A Scalable Lighting Simulation Tool for Integrated Building Design

A NIST ATP Project
Integrated Concurrent Design of High Performance Buildings

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Outline of Presentation

• Introduction and Motivation
• Objectives and Methodology
• LEED Credit Calculation
• Conclusions
Integrated Concurrent Design

- Architectural charette process involving the owner and design/construction team stakeholders throughout the design process
- Analysis by project phase of design alternatives with a fidelity appropriate to the design stage
- Drive all analysis modules automatically from the same candidate building description for accuracy and to avoid unnecessary work
- Ability to checkpoint alternatives and roll-back as needed
Tools for Concurrent Design

- Equipment Models
- HVAC & Building Model
- Internal Loads
- Lighting
- Radiance
- Blueprints
- Airpak
- Controls
- Lifecycle costing
- Autodesk
- EnergyPlus
- United Technologies Research Center
- Carnegie Mellon
Early Energy Analysis

• The benefits of early energy analysis have been well documented
• Automatic import of building geometry by energy analysis tools is becoming more commonplace
• This project chose Green Building Studio web service using eQUEST and EnergyPlus for early energy analysis
• AutoDesk Revit was used to create the building description with export to gbXML
• Hence, gbXML was a convenient and strong candidate for non-energy aspects of integrated building design such as lighting and daylighting
Lighting Simulation

• A survey was conducted of lighting simulation tools for their suitability for this framework and their output fidelity

• Radiance was chosen, in part, due to its physical accuracy, continuing development and support, and the use of text input files

• Lighting simulation is often left to end stages of a project due to complexity of setup and, in general, the need for an experienced specialist to achieve a solution that meets design objectives, and a reputation for being expensive
**Objective 1**
Reduce the resources required to conduct a lighting simulation and assess the characteristics early in design.

- Geometry Modeling
- Variables Definition (e.g., Materials & Location)
- Simulation Parameters Definition
- Simulation
- Results processing
Objective 1
Reduce resources required to conduct lighting simulation
Examine the process for opportunities for automation

Even though Radiance runs can be long, setup time can consume more wall clock time

Why should we spend time on this?
Objective 1
Reduce resources required to conduct lighting simulation

Automatic Processing

Drawings
Documentation
Etc.

User-editable Input

Automatic Default Values

Automatic Engine Selection

Automatic Simulation Files Creation

Improved Analysis Features

Results processing
**Objective 1**
Reduce resources required to conduct lighting simulation
Definition of appropriate simulation parameters requires much training and tacit knowledge

Use default values for required parameters drawn from a database of characteristics relevant to the lighting domain

**Finite element Radiosity parameters**
Objective 2

Efficiency and consistency in defining BIM and assumptions
Externalize project shared information

- Shared Building Information Model
- Shared Construction Properties Database
- Shared Location Information Database

SHARED OBJECT MODEL

LIGHTING SIMULATION ASSUMPTIONS
- geometry abstractions
- material properties (reflectance, specularity, etc)
- luminare specification
- schedules

ENERGY SIMULATION ASSUMPTIONS
- geometry abstractions
- material properties (conductivity, specific heat, etc)
- lighting design level
- schedules

Conflict? Information Update?

Building Modeler

Lighting Tool

Energy Tool
Objective 2
Efficiency and consistency in defining BIM and assumptions
Externalizing project shared information
Objective 3
Obtaining Operative Information for Design Decisions
Lighting simulations address low-level objectives, not higher-level questions typical of primary design inquiries.

1. Design Question
   Is the lighting sufficient in this building?

2. Formulating well-formed problem by considering context and making relevant assumptions.

3. Formulating objectives solvable by lighting simulation
   - Is there sufficient illuminance on workplane in all occupied spaces?
   - What is the illuminance distribution in this space?

4. Analysis of results
   - Check all occupied spaces if illuminance > threshold on workplane

5. Operative Information for design decision
   - Check if number of satisfactory spaces compliant with regulations

Typical Lighting Simulation

Simulation Results (Illuminance data)
Objective 3
Obtaining Operative Information for Design Decisions
Providing post-processing analysis toolkit
Luminance and Contrast Ratio
LEED Credits

Tone-mappers
Luminance data inspection and false-color analyses
Luminance ratios calculator
Data comparisons

LEED rating system Credit 8.1 & 8.2 calculators
Tabulation of results
Results
**Results** - Lighting simulation Tool – Version 0.5

- Java based application – ease of prototyping
- General Parser – Revit-exported gbXML files & extended XML schema
- Radiance engine integration – automatic simulation files generator
- External Libraries – Location & Construction complete, rule based context recognition
- Visualizations – HDRI support, False-color, Inspector, Comparator, Luminance Ratios
- Post-processing – LEED Credit EQ 8.1 & 8.2 calculators and tabulations

Prototype of 2007 CMU Lighting Application v.0.5. The 3-step process to saving time.
Results
Application Design

BIM

Construction Database

Location Database

BIM Parser

Construction Database Parser

Location Database Parser

Automatic Variable Populater

Application Data Manager

GUI

Internal Simulation Engine

Simulation Files Generator

Regulation Calculators

Visualization Tools

External Simulation Engine

United Technologies Research Center

Carnegie Mellon
Demo 1

Dramatic reduction in effort to conduct lighting simulation

- Revit Model
- Export as gbXML file
- Automatic processing by CMU Lighting Application
- Lighting Simulation Results
Demo 2 – Batch Series of Runs
Parametric Variation Studies
Demo 3
Design investigations and analyses

Revit Model
Automatic processing by CMU Lighting Application
Results Analysis
Comparison between design changes
LEED Credit Calculation

45% of projects through 2006 used Credit 8.1
75% of projects through 2006 used Credit 8.2

USGBC LEED Rating System
EQ 8.1 & 8.2 – Daylight and Views

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

**EQ 8.1 (Opt 1)** – Achieve a minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas

**EQ 8.2** – Achieve direct line of sight to the outdoor environment via vision glazing between 2’6” and 7’6” above finish floor for building occupants in 90% of all regularly occupied areas.

- Voluntary rating system
- Widespread use by both governmental and private industry (Landman, 2005)
- 2 lighting performance benchmarks
# LEED Credit Calculation

## Table 1: Daylighting Design Criteria

<table>
<thead>
<tr>
<th>Window Type</th>
<th>Geometry Factor</th>
<th>Minimum T&lt;sub&gt;vi&lt;/sub&gt;</th>
<th>Height Factor</th>
<th>Best Practice Glaze Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylighting</td>
<td>0.1</td>
<td>0.7</td>
<td>1.4</td>
<td>Adjustable blinds&lt;br&gt;Interior light shelves&lt;br&gt;Fixed non-adjustable exterior shading devices</td>
</tr>
<tr>
<td>Daylighting</td>
<td>0.2</td>
<td>0.4</td>
<td>1.0</td>
<td>Fixed interior&lt;br&gt;Adjustable exterior blinds</td>
</tr>
<tr>
<td>Daylighting</td>
<td>0.3</td>
<td>0.4</td>
<td>1.0</td>
<td>Fixed interior&lt;br&gt;Exterior louvers</td>
</tr>
<tr>
<td>Daylighting</td>
<td>0.5</td>
<td>0.4</td>
<td>1.0</td>
<td>Interior fixed&lt;br&gt;Exterior fixed louvers</td>
</tr>
</tbody>
</table>

## Table 2: [LB3] Glazing Factor Tabulation Spreadsheet

<table>
<thead>
<tr>
<th>Regularly Occupied Space ID</th>
<th>Regularly Occupied Space Name</th>
<th>Regularly Occupied Space Area [SF]</th>
<th>Percentage of Regularly Occupied Space with a Minimum 2% Glazing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 Office</td>
<td>820</td>
<td>720</td>
<td>78%</td>
</tr>
<tr>
<td>102 Office</td>
<td>880</td>
<td>10</td>
<td>12%</td>
</tr>
<tr>
<td>104 Open Office (Daylight Area)</td>
<td>2250</td>
<td>118</td>
<td>53%</td>
</tr>
<tr>
<td>105 Office (Non-Daylight Area)</td>
<td>685</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>106 Open Office</td>
<td>250</td>
<td>0.9</td>
<td>0%</td>
</tr>
<tr>
<td>107 Office</td>
<td>250</td>
<td>0.9</td>
<td>0%</td>
</tr>
<tr>
<td>Total Regularly Occupied Space Area (SF)</td>
<td></td>
<td></td>
<td>Percentage of Regularly Occupied Space with a Minimum 2% Glazing Factor</td>
</tr>
<tr>
<td>4585</td>
<td>3370</td>
<td>78%</td>
<td></td>
</tr>
</tbody>
</table>

## Table 1: Determination of Compliance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>101 Office</td>
<td>820</td>
<td>790</td>
<td>820</td>
<td>Yes</td>
<td>820</td>
</tr>
<tr>
<td>102 Conference</td>
<td>330</td>
<td>260</td>
<td>330</td>
<td>Yes</td>
<td>330</td>
</tr>
<tr>
<td>103 Open Office</td>
<td>4,935</td>
<td>4,641</td>
<td>2,641</td>
<td>Yes</td>
<td>4,641</td>
</tr>
<tr>
<td>104 Office</td>
<td>250</td>
<td>210</td>
<td>250</td>
<td>No</td>
<td>250</td>
</tr>
<tr>
<td>105 Office</td>
<td>250</td>
<td>175</td>
<td>175</td>
<td>Yes</td>
<td>175</td>
</tr>
<tr>
<td>Total</td>
<td>6,585</td>
<td></td>
<td></td>
<td></td>
<td>5,966</td>
</tr>
</tbody>
</table>

Percent Access to Views [5,966/6,585] 90.5% Credit Earned
Demo 4
Calculating LEED credits, tracking during design investigations

Revit Model

Material Properties Inspection and Editing

LEED Credit EQ 8.1. Glazing Factors

LEED Credit EQ 8.2. View-out Availability

United Technologies Research Center

Carnegie Mellon
Dynamic Update of LEED 8.1 Values as Building Model is Modified

Parameters Inspection in Lighting Tool, no user intervention
Output is Presented in Same Form as LEED Templates

Daylight and Views - Intent

Daylight 75% of Spaces

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

- LEED-NC v2.2 pp.373

To achieve this credit, fulfill EITHER Option 1 OR Option 2

Option 1 - Glazing Factor Calculation

Achieve a minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas. The glazing factor is calculated as follows:

\[
\text{Glazing Factor} = \frac{\text{Window Area}}{\text{Floor Area}} \times \frac{\text{Window Geometry Factor}}{\text{Actual Tc}} \times \text{Window Height Factor}
\]

Percent area with minimum glazing factor of 2% 77%  Calculate  Details

Option 2 - Daylight Simulation

Link to simulation under construction
### Example of 8.1 Daylight Availability Output

**Glazing Factor Tabulation**

<table>
<thead>
<tr>
<th>Space Details</th>
<th>Opening Name</th>
<th>Windows</th>
<th>Skylights</th>
<th>Horizontal</th>
<th>Glazing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Id</td>
<td></td>
<td>Vision Area</td>
<td>Daylight Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rm101 Room</td>
<td>su-8-op-1</td>
<td>2.75</td>
<td>-</td>
<td>-</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>su-11-0p-2</td>
<td>1.26</td>
<td>-</td>
<td>-</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>su-11-op-3</td>
<td>1.26</td>
<td>-</td>
<td>-</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>su-10-op-1</td>
<td>5.49</td>
<td>-</td>
<td>-</td>
<td>1.18</td>
</tr>
<tr>
<td>Total Occupied Area</td>
<td></td>
<td>112.6</td>
<td>Total Occupied Area with Minimum 2% Glaze Factor</td>
<td>87.5</td>
<td>Percent Occupied Area with 2% Glazing Factor</td>
</tr>
</tbody>
</table>

Space total Glaze Factor: 2.32%

| Rm102 Room                    | su-19-op-1   | 2.75          | -             | -          | 1.78           |
|                               |             | 0.81          | Daylight Tsc  |            |                |
| Total Occupied Area           |              | 25.0          |               |            |                |

Space total Glaze Factor: 1.78%

| Rm201 Room                    | su-21-op-1   | 5.49          | -             | -          | 7.11           |
|                               |              | 0.81          | Daylight Tsc  |            |                |
| Total Occupied Area           |              | 12.5          |               |            |                |

Space total Glaze Factor: 7.11%

| Rm202 Room                    | su-28-op-1   | 2.75          | -             | -          | 0.18           |
|                               |              | 0.22          | Daylight Tsc  |            |                |
| Total Occupied Area           |              | 75.0          |               |            |                |

Space total Glaze Factor: 0.16%

| Rm203 Room                    |              |              |               |            |                |
| Total Occupied Area           |              | 12.5          |               |            |                |

Space total Glaze Factor: 0.0%

**Tabulation for LEED EQ 8.1 submittal**
LEED 8.2 Calculation of Views

Figure 1: Direct Line of Sight to Perimeter Vision Glazing, used in the area determination

Figure 2: Horizontal View at 42”, used to confirm access to views

Table 1: Determination of Compliance

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<td>280</td>
<td>330</td>
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<td>330</td>
</tr>
<tr>
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<td>4,641</td>
<td>2,641</td>
<td>Yes</td>
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</tr>
<tr>
<td>104 Office</td>
<td>250</td>
<td>201</td>
<td>250</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>105 Office</td>
<td>250</td>
<td>175</td>
<td>175</td>
<td>Yes</td>
<td>175</td>
</tr>
<tr>
<td>Total</td>
<td>6,585</td>
<td></td>
<td></td>
<td></td>
<td>5,966</td>
</tr>
</tbody>
</table>

Percent Access to Views [5,966/6,585] 90.5% Credit Earned
**Access to Views Output**

![Access To Views Tabulation](image)

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>Area</th>
<th>Occupancy</th>
<th>Multi Occupant</th>
<th>Area with View Access</th>
<th>Compliant Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>sp-Rm101-Room</td>
<td>Rm101</td>
<td>75.0</td>
<td>Occupied</td>
<td>True</td>
<td>68.75</td>
<td>68.75</td>
</tr>
<tr>
<td>sp-Rm102-Room</td>
<td>Rm102</td>
<td>25.0</td>
<td>Not Occupied</td>
<td>True</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>sp-Rm201-Room</td>
<td>Rm201</td>
<td>12.5</td>
<td>Occupied</td>
<td>True</td>
<td>12.12</td>
<td>12.5</td>
</tr>
<tr>
<td>sp-Rm202-Room</td>
<td>Rm202</td>
<td>75.0</td>
<td>Not Occupied</td>
<td>False</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>sp-Rm203-Room</td>
<td>Rm203</td>
<td>12.5</td>
<td>Occupied</td>
<td>True</td>
<td>3.25</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Total Occupied Area: 112.5
Total Compliant Area: 106.2
Percent Occupied Area with Access to Views: 94.4%

Tabulation for LEED EQ 8.2 submittal
Summary 1

- Demonstrated interoperability using Shared Object Modules
  - Auto setup of geometry Revit→gbXML→Radiance
  - Use of optical properties of surfaces as needed for Radiance from SOM database as they become defined
  - Use of location information from SOM for daylighting calculation and LEED
  - Results can be posted to be made available to the design team
  - Eventually augmentation of gbXML may be recommended to capture information specific to the lighting domain
Summary 2

• Demonstrated scalability with changing level of detail and improved fidelity as design stages change and user input is substituted from defaulted values and screen color changes from red to blue; should be better than using just rules of thumb in early design

• Permits evaluations early in design before a professional lighting specialist may be participating, especially for smaller projects

• Speeds up the work of the lighting specialist by removing manual steps and lowering the chance for errors
Summary 3

• Parametric variation studies are easily set up for batch processing

• Demonstrated the generation of operative information using postprocessing features
  – False color encoding of luminance and contrast ratios from Radiance
  – LEED credits calculated in real time

• Should permit more use of lighting simulation earlier in the design process yielding better integrated designs; lighting issues are difficult to fix after the fact
Thank you