VISUALIZATION OF BUILDING ENERGY PERFORMANCE IN BUILDING INFORMATION MODELS

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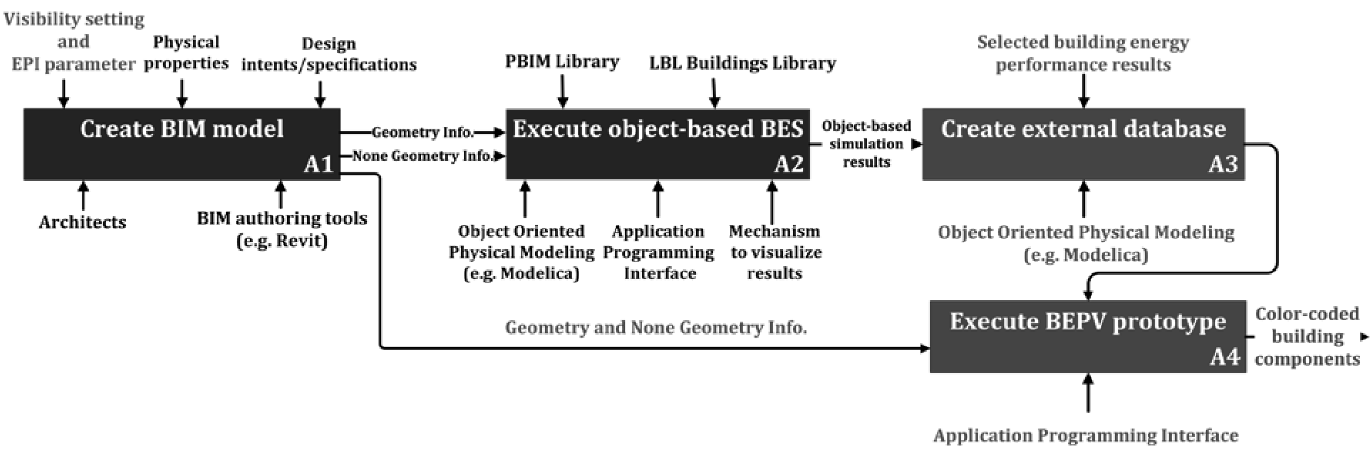


1 Overall process diagram using IDEF0. Dark blue components represent the thermal simulation prototype of our Physical BIM project, and dark red shows the BEPV workflow

ABSTRACT

This paper presents the results of research and development of Building Energy Simulation (BES) visualization methods. In this effort the authors used Building Information Modeling (BIM) Authoring Tools' Application Programming Interface (API) to visualize BES results in BIM. We also used an external database to store and manage the object-based simulation results from a BES tool. Based on these methods, we created a prototype: Building Energy Performance Visualization (BEPV), which translates information from the result database to the Energy Performance Indicator (EPI) parameter in BIM. Using the prototype, when BIM models are created for building design, the building energy performance can be expressed visually as color-coding on the BIM, allowing users to see energy flows directly. The developed prototype lets architects use BIM as a common user interface for building design and performance visualization, and may improve their designs in early stages.

INTRODUCTION

Lack of information visualization after conducting Building Energy Simulation (BES) may reduce the effective use of simulation results in developing schematic design. In this paper, we investigate a new platform to visualize building energy performance, especially thermal energy, in Building Information Modeling (BIM) by color coding components in the building based on energy flow values. First, we created a BIM model of BESTEST Case 600 (ANSI/ASHRAE Standard, 2010) using Autodesk Revit as a test case. Second, we created an Energy Performance Indicator (EPI) parameter for each building component to store building energy performance results that are produced by the Building Energy Simulation (BES). Third, we designed a visibility setting to color-code building components based on their values of energy flow. Lastly, we developed Building Energy Performance Visualization (BEPV) using the Application Programming Interface (API) of the BIM authoring tool, which loads the BES results into the EPI parameter of each component and changes the building components' colors automatically. The effect is somewhat like an infrared time-lapse animation of a building.

The developed platform (1) provides the result of building energy performance through the EPI parameter in BIM, (2) displays a series of energy performance results as color-coded building components, and (3) enables architects to utilize BIM as a common user interface for architectural modeling and Building Energy Performance Visualization (BEPV).

The following sections present details of the research methods, implementation and results. Findings on interfacing BIM and BES results for visualization will be discussed. In this paper, the terms "Building Information Modeling" and "Building Information Models" are used interchangeably as BIM in different contexts.

PROBLEMS AND CHALLENGES

BES tools have become an important support for sustainable design. Most current thermal simulation applications require acquisition of building geometry from computer-aided design tools (Bazjanac 2001) or exchange of BIM data with thermal modeling (Mitchell et al. 2007). Interoperability between these software systems remains a problem. Some BES tools support integration with BIM, for example, Autodesk Green Building Studio can be used with Revit (a BIM authoring tool) in the simulation process. In addition, research efforts to visualize energy simulation results (Sreshthaputra, Haberl, and Andrews 2004; Haberl and Akleman 2010) are invested in supporting a better understanding of building energy performance analysis. However, the feedback provided by the BES is difficult to apply to the design process. Although energy performance results are typically displayed as a series of tables and numbers, it may be difficult to find the relationship between simulation results and building components, in order to determine which components are performing well and which are not—information that is needed to improve the design.

GOAL AND APPROACH

The goal of this research is to enhance sustainable design at the early design stage by informing design decisions with BES results. To achieve this goal, we developed an integrated environment combining BIM and the results from object-based BES tools, integrating the capability of the BES visualization into BIM.

For the integration, our new method is based on the emerging technologies of BIM and the object-based BES tools through Object-Oriented Physical Modeling (OOPM). While BIM facilitates the access of comprehensive building data during a building's lifecycle (Eastman et al. 2008) and supports parametric modeling for design stage, OOPM supports object-oriented simulation results (Fritzson 2004). Our suggested method combines the advantages of BIM and OOPM for the visualization: object-based modeling approach and object-oriented programming methods. The object-based modeling approach allows direct access of BIM and simulation results, and the object-oriented programming methods facilitate the development of system interface for the visualization. Figure 1 shows the overall process of this research.

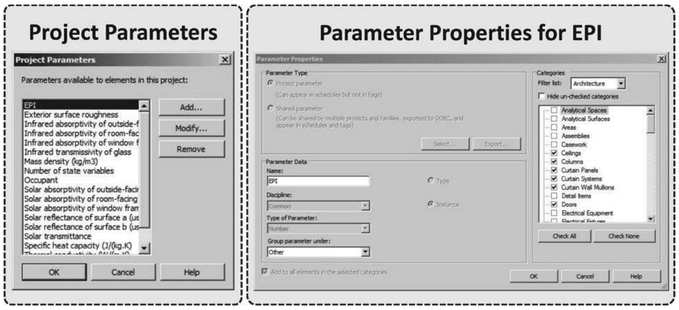
In our previous research, we used the Modelica Buildings Library developed by Lawrence Berkeley National Lab (LBNL) to perform energy simulations and wrote new software to export Revit BIM models to Modelica-based energy models (Yan et al. 2013). We used Dymola® Modelica development environment as an OOPM authoring tool, and extended that software system to develop the BEPV prototype by using Autodesk Revit and its API through the C# programming language to visualize the BES results.

METHOD

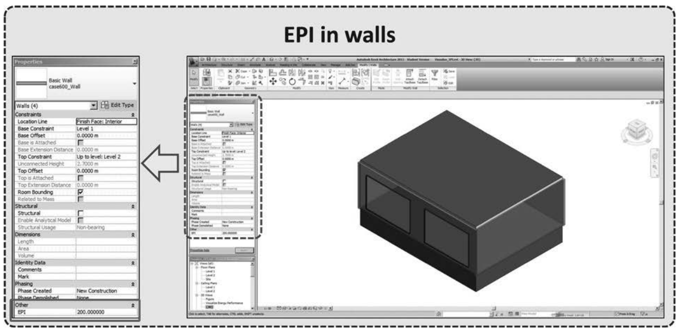
Our method involves preparing a BIM to hold the energy simulation results in each component, creating a method to change the visualization of the BIM-based on energy simulation results, writing the system interface through Revit's Application Programming Interface (API) for BEPV, and conducting a case study with a benchmark energy model to verify the operation of the prototype software.

PREPARING THE BIM

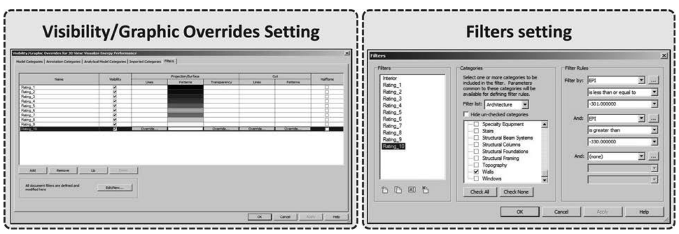
Before executing BEPV, the Revit model is preprocessed to include a parameter for the EPI and visualization settings to change the appearance of the model. The EPI is intended as one of many performance indicators that can be generated by the BES. The values in our prototype represent a heat flow rate. The values of EPI can range widely based on what kind of BEP results can be visualized. In a more advanced prototype, the EPI can be a function of multiple energy performance parameters, and users can select among many performance parameters for the EPI visualization.



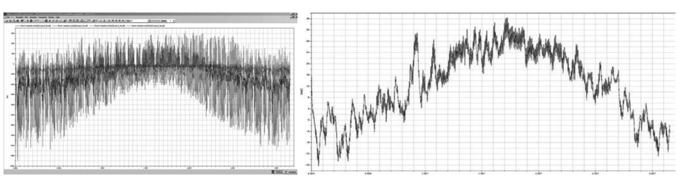
2 EPI parameter creation to communicate BEP results in Revit



3 EPI parameter applied in wall components



4 Visibility setting to create color-coded building components



5 Object-based BES results from OOPM

Using Revit commands, we created the EPI parameter as a project parameter so that all of the building components can include the information of BES results. Figure 2 shows how to create the EPI parameter in Revit as a project parameter of type Number, and how to apply it to building components that affect energy performance.

After creating the EPI parameter, users can check the assigned parameter by selecting building components (Figure 3). Visibility settings can be used to create color-coded building components based on the updated values in the EPI parameter. The settings are a series of ranges and each range has a different color. For example, a range from 101 to 130 Watts can be assigned as red color and if the value of EPI parameter is within the range, the component containing the value will be visualized in red. As shown in Figure 4, we used Revit commands to create a rating system by using the Filters dialog in the visibility/graphic overrides window. The rating system has ten levels and different colors, and each level is divided into thirty increments. For example, the values in the 10th level are between 301 and 330 Watts.

VISUALIZATION COMMANDS

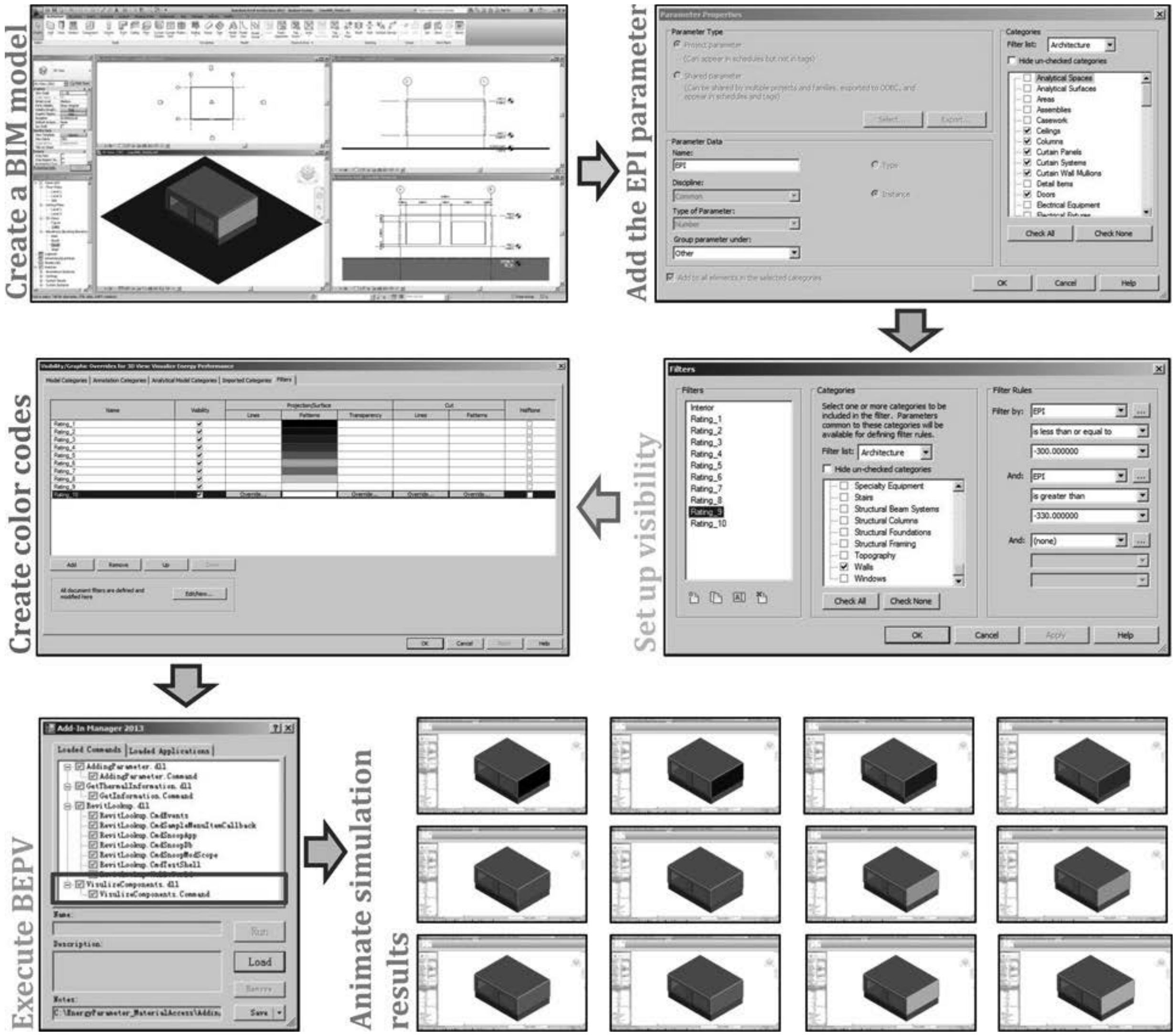
The final step in developing the prototype was to write software to feed the information from the BES tool into the EPI parameter. When the value of the EPI parameter is updated by the software, the visibility settings change the color of the building components for the simulation time based on the EPI values.

The thermal simulation results are generated by the BES tool for a designated time interval and step for each building component. An export function in the BES tool produces a Comma-Separated Value (CSV) format file that can be imported into Microsoft Excel. Sample results have been charted as shown in Figure 5: the left and right graph represents heat flow rate through opaque surfaces and annual indoor temperature respectively. The results will be exported to a CSV format file by the export function in the BES tool.

The visualization command checks each building component and saves its identification number. Using the identification number, a command retrieves simulation results from the database and stores them in the EPI parameters in Revit. Once the building components have their EPI values, the components are represented as designated colors by automatically applying the visibility setting described previously. Figure 6 shows the workflow diagram of the BEPV. After the BEPV execution, the prototype continues to update the color of building components according to the simulation results.

VERIFYING

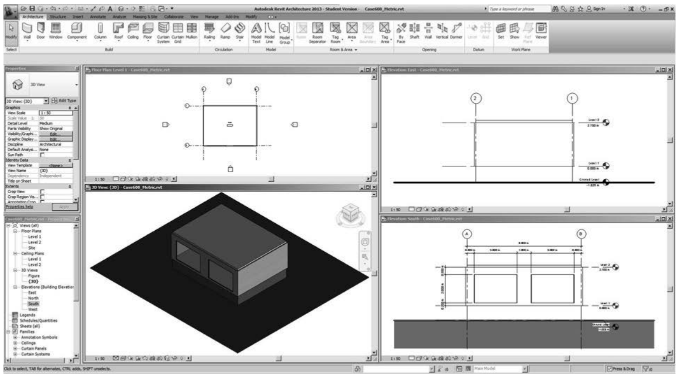
We conducted a case study to verify the operation of our prototype by creating a corresponding BIM model for BESTEST



6 Workflow of BEPV using Autodesk Revit and its API

Case 600 (Figure 7). The case study visualizes one of thermal simulation results (heat flow rate) in wall components. After creating the BIM model, we added the EPI parameter into project parameters (Figure 2 and Figure 3). As shown in Figure 2, all wall components are provided with BES results through the EPI parameter. Then, we executed the object-based BES tool to generate object-based thermal simulation results. The explanation of how to execute the BES tool from BIM was presented in our previous research (Yan, et al. 2013). The values from the graphs in Figure 5 are translated into a CSV file by an export function in Dymola.

After generating the external database for the information of the heat flow rate, we performed BEPV for a one-year thermal simulation. While the database provides 26283 different time snapshots for each wall, we only retrieved twelve of them for each wall for the visualization. The BEPV starts the visualization from the north wall, and continues it to the west wall, the south wall and the east wall sequentially. Table 1 shows the visualization of EPI values for one year: each column shows the conductive heat flow through the designated opaque wall with a range of colors in the visibility setting. On the west wall, dark red color means less conductive heat loss than light green color.



7 BESTEST Case 600 Revit model.

	North wall		West wall		South wall		East wall	
Simulation Day and Time (12:00AM)	BEPV	EPI values (Watts)	BEPV	EPI values (Watts)	BEPV	EPI values (Watts)	BEPV	EPI values (Watts)
1st day		-121.985		-89.1739		-27.4206		-90.982
25th day		-191.708		-137.254		-41.4957		-137.747
50th day		-233.326		-164.698		-50.05		-168.532
75th day		-183.664		-127.868		-38.6838		-127.864
100th day		-178.486		-133.836		-39.4182		-129.839
125th day		-99.7078		-74.075		-22.3002		-72.7548
150th day		-55.3042		-34.371		-9.83371		-39.9014
175th day		-29.4882		-20.8895		-4.01899		-15.3424
200th day		-32.6796		-17.2257		-4.52015		-19.5339
225th day		-31.8205		-17.1274		-4.51702		-19.57
250th day		-29.754		-15.9262		-4.19966		-21.5423
275th day		-171.188		-119.39		-36.0586		-123.102

Table 1 BEPV execution in BIM and EPI values

The values of heat flow rate are calculated by how many joules are measured per second (Watts) and they are stored as the EPI parameter in BIM. The heat flow rates at midnight are positive in the summer and negative in the winter as shown in Figure 5, where the positive values indicate that heat flows are from outside to inside of a wall and the negative values indicate the reversed heat flows from inside to outside. Since we visualized the values of the first hour, midnight, in each day, Table 1 shows all negative values.

Based on the visibility setting in which the range of each level includes thirty Watt interval and assigned a color, if the EPI value in a wall is in a certain level, the wall can be represented as a color representing that level at a certain time. When the time changes, the color may change according to the actual heat flow rate. For example, the north wall is represented by a dark orange color on the 175th, 200th, 225th, and 250th days because the values for the days are in the same level. In addition, Table 1 shows which wall is critical for heat flow in a specific date, for example, the north, west, south, and east walls are represented by green, dark red, black, and dark red color respectively on the 275th day.

CONCLUSIONS

Our approach demonstrates a new method to visualize building energy performance for BIM users. Future use of this method may benefit sustainable building design by illustrating building components' thermal performances within the BIM authorizing environment. In addition, the prototype shows the capability of BIM as a common user interface that enables architects to check BES results explicitly through visualized building components for building design. Moreover, our method allows architects to identify the building components that are critical for energy efficiency by investigating color-coded building components. Our prototype illustrates how architects could be better informed to improve their sustainable design at the early design stage where the impact of design decisions is significant on building energy performance.

FUTURE WORK

This research is part of an ongoing research project about the integration of BIM and BES (Yan et al. 2013). We expect to further investigate the integration of more object-based simulation results, e.g., infiltration, indoor air temperature, solar radiation into BIM. Furthermore, we plan to conduct a study about how designers can become informed by the visualization prototype.

ACKNOWLEDGEMENTS

We would like to thank Dr. Michael Wetter and the Simulation Research Group at LBNL for their great support of our project. This material is based upon work supported by the National Science Foundation under Grant No. 0967446. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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