Integration of Computer-Aided Solar Energy System Design in Building Information Modeling

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ABSTRACT

For the purposes of integrating a solar energy system design into BIM, this study proposes a new design model, which deploys solar panels and design evaluation directly into BIM. In the proposed model, the functions of energy analysis software and solar design software are integrated into customized BIM tools developed using Revit and its API. Such integration allows users to perform solar system design for buildings in a BIM environment; further, the design is directly integrated into BIM. The user first uses BIM tools to build a BIM for a building, then the geometric information of BIM is exported to an energy analysis software for radiation analysis on the building envelope. After analysis, BIM tools imports and displays the analysis results using color contours on BIM. Based on the color contour of BIM, the user can choose optimal locations on the envelope of BIM to install solar panels. Finally, BIM tools can calculate the power generation of current deployment. Since the aforementioned design operations are all performed in a BIM environment, the user can continue revising and re-evaluating the design directly on BIM to reach an optimal design.

INTRODUCTION

Humans construct buildings and their everyday living takes place inside buildings, however the conditions inside buildings are not always suitable due to the effects of the seasons, surrounding environmental conditions, etc. Therefore, in order to create an indoor environment that is suitable for human life, we use lightings, heating and air conditioning, and other electrical appliances to maintain a comfortable living space. Operating such equipment inside buildings consumes electric energy, but we can reduce building's energy consumption through developing energy efficiency. Thus, many ways to achieve energy efficiency are imported into both new and old buildings, such as: using plants as a shield against sunlight, adopting air vents to dissipate indoor heat, installing solar panels, etc.

Given solar power can be said to be inexhaustible and does not produce byproducts during power generation, it is considered to be an environmentally friendly energy. Solar panels are a power generation product using solar power. Using solar panels requires relative areas to receive sunlight; larger areas are capable of increased electricity generation while smaller areas have a reduced capacity for electricity generation. However, for countries with a high population density, it is difficult to find space to set up a large-scale, solar energy generation system. Consequently, a common practice is to install solar panels into the building envelope; this practice takes advantage of solar energy without affecting the environment.

Building Information Model (BIM) is a new trend in the construction industry. Replacing the traditional 2D drawings, it uses parametric 3D models to store information regarding the construction projects. As the main design tool for BIM, BIM software should provide sufficient functions to allow designers to design practical BIM with complete information. However, a construction project covers many areas of expertise, making it difficult for designers to rely on a single tool for designing models. For example, a structural analysis requires structural analysis software and an energy analysis requires energy analysis software. BIM contains various design software covering different areas of expertise.

The concept of building energy efficiency must be implemented into the new BIM design model. Many studies have added energy analysis into the design process of BIM, aiming to optimize its energy-efficiency. Cho et al. explored the design process in the context of building energy efficiency with BIM. By assessing the energy consumption at the conceptual design stage, establishing an energy-saving target, and modifying the design, they adopted EnergyPlus and IES software in order to confirm whether the modified design complied with the target. Furthermore, in order to reduce the complexity of the operation, another study attempted to integrate both BIM and energy analysis software. Bazjanac proposed the use of IFC HVAC standards as an exchange format in order to integrate both energy analysis and BIM software; Vladimir also discussed the potential problems with the integration of EnergyPlus and MagiCAD. Bazjanac converted the geometric information of buildings into energy analysis software, achieving semi-automated energy analysis.

As the existing BIM software is mainly based on the basic design components of structural buildings, it still does not have operations related to solar panel components; thus adopting solar power design into BIM also requires the use of energy analysis software and photovoltaic design software to support the design. First, the process would involve establishing a BIM of the building within the BIM software, then exporting the geometric data into energy analysis software to perform an analysis on the insolation to obtain the envelop zone with an adequate amount of sunlight, and finally using the photovoltaic system design software, while selecting the suitable solar panel and its number, in order to calculate the energy generation efficiency of the device. The software products mentioned above are generally not provided by the same developers. Among the software products, there are issues such as poor data compatibilities, user interface differences, etc. The results cannot be directly fed back into BIM software. After the designer has completed operating the other two software simulations they are required to return to BIM software to modify the design, so that the design is complete. This implies that the designer must

synchronize the data of the tripartite software voluntarily, increasing the probability of human error.

RESEARCH OBJECTIVE

The objective of this research is to establish a prototype design support system for solar power inside BIM software. The system provides design functions for a solar photovoltaic system. Through the concept of system integration, we linked BIM software, energy analysis software, and photovoltaic design software together to ensure consistency of data exchange and to simplify the user operation process; this approach aims to improve the complicated procedures of interoperating multiple design software. The concept of the prototype system, established by this study, is as follows. BIM software is still used as a tool to establish a BIM model; whereas the solar-panel-related functions in the energy analysis software and the photovoltaic system design software have been enabled to be the functions of BIM software via system integration in this study. Both the energy analysis software and the photovoltaic design software are professional software. For the software functions, such as heat load analysis, ventilation simulation, water consumption analysis, and other functions, except the insolation simulation in the energy analysis software as well as many electrical professional designs, energy consumption analysis and other functions in the photovoltaic system design software have been streamlined in this study; only functions that are closely related to solar system design have been retained and integrated into BIM design software. For the energy analysis software, its insolation simulation function has been linked to performance on the designated BIM, eliminating the file operations of exporting and importing between both the software and turning into programmable automation to handle the data exchange. After the insolation analysis was complete, in order to take full advantage of 3D visualization, the simulation result was presented on the 3D model by using visual feedback. Using different colors to show different variations of insolation, this presents a more intuitive analysis for the designer and negates the need for them to check numerical data. For the photovoltaic system design software, two functions have been retained. The functions are the estimate of electricity demand for the building and electricity, and the estimate of power generation from solar panels. As these two functions are less involved in the professional design software interior of the photovoltaic system, we could achieve these functions on our own in this study. Thus, regarding the external functions of the photovoltaic system, we have written similar system functions without the need to link to the photovoltaic system software.

SOFTWARE TOOLS FOR DEVELOPING THE PROPOSED SYSTEM
REVIT ARCHITECTURE

Revit is a series of software, issued by Autodesk. This study adopted Revit Architecture 2012 as the BIM software tool. Revit software is built specifically for BIM, empowering design and construction professionals with a coordinated and consistent model-based approach to develop ideas from concept to construction.

Revit API. In order for Revit to handle a variety of customized needs, Autodesk provides user groups with Revit API, so developers can access a large number of functions within the Revit software. This is the basis for software expansion. Following the framework of Revit API, developers can perform the function expansion on the existing Revit.

EnergyPlus. EnergyPlus is building energy analysis software, developed by the US Department of Energy, based on two well-known simulation engines BLAST and DOE-2 in Fortran 90 language. Like many energy analysis software, the most important function is to analyze the energy consumption of a building. Users will need to provide inputs of architectural design information and the existing environmental information around the building into EnergyPlus. The software will be able to carry out analytical energy simulation on the exterior and interior of the building, allowing the designer to understand the energy consumption of the existing building design. After analyzing the data, the designer can modify its architectural design to optimize the energy consumption. EnergyPlus can simulate numerous items, but its user interface has only partial flow control options. The main mode of input and output in EnergyPlus are text-based, i.e. it uses plain text files to define the model, and it has considerable number of relevant parameters.

OpenStudio. OpenStudio was developed by the Nation Renewable Energy Laboratory (NREL). Its purpose is to support the quick convert of building information into EnergyPlus for energy analysis and provide richer graphical user interface (GUI) to develop the input file of EnergyPlus. From the user perspective of energy analysis software, OpenStudio provides more complete GUI, allowing users to operate EnergyPlus; the OpenStudio interface provides more functions than EnergyPlus. Users can use this interface to set many simulation items and detail information of EnergyPlus, such as setting the meteorological data surrounding the building, the building materials of each component, the analysis items and parameters, the planning timeline, the configuration of HVAC equipment, etc. All these are operated by GUI operation to replace the time-consuming process of only plain text file written input into EnergyPlus.

SYSTEM OPERATION PROCESS

In order to improve the efficiency of solar energy generation design introduced into BIM design, this study established a prototype design support system for solar power in Revit software. As the functions provided by this system are to be used in the Revit interface, the process needs to be integrated with the functions of the system as well as Revit's existing functions. Among several new functions of the system planning in Revit, the system operational process in the planning process is depicted in Fig. 1 below. The left side of the figure illustrates that the user employs the internal functions of Revit software to carry out the design process of the model and the designation of solar panels. First, designing the exterior of BIM, designers establish a building body in the Revit software using the basic components of walls, floor, roof etc. After the building body design is complete, the designers then

continue the design work for the solar panels components. Since Revit has not yet provided a unified solar component, designers can customize an appropriate component exterior and parameter to represent the solar panels and install them on the building envelope. Throughout the installation of solar panels, due to lack of the information in insolation on the building envelope, designers can only rely on their own experience to carry out the designation. Thus, there is no guarantee that the cumulative insolation of the installation on the building envelope is in line with expectations. It is difficult for the solar panels to unleash maximum efficiency. After completing the installation of solar panels, a verification on the design must be performed by calculating the energy generation of solar panels in the model in order to confirm whether the designation of solar panels in the model is suitable; whereas inside Revit, as the function for calculating the solar power output is yet to be provided, designers have to manually calculate the energy generation.
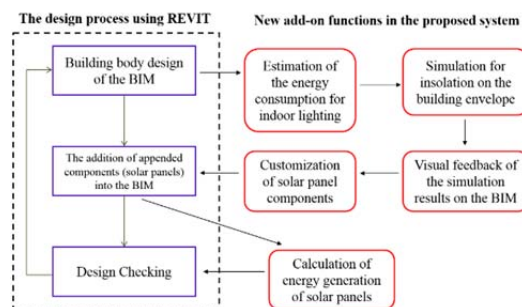

Figure 1. System operation process

The right side of the figure lists the functions the prototype system should possess, as proposed by this study. Adding new functions would change the operation process of this current design. When designers complete the design for the BIM model, the designer should be aware of energy consumption in the building, and then choose to modify the original design to reduce building energy consumption or employ a certain number of solar panels to replace the consumed energy. First, the system estimates the energy consumption for indoor lighting to provide designers with energy consumption references of designs from the past. The next step is to conduct an insolation analysis on the building envelope, providing designer cumulative insolation on the building envelope for over a one-year period, in order to distinguish the suitable envelope zone for the installation of solar panels. In order to provide designers precise cumulative insolation on the envelope, this function must be integrated with the function of external energy analysis software to conduct an insolation analysis of the whole building. The insolation analysis is generally averaging insolation over a one-year period as a benchmark to calculate the annual average insolation on the building envelope. After having performed an insolation analysis on the building, designers will be able to learn the difference between insolation on different building envelopes from the analysis results. As a result of employing external analysis software, the analysis results will not be displayed in BIM software, so designers are required to cross-check the BIM and the analysis results on their own. If the building is large, this repetitive action is quite time-consuming. In order to save the processing time for checking the external analog

data, the system possesses the function, which gives feedback regarding the insolation analysis results to the BIM software. Simultaneously, taking into consideration the direct presentation of 3D in BIM, it takes the form of visual feedback to directly display the simulation results on the 3D model of BIM. By using the colors on the 3D model, with different colors representing the value of insolation, designers can identify the quantity of insolation by looking directly at the colors of the building envelope. Since Revit has not been providing a consistent solar component, we customized the appearance and parameters of the solar panel component, required in the system, according to the BIM component structure of Revit. Using this component as a basis, designers can change the specifications of the actual solar panels to ensure that the solar panel component can interact with the system. After the designer has installed the solar panels, the last function is the calculation of energy generation of solar panels by the system. In combination with the previous cumulative insolation on envelope from the energy analysis software, the system calculates energy generation of the solar panels (saving the designer from undertaking manual calculations as in the past) and providing the energy generation results as a reference for designers. Outlined above is the planned system as proposed by this study. Following this new process, designers can operate the system in Revit to carry out design modifications on a single model in order to achieve optimization in solar power design.

SYSTEM FRAMEWORK AND OPERATING MECHANISMS

For the BIM solar design support system, as proposed by this study, the system framework consists of five functional modules, as illustrated in Fig. 2. It represents the information exchange mechanisms between each module as well as its side-operational relationship with Revit project data and energy analysis software. The left side of the figure illustrates BIM software operated by designers. The system can perform data access with BIM while being used by the designers. The middle part of the figure illustrates the main function of the system. It is divided into several modules. The data acquisition module is responsible for retrieving specific types of components in BIM, like walls, roofs and other components, and then delivering them to other functional modules. Three modules receive this information from the data acquisition module. These modules are the functional modules of energy consumption estimation, insolation analysis, and energy generation calculation.

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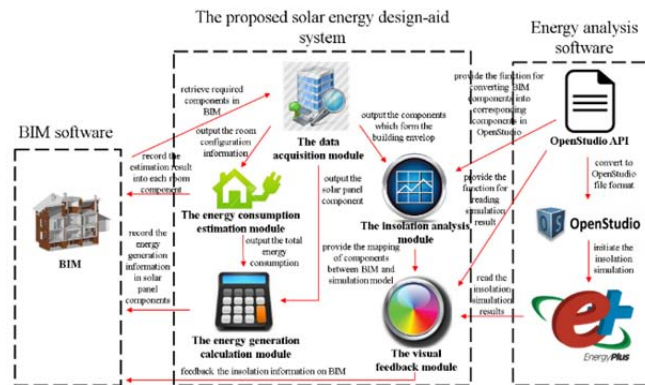

Figure 2. The system framework

The energy consumption estimation module mainly requires the configuration data of the rooms in the building. After receiving room information from the data acquisition module, it will carry out energy consumption estimates of lighting according to the size of the room. After the estimates are complete, the results are recorded sequentially into each room component. This provides the designers with information to understand the lighting energy consumption of the room. Further, the total energy consumption will be sent out to the energy generation calculation module.

The insolation analysis module is mainly responsible for the data exchange with OpenStudio and the data pre-processing. First, this module will call the data acquisition module to obtain the geometric data constituting the main building in order to convert the building information of Revit into the OpenStudio format; it will then pre-process the geometric data of the building. Following the complete pre-processing, the insolation analysis module then calls through OpenStudio API to convert the parsed data of the building into the OpenStudio format and open OpenStudio software to read the converted information. Subsequently, designers can use EnergyPlus to conduct insolation simulation through OpenStudio. After OpenStudio converts the building data into EnergyPlus format and initiates the insolation simulation on the building in accordance with the simulation parameters assigned in the system.

After simulation, EnergyPlus will produce multiple results files for the designer to view. The visual feedback module will read the insolation simulation results in the files. While reading, the visual feedback module will sequentially check the corresponding insolation data according to the component list from the pre-processing in the insolation analysis module. After reading the simulation results, the module converts the data into colors to represent and change the surface color of the components on the 3D model by tinting. This feedback will be recorded in the 3D model of Revit, as shown in Fig. 3.
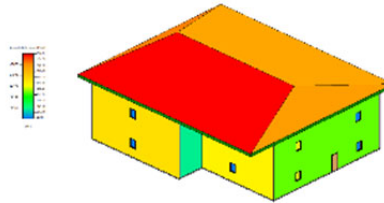
Figure 3. Visual feedback of insolation using colors

The energy generation calculation module will assist designers to perform design verification. After receiving the information about solar panels components, the module will inquire about the insolation received by each solar panel, as well as read the parameters of the internal area and the energy generation efficiency. Based on the data above, it calculates the energy generation of that solar panel and saves the information in that component. Finally, it sums up the total energy generation of solar panels in the building, calculates the total energy consumption in lightings from the energy consumption estimation module, and then informs designers whether the design meets the practical requirement.

CONCLUSIONS

The solar energy generation design support system proposed by this study, successfully integrated the processes of solar component design under a BIM environment. As long as designers operate the functions of this system in sequence, they can attempt to optimize the ratio of solar components and building configurations at the design stage. The EnergyPlus integrated by the system is professional energy analysis software; it has a high learning curve and is not suitable for beginners. Nevertheless, after integration with OpenStudio, the operational process of EnergyPlus was automated; therefore, users do not need to be familiar with the operational methods of EnergyPlus to use the function for insolation analysis; this has greatly reduced the operational difficulties for designers. For the photovoltaic software, this study has only taken the two functions of energy consumption estimation and energy generation calculation by achieving the functions on our own in the system. Although the integrity of the functions and the interface have been streamlined, it indeed links up the entire design process, starting from design to finish. This system can support users to carry out designs for solar systems at different stages of the design process.

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