



Interoperability from building design to building energy modeling

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ABSTRACT

Interoperability issues have been well acknowledged as an impediment to improve productivity in the Architecture, Engineering and Construction (AEC) industry. The current information exchange from building design to building energy modeling has numerous problems, including object parametric information deficiencies, geometric misrepresentations and re-input data confusion. These problems lead to major money, time and effort losses. This paper presents an automated solution through the design of a novel Extensible Style Sheet Language Transformation (XSLT), which includes a series of instructions to facilitate the information exchange between building design and energy modeling fields. The proposed solution has been implemented with Microsoft Visual C# Studio 2013. The effectiveness of the solution has been tested in three real case studies. The test results demonstrated that the proposed solution could rectify the overall geometric and material misrepresentations inherent to the current information exchange process.

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1. Introduction

The building sector annually consumes a significant amount of energy and accounts for a large segment of spending by households, businesses and industries. In 2010, for example, the energy consumption of residential, commercial and institutional buildings in Canada reached up to 28% of the total energy used by final consumers [1]. It means that around \$163 billion was spent on energy to heat and cool their homes, offices, etc., which was almost equivalent to about 11 percent of the gross domestic product [1]. Similarly, in the U.S., nearly 40% of energy consumption in 2013 was consumed in residential and commercial buildings, which was almost equivalent to be 40 quadrillion British thermal units (BTU) [2].

Such a large amount of spending in energy use has concerned building owners and operators about their building energy efficiencies. This is especially true, considering the fact that how much energy a building uses or wastes might have a serious impact on the overall profitability from building operations. Also, the efficient energy use in buildings could offer a pathway to generate other substantial positive impacts in terms of improving air quality, reducing fuel consumptions, lowering utility bills, reducing pollution and greenhouse gases, and moreover enhancing competitiveness. Therefore, it becomes common to perform

building energy modeling (BEM) at the building design stage, so that different design alternatives could be compared in terms of building energy efficiency. The comparison results will help building owners and designers make wise decisions about what kind of the design of the building envelope, windows, lighting, etc. should be selected and adopted.

The recent development in building information modeling (BIM) offers the ability to facilitate the BEM solutions at the building design stages. BIM makes it possible for the building design information from multiple disciplines, e.g. architecture, structural engineering, and mechanical engineering, to be covered within one model, which provides the potential to analyze building energy consumptions [3]. However, the lack of interoperability between existing BIM and BEM software applications (i.e. the correct exchange and interpretation of information between one another) is a major impediment [4]. These interoperability issues include but are not limited to re-input data confusion, insufficient information provided by one product to another, loads of geometric misrepresentation and loss of parametric information [5]. Therefore, the current building information exchange process for the integration of BIM and BEM is tedious, time-consuming and costly. A study by the National Institute of Standards and Technology (NIST) once identified the efficiency losses resulting from the interoperability issues such as those mentioned above could produce additional cost of \$15.8 billion [6].

In order to reduce the interoperability issues between BIM and BEM software applications, one possible solution is to use the software applications from the same software company. For example, Autodesk Inc. has the Revit software for three dimensional

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(3D) BIM and the Ecotect software for BEM [7]. However, the solution requires building team members to use specified software applications, which may increase their costs in staff training, hardware upgrade and software purchase. Instead of restricting the use of the software applications from the same company, another way is to promote open standard schemas for information exchange between the software applications from different companies. So far, the exchange using open stand schemas is still not fully supported among all software applications. It is common to have large numbers of geometric misrepresentations and loss of parametric information during the current information exchange process. For example, Lam et al. noted that a 3D Revit Model might have continuous single surfaces for the intermediate floors, but after the information exchange, the intermediate floors having exterior boundary conditions were totally missed in a BEM software tool, such as eQUEST [5].

This paper proposes a new idea to facilitate the information exchange of BIM and BEM software applications under the support of open standard schemas. The idea is built upon the design of a novel Extensible Style Sheet Language Transformation (XSLT), which includes a series of conversion instructions to facilitate the information exchange between the building design and energy modeling fields. Considering a large number of BIM and BEM software applications available in the market and they might support different open schemas, the proposed idea here is focused on the information exchange between the gbXML and DOE-2 schemas. The gbXML schema has become a defacto industry standard schema, which has been supported by several leading design software developers, such as Autodesk, Graphisoft, and Bentley [8]. On the other hand, the DOE-2 schema is supported by the eQUEST, which is one of the most widely used graphical building energy analysis tools in the world [9].

The proposed idea has been implemented with Microsoft Visual C# Studio 2013 and integrated into the Autodesk Revit modeling environment as a plug-in. Its effectiveness has been tested in three real case studies. The test results demonstrated that the proposed XSLT based solution could rectify the overall geometric and material misrepresentations inherent to the current building information exchange process. Therefore, it could significantly facilitate the transfer of building information from the building information models to building energy analysis models.

2. Background

2.1. Interoperability Issues between BIM and BEM

According to ISO/IEC 2382-1 (Information Technology-Vocabulary-Part 1: Fundamental Terms), interoperability was defined as “the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units” [10]. From a purely technology-based view, interoperability in the Architecture, Engineering and Construction (AEC) industry indicated “the ability to manage and communicate electronic product and project data among collaborating firms” [4]. Following these definitions, interoperability here means that the information stored in the building design models could be seamlessly transferred into existing building energy simulation tools, so that the performance of building energy consumption could be simulated and analyzed without the need of spending manual efforts on correcting potential errors that occur in the information exchange process.

Currently, a typical building information conversion from a building information model to an energy analysis model presents several interoperability issues, including the loss of object

parametric information, geometric misrepresentation, and re-input data confusion. These interoperability issues have been well identified in the AEC industry. It was once estimated that the interoperability issues almost accounted for 3.1% of a typical project budget, and manually re-entering data from one application to another was one major reason as staff duplicated work already completed by other project partners [4]. Gallaher et al. indicated that the cost of inadequate interoperability in the U.S. capital facilities industry could reach \$15.8 billion a year [6]. Therefore, most engineers and contractors ranked improving interoperability between software applications as highly important [4].

Also, the lack of interoperability, especially the lack of interoperability between BIM and BEM software applications, has been noted in several research studies. For example, Lam et al. once conducted a detailed identification and analysis on the interoperability gaps between BIM and BEM software applications [5]. In their study, the interoperability issues between these applications are tabulated and analyzed in terms of the distortion of building model information and the loss of geometric precision. Moon et al. also performed a case study to investigate the interoperability issues between existing BIM and BEM software applications using a two-story office model, and the results showed that each BEM software tool had its interoperability issues at different levels [11]. Moreover, the interoperability issues are not only limited to the use of different software applications. They are even produced within the same software application, when the new software versions are released. Therefore, Kumar concluded that building information must be ideally and effortlessly exchanged between existing BIM and BEM applications in order to have a successful building energy analysis process [12].

2.2. Existing solutions for interoperability issues

A number of modeling software applications are available today, which aid in the current practices for building design and energy analysis. These applications vary significantly in their levels of detail and complexity. In those applications, there are two main types of solutions to address the interoperability issues between the BIM and BEM. One is to use the BIM and BEM software applications from the same companies following their proprietary data formats. The other is to support the information exchange using open standard schemas, if the BIM and BEM applications have no proprietary integration capabilities.

2.2.1. Information exchange using the produces from same software companies

In the building design community, several commercial BIM companies provide a set of products for performing building energy analysis and addressing the interoperability issues between BIM and BEM. One example is Autodesk Inc. Autodesk Inc. acquired the Ecotect from its original creator, Square One Research, in 2008 [13]. The Ecotect offers an excellent and easy to use graphical interface that allows designers to simulate building performance in the early building design stages [3]. As an alternative solution to current interoperability issues in the building energy analysis process, the Ecotect is able to offer great import and export solutions to the software products from Autodesk Inc. [14].

In addition to the Ecotect, Autodesk Inc. also provides the Green Building Studio. The Green Building Studio is a web-based energy analysis tool [15]. It allows designers to upload their own gbXML (Green Building Extensible Markup Language) files for free energy simulation analyses. A quick, graphical feedback for the analysis results could be generated based on a survey of similar buildings and loads.

Another example is Bentley Systems Inc. Bentley provides the AECOsim Energy Simulator and Hevacomp, both of which were

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