EVALUATING LIGHTING SIMULATIONS IN AUTODESK 3DS MAX DESIGN

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ABSTRACT

This paper assesses the accuracy and workflow of the lighting analysis features of Autodesk's 3ds Max Design, a 3D modelling and rendering tool used by architects and designers. The validation methods initially examined simple test cases with a minimum number of parameters using analytical data test cases proposed by the 'CIE 171:2006 Technical Report' (CIE, 2006). The tests indicate that the software has the capability of offering accurate results for simple model cases. Following these initial tests, we examined 3ds Max Design's ability to accurately simulate real case environments and more complex scenarios. These tests included sky-tube systems when dealing with daylight. We conducted a series of parametric tests in order to evaluate the degree of complexity that the software is capable of simulating. Our experiments resulted in an optimum method for an architect/designer to model a space in order to evaluate its light penetration through sky-tubes. By using a real case workflow example and parametric testing, we outline 3ds Max Design's effectiveness in conducting daylight analysis for geometries and material types of varying complexity and provide guidelines for future improvements.

INTRODUCTION

3ds Max Design shares the same core technology and features with 3ds Max but also includes a lighting analysis tool. By combining 3d modelling, rendering and lighting analysis and by being at the same time compatible with many file formats,, 3ds Max Design has proved to be a versatile platform for architects and designers.

Typically, lighting analysis tends to be conducted either in the early design stages as a preliminary test, or as a more complex lighting assessment of the project that results in a visual proof of the proposal (Ampatzi, 2005). 3ds Max Design introduces a new form of workflow that enables lighting analysis of the project during the whole design cycle (Breton et al, 2009). It eliminates costly errors by removing the need to alter the workflow by importing, exporting and creating various models for each software. This enables the designer to improve the cost and environmental profile of the project.

3ds Max Design introduces an approach to lighting analysis that is close to the needs of an architect or light designer at various stages of their work. Moreover, it is compatible with standard weather files and sky models; a fact that allows the designer to achieve a more realistic outcome. Real daylight conditions can be assessed and combined through a number of metrics that are used as assessment tools by various organisations. One such organisation is LEED 2.2 green building rating system that uses CIE clear sky models to evaluate the indoor illuminance of a space.

The National Research Council Canada (NRC) has validated the first version of 3ds Max Design in 2009, by comparing the simulations conducted in 3ds Max Design and DAYSIM 3.0 to NRC daylight test case measurements (Reinhart et al., 2009). The study used indoor illuminance of a side lit space configured with five fenestration and glazing options and under a variety of sky conditions. According to the authors, both programs succeeded in reproducing measurements for a side lit space with and without a light shelf. While 3ds Max Design consistently underestimated the incoming light flux going through a translucent panel, DAYSIM results were lower than measurements for the internal venetian blind test case. The results suggest that the accuracy of both programs is sufficient for typical daylighting design investigations of spaces with complexity comparable to the five investigated daylighting test cases. Thus far, this validation paper is the only one published from Autodesk on this topic. The objective of this paper is to provide an additional data point and evaluate the capabilities and accuracy of 3ds Max Design as a lighting analysis tool.

METHODOLOGY

The methodology we followed includes both a quantitative and a qualitative approach. First, we used 3ds Max Design to test different aspects of lighting conditions separately using the analytical test cases included in the 'CIE 171:2006 Technical Report' (CIE, 2006). We then compared the software results to those obtained from scale models designed particularly for this study. Finally, we compared the software results to those obtained from real-world measurements. Moreover, we conducted parametric tests as a supplementary assessment tool to

investigate the optimum way of modelling certain parameters such as room clutter, external obstructions, and materials with special properties.

The qualitative part of this study aimed to clarify the lighting analysis process by using a real case workflow example combined with a simple parametric test. Our aim is to indicate the tools and parameters that need to be used as well as the ones that have to be ignored or turned off to achieve an accurate lighting analysis result. As a secondary outcome of this process, we created a guide that introduces the concepts and workflows of lighting analysis using 3ds Max Design.

CIE 171:2006 PROPOSED TEST CASES WITH ANALYTICAL DATA

To ensure that the software can cope with simple daylight calculations, we selected five analytical tests that are part of the CIE 171:2006 Technical Report (CIE, 2006). These tests evaluate the following light aspects separately:

Directional Transmittance of Clear Glass

The importance of this test is related to the influence that a glazing material can have on daylight availability inside a building. We chose 'Autodesk Clear Glass Default Material' for this test. We set the material reflectance to 0.04 and examined two alternative values for the colour setting; for the case 'Glass A' we set the 'Color' option to 'Custom' and the 'Color Value' to 1.0. In case 'Glass B' we set the 'Color' option to 'Clear'. Since a single direction beam is not an option in 3ds Max Design, we created a 'Target Light' with 'Light Distribution' set to 'Uniform Diffuser' with an intensity of 10,000cd, as a primary light source.

The results indicate that the directional transmittance is taken into consideration by the software in both clear glass material cases [Figure 1]. However, since the glazing type is not specified in more detail by the CIE report, the values do not follow accurately the analytical data. The zero value reached at the case of the 80 degrees angle, can be attributed to the thickness of the wall, therefore it should not be considered as a limitation of the software.
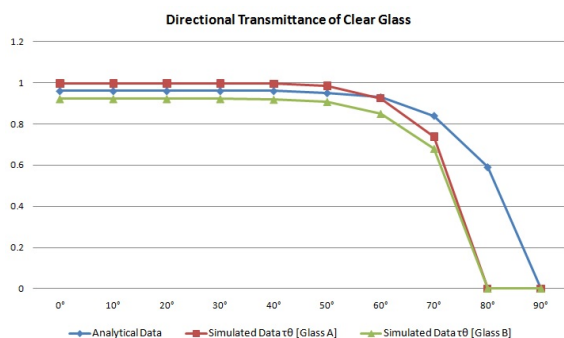

Figure 1 Directional transmittance of clear glass: analytical and simulation results

Light Reflection Over Diffuse Surfaces

The importance of this test is related to the inter-reflections of the light inside the room and also to the reflection of daylight to the external ground and masks. We created three scenarios considering the influence of the size and reflectance value of the ground surface (S_2).

- Scenario A: S_2: 0.5m x 0.5m, reflectance: 80%. Primary light source angle: 45°.
- Scenario B: S_2: 4m x 4m, reflectance: 30%. Primary light source angle: 35°. [Figure 2]
- Scenario C: S_2: 500m x 500m, reflectance: 30%. Primary light source angle: 45°.
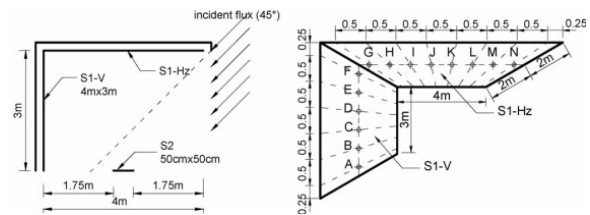

Figure 2 Light Reflection over Diffuse Surfaces: Scenario A: Geometry and measurement points (CIE 171:2006 Technical Report, 2006).

The direct illuminance received by the surface (E_{hz}) is perceived as the average surface illuminance of the surface for each scenario. It is calculated from the values given by a Light Meter covering the total area of the surface with a grid of 25x25cm for Scenario A and B and a grid of 50x50cm for Scenario C.

Although the simulated results appear to be close to the analytical values for Scenarios A and B, in Scenario B the light distribution did not follow the analytical data curve as closely as in Scenario A [Figure 3]. The results for Scenario C give extremely high values, a fact that could be attributed to the method used to measure the E_{hz} value, since in Scenario C, because of the size of the surface, the average illuminance reached only a very low value. However, as it can be observed that the curve of the simulated results follows the curve of the analytical ones indicating that the light distribution is calculated accurately.

Diffuse Reflection with Internal Obstructions

Such a test is deemed of paramount importance, since additional errors are expected with the presence of obstructions (furniture) which can introduce a higher level of complexity and make the simulation results more sensitive to the calculation parameters.

Since a single direction beam, as indicated in the CIE Report, is not an option in 3ds Max Design, we chose as a primary source of light a 'Target Light' with the light distribution set to 'Uniform Diffuser' in the first case and to 'Spotlight' in the second case, with an intensity of 10,000cd.
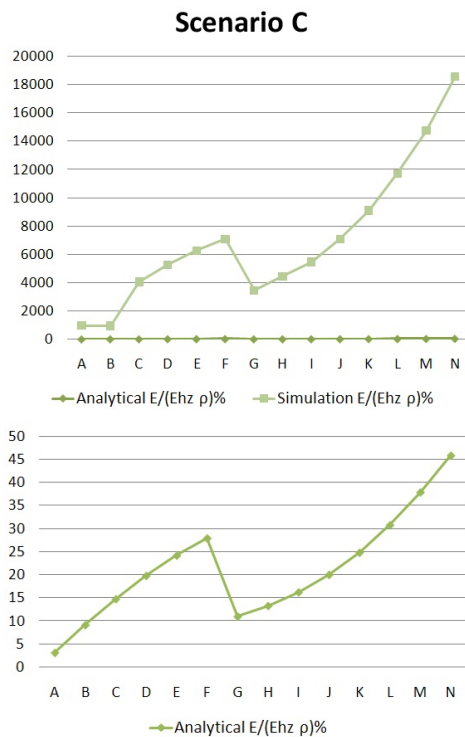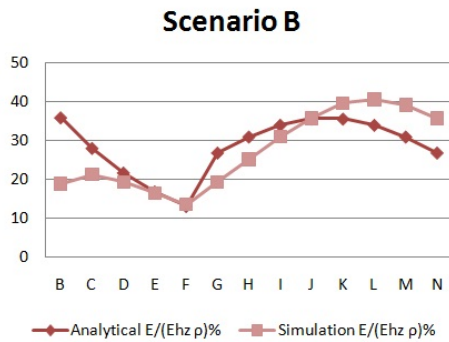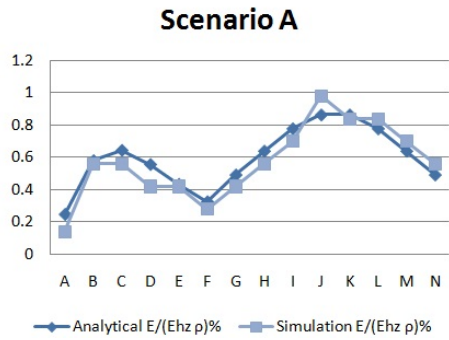
Scenario A

Scenario B

Scenario C

Figure 3 Light reflection over diffuse surfaces: analytical and simulation results.

Comparing the simulation results under the 'Uniform Diffuse' distribution light and the 'Spotlight', it appears that the 'Target Light' with the 'Uniform Diffuse' distribution follows the analytical results curve in the graph [Figure 4] although at a quite lower percentage, whereas the 'Spotlight' distribution values are much lower. If the 'Uniform Diffuse' distribution light is considered as the one appropriate to represent the light source described at

the test scenario, then it can be argued that the predicted values underestimate the diffuse reflections received by the vertical surface, or the influence of the obstruction is highly rated. However, a similar light distribution is followed.
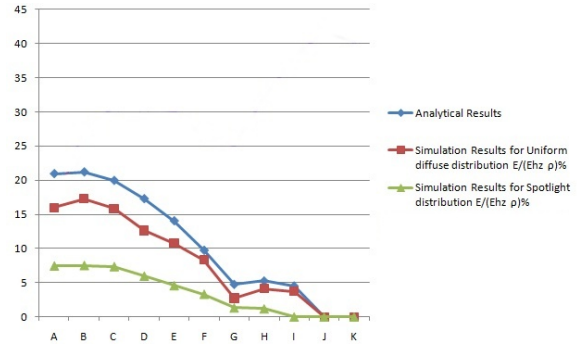

Figure 4 Diffuse reflection with Internal obstructions: analytical and simulation results.

Sky Component (SC) for an Unglazed Roof Opening and the CIE General Sky Types

In this paper, we tested only the CIE overcast sky type. The results indicate that 3ds Max Design can be considered reliable in calculating the SC, giving an error of no more than 3% for both roof opening scenarios [Figurte 5]. However, the acceptance of the error is always connected with the requirements of the project. The minimum daylight factor levels accepted for office spaces according to 'CIBSE Lighting Guide 7: Office Lighting' (CIBSE, 2005) are 2%, hence an error of 1-2% can be important in design decisions. However, variations of up to 5% are observed for Lightscape software concerning the same case, whereas Relux software show a better agreement with the analytical data, similar to those of 3ds Max Design (Adra et al., 2006).
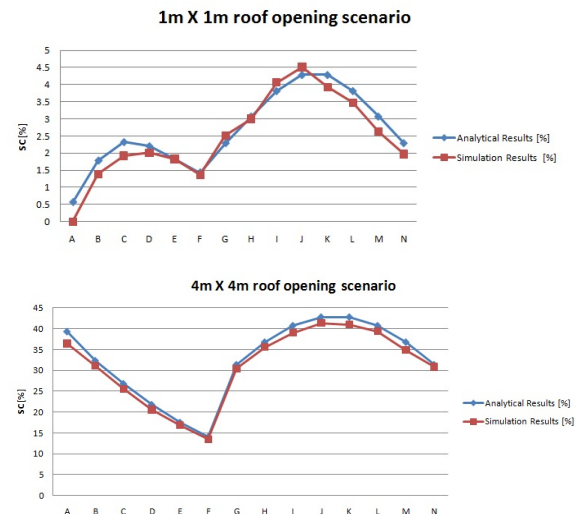

Figure 5 1m x 1m and 4m x 4m unglazed roof opening scenarios: analytical and simulation results.

Sky Component Under a Glazed Roof Opening

For this case, we tested the influence of glass with a given directional transmission under an overcast sky. We started by adding to the model an Autodesk 'Clear Glass' default material of 6mm thickness, a material reflectance of 0.04, with the color option set to 'Custom', and a 'Color Value' of 1.0, as these parameters proved to be the best option to represent clear glass material in the first CIE test case, "Directional Transmittance of Clear Glass".

The results given by the glazed opening appear to overestimate the SC although they follow the analytical result curves. This error can be related to the high transmittance of the glass. The 'Thin Geometry' glass material gives the same results as the 'Solid' one, whereas the 'Physical' glass material simulation results in higher daylight factor levels closer to the analytical results but with an altered curve. In comparison to the 'Autodesk Clear Glass Default Material' the A&D default settings for the glass materials appear to underestimate the sky component, but apparently this should be attributed to the material specifications.
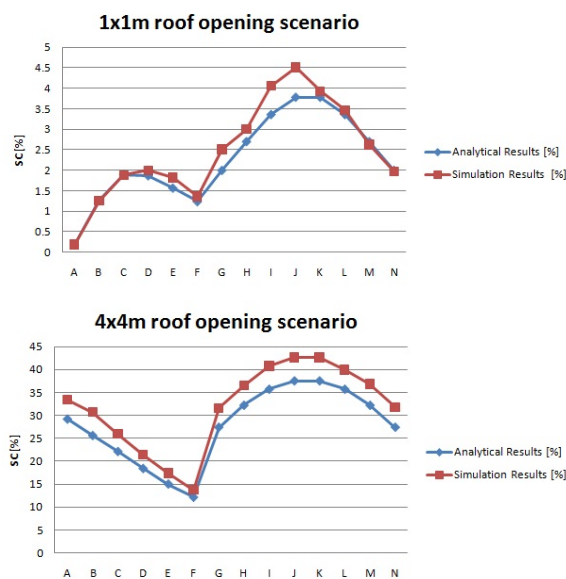

Figure 6 1m x 1m and 4m x 4m glazed roof opening scenarios: analytical and simulation results.

Conclusions

The multiple parameters that needed to be input to specify each material in 3ds Max Design, in addition to the limited material and glazing specifications given by the CIE 171:2006 Report, resulted initially in uncertainties concerning the veracity of the test procedure and the accuracy of the results. These data limitations led us to the investigation of different modelling approaches. For example, in order to test the directional transmittance through clear glass and the sky component under a glazed roof opening, we conducted several parametric tests on the different glazing types and light source options, which pointed out what parameters affect the lighting analysis results and to what degree.

The tests related to the evaluation of the inter-reflections of light inside the room gave satisfactory results regarding the accuracy of the software on the whole as well as the calculation of the luminance levels received from the sky (CIE Overcast Sky type), indicating that the software has the capability of offering accurate results for simple model cases and therefore should be tested further for more complex cases in order to discover its limits.

PARAMETRIC TESTS: THE EFFECT OF THE SKY TUBE SIMULATION SETUP

An important part of this study was to conduct a series of parametric tests in order to evaluate the degree of complexity that the software is capable of simulating. We chose to test a sky-tube element that is usually made of three parts: a curved dome on top that collects light, a high-reflectance tube that transmits the light downward, and a translucent glass panel at the bottom of the tube that diffuse the light into the space. A sky-tube, even in its simplest form, consists of a composite geometry and materials that might lead to a high number of inter-reflections requiring time and computational effort.

To conduct this experiment, we modelled a 4 x 4 x 3 m room in 3ds Max Design. We simulated the model under overcast conditions with a 'Diffuse Horizontal Illuminance' of 10,000lx. Each of the three sky-tube parts was modelled and evaluated separately.

The results indicated that if the tube's length to diameter (L/D) ratio is higher than 5 the software appears to be unable to cope with the inter-reflections. The software's 'Analysis and Rendering' settings are not capable of reaching a high level of light bounces due to memory limitations of the software's rendering engine (mental ray). Therefore more complex geometries including small diameters, maze-like bends or extensive lengths cannot be calculated in 3ds Max Design using current regular desktop computers.

SCALE MODEL EXPERIMENTAL TEST CASES

We constructed a cubic box with 60 x 60 x 60 cm internal dimensions to represent an empty room of dimensions 3 x 3 x 3 m. We painted the interior of the box in matte white with a reflectance value of 90%. This was done to assure that all light reaching the interior of the box is collected and accounted for by the photocell placed in the centre of the bottom surface of the box. A circular hole with diameter equal to the one of the sky-tube elements (8cm) receives the tubes at the centre of the top of the box [Figure 7]. We conducted measurements under overcast sky conditions with three different tube

types that varied in shape and material properties [Figure 8]:

- Model A: L/D=7.8, 7.7cm diameter, 60cm length, No bends, 'Silverlux' Film (Reflectance of approximately 95%).

- Model B: L/D=9.1, 7.7cm diameter, 70cm length, One bend, 'High Reflective' Film (Reflectance of approximately 99%).

- Model C: L/D=10.4, 7.7cm diameter, 80cm length, Two bends, 'High Reflective' Film (Reflectance of approximately 99%).

Figure 7 The scale model installation - (left) inside the box and (right) box with sky-tube.

Figure 8 The three tested sky-tube types. From the top: A (no bends), B (one bend), C (two bends).

We then compared the Daylight Factors (DF) given by the measured illuminance values to the predicted ones given by the equivalent model in 3ds Max Design. We applied the A&D default 'Matte Finish' with a 'Diffuse Color Value' of 90% to the interior of the model in 3ds Max Design and an A&D 'Mirror' Material with a 'Tint Color Value' of 95% for Model A and of 99% for Models B and C. A 'Daylight' object is created to represent the overcast sky, set to CIE 'Overcast' sky model with 10,000lx 'Diffuse Illuminance' according to the illuminance measurements conducted at the time of the experiment. The upper error limit (TE UL) and the lower error limit (TE LL) where calculated based on similar studies conducted by CIBSE (Slater et al., 2002).

The simulation results appear to depend on the shape of the tube rather than the reflectance value of the surface inside the tube, in contrast to the measurement results. The fact that Model C performed better than model B can be due to the fact that no significant amount of light escaped the complex geometry in both measured and simulated scenarios and thus the results are not as telling as in scenario B. Only the results for Model A are within the TE UL and TE LL error limits. The results for Model C are slightly above the TE UL (0.61 vs. 0.56). However, the simulation results for Model B is approximately 38% lower than TE LL (0.9 vs. 1.45), which indicates that when it comes to such high reflectance values, the software tends to underestimate the performance of the material, indicating that when it comes to comparing different systems, especially in terms of reflective material performances, the software appears to be unreliable [Figure 9].
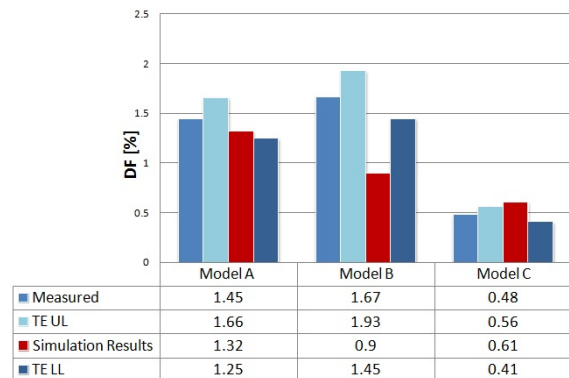

	Model A	Model B	Model C
Measured	1.45	1.67	0.48
TE UL	1.66	1.93	0.56
Simulation Results	1.32	0.9	0.61
TE LL	1.25	1.45	0.41

Figure 9 DF Comparison: simulation results.

Due to the nature of the experiment, certain limitations were considered. The fact that the sky was not a thick overcast at all time might have contributed to the high levels received in Model B since the angle of the tube might have led to the reception of higher sun light levels. Moreover, the aging and dirt factor of the Reflective Films used inside the tubes is taken into account in the prediction of the error limits.

Overall, the prediction error for the DF is no more than 1% divergence which is a useful outcome when deciding if a sky tube system should be used or not. A repetition of the test under ideal overcast sky conditions, as well as the testing of a greater variation of reflective materials can be helpful for a clearer outcome.

REAL-WORLD EXPERIMENTAL TEST CASE

The subject of this section is to compare the daylight predictions of 3ds Max Design to a physical space lit by three commercially available sky-tube elements where the exact installation details and material

properties are known. We chose a space within the School of Psychology at Cardiff University, Wales. Yet, the fact that the space is partly separated from adjacent spaces with internal blinds introduced modelling issues that were examined in a series of parametric tests.

Measurement Procedure

The enclosed area where the measurements take place reaches a maximum length of 10.60m at the corridor and a maximum width of 6.35m at the seating area. The height of the space is 2.50m. The three Monodraught Ltd 'Sky-pipe' systems that lit the space have an opening diameter of 47cm and a length of 1.36m [Figures 10]. Eight upward facing sensors were placed in a grid at desk height (85cm above the floor) with dimensions 1.20 x 1.20 m [Figure 11]. The measurements were conducted at midday on the 20th of July under an overcast sky of medium thickness. The illuminance levels in the room were recorded at 5 minute intervals.

Figure 10 (Top left) Sky-tube, top dome detail. (Top right) Ceiling diffuser. (Bottom left) View of room separator with interior blinds. (Bottom right) Installation with sensors and the person's position.

Modelling

In 3ds Max Design, the indoor surfaces were specified with an A&D Default 'Matte Finish' material with the 'Diffuse Color Value' set according to the surface reflectance measurements [Figure 12]. The sky-tube elements were modelled as to represent the exact system described by Monodraught Ltd drawings. Surface materials were applied accordingly:

- The Top Dome material was modelled as an Autodesk 'Clear Glass' Material with a 'Color Value' of 85%.

- The surface inside the tube was assigned an A&D 'Mirror' material with 'Tint Color Value' of 98%.

- The Ceiling Diffuser was assigned an A&D default 'Translucent Plastic Film Light Blur' material, with the 'Refraction Color Value' set to 85%.
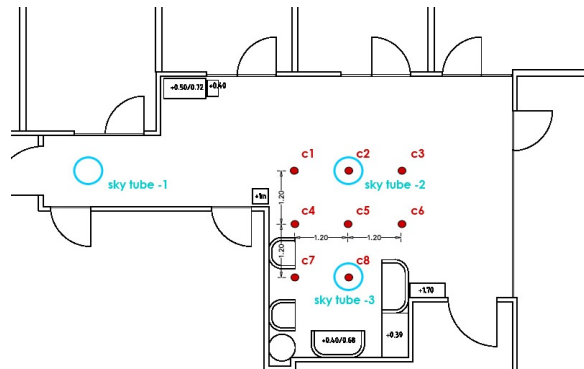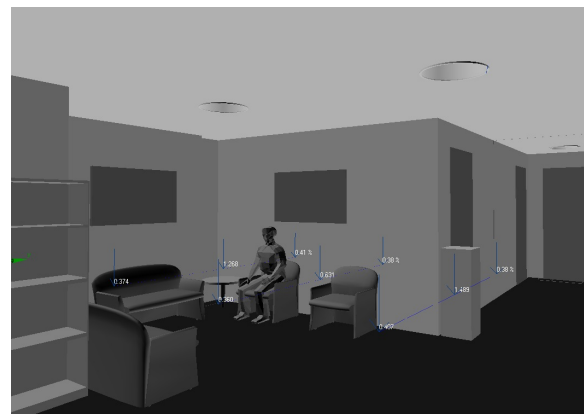

Figure 11 Floor plan detail with sensor positions.

Figures 12 3ds Max Design perspective interior view – Model A.

In an effort to represent the surroundings, we created a simplified geometry of an adjacent building, being the main obstruction to the sky tubes, and a 500 x 500 m plane representing the ground. The obstructions and ground were assigned an A&D default 'Matte Finish' material with the 'Diffuse Color Value' set to '0.5' and to '0.2' respectively.

The inability to measure the internal blinds reflectance resulted in a need to test different methods of modelling this element. In an architectural project it is not always the case that all elements can be modelled in detail nor can it be always feasible to know their specifications. In this case it is useful to be aware of the most efficient (quick and easy) modelling scenario that will approach an accurate result. Therefore, four internal blind scenarios were applied to the initial model.

Simulation Results / Investigating the Effect of External Obstructions

By comparing the simulation results for all four models we can see that the variation is almost non-existent [Figure 13]. The DF value of the most

detailed model (Model D) varies by no more than 0.1 from the DF values of the simplest one (Model A). The other two scenarios (Model B and C) present even lower variations. However, it has to be mentioned that as an occupant of the space, the glazed surfaces as well as the 'thin opening' appear to influence the illuminance in the room more than the simulations show.
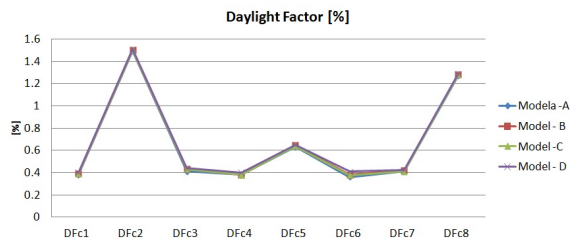

Figure 13 DF simulation results for models A, B, C, and D.

Overall, the simulation results appear to underestimate the illuminance levels in the space, when compared to the measured values [Figure 14]. The average DF value for all eight measurement points given by the simulation of Model D is 0.69%, whereas the measured one is 1.1%. This difference of 0.41% might not appear that important, but in terms of design the difference may be significant. For an outside horizontal illuminance of 10,000lx, for example, 69lx would be predicted for the interior, while in reality it would be 110lx; a significant difference in terms of occupants' comfort.
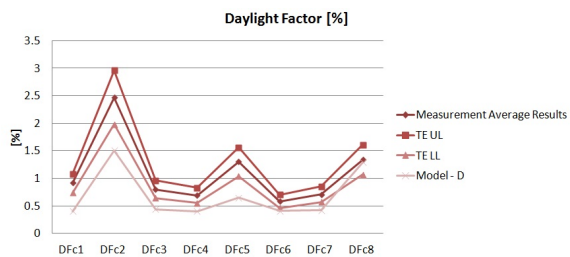

Figure 14 DF comparison – simulation results and measured values (TE UL and TE LL).

DISCUSSION / LIGHTING ANALYSIS WORKFLOW

Before the evaluation tests, a familiarisation research was conducted by using a real case workflow example and simple parametric tests as to indicate the tools and parameters that need to be used as well as the ones that have to be ignored or turned off if we were to get an accurate lighting analysis result.

The fact that the software combines various features (rendering, animation, 3d modelling etc) entails certain limitations that are mainly due to its complex interface. More specifically, the fact that 'Rendering'

and 'Analysis' are intertwined in the design process and workflow followed by 3ds Max Design makes it more difficult and time consuming for those wishing to only conduct lighting analysis. Moreover, the parameters of materials and light sources provided by the software do not always correspond to the ones provided by analytical data cases or the manufacturer's specifications, resulting in uncertainties concerning the simulation accuracy. Therefore, a 'Lighting Analysis' set including Materials with parameters strictly depending on measured data, or manufacturer's specifications should be introduced. All CIE sky types and certain types of light sources that correspond to analytical methods and light assessment strategies should complete this set. The introduction of this feature appears essential in order to maintain a consistent workflow and be able at any time to examine the accuracy of the software.

We observed additional more minor limitations such as the limited 'Analysis Output' options and the lack of sophisticated tools directly indicating the units and the distances within the model.

CONCLUSION

From the user's perspective, which is closely related to the design stage and the level of accuracy required for decisions to be made, 3ds Max Design can be considered a reliable tool.

3ds Max Design daylight predictions, however, are reliable only when it comes to simple geometries and materials. High levels of accuracy cannot be guaranteed when complex geometries and light systems that require an elevated number of inter reflections are included in the simulation model. The results in such cases can be considered satisfactory for the early design stages of a project. Future research should examine the role of increasing computational power and using higher settings in overcoming the current limitations and inaccuracies.

The inaccurate results given by the experimental test cases are mainly connected to the inability of the provided material types of the software to represent the physically accurate material properties when dealing with specialized materials such as diffuse glazing or high reflective surfaces. In addition, the limitations of the software in dealing with a high number of inter reflections as highlighted by the CIE 171:2006 Technical Report test cases, is an important factor related to these unsatisfactory results. However, it is not clear if this failure should be attributed to the calculation method followed by the software or to the fact that the 'Rendering and Analysis' settings are restricted to low levels.

For future research, we suggest carrying out a more detailed investigation concerning the lighting analysis calculations of models with high inter reflection levels, connected to the various material parameters. 3ds Max Design offers a method to

compensate for low light transmission levels by placing artificial 'Sky Portals' that reduce the need for a high number of light bounces and improve the quality of the rendering. We recommend testing sky portals in the future to measure their effect, if any, on quantitative light analysis. In addition, we suggest to examine the application of additional experimental test cases of graduated complexity levels under overcast and clear sky conditions as well as under artificial photometric light sources as to set clearer limits to the accuracy of the software. A comparison of the given results by 3DS Max Design to the ones given by other lighting analysis software is suggested as an extra assessment tool.

Finally, we cannot discount the value of the software for architects and designers for its ability to qualitatively visualise their designs photorealistically, avoid import and export problems, and integrate modelling, rendering, animation and lighting analysis in one software platform. Seeking the views of users of the software, including interviews and questionnaires regarding the reliability and usefulness of the lighting analysis feature could contribute further to the development of this study.

ACKNOWLEDGEMENT

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