Illuminating the Design

Incorporation of natural lighting analyses in the design studio using BIM

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Abstract. The growing demand for sustainable architectural design motivates the integration of BIM technologies and novel design processes into architectural education. This paper presents the results from a set of educational case studies for the incorporation of BIM-based daylighting simulations and analyses into the design studio. With a carefully devised studio setting and the participation of interdisciplinary consultants, the experimental case studies simulated an integrated design process based on rapid information exchange and collaborative decision making. The implemented method enables students to use BIM models and daylighting simulations as significant sources of design information for performance-based architectural design.

Keywords. BIM; daylighting simulations; collaborative design; integration.

Introduction

Current BIM software tools provide capable modules for the creation of task specific analytical simulations of complex building designs. Examples from research and practice demonstrate the potentials of using building analysis simulators with BIM models in the design process (Krygiel and Nies 2008; Schlueter and Thesseling 2009). As Friedman (2007) suggested, BIM presents new advantages for students for the exploration of schematic design in data-rich virtual building environments by accessing measurable correlations among design, construction, and performance. Changing trends in the profession and education affirm that the incorporation of BIM use for performance-based design necessitates further explorations and empirical studies in design studios.

In particular, lighting simulators can rapidly create both numeric and visual data for the achievement of desirable sunlight and daylighting levels in different functional spaces (Kwok and Grondzik 2007). Creation of such data using BIM models offers sound, reliable and immediate information for addressing daylighting related problems in a performance-based design process. These technological advancements coupled with demand professional adept at performance-based design methods challenge design studio education with new opportunities and new problems. BIM tools and current building certification systems such as LEED provide possibilities for students and instructors to incorporate specific performance problems such as daylighting and sunlighting. This study presents the results of incorporating rigorous lighting analysis in a BIM-enabled design process in an academic setting.
Setting and Setup

In this paper we present a set of case studies for examining the educational potentials of BIM driven sunlight and daylighting analysis in the design studio. Embedded in an integrated and a collaborative project setting, BIM models were used to create analytical simulation models for the assessment of daylighting and sun light performance of design alternatives. Cases were post-graduate seminar courses focused upon Building Information Modeling (BIM) and Integrated Project Delivery (IPD). The course has been taught three times at two different schools of architecture.

Students were given a relatively compact but rich architectural design problem with explicit performance requirements for different functional spaces. The program included a museum/exhibition space and a café/waiting lounge integrated into a train station on a university campus. In addition, the station was required to have a covered platform 300 feet in length. Orientation of the site and the canopy system presented particular design challenges for students to achieve an optimum balance between daylighting, solar heat gain, and sun shading in a hot and humid climate environment. Because of the location of the tracks, the building form was necessarily exposed heavily to south and southwest solar gains. As a realistic benchmark for the performance, students were required to meet LEED 8.1 daylighting credit conditions. Daylight level in the museum space was also required to stay in certain limits. Students used software including Revit, Ecotect, Daysim, Radiance and Green Building Studio. Dependence of extensive information about daylighting and sunlighting led to the participation of an external consultant in the studio as a necessary component to introduce advanced levels of expertise for collaborative performance assessments and design evaluations. The consultant possessed significant prior experience conducting lighting analysis for architectural projects using tools such as Daysim, Radiance and Ecotect.

Case studies involved a rigorous data collection framework based on mixed method research approaches. Design students provided BIM models of the created alternatives; self process reports; screen-shots and renderings. Data from analyses included daylighting intensity reports, both numeric and visual materials from the simulations; comparisons and benchmarking tests according to LEED guidelines; and consultant assessment reports. Collaborative design and evaluation sessions were videotaped, photographed and analyzed.

Process and Findings

Daylighting performance simulations and sunlight studies returned significant feedback, particularly for the components in the building shell and canopy.
design. For every design alternative, sunlight models and daylighting simulations were created to support collective evaluation with students and consultants in the studio. In the subsequent paragraphs, we will discuss several project examples generated in the course.

Figure 1 illustrates a project from the Case 2 and results of some of the design decisions for addressing the heat gain and the required natural light levels. As seen in the image on the right, building envelope and canopy in this example were designed using massive elements to block sunlight and heat gain from the south-southwest direction. The north-northeast side of the building, illustrated on the left, consisted of transparent building components with shading elements to allow sufficient daylight for social spaces. These images were generated by Revit.

Sunlight studies were conducted to assess the performance of canopy design during the different times of the year. Simulations demonstrated the shadow progress during Equinox, Winter Solstice and Summer Solstice. Perspective images and animations were used for visualized feedback. Figure 2 is a screenshot from the sunlight studies process from a case study project. Sunlight animation was created using Ecotect. Autodesk Revit also provided quick and effective sunlight analyses and visualizations (Figure 3).

Details of the daylighting analysis process illustrates the depth of analysis connected to the decision making process in the design. The main reason for daylighting analysis during the design process was the early detection of possible problems of glare or lack of daylight in accordance with the LEED Daylighting Credit 8.1. Analysis tasks for daylighting attempted to take advantage of that natural resource for an overall better lighting and to avoid as much as possible the use of artificial lighting for its direct impact on resource consumption and carbon emissions. Design students developed the design schemes in Autodesk Revit, exported them in a 3D Studio 3DS format for the consultant review and daylighting analysis. These files included the solid model of the building envelope and interior configuration. File import and necessary refinements in Ecotect were executed by the consultant. Daysim software was used to perform an annual simulation of luxes obtained in a grid of sensors in the room at a desk or workspace height. After this analysis, Daylight Autonomy was checked. Daylight Autonomy
is the capacity of the designed room or building to provide a minimum of 300 luxes (according to the IES Standards) throughout the year. We also checked for ranges of UDI (Useful Daylight Illuminance) from <100 (lack of daylight), between 100 and 2000 (useful range), and >2000 (possible discomfort glare problems). The ranges previously mentioned are also along a year analysis, and help designers to visualize the performance of their designs regarding to daylight distribution and possible problems. With these results, projects were assessed for whether the design needed to be improved in order to comply with the requirements for a particular task or function in the project. In addition, Radiance rendering analysis was conducted to check for adjacent surfaces with a brightness contrast over 10 times, an indicator of glare problems. Using false color image, the distribution of light was analyzed for uniformity within the given space (Figure 4).

Students used LEED requirements for the daylight performance assessment. According to LEED guidelines, a successful design must achieve a minimum Daylight Factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks (USGBC). After a quick check for LEED daylighting credit 8.1, all projects were simulated for certain daylight factor levels with defined virtual sensors in the BIM model. Table 1 shows the daylighting schemes and daylighting factor percentages (qualified schemes over 75% are shown). The data suggests that design teams had the tendency to control daylight requirement, by staying either over or close to 75%.

Examples created by students show the depth and comprehensiveness of the daylighting simulations conducted during the design process (Figure 5).

Figure 6 shows the connection between daylighting analysis and design revision for maintaining the desired level of daylight in the exhibition space. Radiance simulations returned reliable daylight values. Designed louvers during the second week of the

![Radiance rendering with false color image analysis. Design changes on the façade and the building envelope reduced the glare and balanced the daylighting levels.](image-url)
Table 1
LEED daylighting credit comparisons of all case study projects. Yellow designates designs out of compliance with LEED while green designates designs in compliance.

<table>
<thead>
<tr>
<th>Teams</th>
<th>CS1 Team1</th>
<th>CS1 Team2</th>
<th>CS2 Team1</th>
<th>CS2 Team2</th>
<th>CS2 Team3</th>
<th>CS3 Team1</th>
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<th>CS3 Team3</th>
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<tr>
<td>Base Case</td>
<td>61.70%</td>
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<td>80.60%</td>
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<td>84.20%</td>
<td>86.70%</td>
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<td>88.60%</td>
<td>80.40%</td>
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<td>69.70%</td>
<td>71.20%</td>
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<td>88.10%</td>
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<td>72.40%</td>
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Figure 5
Daylighting simulation results of the design alternative for UDI 100lux and UDI 100-2000 lux

Figure 6
BIM model and human sensitivity-daylighting simulation results. Controlled light distributions in the museum/exhibition space were in the range of 250-350 luxes.
case study decreased the direct light and balanced the indirect daylight in the exhibition space.

Students reported their progress, accomplishments and issues during the case studies. Following statements were excerpted from the progress reports.

Using BIM, we were able to share data with the other consultants relatively easily, whose responses and analysis led to various changes or implementation of criteria. One instance led to the major rearrangement of the plan, location of louver for decreasing the direct sunlight in the museum area, and use of a large canopy over the entry based on lighting analysis in relation to the location of programmatic elements.

(Team progress report, Case Study 2)

The setting of the course altered the communication scheme of the studio process by changing the conventional dialogue to a multi-channeled and cyclic communication between students, consultant and studio instructors. It can be claimed that use of BIM-based simulations expanded the scope of studio by the parameterization of quantitative performance aspects for the qualitative interpretation of design students and consultants. Results also showed that the active participation of the consultants played an important role in order to prevent the possible counter-creative effect of overwhelming information from the simulations.

Conclusions

Incorporation of daylighting problems in the studio demanded that students think about multiple layers of the building systems related to the design performance. BIM models and simulators provided computational data and rapid feedback for the performance evaluation and helped students to understand the impact of design decisions on the daylighting and sunlight performance of the design alternatives.

Challenges included both process and software related issues. Students experienced slight difficulties in adapting to the collaborative and performance-centric design process. Project progress reports and the results showed that the data and computations from the simulators necessitated further interpretation for the creation of effective design strategies and specific design solutions. Combined with the learning curve for BIM tools and software interoperability problems, students dedicated significant efforts to achieve an effective studio process. Nevertheless, the experience can be seen as a proof of concept for integrating rigorous lighting analysis into interdisciplinary, collaborative, performance-based design studios in an academic setting.

Case study results and students project examples invite further explorations and studio experiments using BIM-based simulations for daylighting and sunlight performance in complex design problems.

References


Krygiel, E, and Nies, B 2008, Green BIM: Successful sustainable design with building information modeling, Wiley, Indianapolis, IN.

