Developing a physical BIM library for building thermal energy simulation

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ABSTRACT

Insufficient interoperability resulting from complex data exchange between architectural design and building energy simulation prevents the efficient use of energy performance analyses in the early design stage. This paper presents the development of a Modelica library for Building Information Modeling (BIM)-based building energy simulation (ModelicaBIM library) using an Object-Oriented Physical Modeling (OOPM) approach and Modelica, an equation-based OOPM language. By using the ModelicaBIM library, our project investigates system interfaces between BIM and energy simulation, which can perform semi-automatic translation from the building models in BIM to building energy modeling (BEM) using a BIM's authoring tool's Application Programming Interface (API). The ModelicaBIM library consists of OOPM-based BIM classes and OOPM-based BIM structure. OOPM-based BIM classes represent building component information. OOPM-based BIM structure consists of test case models that demonstrate (i) how building information in BIM can be transformed to OOPM and (ii) how design operations in BIM, such as changing a building geometry and editing building components, can be translated into BEM. A case study for simulation result comparisons has been conducted using (i) OOPM-based BIM models in the ModelicaBIM library and (ii) LBNL Modelica Buildings library (a Modelica-based building thermal simulation library developed by Lawrence Berkeley National Laboratory). Our implementation shows that the ModelicaBIM library enables (i) objects in BIM to be translated into the OOPM-based energy models and (ii) existing OOPM library to be utilized as a simulation solver for BIM-based energy simulation.

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1. Introduction

Since 1996, more than four hundred software tools for building energy simulation have been listed in the "Building Energy Software Tools Directory" provided by U.S. DOE (2013). Among the tools, a few are dominantly used in education and industry [1–5]. For example, DesignBuilder, DOE-2, eQuest, Ecotect, Energy-10, EnergyPlus, Green Building Studio, HEED, and IESVE are widely used in the United States [6]. In education, Ecotect, Energy-10, Radiance, CONTAM, and eQUEST are often used [3].

Recently, linking Building Information Modeling (BIM) and energy simulation either with standard data schemas such as the Industry Foundation Classes (IFC) or with common data formats such as Green Building XML (gbXML) is a developing area in research. Some tools were modified to utilize BIM and others were developed to be compatible with BIM authoring tools [5]. In this section we trace approaches and limitations of current BIM-based energy simulation.

1.1. Generating energy simulation models from BIM

Most energy simulation tools consist of the simulation engine and the graphical user interfaces (GUIs). The engines were often written in imperative computer language such as FORTRAN, C, and C++ [7]. The GUIs facilitate rapid input and output processing as well as simulation running when the semantics of input files, parameters of simulation settings, and the formats of output files are dependent on the simulation engines. In many cases, simulation engines and GUIs were developed separately. For instance, Hevacomp and DesignBuilder are independently developed GUIs of EnergyPlus.

Some existing simulation tools and their GUIs were modified for data exchange capabilities between BIM and energy simulation through standard data schemas such as IFC and gbXML, which contain building geometry information and other information of internal loads, occupancy, zone assignments, system configuration, and utilization schedules [4]. Currently, both schemas are supported by BIM tools including Revit, Bentley, and ArchiCAD, as well as energy simulation tools such as Green Building Studio, Ecotect, Hevacomp, eQUEST, HAP, and IES < VE > [8].

RIUSKA, a GUI of the DOE-2.1E engine, has an IFC import feature that can obtain building geometry information from BIM. eQUEST supports direct imports of DWG and gbXML with limitations: only two-dimensional building footprints can be obtained from DWG [9]; and some eQUEST features are not usable for the gbXML model [9].

Many applications and GUIs are developed for EnergyPlus such as Simergy, DesignBuilder, OpenStudio, CYPE-Building Services, Demand Response Quick Assessment Tool, Easy EnergyPlus, EFEN, AECOsim, Hevacomp, and SMART ENERGY [10]. OpenStudio is a collection of applications: a SketchUp plug-in as a building geometry editor; an OpenStudio

application as a main energy modeling interface; RunManager as a simulation interface; and the ResultsViewer [11]. OpenStudio can import gbXML in company with material, construction, surface, space, building, and schedule information from BIM. DesignBuilder can import three dimensional geometry information through gbXML and two dimensional building footprints through DXF. OpenGL solid modeler of DesignBuilder visualizes building façade design and solar studies [10]. Simergy, a GUI of EnergyPlus, supports editing building geometries and HVAC systems, generating EnergyPlus input (IDF) files, running EnergyPlus simulations, and reporting simulation results [12]. Building geometry information in CAD/BIM models can be imported into Simergy through IFC and gbXML or can be generated using the Simergy GUI. Simergy is developed based on Simulation Domain Model (SimModel) that is a XML-based data model [13]. Hevacomp, another GUI of EnergyPlus, can load building geometry and construction information through gbXML, DWG, and DXF, and then generate the EnergyPlus input files.

1.2. Integrating energy simulation tools with BIM authoring tools

Some simulation tools can be plugged into BIM authoring tools as add-ins such as IESVE and Green Building Studio, which allow energy simulation within the BIM environment. Green Building Studio is a web-based energy analysis environment based on DOE-2.2. Energy models are generated from Autodesk Revit models via certain manual preparation processes. Then, simulation is performed by a cloud service and the results are reported to users. IESVE has a Revit plug-in that can generate an energy model based on gbXML in Revit, but editing the exported energy model can be done in the IESVE interface.

Ecotect performs various analyses for solar, daylighting, acoustic, thermal, and airflow using multiple engines such as Radiance, DAYSIM, EnergyPlus, and Ecotect built-in engines. Ecotect can import gbXML, IFC, DXF, etc. from BIM [14]. In addition, Vasari [15], a parametric conceptual building design tool, can generate a Green Building Studio thermal model and perform solar studies, solar radiation analysis, and wind studies. In sum, these tools and their GUIs can read partial information of a building model from BIM through IFC or gbXML.

1.3. Limitations

While energy modeling using data schemas such as IFC and gbXML has been implemented for many simulation programs, reliable energy models can be acquired through manual model checks and modification [16]. Although energy simulation tools have been modified or developed to support the energy model generation process using BIM, the energy simulation analysis in design is still regarded as cost and labor intensive [17].

Generating an energy simulation model from BIM is time consuming, error-prone, and not intuitive [18]. Incongruent information stored in BIM and BEM requires a certain level of translation from BIM to BEM. First, all model information of BIM does not need to be translated into BEM. For instance, a room in an architectural model does not always indicate a zone in an energy simulation model. Second, some values required for energy modeling are not imbedded in BIM. For example, neither thermal zone information nor boundary conditions are stored in BIM. Often, model information in BIM is abstracted in BEM. A wall, a roof, and a floor in BIM are simplified as surfaces in energy simulation. When energy modeling is conducted for a building with complex geometry, manual model inspections become more complex [19]. Studies on BIM-based energy modeling describe that standards or guidelines are required to relieve the problems in building geometry translation from BIM to BEM [20,21]. On the other hand, incorporating simulation results into the design stage is not always obvious [17]. For designers, what the simulation results imply and how building design can correspond to such results are not clear. For instance, whole building level simulation results such as annual energy consumption and peak loads are often provided in a format of charts, spreadsheets, and plots. They do not indicate which and how building components need to be modified to achieve a specific energy performance.

Although the functionalities of the building energy simulation tools have been developed, further work is expected to improve the interoperability between BIM and the energy simulation tools [22]. For BIM-based energy simulation in early design, software tools need to have intuitive GUIs [2], seamless data exchange capabilities [19], reliable BIM compatibilities [5], and automated rule-based translation capabilities from BIM to BEM [18]. In addition, tools' good maintainability that allows modification and customization of calculation modules may improve the use of building energy simulation [23].

2. ModelicaBIM library, *Revit2Modelica* framework, and *PBIM* research

Our research investigates a new interface for BIM-based building energy simulation, integrating the architectural design and the energy simulation process. The objectives are: (i) enhancing the interoperability among BIM and BEM, (ii) enabling more reliable BEM generation from BIM, (iii) enhancing the integration and the coordination among multi-domain BEM, and (iv) enabling BIM as a common user interface for the multi-domain energy simulations. To do so, we investigated a BIM-based energy modeling and simulation framework, which integrates BIM and multi-domain energy simulations, and named it as *Physical BIM* or *PBIM* [24]. Building thermal, daylighting, and BIPV analyses are being implemented in the *PBIM* framework, and this paper describes our research on the BIM to thermal BEM in detail.

Revit2Modelica is a framework of BIM-based building thermal simulation (Fig. 1). *Revit2Modelica* consists of Revit Application Programming Interface (API) programs written in C# programming language and the Object-Oriented Physical Modeling (OOPM)-based library (ModelicaBIM library) written in Modelica. Revit API programs have functions that add data sets to BIM, access the BIM data structure, and produce Modelica models using the ModelicaBIM library and Lawrence Berkeley National Laboratory (LBNL) Modelica Buildings library. The ModelicaBIM library consists of a ModelicaBIM Class package and a ModelicaBIM Structure Example package. The ModelicaBIM Class package contains building element classes that use the classes in the LBNL Modelica Buildings library. The need of wrapping classes is driven by the different object semantics and structures between BIM and BEM. Detailed wrapping processes applied in the ModelicaBIM library development will be explained later.

A workflow of *Revit2Modelica* is illustrated in Fig. 2. *Revit2Modelica* translates BIM into OOPM in Modelica, semi-automatically generates BEM (Modelica models) from BIM (Revit models), immediately performs building thermal analyses, and reports simulation results.

- First, the prototype accesses models in BIM to read model information such as geometry, materials, and location information.
- Second, the prototype transforms the obtained information by following the model structure of the ModelicaBIM library.
- Third, by using the transformed model information, the prototype outputs a Modelica BEM and calls Dymola, an Integrated Development Environment (IDE) for Modelica, to run simulation.
- Fourth, the prototype reports simulation results in the BIM user interface. The prototype currently analyzes heat flow of each building component, free floating indoor temperatures, accumulated heating and cooling loads, as well as peak heating and cooling loads. Plots of the simulation results are generated and opened in the Revit user interface.

Three key milestones in the *Revit2Modelica* development are:

- developing an OOPM library (ModelicaBIM library) including OOPM-based classes and OOPM-based models to link BIM and existing OOPM simulation solvers,