Z's raytracing rendering technique was used in generating the images. A total of over 30 lights were used to simulate daylighting results observed in cardboard model studies as shown above. Having this information in place allowed for further design exploration taking advantage of computer generated walk-through animations and immersive panoramic views.

employing desktop computers for daylighting visualization in a teaching context. Although, compared to the previous experience, the hardware capabilities (Power Macintosh 7100) were markedly advanced; the software (form(Z Renderzone 2.x) was still limited in supporting accurate visualization due to lack of support for indirect illumination.

We devised the following strategy to counter this deficiency. Students began their design explorations on the computer. Once they reached a stage where they needed to verify the lighting conditions, they built quick study scale (physical) models corresponding to computer models of the scenes under investigation. These models were built to test multiple lighting strategies, which were then photographed outdoors, simulating sun, site, and time conditions similar to those used in computer models. The student designers then analyzed these photographs to learn the effect of indirect illumination for various schemes. These observations influenced the direction of their designs from that point on. Once the choice of scheme is made, students went back to their computer models and employed additional point/cone light sources, and transparency texture maps to emulate the indirect lighting effects using the photographs of the physical models as a guide (Figure 1).

We were encouraged by this experience. Students were able to produce very convincing photorealistic imagery consisting of immersive Quick Time VR simulations and sequential perspective images emulating walk-though experiences. In our conference presentation we will show more visuals from these explorations than what is possible in the space permitted in this paper. We note that, although these images were very convincingly photorealistic, they were essentially artistic illustrations based on designer's observations of the distribution of light in the physical models. We also note that, although this method was not scientific, these images were deemed useful for design decision-making, the design outcome was generally regarded as of high quality as judged by the faculty jurors.

Current state

Subsequent to our experiences described above, we were inspired by the following two developments:

Radiosity-based visualization systems, such as Lightscape, have become commercially available for use in CAAD. Desktop computers to actually run such systems for practical use have become more powerful and affordable. Some schools in the US have demonstrated that such computer media (physics-based) can be an effective daylighting tool in teaching context [Massadi, 1998]. Also some critically acclaimed computer graphic imagery of great daylit architectural spaces has been generated on such systems [Larson, 1999].

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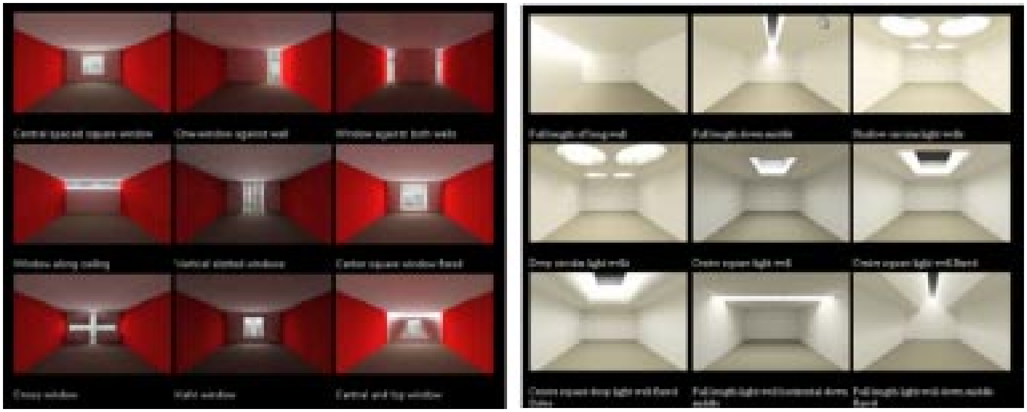

Figure 2. Box study for parametric variations of aperture placements and shapes. (Left: Conditions studied: glazing 25% of wall area; facing south; Sept 21 - 10:00 am; Cloudy; Red side wall.) (Right: Conditions studied: glazing 10% of ceiling area; Sept 21 - 10:00 am - Partly Cloudy)

Physical model and computer aided image analysis combination approaches have been developed. Demers [1999] identifies the differences between the entirely computerized method of light analysis and a new alternative involving the use of photography in physical models with the computer as a tool of image analysis. He makes a convincing case that this approach is particularly more appropriate for earlier stages of design than entirely computerized methods.

Work in Progress

Informed by the above, we extended our approach to include the scientific basis, which we describe in the next section. We reconfigured our design studio facilities to include: form•Z 3.5 (for 3D modeling), Lightscape 3.2 (for radiosity), 3D Studio Viz (for walk-though animation), PhotoShop 6.0 (for texture preparation), and Premiere 5.0 (for digital movie editing) on high-end dual processing computers, digital cameras to allow instantaneous photography of physical models, computer controlled lighting sensors to measure lighting in physical models, and a 3D digitizer to allow tighter integration between physical and computer geometry [Paranandi, 2000].

In Fall 2000, we started with simple tests to understand the credibility of the imagery generated by Lightscape to understand how a cube interior gets modeled under various lighting conditions (see Figure 2) [http://www.muc.muohio.edu/~studio/ mark/html/ Morphologicalbox.htm: May 2001].

We then expanded the scope by modeling a couple of spaces on campus that we were very familiar with (Figures 3, 4). We then compared the results of the Lightscape images in two ways. First, visual assessment of how realistic the images were compared to the photographs of the actual spaces and to our own perception of these spaces based on our experiences. Second, we measured the light levels in these spaces and compared it with Lightscape calculations.

Proposed Framework

Encouraged by above experiences we proposed the following method involving a combination of computer and physical models. Early design explorations can begin in any medium that the designer feels comfortable with, including but not limited to paper, computer, or cardboard, etc. Once these explorations reach a preliminary solution stage requiring concept testing (i.e. assessment of daylighting in this case), a 3D solid model of the solution is built on the computer (using form•Z). Computer model can expedite the process of constructing the cardboard model by providing templates (by unfolding, contouring etc.) and necessary geometric information [Paranandi, 1999].

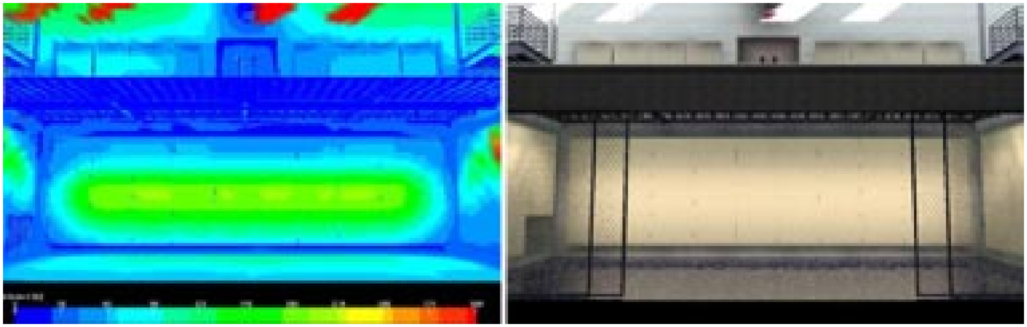

Figure 3. Study for design of electrical lighting in Miami University architecture department's gallery.

Figure 4. Study of Miami University architecture department's atrium. Shown on left is a photograph of actual space and on right is a Lightscape rendering.

Digital cameras with wide-angle lens are then used to photograph the interiors of cardboard models under simulated daylighting conditions. Images of the interior spaces are available almost instantaneously for the designer to contemplate and adjust (e.g. widening an opening, or changing the curvature of a light scoop etc.).

Designers find working with cardboard models for such situations both natural and easy. If desired, it is also possible to measure the illumination levels using a light meter on any given surface inside the physical model. Once a palatable solution has been reached, the computer model geometry is updated (a 3D digitizer can be used when appropriate), and a radiosity solution is generated. Both the rendered image and the light levels of such a solution can be compared to the corresponding image and the light levels measured in the physical model to verify the integrity of the solution. If there is a reasonable match, then the investigation can continue by creating walkthroughs and color studies. If there is no match then the settings for material properties in the computer model are tweaked until the radiosity solution gets close enough.

We incorporated the above model in a 4-week design project during Spring 2001 semester. The conference presentation will include the images from some of the student work.

Discussion

Beginning with a weeklong exercise of visualizing daylight in a familiar space was useful in developing students understanding about the capabilities and the traits of the tools. This knowledge gained about the use of tool from a known situation was effective in dealing with modeling an unknown (student designs

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under development). Students verified their Lightscape simulations visually and empirically by building physical scale models periodically at critical junctures. Adjustments were made to the computer simulation settings, when necessary. Once a palatable lighting solution was achieved, it was fairly easy to generate interactive (OpenGL) walk-through simulations and to modify colors.

Learning involved in understanding the interface, capabilities, and shortcomings of Lightscape was significant. We needed to deal with interoperability issues, fuzzy settings for materials and daylight, and understanding the limitations of the underlying simulation models and algorithms. Design models developed in 3D modeling program cannot necessarily be used in Lightscape without special preparation. We refer the interested reader to Lairserin's [2000] "Many Models Make the Rose Center" article, where he discusses at some length on how messy this process gets in practicality. Lightscape was less forgiving of modeling blemishes and high number of polygons. Understandably, novice students became timid with their moves in 3D modeling program, as it involved considerable effort in preparing the models for exporting to Lightscape. Our students shared some of techniques to get realistic looking imagery with each other using the web [http://www.muc.muohio.edu/~studio/mark/html/tutorials.htm: May 2001]. These included guidelines on preparing models and textures using form(Z and Photoshop to work smoothly in Lightscape.

In a studio setting, architecture students are typically focused on producing photorealistic imagery. In order to reach a level of sophistication they often exert a lot of time and energy in adjusting various rendering parameters. Often this is done with no relation to real world but with such random acts as inflating reflectivity values for materials, placing light sources at absurd locations, and creating nebulous effects such as lens flares etc. Some describe this as "image making" [Gross, 94], distinct from "space making". We found our approach helpful in addressing this issue by keeping the students on track and grounding them in reality. The false color display (figure 3) was particularly useful in assessing the lighting distribution.

We ran into a few other limitations of Lightscape, such as lack of support for bump maps and caustics, inability to accurately simulate translucent materials, specify sky/ground cover etc. We believe a combination of computer and physical models would be an effective approach to address the shortcomings of each and to achieve the extended possibilities (table 1).

Conclusion and future work

Even scientists are skeptical of the usability and the cost of current photorealistic visualization approaches for design decision-making [Habbard, 2000]. Since it doesn't look likely that this situation will change anytime soon, it is appropriate and necessary for designers to find creative ways to use computers for design. We believe our work attempts to accomplish this by enhancing the fluidity of the design process making it quicker, more precise, and enjoyable. Fluidity is the key to allow iterative explorations.

In the near future, with the advances in 3D printing and scanning technologies, the process of going back and forth between physical and digital models will become affordable and achievable, making our proposed model even more fluid.

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Table 1. Comparative summary of physical and computer models for design.

Facility for design	*Physical*	*Computer*
Accuracy	*Strong*	
Ease of use	*Strong*	
Quick Feedback	*Strong*	
Flexibility for change		*Strong*
Ability to walk-through		*Strong*
Change color		*Strong*

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