CONVR 2006

Application of 3D Modeling Software for Daylighting Simulation of Shading Devices

Svetlana Olbina
University of Florida
Gainesville, FL 32611-5703
solbina@ufl.edu

Yvan Beliveau
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0156
yvan@vt.edu

Abstract
This paper explains research on application of 3D modeling software, Autodesk VIZ, as a daylighting simulation tool. During the design process, building designers need to select the appropriate shading device system to obtain sufficient amount of daylight in the space. This research developed the decision-making framework (DMF) for selection and design of shading devices based on daylighting performance. Daylighting performance of shading devices can be tested experimentally or by simulation. Experimental testing is expensive and time consuming. 3D simulation software is affordable, but can also be time consuming. To evaluate daylighting performance of shading devices, the 3D modeling software Autodesk VIZ was used as a simulation tool in this DMF. Among available daylighting software, Autodesk VIZ was selected because of its ease of use. Also, designers use Autodesk VIZ for the 3D modeling of the building, so the use of Autodesk VIZ for daylighting simulation does not require additional training. This paper describes input for the simulation, daylighting simulation procedure, and output of simulation obtained by the application of Autodesk VIZ as a part of the decision-making process for the selection and design of shading devices. The case study was performed to validate the appropriateness of the Autodesk VIZ application as a 3D daylighting simulation tool and to validate the DMF. The validation showed that the DMF works, and that Autodesk VIZ is a useful daylighting simulation tool in the DMF.

Keywords
3D modeling, daylight simulation, Autodesk VIZ, decision-making framework, shading devices

---

1. INTRODUCTION

Most shading device systems installed in windows or glass walls are used only for protection from overheating and glare, neglecting other possible functions, such as increasing the daylight level in the space. There is also a need for specific guidance for the selection and design of shading device systems in the windows. In the process of selecting the preferred shading device for a particular building, architects need to analyze a blind's performance in various areas (thermal, visual, acoustic, and aesthetic) as well as the cost and the control strategy for the blind's adjustment. The daylighting performance of blinds can be tested experimentally or by using simulation software. For the purpose of the blinds' selection in the conceptual design phase, experimental testing of the blind's daylighting performance would be expensive and time consuming. Daylighting simulation software is affordable but can also be time consuming. Very often daylighting software is not user friendly and is separated from the architectural 2D and 3D modeling software. Use of such software by architects, engineers, manufacturers of shading devices, and students would require additional training. ”We seek to determine if there is room for daylighting analysis as one of the ingredients within the dynamics of an electronic design studio, without requiring a daylight seminar course or a studio entirely dedicated to exploring light and space. Most architectural daylighting experts are of the opinion that daylighting can be addressed in a studio only when supported by a parallel seminar course. We also found that very few people worldwide can accurately model complex buildings with RADIANCE.” (Sarawgi and Paranandi 2002) Also, most of the performance simulation software is not capable of handling complex geometries. “Many buildings designed today are not the simple box or cube with a limited number of rectangular apertures, which are often used in validation studies and software development.“ (Ubbelohde and Humann 1998) There is a need for a daylighting simulation tool that will be user-friendly, fast, capable of modeling complex geometries, and accurate. “A survey of architectural firms (Hattrup 1990) discovered that architects who were interested in using daylight in their buildings tended to explain daylighting to the client as an aesthetic rather than energy issue, and desired to have computer software which could predict the daylighting performance of their designs.” (Ubbelohde and Humann 1998) This paper describes application of Autodesk VIZ for 3D daylighting simulation of shading devices in the process of the shading device selection and design. Autodesk VIZ is a 3D modeling, rendering, and animation type of software. VIZ has additional features for calculating daylight levels in the space.

2. DECISION-MAKING FRAMEWORK FOR SHADING DEVICE SELECTION AND DESIGN

This research developed a decision-making framework (DMF) based on daylighting that can be used by architects, engineers, manufacturers of shading devices, and students. The DMF is a guide for the user in analyzing the shading device’s daylighting performance in the process of selection and design of the shading device (Figure 1). The DMF includes:

- Possible variables (independent, dependent, and shading device variables) developed in detail:
  - Independent variables are given to the user of the DMF, and the user cannot change these variables.
  - The user defines dependent variables in the DMF.
  - Shading device variables are independent in the process of the selection of the shading device system because the user of the DMF cannot change the variables. Shading device variables are already defined by the manufacturer and given to the user. The performance of the shading device is

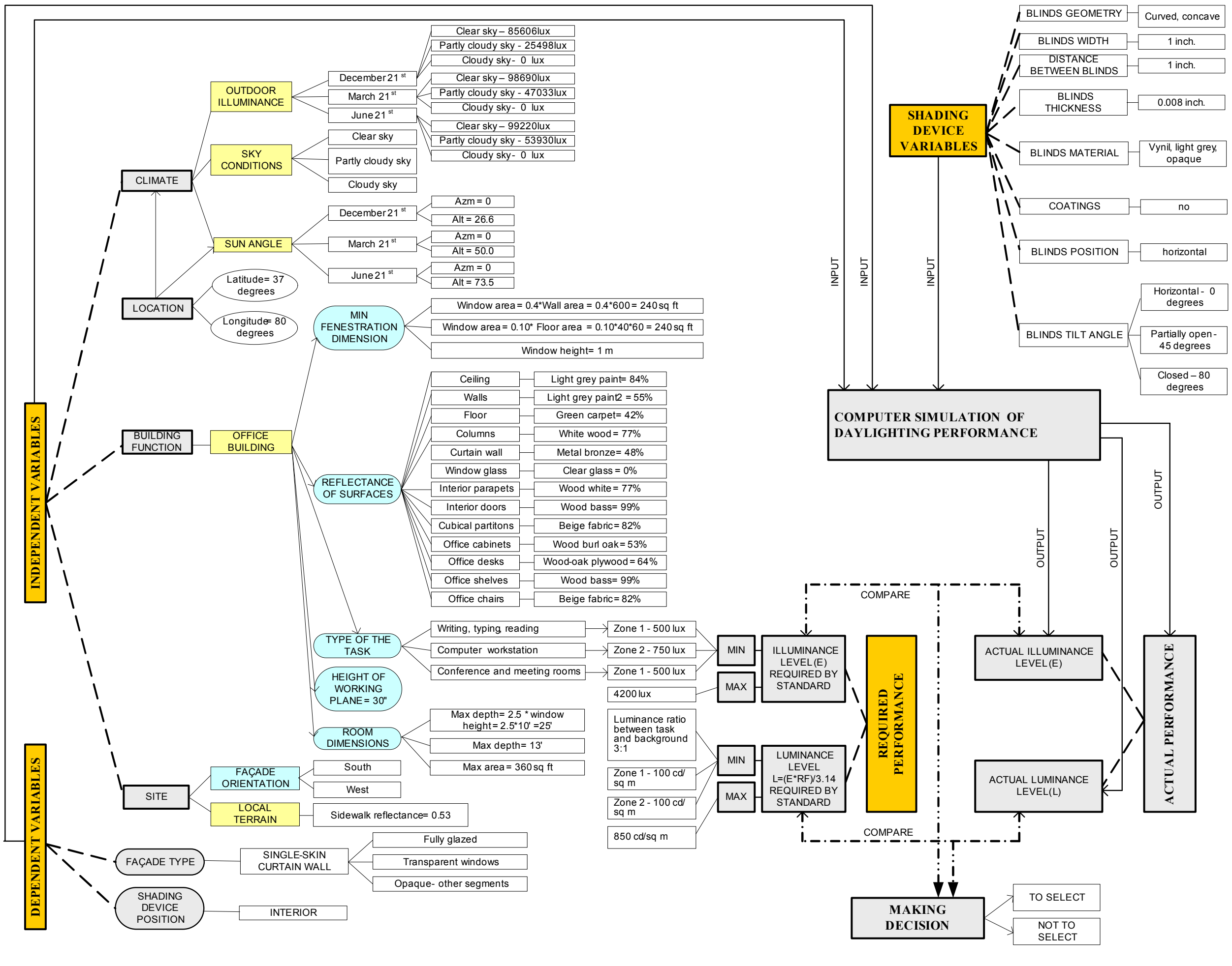

Figure 1 Decision-making framework based on the shading device daylighting performance

directly affected by shading device variables in addition to the influence of the independent and dependent variables.

- Performance parameters for a shading device system: illuminance and luminance levels. Performance parameter values are affected by independent, dependent, and shading device variables. Performance parameters are used as criteria for the blind's evaluation.
- Relationships and interactions between variables and performance parameters.

The users of the DMF analyze various systems of blinds applied on a particular building and at a given location. The users of the DMF can apply either an experimental procedure or a computer simulation that provides information about illuminance and luminance levels in the space. Based on the analysis of the results of the experiments or simulations, the user of the DMF decides which blinds to select. In this research, simulation is selected as the preferred testing methodology in the DMF because simulation software is affordable. Several daylighting software programs such as Superlite, RADIANCE, ADELINE, and Autodesk VIZ were compared to understand their advantages, disadvantages, and usefulness for application in this DMF.

2.1. Comparison of Daylighting Software

The software **SUPERLITE** (LBNL 1994) is based on the radiosity method. SUPERLITE is MS DOS-based software. Output information provided by the SUPERLITE software is: illuminance distribution and daylight factor. Advantages of SUPERLITE are as follows:

- Models geometrically complicated architectural spaces.
- Calculates daylight levels from both diffuse sources and direct sunlight in the room.
- Calculates the contribution of electric lighting to the illuminance of the space.
- Data are given numerically in terms of illuminance levels and daylight factor in tabular format.
- Results can be obtained in very short time

Disadvantages of SUPERLITE are as follows:

- Not user-friendly software.
- Assumes that all reflection of light by surfaces is perfectly diffuse.
- Assumes that scattering or absorption of light cannot take place other than at room surfaces.
- Number of surfaces, windows, and nodes is limited.
- Colors of the surfaces are not taken into account.
- Complex fenestration systems, such as Venetian blinds and light shelves, cannot be simulated.
- Does not simulate partly cloudy sky conditions.
- Electric lighting calculations cannot be thoroughly examined.

The software **RADIANCE** (LBNL 1990) is based on the ray-tracing method. RADIANCE uses UNIX operating system. The output of a RADIANCE simulation is a photorealistic color image with a numeric prediction of light levels at any point in the scene. Advantages of RADIANCE are as follows:

- Provides a digital view of an illuminated space, excluding the need for the physical model.
- Promotes an energy-efficient lighting design.
- Considers reflections from shiny surfaces.
- Calculates interreflections between surfaces.
- Colors of the surfaces are considered.

Disadvantages of RADIANCE are as follows:

- Not a user-friendly program since it uses the UNIX operating system and text files.
- There are problems with using the CAD program.
- Works with surfaces so the objects are calculated as hollow, not solid.
- Does not have a function for accurate calculation of transparent blinds.
- Simulation running time is long.

The **ADELINE** (LBNL 2002) software is based on both the radiosity technique and ray-tracing technique. It uses either MS DOS or Windows 95/NT operating system. Output of the lighting simulations is photorealistic images with illuminance and luminance distributions in the space. Advantages of ADELINE are as follows:

- Provides a photorealistic image of the architectural space.
- Gives 3D images of daylight level in the space.

Disadvantages of ADELINE are as follows:

- Building model is numerical.
- CAD input file cannot be used directly.
- Does not simulate partly cloudy conditions.

Autodesk VIZ 4 software integrates two lighting algorithms: ray-tracing and radiosity. It works in Wndows XP operating system. The output of Autodesk VIZ 4 is a photorealistic three-dimensional image of the space with illuminance and luminance levels defined by the range of colors. Advantages of Autodesk VIZ 4 are as follows:

- Provides a realistic digital 3D view of the space.
- Takes into consideration daylighting and electric lighting in calculating illuminance and luminance.
- Considers color of the surfaces.
- A user-friendly software.
- AutoCAD files are easily imported to Autodesk VIZ 4.

- The shading device can be easily simulated by making an input of a 3D model of the blinds and defining materials.

Disadvantages of the Autodesk VIZ 4 software are as follows:

- Does not calculate the glare.
- Simulation time is very long, even for the simple spaces.
- Works with surfaces so refraction and internal reflection are not fully represented.
- Has been validated only for accuracy of direct illumination from IES sources. It has not been validated for illuminance/luminance in complex environments with multiple reflections.

Autodesk VIZ 4 was useful for this research since it calculates illuminance and luminance levels in the space and gives a three-dimensional photorealistic picture of the space with numerical values of light levels in the space.

Among available daylighting software, Autodesk VIZ was selected because of its ease of use. Designers use Autodesk VIZ for the 3D modeling of the buildings. Use of the same software as a daylighting simulation tool in this DMF will avoid additional training for the designers.

2.2. The Decision-Making Process for the Analysis of the Shading Devices

Daylighting simulation of shading devices is one of the steps in the DMF. The decision-making process for the analysis of the shading device systems consists of the following steps:

1. Identifying input variables and performance parameters
2. 3D daylighting simulation of the shading device systems
3. Obtaining output performance parameter values
4. Making the decision

In the first step of the decision-making process, the user of the DMF identifies the input parameters. The input parameters are assigned particular quantitative or qualitative values. The objective in this decision situation is to select the best possible shading device among several alternatives. In this situation, each of these alternatives must be tested separately. As a result, input for the shading device variables must be prepared individually for each system.

In the second step of the decision-making process, 3D daylighting simulation of the shading device system is performed by using 3D modeling software. The input parameters prepared in the first step are used for simulating the daylighting performance of the various shading device systems. For each type of shading device, simulations were repeated for different days during the year, using at least one day from each season and using different times for each of those days. Simulation is repeated individually for each type of shading device to find out how application of these shading device systems in the building affects illuminance and luminance levels in the space. If the blinds are adjustable, then the shading device system is tested for various blind tilt angles, from completely open to partially open/partially closed, and finally to completely closed. This testing is helpful in establishing a control strategy for a shading device for different sun and sky conditions to keep the required illuminance and luminance levels in the space.

The output of simulation is actual values of illuminance and luminance levels in the space, as a result of the application of the specific shading device system in the building. The output is represented by the 3D photorealistic images of the analyzed space. In the third step of the decision-making process, the output information is gathered, organized, and prepared for analysis.

In the fourth step of the decision-making process, a decision about the selection of the preferred blinds for a particular building is made based on the analysis of the 3D daylighting simulation's output results.

3. 3D DAYLIGHTING SIMULATION OF SHADING DEVICE SYSTEM

The Autodesk VIZ software is used for 3D daylighting simulation of shading devices in this research. Autodesk VIZ is a tool for a three-dimensional simulation of the space, which gives photorealistic images as an output. Autodesk VIZ also has a feature that simulates lighting and gives photometric values of illuminance and luminance levels in the space. In the process of the shading devices' testing, the user of the DMF needs to understand how Autodesk VIZ simulates blinds on a particular building at a given location. Description of the input and output of Autodesk VIZ helps the user of the DMF in understanding how to prepare:

- Input information for the simulation.
- An analysis of the output from the simulation.

3.1. Preparing Input for 3D Daylighting Simulation

Table 1 is an overview of input variables for a 3D daylighting simulation. The first column shows the variables that are the input for simulation. These variables are independent, dependent, or shading device variables in the DMF. To perform the simulation, a user of the DMF needs to provide the input for the software. For example, the values of the independent variables are given to a user, but the user needs to input these variables in software. For that reason, source of input in Table 1 is a user even for the independent variables. Table 1 shows that the input for the site, building space, façade type, windows, position of shading device, and shading device variables is prepared/drawn by the 3D modeling software, such as AutoCAD and Autodesk VIZ. Based on the building location (longitude and latitude), climate characteristics can be determined by using software. Autodesk VIZ calculates sky conditions and sun angles automatically when the DMF user enters the geographic location, date, and time. The simulations can be done for different climate zones. Dates and times, for which the simulations are performed, are defined by the user of the DMF. The simulations can be done for various days during the year, for example, one day per each season. Also, simulations can be performed for different times of the day depending on the façade orientation and frequency of the space usage. Site as an independent variable is given to the user of the DMF, but the user needs to prepare a 3D drawing of the site as part of an input for simulation. A 3D drawing is produced by AutoCAD and Autodesk VIZ. The drawing includes surrounding buildings, local terrain, and existing vegetation. Materials are selected from the Autodesk VIZ library and attached to the surfaces in the drawing. The self-shading properties of the façade and façade orientations of the proposed building are also determined by a 3D drawing. Dependent variables are defined by the user of the DMF. The user's input for the dependent variables for the daylighting simulation in this DMF is the three-dimensional drawing done by using AutoCAD and Autodesk VIZ. The user draws a 3D model of the building in which he defines:

- Geometry:
    - Shape and dimension of the spaces/rooms
    - Geometry and type of façade
    - Dimensions and positions of the windows
    - Position of the shading device relative to the window
    - Shape, dimensions, and position of furniture that are used in a particular space
- Materials for:
    - The interior surfaces
    - Furniture
    - The window frames and the glazing

Table 1 Input for the simulation

Input for the simulation		Source of input
Independent variables in the DMF	Date	User's input/quantitative value
	Time of the day	
	Location	User's input/qualitative value
	Sun angle	Simulation software – calculates automatically
	Sky conditions	User's input based on statistical data/qualitative value
	Site	3D drawing done by AutoCAD and Autodesk VIZ. Material properties included in the drawing.
Dependent variables in the DMF	Building space	
	Façade type	
	Position of the shading device	3D drawing done by AutoCAD and Autodesk VIZ.
	Windows	3D drawing done by AutoCAD and Autodesk VIZ. Material properties included in the drawing.
Shading device variables in the DMF		

Because the materials for the interior surfaces and furniture are selected from the 3D software material library, the pre-defined optical properties, such as reflectance and transmittance, will automatically be defined.

If the existing blinds are simulated, then the 3D model that defines shading device variables can be provided by the manufacturer. If such information is not available, the user of the DMF needs to prepare input for the shading device variables. In AutoCAD and Autodesk VIZ, the user draws a 3D model of the shading device in which he defines:

- Geometry:
    - Shape and dimensions of the blinds
    - Distance between the blinds
    - Blinds' tilt angle
- Materials for the blinds with the materials' properties such as reflectance/transmittance.

3.2. 3D Daylighting Simulation

3D daylighting simulations are performed for the particular building type, façade type, and different shading device types at the chosen location. For each type of shading device and its fixed position relative to the window, multiple simulations are performed since the analysis is done for different dates and different times per day, as well as for various sky conditions. If the blinds are adjustable/moveable, the number of simulations is multiplied by the number of various blind tilt angles. The daylighting simulations are performed for the different types of shading devices based on the following shading device variables:

- Blind's material
- Blind's geometry
- Blind's tilt angle
- Shading device position relative to the window

The following input variables were changed in the Autodesk VIZ file to get different performance parameter values:

- Climate variables:
    - Sun angle: changes based on time (hours, minutes, seconds), date (month, day, year) and location (longitude and latitude).
    - Sky conditions: clear, partly cloudy, cloudy
- Time variables:
    - Date
    - Time of the day
- Shading device variables

In this research, the following parameters were fixed in the Autodesk VIZ file:

- Building geometry
- Surface materials
- Furniture
- Camera position and field of view

To simulate daylight and get a 3D photorealistic image of light levels in the space, it is necessary to define the camera position in the space. The camera position affects the output of simulations, that is, the limits of the 3D image of the space with calculated illuminance and luminance levels. After input variables are defined, the software Autodesk VIZ simulates the actual illuminance and luminance levels as a result of the application of the specific type of shading device.

In order to start simulations after completing the input, the user of Autodesk VIZ defines rendering parameters such as:

- Radiosity
- Environment

The Autodesk VIZ 4 (Autodesk, Inc. 2004) software integrates two lighting algorithms in order to accurately model lighting in the space: ray-tracing and radiosity. In Autodesk VIZ 4, radiosity is used for rendering diffuse-to-diffuse inter-reflections while ray-tracing is used for specular reflections. In the radiosity dialog box, the processing parameter rollout initial quality is set to 75%, and possible rendering options are set to render direct illumination[1] and regather indirect illumination[2]. The radiosity process is re-run each time the user changes the shading device variables, date and time of the day, or outdoor conditions (sun angle, sky conditions). The user defines the exposure control in the Environment dialog box. The pseudo color exposure control is used to determine light levels in the space. Pseudo Color Exposure Control is actually a lighting analysis tool that provides an intuitive way of visualizing and evaluating the lighting levels in scenes. It maps luminance or illuminance values to pseudo colors that show the brightness of the values being converted. From darkest to brightest, the rendering shows blue, cyan, green, yellow, orange, and red (Autodesk, Inc. 2004).

After radiosity and environment parameters are set, the scene is rendered. In the Render Scene dialog box, the "Use radiosity" box must be checked. The output of the rendering is a three-dimensional photorealistic image of the space with either illuminance or luminance levels represented by the colors. The illuminance and luminance values can be read from the scale shown in the Pseudo Color Exposure Control dialog box.

3.3. Presentation of Output of 3D Daylighting Simulation

Variables are changed in this DMF in order to present different simulation situations. A combination of all these variables requires thousands of simulations and gives as an output a large quantity of data that needs to be represented in a simple, organized, and understandable format. The output of the simulation is the values of the illuminance and luminance levels calculated for different combinations/values of the input variables. Since the values are given in the format of the three-dimensional image (Figures 2 and 3), the values are read at different points in the space and recorded in the format of matrixes of the data. These results are then presented in the format of charts that compare daylighting performance of different types of blinds and different sky conditions. For example, one chart (see Figure 9) shows

---

[1] a longer render that calculates shadows by the standard renderer so they are better quality

[2] the longest and best render that calculates shadows from the light sources and corrects artifacts and shadow leaks

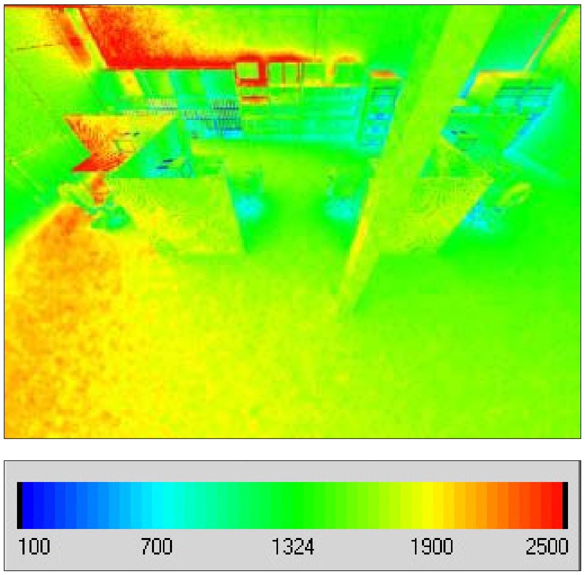

Figure 2 Output of the simulation's three-dimensional image of the space – illuminance (in lx)

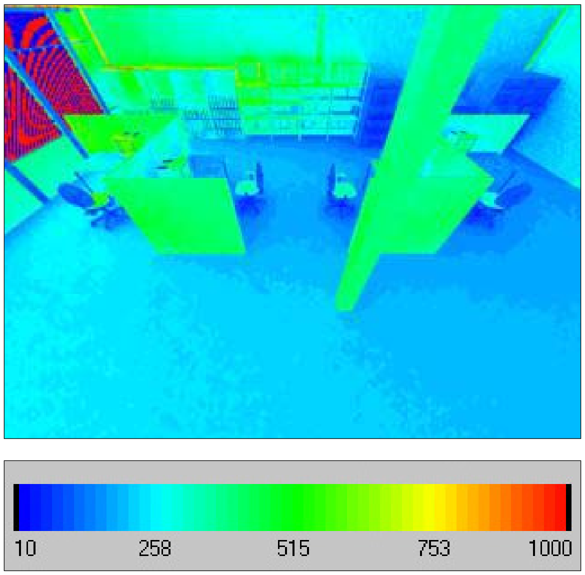

Figure 3 Output of the simulation's three-dimensional image of the space – luminance (in cd/sq m)

illuminance level values on the vertical axis and different sky conditions (clear, partly cloudy, and cloudy) on the horizontal axis. In the chart, three lines represent the performance of the three types of blinds.

4. CASE STUDY

4.1. The Case Study Description

In order to validate an application of Autodesk VIZ as a 3D daylighting simulation tool and to validate a DMF based on daylighting, a case study was performed. A proposed office building was used in this case study. The proposed building was located in Roanoke, Virginia, which has a latitude 37ºN and longitude 80ºW and a moderate climate. The following input variables for the simulation are described: site, building, façade, time frame, sun and sky conditions, and shading devices.

Site: The building site conditions were proposed in the case study to simplify the geometry of the site and the size of the input for Autodesk VIZ, resulting in a reasonable simulation time. A sidewalk was designed around the building to simulate the ground, which reflects the daylight into the interior space. The sidewalk was 5′ wide and was made of grey concrete with a reflectance of 53% (Figure 4). The site parameters, such as existing surrounding buildings and vegetation, were not considered in this case study in order to decrease the time of the simulation.

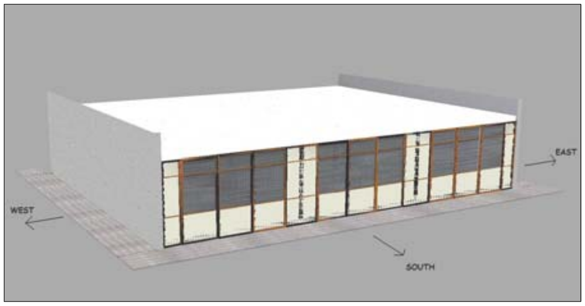

Figure 4 Perspective view of the office building

Building: The 3D building model was made by using AutoCAD and Autodesk VIZ. An analysis was done for a rectangular office space 60′ wide, 40′ deep, and 10′ high to decrease the time of simulation, that is, rendering three-dimensional images of the analyzed space (Figure 4). The office space was divided into separate work spaces by cubicles. Each cubical space contained an office desk, a chair, and a computer. Shelves and cabinets lined the interior walls (Figure 5). Only four cubicles were presented in the model of the proposed space in order to decrease the time of the simulation, and, at the same time, provide enough

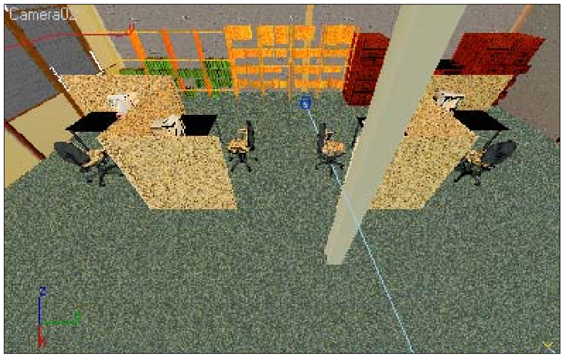

Figure 5 Perspective view of the interior space

Figure 6 Existing shading device

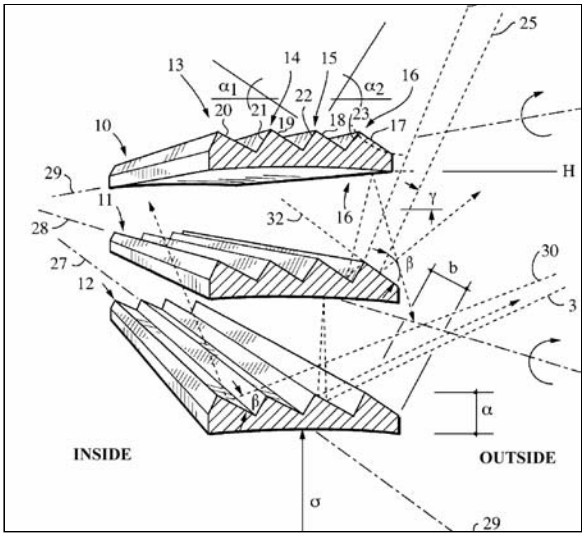

Figure 7 The patented shading device

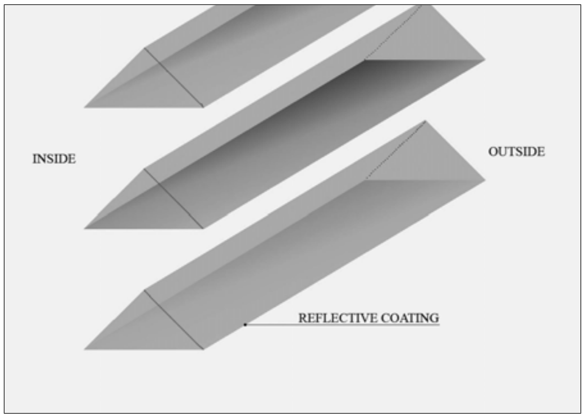

Figure 8 The new shading device

results for the analysis of the blind's performance.

Similar office furniture would be repeated in the remaining space. Reflectances of the interior surfaces were based on the choice of materials from the Autodesk VIZ materials library.

Façade: The 3D model of the façade was a part of a 3D model of the building, drawn in AutoCAD and Autodesk VIZ. The south-facing curtain wall had a 600 sq. ft. area and a completely glazed outside layer. The transparent/window area was 315 sq. ft., and one window assembly consisted of two parts: lower (4.5′ x 5′) and upper (4.5′ x 1.75′). It was located 3′ above the floor. The opaque parts of the façade had wooden boards as an interior finish and an area of 345 sq. ft. (Figure 4). The window-to-wall ratio was 0.47 while the window-to-floor ratio was 0.13.

Time frame: 3D daylighting simulations of the shading devices were done for one day per season: December 21, March 21, and June 21. Usually an office building is occupied from 9:00 a.m. until 5:00 p.m. Simulations were done three times per day:

- For the south-oriented façade: 11:00 a.m., 12:00 p.m., 3:00 p.m.
- For the west-oriented façade: 12:00 p.m., 2:00 p.m., 4:00 p.m.

Sun and sky conditions: Autodesk VIZ automatically calculated values of the azimuth and altitude sun angles and the outdoor illuminance used for the simulations in this case study. Values were identified for various dates and times and for the given location (Roanoke, Virginia). For each date and time of the simulation, the shading devices were tested for all three possible sky conditions: clear, partly cloudy, and cloudy sky. The blind's tilt angle was changed depending on the sky conditions.

Shading devices: The 3D models of the blinds were drawn in AutoCAD and Autodesk VIZ. In this case study, three shading device systems were simulated:

- Existing system: Mini Venetian blinds (Kays 2004) (Figure 6). The slat has the curved, concave shape in the cross section. The blinds are made of grey vinyl with a reflectance of 40%, and they are opaque.
- Patented system: The shading device was patented by U.S. Patent no. 6,367,937 (Koster 2002). The blinds have a tooth-shaped upper surface and a slightly curved, concave bottom surface. The slats are made of clear plastic with a transmittance of 100% (Figure 7).
- New system: A new shading device system was proposed by this study (Figure 8). The slat has a right triangle shape in the cross section. The

slats are made of clear plastic with a transmittance of 100%. A silver reflective film, which has a reflectance of 94%, was applied on the hypotenuse outside surface.

The blind tilt angle is one of the most influential variables in the performance of the shading device. The shading devices were simulated for the various blind's tilt angle in relation to the sky conditions. The blind's tilt angle was fixed in the particular 3D model. If the blinds were adjustable--for each new tilt angle of the blinds--a new 3D model and VIZ file was created. In this case study, all shading device systems were simulated for a completely open position, which corresponds to the 0º tilt angle of the blinds. In addition to completely open position simulations, the existing system and new system were simulated for a completely closed position (90º) and a partially open/partially closed position (45º). Theoretically, the shading device has one of three basic positions: inside, between, and outside the façade. However, blinds are almost always installed in the position that is predetermined by the design. In this study, the existing blinds were installed on the interior side of the window, and patented and new blinds were installed between two panes of glass. For each different position of the blinds a new VIZ file was created.

4.2. The Case Study Limitations

This case study focused only on the daylighting performance of the shading device and only on illuminance and luminance. The case study did not analyze the occurrence of glare in the space. The case study was conducted only for:

- One fixed camera position at a task level, that is, one view of the three-dimensional space drawn by using Autodesk VIZ
- An office building that contains computers
- Horizontal Venetian blinds
- Roanoke, Virginia
- Climate conditions on March 21, June 21, December 21
- Two orientations: south and west
- Three times of the day – 11:00 a.m., 12:00 p.m., and 3:00 p.m. for south orientation, and 12:00 p.m., 2:00 p.m., and 4:00 p.m. for west orientation

4.3. The Autodesk VIZ Limitations

Autodesk VIZ 4 has the capability to produce a three-dimensional image of the space and only illuminance and luminance levels. Autodesk VIZ 4 calculates reflection and transmission through transparent materials. VIZ works with surfaces so refraction and internal reflection are not fully represented. The new and patented blinds tested in this case study were calculated as the hollow objects. Autodesk VIZ 4 has been validated only for accuracy of direct illumination from IES sources. VIZ has not been validated for illuminance and luminance in complex environments by multiple reflections so the results of the simulation are biased.

4.4. Technical Issues Understood from the Case Study

In this case study, preliminary 3D daylighting simulations were performed to set rendering parameters properly and to obtain the best possible quality of the output. The rendering parameters in VIZ must be set to get the high quality three-dimensional images. The output results need to be read accurately from these images. In this case study, the output size in the render scene dialog box was set to 320x240 pixels, because smaller images are rendered faster. Simulation time ranged from 30 minutes to 90 minutes for one scene. Simulation time was affected by:

- The type of the blinds: the existing blinds required the least amount of time for the rendering, because blinds had a simple geometry and were made of the opaque material. Time for the 3D daylighting simulation for the patented and new blinds was longer because the blinds had the complex geometries and were made of the clear plastic. Calculation of radiosity is time consuming for the transparent materials, because both the reflection and refraction need to be calculated.
- The sky conditions: the cloudy sky condition took the least amount of time. Simulation time for the blinds in the clear sky condition was the longest. Outdoor illuminance level for clear sky conditions is higher, so calculation of physic for this daylight takes longer time.
- Blinds' tilt angle: Completely closed blinds (90° tilt angle) required the least amount of simulation time. Completely open blinds (0° tilt angle) took the longest simulation time, because the more daylight passes between the blinds and is reflected from the blinds, or refracted through the blinds in the case of the transparent blinds. VIZ calculates physics of this daylight for a longer time.

When the initial simulation was designed, many variables caused approximately 46,600 simulations to consider all the cases. This number was too demanding to deal with. A systematic look at the variables was done to reduce the amount of simulations to a reasonable number while giving enough information to interpret the results. This resulted in a final number of simulations run to be 470. Three computers were used to accomplish 470 simulations.

4.5. Results of Case Study

Output of simulation in this case study gave 470 images. Two performance parameters, illuminance and luminance, were measured by the simulations and were determined for two points in the space:

- Office desk at the distance of 96″ from the window; height of the top of the surface is 30″
- Office desk at the distance of 343″ from the window; height of the top of the surface is 30″

The required values of illuminance and luminance in this office space were taken from the standard. The following ranges of values were used:

- For illuminance: minimum 750 lx and maximum 4200 lx
- For luminance: minimum 100 cd/sq. m. and maximum 850 cd/sq. m.

In this case study the camera position was fixed at the top surface of the two office desks for all simulations and renderings to get the same view in each simulation. From the three-dimensional images, the values of illuminance and luminance were read for these two points from the scale shown in the Pseudo Color Exposure Control dialog box. The display range used for illuminance was from 100 lx to 2500 lx and for luminance was from 10 cd/m^2 to 1000 cd/m^2. A physical scale of 9000 cd was used.

Results of the case study, obtained by the simulation by Autodesk VIZ 4, were presented in the format of:

- Matrixes of data: because matrixes of data include all simulation results as the they were obtained, without averaging the results. For each combination of the input parameters, the obtained result was recorded in the matrixes of data, which represent the most accurate and precise way of presentation of the output of simulation.
- Charts of results, based on the matrixes of data and developed to be used by the user of the DMF: Matrixes of data consist of a large number of output results, which lead to a complicated and time-consuming analysis of results to be performed by the user of the DMF. To simplify the analysis of the results, the results from the matrixes of data were averaged and presented as the values of illuminance*-days/year and luminance*-days/year for each type of blind, two measurement points in the space, and three sky conditions. In this way, the results are decreased to a reasonable number that could be quickly, easily, and accurately analyzed.

By comparing the values of illuminance-days and luminance-days for three types of blinds, the user of the DMF can conclude which type of blind provides the illuminance (or luminance) levels required by the standard for the longest period of time. The shading device system that shows the best daylighting performance for the longest time should be applied to the building given economic viability.

By analysis of the charts for illuminance levels in the space, as a result of the application of the different types of shading devices, the user of the DMF can make a decision about the selection of the preferred blinds. The following tasks were performed to analyze the charts:

- Comparison among the performances of the different types of shading devices.
- Comparison of the performance of each type of shading device with the performance required by the standards.
- Evaluation of the effect of the sky conditions on the performance of the shading device.
- Comparison between the performance for the south and west orientations for each shading device system.
- Comparison between the performance for two points in the space (window and interior) for each type of shading device.

The charts shown in Figure 9 present values of illuminance*-days/year for three types of shading devices (existing, patented, new), for three sky conditions (clear, partly cloudy, cloudy), for south and west façade orientations, and two points in the space (window desk and interior desk).

An analysis of the four charts in Figure 9 showed that the new shading device gave the highest values of illuminance*-days/year, compared to the other two types of blinds, given the limitations of this study. The new shading device gave the overall best performance among the three simulated shading device systems due to its geometry and material. The triangular cross section of the blind and the clear plastic with the silver reflective coating applied on one side of the triangle contributed to higher illuminance levels in the space, compared to the other two types of shading devices. The new shading device met the minimum requirements of the standard for all sky conditions at the point close to the window, even for cloudy sky conditions, which was not the case with the other two shading device systems.

The new shading device did not meet the minimum requirements of standards for light level in cloudy sky conditions at the point close to the interior wall. This was to be expected as a result of a low outdoor illuminance level in cloudy sky conditions and the large distance of the measurement point from the window wall.

Sky conditions have a significant effect on the light level in the space, as well as on the daylight performance of the shading devices. The level of outdoor illuminance and, consequently, the level of indoor illuminance decrease by increasing the percentage of the sky cover. This was the reason that shading devices had a satisfactory performance for clear and partly cloudy sky days and very low performance for cloudy sky days.

The shading device showed a better performance at the point close to the interior walls for partly cloudy sky conditions than for clear sky conditions. This is due to the natural phenomena that sunlight is additionally reflected from the cloud edges, which contributes to increasing the illuminance for partly cloudy sky conditions by 10% to 15%.

An analysis of the new shading device's performance for the south and west façade orientation showed that the new shading device performed better for the west orientation. Averaging the results of the simulations had the result of higher levels of light for the west façade because of the direct sunlight at 4:00 p.m. for all the simulated dates. This was the case in both clear and partly cloudy sky conditions for the point close to the window. The performance was almost the same for both orientations in cloudy sky conditions. This analysis shows that all three tested systems had an acceptable performance at both orientations.

Based on the conclusion that the new blinds showed

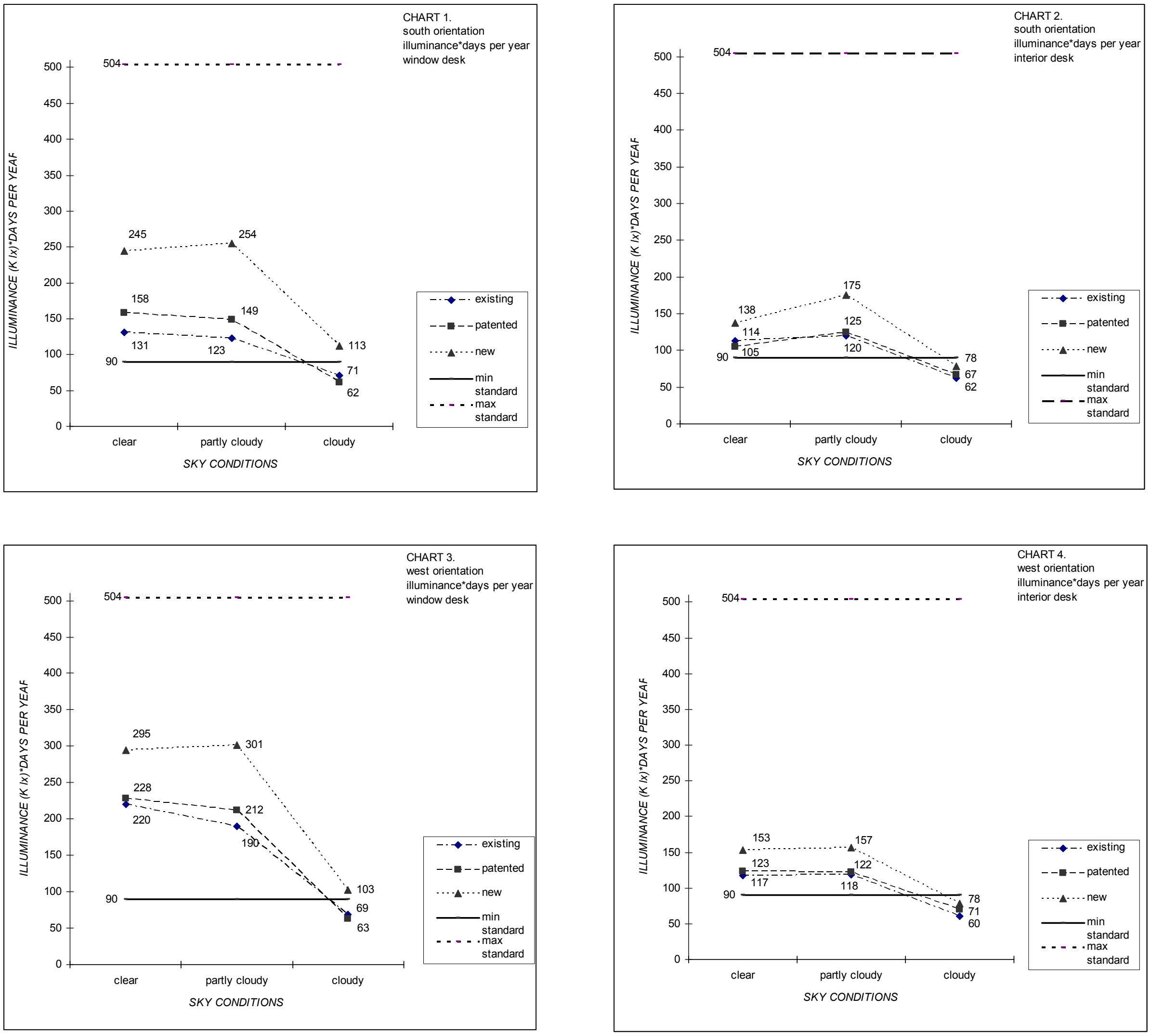

Figure 9 Relationship between illuminance – days, levels, and sky conditions for three types of blinds

the best performance overall and for most of the time met the requirements of the standards for both the illuminance and luminance levels in the space, the designer could make a decision to choose the new blinds to be applied at an office building in Roanoke, Virginia, given the economic consideration and limits of this case study.

5. CONCLUSIONS

This paper explains research on the application of 3D modeling software as a daylighting simulation tool. The decision-making framework (DMF) for selection and design of shading devices based on their daylighting performance was developed. Shading device daylighting performance was tested by using Autodesk VIZ as a 3D simulation tool. The DMF is intended to be used by architects, engineers, manufacturers of shading devices, and students. The use of Autodesk VIZ in the DMF does not require additional training of the designers because the designers already use VIZ for the 3D modeling of the buildings.

The decision-making process for selection of a shading device consists of four steps: identifying input, 3D daylighting simulation, obtaining output, and making the decision. Autodesk VIZ is used in the second step of the decision making process, that is, 3D daylighting simulation. Input parameters for Autodesk VIZ include: climate variables, time variables, site and building variables, and shading device variables. Time and location variables are selected by the user of the DMF, and Autodesk VIZ automatically calculates the values of climate variables. Site, building, and shading device variables are defined by a 3D drawing produced by the user of the DMF. Based on input variables, Autodesk VIZ simulates daylighting performance; that is, it calculates values of illuminance and luminance levels in the space as a result of application of the specific shading device. The output of the simulation is 3D photorealistic images of the space with defined illuminance/luminance levels represented by colors. The output results are organized in the format of matrixes and charts to analyze daylighting performance of the various types of blinds. Based on the analysis of these results, the user of the DMF can make a decision about the selection of the preferred blinds.

The case study was performed to validate the DMF and to find out if Autodesk VIZ is an appropriate 3D daylighting simulation software.

In the case study, the proposed office building located in Roanoke, Virginia was tested. Three different types of blinds were simulated by using Autodesk VIZ: existing, patented, and the new blinds proposed by this study. The objective was to select the blinds with the best daylighting performance. Based on the output of simulation, i.e. 3D photorealistic images of the space, the blinds' daylighting performance was analyzed. The analysis showed that the new blinds seemed to provide the highest levels of illuminance/luminance in the space, given the limitations of this study.

This study showed that Autodesk VIZ can be used as a 3D daylighting simulation tool in the design process. The designer can use Autodesk VIZ to obtain information about daylight levels in the space as a result of the application of different shading device systems. This information provides guidance for the designer in the process of the selection of the preferred blinds.

6. REFERENCES

ADELINE Copyrighted © 2002 by Fraunhofer-Institut für Bauphysik.

Autodesk VIZ 4 User Reference (2004). Autodesk VIZ 4 Copyright 2004 Autodesk, Inc.

Koster, H. (2002). Sun Protection Installation Comprising Sun Protection Lamellae Having a Toothed Upper Side. U.S. Patent 6,367,937.

RADIANCE Copyrighted © 1990 by The Regents of the University of California through Lawrence Berkeley National Laboratory (LBNL).

Sarawgi, T., and Paranandi, M. (2002). Daylight Simulation: Examining its place during Conceptual Stages in a CAAD Studio. ACADIA.

SUPERLITE Copyrighted © 1994 by The Regents of the University of California through Lawrence Berkeley National Laboratory (LBNL).

Ubbelohde, S., and Humann, C. (1998). Comparative Evaluation of Four Daylighting Software Programs. ACEEE Summer Study on Energy Efficiency in Buildings.

http://eetd.lbl.gov/btp/superlite20.html

http://kaysnet.com/gus/product.asp?brand=kays&cat%5Fid=15&zone%5Fid=&prod%5Fid=192565&offer%5Fid=&extra=&mscs_sid=4V1HU0F0FQV48NSMDSG5DPQF4TTJ27C2&fh_secondid=192565&fh_search=mini+vynil+blinds

http://radsite.lbl.gov/adeline/HOME.html

http://radsite.lbl.gov/radiance/HOME.html