Determining the Suitability of Computer-Aided Daylight Simulation Method in the Design Process

Tina Sarawgi
Determining the Suitability of Computer-Aided Daylight Simulation Method in the Design Process

Tina Sarawgi

The successful use of daylight in a building requires that the associated forms and devices be conceived as an integral part of the architectural design. The popular methods of simulation for daylighting design: manual methods, physical scale model and computer graphics based rendering do not provide a robust model for daylighting decision-making during the design process due to their individual limitations. The recent advances in computer-aided design and rendering compel another look at visually simulating daylight. This paper discusses a project undertaken to test a computer-aided daylight simulation program’s accuracy and ability to allow quick iterative daylight explorations, essential to any design decision-making process. Real buildings with their existing complexities are selected as case studies. The outcomes are discussed and recommendations for future daylight simulation software programs to be suitable in the design process are suggested.
1. Introduction

The contribution that light has in affecting the use and enjoyment of our environments is unmistakable. Daylighting is known to enhance the qualitative experience of the environment for the occupants; aid visual tasks such as reading, writing, working and movement; and lower energy consumption in buildings by replacing electric lighting. Several studies have shown that people are significantly more productive in a naturally lit environment where windows and skylights let in more daylight [1-3]. The successful use of daylight in a building requires that the associated daylighting devices, such as windows, clerestories and skylights be conceived as an integral part of the architectural design. This makes it very important to envision the effects of daylighting in the buildings during the design decision-making process itself. However, predicting the performance of daylight is not as simple because of its variability and unpredictability with respect to the time of day and year, location and environmental conditions [4]. This issue has been repeatedly reported in the literature as a challenge that has yet to be satisfactorily resolved [5, 6].

This paper discusses a project examining the performance of Lightscape, a commercially available software program, in conducting quick iterative daylight explorations and producing photometrically accurate results, essential to any design decision-making process. This has been accomplished by comparing data from computer daylight simulation model to that of physical scale model and the actual space. Real buildings with their existing complexities are used as case studies, extrapolating the observations and results to the design process.

1.1. Daylighting simulation tools

Manual methods, physical scale models, and computer-graphics based rendering are the three most popular methods of evaluating daylighting design [7]. These simulation tools are intended to help designers with the qualitative and quantitative elements of daylighting design through features that commonly include visualization of the luminous environment for a given design and prediction of illumination levels in a space lit by diffuse daylight. By providing information on these features the tools play a significant role in the decision-making process that characterizes daylighting design. However, each has limitations that prevent it from being the ideal robust method for daylighting design. The manual methods are mainly suitable for simple calculations and are unable to predict the visual quality of daylighting design. The physical scale models have limited flexibility and restricted range in observation of the interior of a model. They are also time-consuming to construct and require testing under the real sky, which can be variable and unpredictable, or in artificial sky simulators, which are expensive, and of limited availability.
Computer-graphics based tools can extend the possibilities of manual methods and physical scale models because of their flexibility, walk-through animation capability, and the ability to conduct advanced computations [7, 8]. The ongoing advances in computer-graphics based rendering methods that take the physics of light into account in rendering the distribution of light created by daylight and electric light sources are based on radiosity and raytracing algorithms computed from established mathematical models [7]. With these methods, the designer can alter the input data to perform simultaneous qualitative and quantitative analyses of alternative daylighting settings to aid the design process.

1.2. Computer-aided daylight simulation

A review of related literature relevant to computer-aided daylight simulation reveals that the inclusion of computer-aided daylighting analysis in the design process has been largely overlooked. The previous works are based on comparative evaluation of different software programs [9-12], or contrasting different daylighting techniques such as physical scale models, computer models and full-scale mockups [13, 14], or application of daylighting methods in a design studio or environmental systems seminar course [15-18]. Critical evaluation of the available daylighting simulation packages needs to be conducted for widespread and proper use in design process. Simple boxes or cubes with limited number of rectangular apertures are often used for daylighting simulation software development [12]. A daylighting software should ideally be able to model and simulate the complexities of real buildings to contribute significantly during the design process. However, their use is often impeded by the fact that the operation of these programs, especially the model input, is extremely complicated and time-consuming for complex building systems.

Lightscape is observed to have the shallowest learning curve according to most studies. A study compared Lightscape, RadioRay, Microstation and ADELINE with a physical model under two types of artificial sky to test the photometric accuracy and ease of use of the software programs with a simple box model [10]. The study found that by leaving the majority of geometrical construction to other applications, Lightscape achieves a relatively straightforward interface, and provides sufficient accurate simulation to be of use in daylight design. The renderer in Microstation is easiest to learn for only experienced Microstation users while the rendered results using RadioRay are the least accurate. ADELINE produces very fine results, but falls far short of all the other software in terms of interface with the lack of simple zoom functions to view rendered data.

Another study focused on the following four software packages: Lumen Micro, Superlute, Radiance and Lightscape [12]. The study states that the ease with which a working understanding of Lightscape can be acquired, the constant updating of input and translation functions to accommodate other
software used in practice, and the relative speed with which renderings can be produced compared to other software programs are very attractive features to architects and lighting designers. Lumen Micro and SuperLite work well only when used with the kind of space they are capable of modeling: rectangular rooms with rectangular apertures. Radiance proved to be much more accurate in predicting illumination levels, but requires a great deal of time and training to use well.

Although most studies to evaluate Lightscape’s accuracy and capability have been conducted by researchers, nearly all of the projects previously studied were conducted in idealized situations to create accurate and realistic representations of the architectural environment from a graphics standpoint. This project examines Lightscape’s capabilities in allowing quick daylighting simulation for examination and revision while facilitating a photometrically accurate understanding of daylight in a real building with its existing complexities.

2. Project description

Three easily recognized barriers that hinder appropriate integration of the daylighting aspects in building design summarized in the International Energy Agency book on Daylighting in Buildings [4] are:

1. Lack of appropriate and user-friendly daylighting design tools.
2. Lack of knowledge on the performance of daylighting systems and lighting control strategies.
3. Lack of evidence of the advantages of daylighting.

This study focuses on one aspect of the first barrier: It compares three sets of data to determine the appropriateness and effectiveness of computer-based daylighting simulation tools in the design process. The data were derived from the following methods:

(1) computer-based daylighting simulation method using Lightscape; (2) traditional method of making a physical scale model; and (3) actual space monitoring. The daylight simulation models were prepared for this project by setting only the basic parameters. This strategy was adopted to test the performance and application of the computer-aided daylight simulation method in a time-bound project where daylighting design is one of the major issues to be considered in the design process.

2.1. Case studies

Few architects have mastered the techniques of daylighting in their buildings as skillfully and sensitively as Alvar Aalto [19]. Atrium spaces in two buildings demonstrating an exclusive use of pyramidal and conical skylights, designed by architect Alvar Aalto, were selected to develop the resources for the project. One space was the central atrium of the Academic Bookstore in
Helsinki, a subsidiary of Stockman's bookstores in Finland. The atrium is naturally lit by three huge pyramidal skylights, which are suspended in the ceiling and are the major visual elements in the space (Figures 1a, 1b and 1c).

The other evaluated space involved the central atrium of the Rautatalo Building in Helsinki. This atrium is naturally lit using a skylighting system comprised of forty conical skylights (Figures 2a, 2b and 2c). The conical skylights provide a uniform daylight distribution in the space that serves as a foyer for the Nordea Bank in Finland. No other apertures contribute towards daylighting the atrium spaces in these two buildings.

2.2. Methodology

The project was conducted in three phases with the intent to gauge the performance of computer simulation in comparison to other methods in conducting daylight visualization and assessment of the two atrium spaces. Quantitative and qualitative data were recorded for each phase followed with comparative analysis of the distribution of daylight levels. The quantitative evaluation of the spaces was conducted in terms of daylight factor. Since the daylight factor method is generally used with uniform or CIE (Commission Internationale de L’Eclairage) overcast skies, the simulations were generated for overcast sky conditions as much as possible [7]. The qualitative data depicted the visual distribution of daylight within the spaces. The three phases of the project are described as follows:
Documentation of daylight in the actual space

The use of an existing building offers two reference points for the evaluation: the realities of a building design and the opportunity to measure the actual daylighting conditions in the building for comparison with the other simulation data [12]. On-site data was collected on two different occasions to reduce error related to uncontrollable parameters such as variable sky conditions and motion-sensitive electric lights in the spaces. The data less influenced by the changing parameters in the atrium was used for comparative analysis with the physical and the computer model simulation data.

The quantitative data consisted of daylight factor readings taken at 900mm height using a Li-COR light meter (Model LI-250) at regular intervals in the atrium space. The data was measured once the interior electrical lighting sources were switched off to the extent possible (Figure 3).

The qualitative data was collected in the form of images and panoramic movies of the atrium spaces using a digital camera with manual aperture and exposure controls (Figure 4).
Daylight simulation of the physical scale model

Due to the short wavelength of light, a physical scale model yields identical results in simulating the behavior of daylight penetrating into and inter-reflecting in a full-scale building. The familiarity of designers with constructing and using scale models make them the more popular method of predicting daylight in a space [19]. Physical models of the atrium spaces were built at 1:25 scale, large enough to accommodate the photocells and camera for quantitative and qualitative measurements for daylighting analysis. Because both the spaces are almost symmetrical, only one half of the atrium space of each building was built for the physical model. A reflecting mirror was used to reflect the other half as constructing the entire model of both buildings would have been tedious and time-consuming. Since the model was going to be tested only for overcast sky condition, inaccurate reflections due to direct sunlight reflecting on the mirror into the space was not a problem. The use of a mirror was also considered suitable because the areas unaffected by the skylights in the atrium (equivalent to 1.5 times the ceiling height) were not required to be built, as shown in Figure 5.

Figure 5. First floor plan of the Academic Bookstore showing the constructed area of the atrium space and the shaded areas unaffected by the skylight.
The physical model accommodated the principal space-defining elements, skylight details, and relevant interior features such as color, textures and reflectance of surfaces that influence the daylight penetration and its distribution inside the building. Images of all textures were selected from the actual space photographs following brightness and scale adjustments made using Adobe Photoshop. The clear glazing materials were omitted from the model since it is difficult to reproduce their transparency and scale [19]. The time of day was not considered for the physical model simulation because the models were simulated for daylight under a mirrored uniform sky simulator (conforming to CIE overcast sky) where the external illuminance value is unchangeable [7]. Cosine-corrected and color-corrected photocells were placed at the desired locations at 900 mm height (scale) to measure the quantity of available daylight entering the space in terms of daylight factor. The luminous environment created within the space was recorded through digital photography (Figures 6a and 6b).

Daylight simulation of the computer model

When analyzing the contribution daylight can make to a space, a daylighting simulation program that can provide meaningful results in a reasonable amount of time was required. Lightscape, a lighting and visualization application founded on a physically based simulation of the propagation of light through an environment was chosen as the software tool for daylight visualization for this project based on results from previous studies [9-12]. Since Lightscape does not have the requisite geometric modeling capabilities, the construction of the model geometry of the two buildings was conducted using Form•Z, a 3d modeling software program. Form•Z offers a user-friendly interface for modeling and has the required facility for exporting files directly into Lightscape (Figure 7). Lightscape computes the light incident on each surface present in the model; thus all the unwanted surfaces not receiving the daylight from the skylights were deleted to optimize the rendering time.
The material, orientation and properties (occluding, receiving and reflecting light) of different surfaces were specified in Lightscape. The material assignment was conducted using the material libraries in Lightscape and imported texture maps. The sky condition setup was done by selecting the overcast sky condition from the three available choices of clear, intermediate and overcast.

The qualitative data was obtained in the form of rendered images and panoramic movies of the two spaces from the radiosity solution followed by raytracing. The radiosity feature of Lightscape produces photometric simulations of diffuse lighting like indirect light, color bleeding between surfaces and soft shadows. The feature is an iterative procedure, which is visible all the time, allowing the user to stop the calculation if the result is not suitable. The raytracing algorithm accounts for direct illumination, specular reflections, and refraction through transparent materials [20]. The quantitative data was derived from the radiosity model by placing a non-occluding and non-reflecting plane at the height of 900 mm from the atrium floor level. The interior and exterior illuminance measurements were noted on this plane by imposing a grid equivalent to the one used in the actual space and the physical model, to obtain the daylight factor.

3. Observations and results

The luminous environment of the atrium spaces are dictated by the shape and configuration of the skylights. In the Academic Bookstore, the pyramidal skylights extend below the ceiling refracting light onto the ceiling directly. The resulting increased ceiling luminance serves to reduce brightness contrast with the skylight itself, creating a feeling of an open-to-sky environment.
atmosphere. In the Rautatalo Building, the convex shape of the conical skylight well diffuses the light admitted through a small roof opening over a larger area before entering into the atrium space. The skylights here create a mostly uniform lighting in the space [19]. The following sections discuss the daylight simulation model generation process, qualitative and quantitative observations and results.

3.1. Daylight simulation model generation interface

The basic geometry of the computer model was generated in Form•Z, which was imported into Lightscape for daylight simulation. The transition from modeling to daylighting simulation is a tedious and time-consuming process, requiring conversion of model geometry into surfaces and laborious surface orientation and properties settings before Lightscape can make accurate daylight predictions. Lightscape's inbuilt interface for making changes in the model geometry after the importation of the model is not robust. Moreover, Lightscape takes more time to compute as numbers of polygons in a model increase. This limitation discourages the use of crude design process models that are usually not mindful of the number of polygons.

The radiosity algorithm in Lightscape makes it more suitable in the later stages of the design process. Once the spatial geometry decisions have been made, the radiosity feature has the provision to try alternate materials or surface conditions by pausing successive computation for propagation of light within an environment. The computation then takes off from where it was paused instead of starting all over. Also, unlimited flexibility in setting up the 2d and 3d views while working in Lightscape contributes greatly to conducting the iterative explorations.

3.2. Qualitative results

For qualitative analysis, computer-generated daylighting simulation images were compared to the photographs of the actual space and the physical model using the following two formats:

- The data obtained from the aforementioned three phases of the project was compiled in the form of (a) the type and configuration of the light fenestrations in the building; (b) photographs of the actual space; (c) physical model simulations; (d) computer model simulations; and (e) false color rendering from the computer model simulations. Table 1 provides an overview of the range of visual conditions in each phase.

- Panoramic images of the actual space and the computer daylighting simulation were generated showing a 360° view of the atrium spaces to allow for a three-dimensional comparison and analysis. The panoramic images are shown in Figures 8a, 8b, 9a and 9b.
<table>
<thead>
<tr>
<th>Building Project</th>
<th>Actual Space</th>
<th>Physical Model</th>
<th>Computer Model</th>
<th>False Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rautatalo Building</td>
<td><img src="image1.png" alt="Actual Image" /></td>
<td><img src="image2.png" alt="Physical Model" /></td>
<td><img src="image3.png" alt="Computer Model" /></td>
<td><img src="image4.png" alt="False Color" /></td>
</tr>
<tr>
<td>Skylight Type: Conical</td>
<td><img src="image5.png" alt="Actual Image" /></td>
<td><img src="image6.png" alt="Physical Model" /></td>
<td><img src="image7.png" alt="Computer Model" /></td>
<td><img src="image8.png" alt="False Color" /></td>
</tr>
<tr>
<td>Academic Bookstore</td>
<td><img src="image9.png" alt="Actual Image" /></td>
<td><img src="image10.png" alt="Physical Model" /></td>
<td><img src="image11.png" alt="Computer Model" /></td>
<td><img src="image12.png" alt="False Color" /></td>
</tr>
<tr>
<td>Skylight Type: Pyramidal</td>
<td><img src="image13.png" alt="Actual Image" /></td>
<td><img src="image14.png" alt="Physical Model" /></td>
<td><img src="image15.png" alt="Computer Model" /></td>
<td><img src="image16.png" alt="False Color" /></td>
</tr>
</tbody>
</table>

**Figures 8a and 8b:**

Tina Sarwegi
In general, the computer model images look pale and flat with low contrast values. The physical model images appear much brighter with high surface reflectance. The possible factors affecting the qualitative aspects of lighting distribution pattern in the computer and physical models are discussed in detail in the following paragraphs.

One of the most important factors influencing daylight distribution in the simulation models is the sky condition setting. It is not possible to reproduce the sky condition that exists in the actual spaces using available options of only clear, partly cloudy and overcast sky in the computer simulation. On the other hand, the luminance distribution of the mirrored uniform sky simulator (CIE overcast sky) used for physical model simulation was much higher than the real overcast sky condition on the days of the on-site measurements in Helsinki, Finland. As a result, the images of the physical model are brighter than other images. This effect seems to be diminished in the Rautatalo Building, which may be due to the smaller size of the skylights that allow less light to come through.

The settings of the computer screen brightness can have significant impact on one’s perception of the lighting levels in a computer-generated daylight simulation model. Improper brightness, contrast and ambient default setup in the display option of the computer simulation program add to illumination inaccuracies when rendered. The chief limitation of most display methods is dynamic range. There are no generally available display methods that approach the dynamic range of a real scene (luminance ratio on the order of 10000:1) compared to maximum dynamic range of most monitors (100:1) [21]. The false color image representations shown in computers in Table 1 overcome limitations in the dynamic range of displays to an extent by replacing tone mapping with a numerical legend. They help to take note of minute light changes in the spaces otherwise indiscernible by the human eye. To enable further comparison of the computer-generated false color renderings to physical model and the actual space images, a follow-up study
utilizing the method proposed by Debevec and Malik [22] may be suitable. This method recovers high dynamic range radiance maps from multiple photographs with different amounts of exposure that can be directly compared with false color renderings.

Accurate material representation in both the physical and computer models is cumbersome. The reflective and transmissive properties of the materials should ideally match those used in the actual building for accurate reflection, refraction and absorption of light. The photographs of textures taken from the actual space were affected by the exposure time of the camera. This is because the response of the camera to the light is different from the human eye. Light meter in a camera cannot respond simultaneously to light and dark areas. If responding to light areas, dark areas of an image may be too dark. If responding to dark areas, light areas of an image may get overexposed. The captured textures modified in Adobe Photoshop appear unrealistic in the simulation models, especially in the Academic Bookstore model where a wide variety of textures and materials exist.

One can make approximate material properties settings in Lightscape by tweaking the HSV (hue, saturation, value) value slide bar of materials to get the desired lighting effect. The more difficult problems are to produce semi-reflective and translucent surfaces. Since Lightscape considers all surfaces to be perfect Lambertian diffuse surfaces for radiosity processing, the specularity of the surfaces has no effect on the radiosity solution. In addition, there is no support for bump maps and caustics. These limitations in material representation may be one of the reasons for the pale and flat appearance of the computer images. It is worth noting that with relevant data input such as precise space geometry and surface material properties Lightscape can be made to work well as an image-processing tool to produce convincing images of an actual space, as demonstrated by previous studies [23, 24]. However, the results can be misleading if one does not have a pre-conceived idea of the light distribution in the space. In this study, the physical model and actual space images helped achieve the correct daylighting levels in Lightscape.

It was also noticed that even if the modeling is done accurately and taking the necessary precautions in using Lightscape, the lighting simulation is prone to artifacts at the edge and light and shadow leaks in the final image. For this reason, the final images need to be tweaked further in a 2d rendering program such as Adobe Photoshop. The light leaks are visible at the intersection of the parapet and the ceiling in the Rautatalo Building in Table 1.

While the amount of time taken to arrive at a final daylight solution using Lightscape increased with model complexity, the accuracy of the daylight solution diminished. This is evident in the generation of the less accurate illumination of the larger building, the Academic Bookstore, where the images
appear brighter in the atrium area compared to the images from the actual space and the physical model. However, computer simulated images for the Rautatalo Building were closer to the images of the actual space.

3.3. Quantitative results

While computing the quantitative results, it was observed that the user interface to determine the daylight factor using Lightscape needs adequate improvement. Lightscape does not have a clear-cut way to derive the external illuminance for an interior space model where daylight enters in only through the apertures. In comparison, using photocells and data acquisition system to record quantitative measurements in a physical scale model is fairly easy to learn if one is familiar with the basic terminology for daylighting in buildings.

The daylight factor measurements from the three methods have been graphically represented to illustrate the comparison between them. The graphs were drawn along sections AA’ and BB’ as shown in Figures 10a and 11a. The deviations in the illumination graphs reveal the limitations and strengths of each method.
Figure 10c. Section B-B' showing the daylight factor illuminance graphs for the Academic Bookstore (Day: April 13, 2003; Time: 3:00 pm)

Figure 11a. First Floor Plan of the Rautatalo Building showing the location of the illuminance measurement grid

Figure 11b. Section A-A' showing the daylight factor illuminance graphs for the Rautatalo Building (Day: April 9, 2003; Time: 10:00 am)
In general, the figures show that the computer model graphs tend to follow the actual space graphs more closely giving a better idea of the illuminance distribution pattern compared to the physical scale model. The physical model graphs, in consonance with the qualitative results, show higher illuminance values, which may be attributed to the mirror-box artificial sky in which they were tested. A major illuminance pattern discrepancy in the physical model graphs for the Academic Bookstore occurs at the center point in section B-B’ (Figure 10c). This discrepancy may have been caused by the use of the mirror at the center of the atrium space accounting for higher illuminance than measurements in the actual space. The reflected light at the mirror or the unexpected light passing through the gap between the model and mirror may account for this phenomenon. Although tedious and time-consuming at a large scale, building the whole physical scale model is the best option.

The actual space measurements in the Academic Bookstore suffered some inaccuracies that may be due to the moving sun, changing density of clouds or dust in the atmosphere, and surrounding buildings and foliage. The central atrium space was full of furniture and books that may have further obstructed the readings. The graph for the Academic Bookstore dips down and tends to flatten at the center (Figure 10c). Substantial deviation is observed in the actual space graph of the Rautatalo Building at point D’3 in Section B-B’ (Figure 11c). This may be because of the circumstantial obstacles such as motion-sensor-controlled electric lights that could not be switched off while readings were being taken.

Overall, the computer model daylight factor illuminance graphs demonstrated less deviation (17.98%) compared to the physical model (20.82%). Also, the computer model illumination graphs of the Academic Bookstore, the larger of the two spaces, showed more deviation (19.89%) compared to the Rautatalo Building (16.08%). Hence, the quantitative results indicate that Lightscape is more accurate in predicting the illuminance levels of a simpler and smaller space that have lesser number of polygons.
4. Conclusions

In the design process, one of the main obstacles that designers face is the inability to predict accurate daylighting levels to utilize it in building design. It is necessary to examine different scenarios through an iterative process to find appropriate daylighting solutions. This requires simple but accurate daylighting simulation methods. Not all visualization materials are well suited to exploring and recording ideas. Materials that involve the designer in difficult techniques absorb energy and divert attention away from thinking [25]. This research brought forth the potential and limitations of Lightscape as a computer daylight simulation tool in comparison to physical model and actual space for use in the design process. Although Lightscape was the only software program used in this study, the observations, results and recommendations can be extended to other daylight software programs to determine their suitability in the design process.

The results show that Lightscape produces daylighting simulation results fairly similar to that in the actual spaces. Computer model simulation images shown in Table 1 and Figures 8a to 9b have obvious flaws and are not completely photo-realistic. However, they are sufficiently accurate for making daylighting design decisions based upon visual qualities. It is much more important to have a quick means to produce an overview of the implication of the design choices than to give precise information regarding a hypothetical final solution during the design process. The designer can then easily and quickly solve the day-to-day problems while only complex daylighting strategies or systems remain the specialist’s concern [12].

Both qualitative and quantitative simulation results of the Rautatalo Building appear more accurate than the Academic Bookstore, which was a larger building. Lightscape took several hours to generate the daylight simulations, the amount of time taken increasing with model complexity. This shows that the performance of Lightscape in simulating daylight tends to be more accurate and user-friendly in a simple and smaller space. The software program needs to incorporate a simple and direct method to obtain the daylight factor readings into the qualitative analysis interface, beyond the ability to determine the illumination readings at discrete points in the space. The software program should also have the facility for specifying more detailed sky condition settings. The provision to control only superficial changes in the simulation model such as materials, textures and color makes Lightscape more suitable in the later stages of the design process. To be appropriate for early design stages, a software program based on the convergence of modeling and simulation capabilities should allow iterative modeling for spatial explorations and generate quick simulation results. A quintessential model that can be used for several purposes by facilitating means to many ends, daylighting visualization being one of them may be an ideal solution.
The quality and accuracy of the computer simulation images is dependent on the rendering parameters. This study has not exhaustively tested all possible combinations to determine the best settings. However, it explored ways to get reasonable results within a reasonable amount of time. Knowledge of the actual space and the physical model simulations was helpful in validating and directing the use of Lightscape to produce preconceived results in this study, unlike a design development stage where the results are unknown till the space is constructed. So the study is not completely controlled for a design process situation. Nevertheless, the research findings can be used by designers to visualize daylighting design scientifically during the later stages of the design process; steering away from illustrating desired lighting effects without a sound photometric basis. Future work will involve testing an actual design process scenario where the time taken to build daylighting simulation models, accuracy of the models, usefulness of the results in informing design-decisions, and experience of the users is studied.

It is worth noting that Autodesk has integrated the functionality of Lightscape and 3d Studio VIZ into Autodesk VIZ, which has both modeling and lighting simulation capabilities combined into one. It promises to increase workflow and productivity by significantly reducing the time required to prepare a model to be tested in Lightscape. During the course of this project, several difficulties were encountered in preparing the lighting simulation model for Lightscape from Form•Z. Future works could explore the suitability of Autodesk VIZ for use in daylight decision-making in the early stages of the design process. Potential studies could also investigate simulation software programs such as AGI32, which have limited photorealistic components, comparing them to Autodesk VIZ or Lightscape.

Acknowledgements

This research work was funded by the Joel Polsky/ Fixture Furniture/ IIDA Foundation. Additional funding was provided by the Office of Research Services, the Teaching and Learning Center and the Office of the Dean at the School of Human Environmental Sciences at the University of North Carolina at Greensboro.

The author would like to thank Professor Dale Brenstrup, Director of the Lighting & Building Energy Technology Laboratory at the University of North Carolina at Charlotte for sharing his research facilities. The author is extremely grateful to all the resource persons at the Alvar Aalto Foundation, the Helsinki University of Technology, the Academic Bookstore and the Rauttalo Building in Helsinki who helped during the data collection phase of this project. Special thanks to two graduate students, Hyun-Seung Lee and Aditi Hirani, for their invaluable help in implementing the project.
References


Tina Sarawgi,
University of North Carolina at Greensboro, Department of Interior Architecture, 325 Petty Building, Greensboro, NC 27402, USA
tina_sarawgi@uncg.edu

Determining the Suitability of Computer-Aided Daylight Simulation Method in the Design Process