Computer daylight simulation systems: An experimental evaluation

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This paper investigates Daylight Simulation Systems in computer visualization programs. Computer visualization has provided qualitative appearance in architectural presentation. There are two aspects, one objective and another subjective, that should be considered in lighting simulation. The objective aspect is concerned with accurate prediction of daylight levels. The subjective aspect is associated with the evaluation of lighting quality. The objective aspect of lighting has often been neglected by visualization designers during the process of simulation. The relevant concepts of lighting to ensure accurate simulation techniques have been defined in order to highlight and resolve the dilemma of accurate lighting visualization. This paper has attempted to provide guidance for the future development of visualization programs and information on innovative ways to accommodate computer visualization for architectural usage and needs.

Introduction

In terms of environmental perception of daylight, the representation of this element in particular has been the subject matter of computer science and design methods, as well as computer aided design research. There are many tools of Computer Aided Architectural Design (CAAD) which have been developed to support early decision-making based on the simplified performance modeling approaches. These tools are insufficient to accurately assess the performance implications of the design parameters. By contrast, in the final design stage, computer visualization can provide photo-realistic simulation of material and lights, as well as volume and form. This geometrical and visual information has speciously supported the environmental perception of design. For example, evaluating lighting conditions involves looking at space, volume, form, texture and color collectively. These factors can be obtained from computer rendered images or animation, but for an accurate simulation of daylight, computer visualization does not sufficiently address the implications of the solar irradiance and illuminance.

Testing specifications — A multi-dimensional approach

According to Hopkinson's theory [1963], psychophysical experiments are designed for establishing standards for building practice, innovating techniques to reach these standards and determining means of assessing the success of a building to meet these standards. This study has followed the same principles of Hopkinson's theory and attempted to provide information for innovation in computer aided architectural design.

The experiment carried out by this research has been divided into three categories: a) Performance tests; b) Physiological tests; c) Cognitive (mental) assessment tests. The first two are behavior studies, and the third is an introspective study.

a) Performance tests (Subjective evaluation / appraisal)
In this experiment the ability of the computer visualization program to perform a given task is examined under a range of physical conditions such as its lighting simulation methods.

b) Physiological tests (Objective measurement)
Measurements are made of some physiological factors, such as the illumination of a room.

c) Cognitive assessment tests (The link between objective and subjective evaluation)
The tests in this research are based on evaluating the computer visualization programs and their abilities to represent the environmental perception of design, in order to ascertain the direction of future development.

Case study models description; Computer modeling and data logging experiments

For the sake of this case study, the model, Room 38, Life Modeling Studio, Glasgow School of Art, has been created by this research through the 3D studio R4. Software. Glasgow School of Art was designed by Charles Rennie Mackintosh. Glasgow School of Art has been described as the first important architectural work of the Modern Movement in Europe. It is one of the oldest and largest art schools in Britain. Established in 1845, the building was built in two phases: the east wing begun in 1897 and completed in 1899, and the west wing and attic storey between 1907 to 1909 [Grigg 1987] [Fiell 1997] [Harbison 1989]. Room 38, Life Modeling Studio, is located on the first floor. It is an open space studio with north light. There are timber mullion windows looking north. The top-lighting is concealed externally by the cornice. The timber floor is painted a grey color, and each wall in the room is white in color.

Statistical analysis and measurement program

The measurement of daylight took place in Room 38 (Length=10.53m, Height=7.30m, Width=8.53m) with a computerized monitoring station and a remote portable computer to operate and control the monitoring process. The station consists of seven color corrected light sensors, seven amplifiers and seven dataloggers, and a portable computer running the EASYLOG software to download data. The readings were logged over the period of five hours at one minute intervals. Figure 1. shows an illustration of the plan with the orientation and location of the sensors. All the sensors were placed horizontally except sensor No.6 which was mounted vertically on the east wall to measure the incoming daylight on a vertical plane. All the logged results were pulled into EXCEL and converted into graphic diagrams.

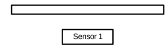
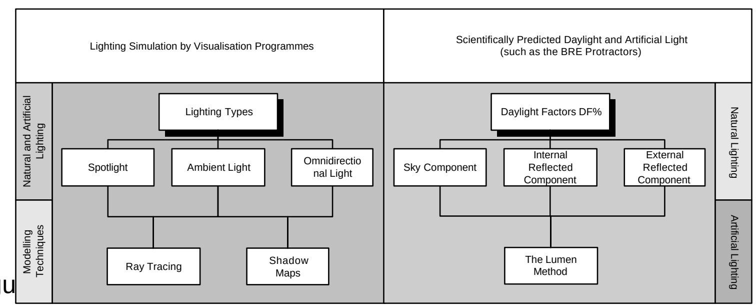


Figure1. An illustration of sensors' location
in Room 38, Glasgow School of Art
Scotland, UK.

Computer visualization and the modeling of lighting performance

The lighting condition in room 38, Glasgow School of Art, is under a natural daylight source from large timber mullion windows and the skylight. Two daylight level measurements were recorded under summer and winter conditions (July and December), and a series of photos were also taken during the winter measurement session. The records were used as references against which the computer simulated images of the changing lighting conditions over time could be compared.

Lighting simulation used by advanced visualization programs including 3D Studio do not take into account the three components of the daylight factors: skylight, internal reflected light and external reflected light. 3D Studio provides three types of lighting sources: ambient light, omnidirectional lights and spotlights, which enable visualization designers to simulate these daylight factors. The lighting reflection is calculated during the light tracing operation. In order to simulate daylight factors, the three light types and two rendering methods in the 3D Studio program are used for controlling the lighting environment [Figure2].



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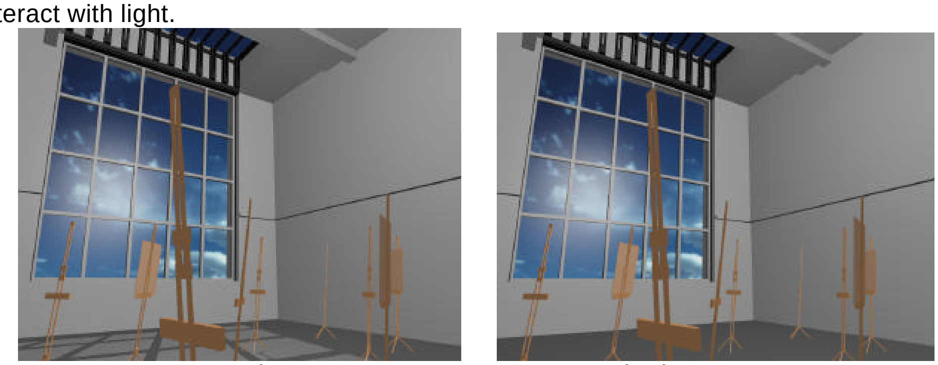
Rendering techniques

There is a variety of algorithms which can be used to calculate shadows and shading on the object surfaces, as well as reflection of light such as Radiosity and Ray tracing. These two fundamentally different rendering techniques are extreme variants of the same basic technique. There are many different Radiosity methods, each with its own advantages and disadvantages. Most of them are analogous to Monte Carlo particle tracing in a view-independent way, while ray tracing is view-dependent. Radiosity methods can accurately model area light sources, diffuse reflections, color bleeding effect, and realistic shadows.

The first rendering technique used in this study is 'Shadow map' which is simulated and based upon the size and shapes of the object from the camera position (viewer's position) of the shadow-casting light sources. The rendered image has resulted in a soft-shadow appearance With the ray tracing technique, the result of rendering has an extremely bright sunny effect. The spotlight passing through the glass object has created very clear and sharp shadows of the mullion window frames. Before these two renderings took place, there were several trial-and-error experiments on the lights' levels and the spot light position adjustments. The reference was based on the mid-day on-site photo. The spotlight position is an essential issue during these trials. The daylight effect appearance resulted in very different ways with each rendering of different altitudes of spotlight. Figure 3 shows the two images in which the spotlight positions were placed in lower altitudes. The rendered images exhibited much stronger characteristics in each rendering technique. The results of these two rendered images were almost photo-realistic. The reason these two images are represented in this style is because a lower position of a spotlight creates a local illumination effect, even if set up as a Global setting. The light emitted by the light sources is used to calculate the illumination of individual objects only. They clearly ignore the physical reality that objects interact with light.



Ray Tracing — Shadow Map

Figure 3 the rendered images with lower altitude of spotlight in different rendering techniques

The physiological factor: Lighting level in computer visualization

Lighting level in computer visualization is usually used to specify a range of numbers. In 3D Studio, the lighting intensity is defined inaccurately by a parameter, which is the color of light. This parameter contains the three primary colors of the standard computer graphics color systems: a) Red, Green, and Blue, b) Hue, Luminance, and Saturation. Both ranges of the RGB and HLS values are from 0 to 255, with 0 being no color and 255 being full color. In addition, the program also provides a parameter called Multiplier which can change the value of the color's luminance by increasing the multiplier value between -9999 to +99,999. Only around -10 to +10 can the differences be seen. 3D Studio uses the light color as illumination; the lighting intensity reacts to the color system and the value is always between 0 to 255.

Using computer visualization to simulate daylighting by the traditional trial-and error technique together with reliable sources, it is possible to reproduce photo-realistic images which look like the on-site photos. However, computer lighting simulation is not used for the purpose of 'reproduction' of architectural design; rather, it should be used to more accurately predict and represent lighting behavior.

In terms of daylight that changes over time, computer visualization programs can simulate the sun's position and movement as well as different lighting intensities within the animated sequence, but does the simulated animation precisely represent the daylight changing over time?

This first measurement of daylight for the case study in Room 38 was taken in July 1996, and a second measurement was taken in December 1996. The summer daylight readings show that the intensity (readings) from each sensor was inconsistent but proportionate to one another. The winter readings were consistent and the daylight intensity reduced after mid-day. Both readings of Sensor No.6, the vertical illuminance of the east wall were the lowest intensity. Sensor No.1 was located next to the timber mullion windows and under the skylight; its readings were the highest due to its location. The other sensors' readings were more affected by the internal and external reflection of light shown graphically by the differences between each sensor [Figure 4, Figure 5, Figure 6, Figure 7].

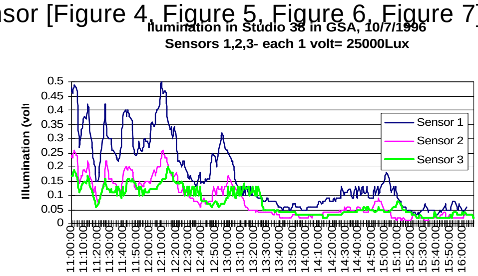


Figure 4 Summer time measured values of daylight on a horizontal plane from sensor 1,2,3., Calibration values: each volt=25000 Lux

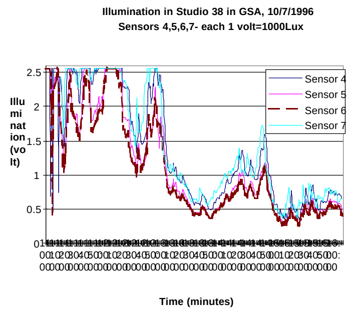


Figure 5 Summer time measured values of daylight on a horizontal plane from sensor 4.5.7. and on a vertical plane from sensor 6. Calibration values: each volt=1000Lux

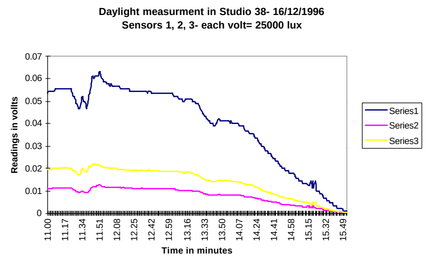


Figure 6 Winter time measured values of daylight on a horizontal plane from sensor 1,2,3. Calibration values: each volt=25000 Lux

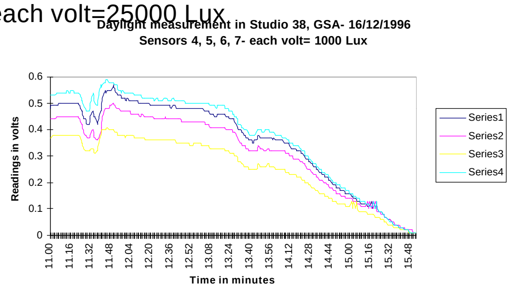


Figure 7 Winter time measured values of daylight on a horizontal plane from sensors 4,5,7., on a vertical plane from sensor 6., Calibration values:each volt=1000 Lux

In this case study, the daylight that changes over time simulation was based on the information from the sensor No.1 winter time measurement which received more direct daylighting compared to other sensors, and the on-site photos taken every hour during the measurement. The animation was simulated under the Keyframer module using references. The animation which lasts less then a minute was created with sixty frames with each frame modifying the lighting intensity at a period of a five minute time and producing a total of five hours of daylight changes.

This simulation of daylight changing over time was created by the sources and the software's capabilities. The rendering technique was the Ray tracing method. Throughout the entire sequence of images, changing the nature of daylight over time was subjectively simulated. In addition, there is no control over the parameter of background information from the software. Therefore, in animating the sky the image did not change, while the lighting level condition was changing.

This result validated that computer animation can simulate daylight changes over time with the manual input of lighting references. Therefore, this animation lies somewhere between the objective data and the subjective visualization to a "photo-realistic" daylight animation.

Cognitive assessment tests: An evaluation of how computer visualization and animation represents the environmental perception

Lighting simulation by using different rendering techniques described in the previous section results in different effects. The lighting setup within the program is also an influential parameter on lighting simulation and, by implication, on the perception of the environment. The following is a summary of lighting simulation produced by a typical visualization program.

a) The parameters for the lighting intensities are unclear. The lights can be accurately simulated with Ray tracing algorithms but the daylight levels information cannot be accurately added during the rendering process.

b) The position of a spotlight is an important issue because it is used to represent the sun as the daylight source. For a realistic daylight simulation, the position of the light source should be placed as far as possible from the object it is illuminating. The daylight appearance of the rendered images can be different, depending on different altitudes of the spotlight source.

c) The material attributes are often neglected by the visualization designer. The simulation of materials is not only concerned with realistic appearances but also the reality of a material's behaviors, i.e. reflection, transparency. The simulated images may look photo-realistic but realistic design information should be demonstrated.

c) The integration of computer visualization with other daylighting programs should be seriously considered. Programs such as Lumen Micro, provide physical attributes of indoor lighting computation, such as Horizontal illuminance, Vertical illuminance, Visual Comfort Probabilities (VCP) as well as the Relative Visual Performance (RVP).

Overall, the daylight parameters were manipulated manually in most visualization programs. With these visualization programs the designer has to conjecture daylight simulation which in most cases produces inaccurate results and integrations. This user-determined orientation of the realistic aspect of computer visualization should be questioned.

The representation of daylight and artificial light on the environment

The lighting simulation produced by computer visualization programs is not sufficient to give light intensity. In the 3D Studio, it provides only two color systems (RGB and HLS) which indicate the color of the light as well as the intensity of the light. The process of simulating the natural and artificial lights has no difference between the settings. It only relies on the visualization designer's understanding of these two kinds of light and their physical attributes which apply to different simulation techniques, e.g. the rendering methods (Ray tracing or Shadow map rendering technique with global or local setting), light types (Ambient, Omnidirectional and Spotlight), as well as an understanding of the 'color' system for the light intensity.

The rendering methods in the 3D Studio are Ray Tracing and Shadow Map. These two methods can produce different effects of lighting simulations. Nevertheless, for architectural presentations, the computer visualization programs may offer an additional rendering method such as Radiosty rendering methods which can calculate the distribution of light throughout an environment, and the walkthrough animations of that environment can be created in near-real time.

An improvement of the appearance of lighting simulation can be achieved by establishing a personal awareness of lighting knowledge and the relationship of the lighting parameters of the software, and perhaps recording the lighting conditions of the design graphically as well as taking empirical measurements of light levels and contrasts. With these references, this process will help the designer to simulate a realistic lighting visualization.

The lighting simulation of Room 38, life-modeling studio, was comprehensive. The experiments of visual performance were executed from different settings of rendering methods and light types. The experiments may not have been representative of everyday situations and may have drawn undue attention to the particular feature under the test. The various experiments tried to ensure that they eliminated all extraneous variables from the experiment to guarantee that any change in performance was due to changes in the task lighting itself. In the material simulation, the materials in the room were simulated to their original attributes as far as possible. Therefore, the material appearance would not affect the analysis of lighting conditions within the scene.

Simulation of daylight that changes over time
The measurement of light levels and photographics in Room 38, life modeling studio, were needed as a feedback to improve the lighting parameters of the animation generated for the same studio. The animation of daylight that changes over time was created manually. The technique involved the setup for the duration of the animation and the lighting condition was modified every hour in the sequence of images, while the Keyframer module calculated the lighting condition between each frame that changed during each hour. Daylight information can be obtained at any location and any season. Computer visualization should take the daylight changes over time data into account together with real-time simulation to represent a realistic daylight change simulation.

In this way computer visualization and animation could be more useful at providing the adequacy of lighting design parameters automatically, as well as offering a possible solution for designers to create energy-efficient building designs.

Conclusion
It is unclear how the lighting aspect of operation in the computer visualization program, 3D Studio, is supporting the environmental perception of design. In order to provide adequate control parameters for the environmental perception of design, the standards of lighting simulation should be established and the means of assessing the success of a building in meeting these standards should be determined.

This study has investigated the problems encountered in developing the environmental perception of light in computerized architectural representations. The area of parameters' interface has been neglected in lighting simulation and is not sufficient to give light intensity or to add lighting data. As mentioned, only three lighting types are provided by the 3D Studio visualization program, Ambient light, Omnidirectional light and Spotlight and these have to serve the complicated daylight simulation as well as various lighting utilization in architectural practices. The visualization designer, therefore, needs to establish sufficient background knowledge of lighting theory and the fundamental principles of operating computer visualization programs in order to successfully simulate numerous lighting conditions.

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