Title:
Green BIM-based Building Energy Performance Analysis

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Introduction:
This study proposes the concept of green building information modeling (Green BIM), performing building performance analysis (BPA) to obtain design proposals with optimized environmental effectiveness in response to local climate conditions when BIM is used as a basic tool from the beginning of the design process.

Taking building energy performance analysis as an example, in comparison with other domestic and foreign research, the important contributions of the study include: (1) Based on a design decision-making perspective, a Green BIM-based decision-making cycle can integrate the practical steps of BIM and BPA, which will facilitate adjustments for the purpose of establishing an optimized energy conservation design proposal. Furthermore, this study also finds that meteorological data in a format that can be used in BPA is not easy to obtain. (2) Nevertheless, virtual weather station technology developed using cloud technology can enable a building project to obtain simulated meteorological data relying on weather stations closest to the required criteria, and a cloud building energy analysis engine can be used to implement complex analysis involving large amounts of data. As a result, the use of green-BIM technology and concepts can be promoted with greater ease.

When setting energy conservation targets, this study recommends that building energy usage intensity (EUI) be employed as an integrated performance indicator for energy consumption, and percentage of performance optimization be employed as a rating criterion. Nevertheless, the use of energy conservation targets is not essential; depending on the directions in which national governments would like to lead the industry, and the maturity and feasibility of relevant technologies, other feasible high-performance benchmarks proposed in this study may also be used in Green BIM.

Motive and goal
In the face of a rapidly changing climate and global energy crisis, how to apply building information modeling (BIM) and related technologies to perform building life cycle information management applications, and thereby enhance construction efficiency and provide architectural solutions with lower building energy consumption, has become a key topic in building-related industries today. BIM has the two implications of information modeling and information management. Furthermore, the development of building performance analysis software, such as Ecotect, CFD, and Vasari, has enabled the extension of BIM applications to the initial design assessment stage. As a consequence, with the availability of more precise meteorological and environmental information and site condition knowledge, building structural configuration analysis can include performance analysis and

visualization. The integrated application of BIM and BPA technologies can thus enable the formulation of even more optimal design proposals.

Literature review:

The chief categories of Green BIM research include building information modeling (BIM) and building performance analysis (BPA), as well as the integrated application of BIM and BPA to sustainable building design. Apart from use in obtaining 3-D geometric information, BIM can also be used to formulate that part of non-geometric information that can be easily transmitted to building performance analysis software. The integration of BIM and BPA software can promote the use of rational decision-making cycles and optimized development in architectural design. Controlling actions (such as analysis, synthesis, evaluation, and communication, which are considered part of the process of analysis) and design processes can be marked as a series of problem-solving steps (Rowe, 1992). Decisions taken during the early part of the design process will have a major influence on building performance throughout the building life cycle. Design methods based on BIM can enable the assessment and comparison of different design proposals during the early design stage, which can effectively improve a construction project. Because of this, building performance analysis (BPA) has become an indispensable link in the design decision-making cycle and optimized development. The compared BPA items include natural and artificial lighting, indoor lighting, overshadowing and shading analysis, solar radiation and thermal performance analysis, wind ventilation analysis, acoustic analysis, visual access, energy load, and carbon emission analysis.

Theory and Method:

This study takes building energy consumption as an example. As summarized above, Green BIM emphasizes how building information modeling can be used as a basic tool from the beginning of the design process to perform BPA in response to local climate conditions. In addition, a decision-making cycle consisting of design and analysis processes can optimize design and generate candidate proposals offering environmental effectiveness, and ultimately achieve the goal of environmental sustainability. Fig. 1 shows a flowchart of the decision-making cycle in Green BIM.

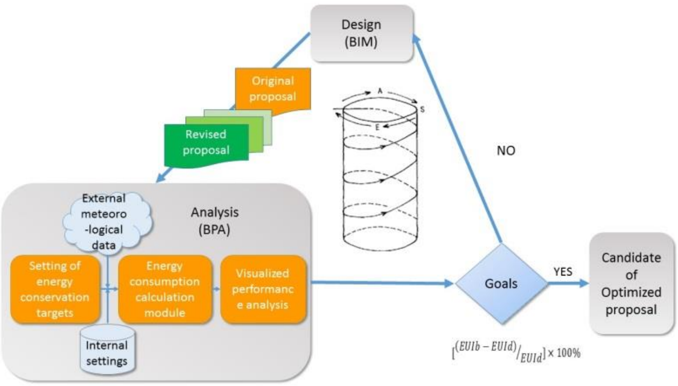

Fig. 1: Green BIM decision-making cycle model.

During the assessment stage, testing was performed to check the fit of the BIM software and ensure that the virtual weather station technology and energy load analysis engine complied with standards. This study recommends the use of Autodesk's Vasari BPA software. Energy load analysis involves the following key elements:

(1) Determination of the scope of the project in the building life cycle: The software simulated building energy load during the operational use stage, and its performance analysis and design optimization decision-making cycle focused on the design stage (including pre-design, preliminary design schematic design, including design development stages).

(2) Setting of energy conservation targets: this study recommends that energy use intensity (EUI, annual power consumption per building unit area) be used as an overall indicator of building energy load, and the ratio of the baseline proposal's EUI value (EUIb) and the optimized proposal's EUI (EUId) to the EUIb value (percentage performance optimization) taken as rating or target during the determination of design settings.

$$\text{Percentage performance optimization} = [{}^{(EUIb - EUId)}/_{EUIb}] \times 100\%$$

(3) External meteorological data: Due to breakthroughs in cloud-based virtual weather station technology, however, Green BIM need no longer be limited to application in certain regions. Autodesk's meteorological database contains meteorological data in the internationally-accepted TMY (typical meteorological year) format Employing TMY data for each weather station, Autodesk derives the corresponding data for virtual weather stations, which helps compensate for differences in data between real weather stations and shrinks the distance between meteorological grid points to less than 14 km, which boosts modeling accuracy (Malkin, 2008).

(4) Internal settings: In accordance with Anderson K. (2014[1]), factors influencing energy load during the building use stage include geometric shape information in the BIM model and non-geometric information.

(5) Energy consumption calculation module: The Vasari software uploads the model's internal settings, including geometric information and non-geometric information, and meteorological data to Green BIM Studio in the gbXML format, which uses the DOE-2 engine to perform energy load analysis. The DOE-2 energy load analysis engine passed ANSI/ASHRAE Standard 140 testing and certification in 2008. (Fig. 2)

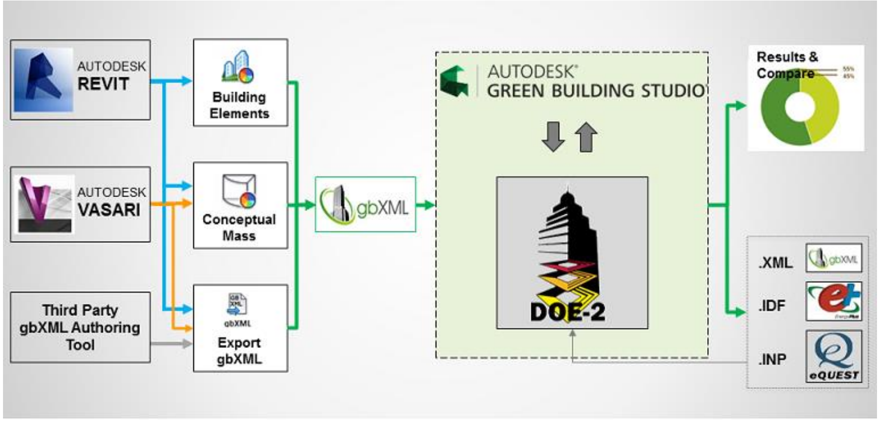

Fig. 2: Software block diagram showing Green Building Studio's DOE2 engine, BIM, and BPA (Whole Building Energy Analysis, 2015).

(6) Visualized performance analysis: It includes virtual performance and various numerical analysis and statistical charts.

(7) Analysis and revision: Hotspot tracking and adjustment of control variables can be performed in accordance with the results of analysis, and a modified proposal obtained.

(8) Candidate of optimized proposal: A modified proposal meeting energy conservation targets can serve as a candidate optimized proposal.

<u>Empirical verification:</u>

This study used BPA and design optimization process for the Chiayi Harbor Hotel Project to verify the practical value of a Green BIM based decision-making cycle model.

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(1) Determination of the scope of the project in the building life cycle: The Green BIM decision-making cycle for this project—Chiayi Harbor Hotel Project—occurs during the initial design stage (PD, SD, DD stages).

(2) Setting of energy conservation target: The energy conservation target in this case study was optimized performance at least 7% better than the baseline proposal.

(3) Input external meteorological data : Taking the Chiayi Harbor area as an example (Fig. 5), we entered project settings, input the site's latitude and longitude, and selected the closest virtual weather station. (Fig. 3)

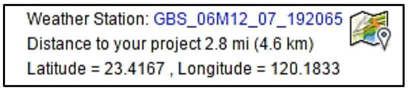

Fig. 3: Site location settings and weather station selection.

(4) Internal settings: The first step was to establish a baseline proposal model (Create Mass/Place Mass). Revit software can be used to output as CAD or the SKP format for import into Vasari, or simple modeling can be performed directly in Vasari. Area allocation was performed, and, in accordance with ordinary practice, the percentage glazing was set at 40% in the baseline proposal. The building type was set as "hotel," and the structural materials consisted of the BIM model's default values.

(6) Visualized performance analysis: Autodesk Vasari's building occupancy schedules are based on the classification standards of the California Non-residential New Construction Baseline Study (1999), and the occupancy schedule of the hotel building in this study was taken to be as shown in Fig. 9, where a value along the ordinate axis of 1 indicates that 100 persons are active during this period, and a value of 0.1 indicates that 100 x 0.1 = 10 persons are active. In the case of this hotel, peak density times combining the density characteristics of weekdays and weekends are 1:00-8:00 in the morning and 19:00-24:00 in the evening. Because of this, after completing basic parameter settings, in accordance with modeling results, the building was determined to accommodate 183 persons and have a power use density of 221 kWh/ m_2*year, which is approximately 13% higher than the general hotel average power use density of 195.6kWh/m_2*year. Power consumption analysis revealed that air conditioning equipment had the highest energy load (73%), followed by lighting with 18%. Inspection of monthly energy load: Use of load composition analysis indicated that heat conduction through the windows and outer walls was the largest source of air conditioning load, and was followed by lighting equipment and solar radiation entering through windows; since the latter two variables are mutually interacting, and experimental revision process was employed to determine a design proposal yielding optimal energy conservation benefits. From the perspective of monthly power use distribution, power consumption is relatively high during the summer months of July and August, and air temperature and solar radiation follows similar trends. We therefore concluded that if the power rate was used to assess power costs throughout the year, improved summer power conservation could reduce operating costs. Analysis of the site's physical environment: In accordance with the results of visualized performance charts, including the wind rose and wind field simulation results in Fig. 4 and solar radiation simulation results in Fig. 5, the directions of prevailing winds were found to chiefly include north and north north-east, and the L-shaped building received intense thermal radiation on the south side.

(7) Analysis and revision:

- Target percentage glazing: reduced from 40% to 25%
- Target sill height: increased from 0.76 to 0.85
- Eaves shading: eaves shading was increased by 3 m on the southern and western sides
- Construction of mass exterior wall: changed from lightweight construction – typical mild climate insulation (R-value of 10) to high mass construction-high insulation (R-Value of 17)

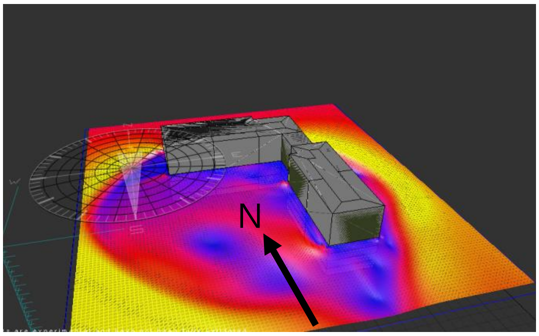

Fig. 4: Dynamic simulation of building wind field.

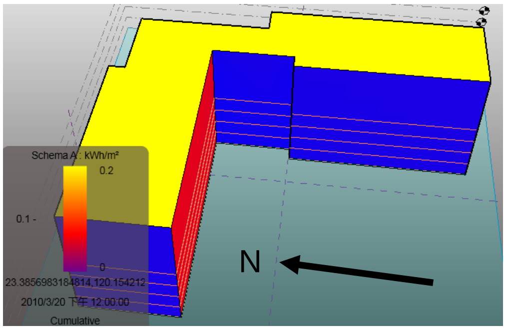

Fig. 5: Distribution of solar radiation on the building's outer walls.

(8) Candidate of optimized proposal

In accordance with the foregoing optimization recommendations, the proposal's EUI was adjusted from 221 kwh/m_2-year to 203 kwh/m_2-year, which was an approximate reduction of 8.1% ≧7%; [(221-203)/221]=8.1%≧7% (Fig. 6). This reduction ratio was greater than the preset energy conservation target, and the revised proposal could therefore serve as a candidate optimized proposal.

Energy Use Intensity

Electricity EUI:	221 kWh / sm / yr
Fuel EUI:	279 MJ / sm / yr
Total EUI:	1,076 MJ / sm / yr

Energy Use Intensity

Electricity EUI:	203 kWh / sm / yr
Fuel EUI:	227 MJ / sm / yr
Total EUI:	957 MJ / sm / yr

Fig. 6: Comparison of energy load of baseline proposal (left) and optimized proposal (right).

Conclusions:

Green BIM decision-making cycle model. Taking energy consumption throughout the building life cycle as an example, the study verified the practical effectiveness of Green BIM in the case of the "Chiayi Harbor Hotel Project." The study input a project drafted using BIM software into Vasari for BPA calculations, and used the gbXML format to transmit the resulting data to the DOE-2 engine via the cloud for building energy performance analysis. Energy use intensity (EUI, annual power consumption per building unit area) was taken as an overall indicator of building energy load, and percentage performance optimization served as the approach to target value settings in the optimized proposal. Nevertheless, energy conservation benchmarks are not necessarily essential. Other feasible energy conservation benchmarks (Anderson K, 2014[2]) include: (1) Energy cost budget, (2) Net zero energy, (3) Passivhaus standards, (4) Carbon footprint target. Apart from this, because buildings must satisfy varied functional requirements, a final optimized proposal will be the result of numerous decisions and trade-offs (Augenbroe, 2011). Trade-offs involved in dealing with various performance indicators and choosing among different candidate proposals will be an important research topic in further studies of Green BIM.

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