Automation in Construction xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Development of openBIM-based energy analysis software to improve the interoperability of energy performance assessment

Jungsik Choi [a], Jihye Shin [b], Minchan Kim [c], Inhan Kim [d,*]

[a] College of Engineering, Kyung Hee University, Republic of Korea
[b] Department of Architecture, Kyung Hee University, Republic of Korea
[c] U Midsystem Co., Ltd, Republic of Korea
[d] Department of Architecture, Kyung Hee University, Republic of Korea

ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form 29 June 2016
Accepted 10 July 2016
Available online xxxx

Keywords:
Building information modeling (BIM)
Data interoperability
Energy performance assessment (EPA)
Energy property information
Industry Foundation Classes (IFC)
IFC-IDF converting system

ABSTRACT

Energy performance assessments (EPAs) are widely conducted on buildings, which consume considerable energy and emit a significant amount of greenhouse gases. However, manual-based traditional EPA methods can cause serious problems, such as recurrent and error-prone data replication, data leaks, and redundant data processing and storage. Building information modeling (BIM), as an integrated repository of information about a particular building, has been applied to EPAs to overcome those problems. Although BIM has the potential to increase work efficiency in the assessment process, low interoperability between BIM data and energy simulation models raises huge barriers to reliable BIM-based EPAs.

This research aims to improve the interoperability of BIM-based EPAs by developing an environment that contains a process, a materials library, and an EPA support system that connects BIM and energy modeling. To validate the suggested environment, we conducted a case study, and the results show that the proposed environment greatly contributes to increased accuracy and efficiency in the EPA with high interoperability.

1. Introduction

The construction sector accounts for 23% of overall energy consumption and 40% of global CO2 emissions [1]. Achieving sustainable development at the national level will require minimizing the effects of buildings on the environment with the low energy consumed by buildings. Buildings provide social and economic benefits, but it also affects the environment because buildings consume enormous amounts of energy over their lifecycles [2]. Therefore, it is essential to analyze buildings' energy performance in the design phase, which is when the most critical decisions are made. The energy performance of a given building is predicted and assessed by conducting an energy simulation. However, the conventional energy performance assessment (EPA) method, in which designers manually create an energy simulation model, faces serious problems, such as error-prone data replication [3], data leaks, and redundant data processing and storage [4].

Building information modeling (BIM) is a technology for improving productivity and efficiency in the construction industry by taking advantage of the information generated throughout the life of a facility using a consistent system [5]. BIM provides the capacity to generate and manage all the information about a building during its lifecycle [34], and it has been applied in EPAs to address their problems [6]. Using BIM in EPAs greatly reduces time and costs because the BIM data already contain more than 70% of the information needed for a building energy analysis [7]. However, there is a huge barriers in BIM-based EPAs including: (i) imperfect simplification of BIM data to make them compatible with the energy simulation input file format (energy model) [8,9]; (ii) insufficient construction information in BIM objects [4,10]; (iii) low-reliability data exchange [11,12]. Such low interoperability between BIM and the usual energy models and the rework required to correct errors and omissions are the main elements inhibiting wide usage of BIM-based EPAs [13,14]. To conduct a reliable and efficient EPA by applying BIM, it is necessary to improve the interoperability between BIM and the energy simulation input file format.

To open a path to an effective design for optimized sustainable construction, EPA method that directly uses BIM data with high interoperability is proposed in this research. A BIM-based environment for EPA is suggested by establishing a BIM-based EPA process and developing a materials library and EPA support system to efficiently conduct the process. The interoperability of a detailed and specific HVAC system is beyond the scope of this research. EnergyPlus, as a DOE-2-based highly accurate energy simulation engine [14] recommended in many BIM guidelines (including in the US, Finland, and Korea), is focused as an EPA tools. This research was conducted in four steps. First, we derived the requirements for improving the interoperability of BIM-based

* Corresponding author.
E-mail address: ihkim@khu.ac.kr (I. Kim).

http://dx.doi.org/10.1016/j.autcon.2016.07.004
0926-5805/

EPAs by analyzing the processes of both conventional and BIM-based EPAs. Second, we established a BIM-based EPA process based on those requirements. Third, we developed a materials library based on the ASHRAE handbook[1] and the openBIM[2]-based energy analysis software as a support system for EPA based on the EnergyPlus simulation and Industry Foundation Classes (IFC) data format. Fourth, we conducted a case study to validate the feasibility of the suggested BIM-based EPA environment in aspects of improvement of interoperability.

2. EPA in the BIM environment

2.1. EPA overview

An EPA is a process in which multiple disciplines and design elements work iteratively and in partnership to allow for synergies. EPAs are typically performed after the architectural design and design document have been produced [15,16]. They are usually conducted by EPA experts after the architecture, mechanical, and electrical designs have progressed sufficiently [1,17]. An EPA generally predicts the energy performance of a given building using energy simulation tools with certain criteria based on thermodynamic principles and assumptions [18]. The accuracy of an EPA depends on the accuracy of the input data for the building. If the input data do not sufficiently represent a real building, the EPA results could be arbitrary and inaccurate. The main barrier to wide usage of EPA methods based on dynamic thermal analysis has been the large amount of manual input work required [4]. In a traditional EPA process, the energy modeler manually creates an energy model using drawings, specifications, and photos [17]. This method, which largely depends on the modeler's proficiency and capability, engenders the problems categorized into low efficiency, dependence on expertise, intervention of subjectivity, arbitrary information, limitation of data integration, and transformation of information. The detailed problems of each category are represented in Table 1. The process carries a high probability of data loss, inconsistency, and inaccuracy when simplifying the available building design information for an energy model and includes numerous opportunities for error and unreliable analysis. It is derived that all of these problems together associate traditional EPAs with time and expense, productivity losses, poor stakeholder communication, and actual defects in the building.

2.2. BIM-based EPA

BIM represents a building as an integrated database of coordinated information [22]. In BIM, the geometry, attributes, and topology of a building, including its design and mechanical systems, are defined as a composed set of objects and their relations [22,23]. Using BIM allows the building geometry, construction information, and other parameters for EPA to be consistent across users, which can improve process efficiency by creating an energy model manually, automatically, or semi-automatically [8,16]. In this research, we define BIM-based EPA as an EPA method that uses BIM to create the simulation input model, as shown in Fig. 1. The process usually involves four steps [4,18,24]:

1. Simplification: Simplify the original building geometry, internal load, and equipment system in the BIM data because it is too rich to use in energy simulations.
2. Extraction: Extract the data for the energy simulation from BIM data using data transformation software.

Table 1
The problems of conventional energy performance assessment.

Category	Problems
Low efficiency	– The EPA process consists of manual or semi-manual work, which makes it laborious and expensive in terms of both time and resources [8]. – There are numerous opportunities for human error [20].
Dependence on expertise	– Generalists are not familiar with every parameter necessary to run an expert simulation [1]. – Available simulation tools are intended for expert use and explicitly require expert knowledge to input the data, run the simulations, and interpret the results [17].
Intervention of subjectivity	– Consistently creating an accurate energy model is difficult because the model must be simplified to accommodate the modeler's understanding of the subject building, knowledge and skill in modeling, experience, and resources. [16].
Arbitrary information	– Preparation for inputting data involves manual or semi-manual transcription and recoding of existing information, which can result in numerous errors [17]. – Simplification of geometry is, in most cases, arbitrary because of different definitions of thermal views, simplifications, and assumptions [18].
Limited data integration	– In the traditional process (EPA is conducted after design), the necessary data for analysis are insufficiently supported by the designer [1]. – The lack of a consistent EPA process leads to redundant data processing and storage and lack of integration of multidisciplinary data [4].
Transformation of information	– All sorts of data that might be needed are transformed from the original form to fit the data form accepted by the simulation engine [17]. – Error-prone data replication or conversion occurs [21]. – Inconsistencies that occur in data exchange between the different applications are time consuming to find and correct [14].

3. Input file creation: Wrap the transformed data into the input format required by the simulation engine. At this point, input the rest of the data, such as weather data, operating systems, and other parameters.
4. Simulation: Run the energy simulation.

In a BIM-based EPA, opportunities for subjective interpretation and improper simplification are less likely to occur because the data needed for the simulation are directly imported from BIM. Furthermore, using BIM makes continuous energy performance management and tracking through the whole building lifecycle possible. Therefore, it is important to determine how to make an energy model from BIM because it will reduce the costs and time required obtaining a reliable result.

2.3. Limitations of current BIM-based EPA tools

To apply BIM in EPAs, developers have created several support systems to automatically generate an energy model from BIM data, run the energy simulation, and visualize the results. GST, GB-IFC2IDF, and Simergy are the most prevalent BIM-based EPA support systems based on EnergyPlus, and they all work with IFC and gbXML. In this paper, we reviewed and analyzed BIM-based EPAs with all three systems to determine their limitations. The results of our analysis are summarized in Table 2.

Although all the systems reduce the amount of manually input simulation data, they could not perfectly generate energy models. In most systems, data loss and errors from IFC occurred when the data were transformed into the energy model, which could result from incomplete or incorrect IFC or gbXML files. Data models such as IFC and XML are imperfect and do not always provide reliable geometry data and construction information [16]. Furthermore, different ways of defining the same information in BIM authoring tools inevitably leads to data loss and errors, even if the converting schema between IFC and Input data format

[1] The ASHRAE Handbook is a publication of the nonprofit technical organization ASHRAE (formerly the American Society of Heating, Refrigerating and Air-Conditioning Engineers). It provides a practical repository of knowledge on various topics related to heating, ventilation, air-conditioning, and refrigeration (HVAC&R).

[2] openBIM is a universal approach to the collaborative design, realization, and operation of buildings based on open standards and workflows. openBIM means IFC standards as ISO 16739 [19].

Please cite this article as: J. Choi, et al., Development of openBIM-based energy analysis software to improve the interoperability of energy performance assessment, Automation in Construction (2016), http://dx.doi.org/10.1016/j.autcon.2016.07.004