A Test Bed for Verifying and Comparing BIM-based Energy Analysis Tools

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ABSTRACT

With the development of Building Information Modeling (BIM) technology, there has been an increased application of BIM-based modeling and energy analysis tools in building design. Although there are several popular energy analysis tools available, there is currently no effective way for users to verify the accuracy and reliability of their results and to compare the differences between different analysis tools. Therefore, the Computer-Aided Engineering Group at Department of Civil Engineering, National Taiwan University is developing a test bed for researchers and practitioners to share verification data, with both the BIM model of a test-case building and the actual measurement data of the energy performance of the building, which can be used for verification and comparison of various building energy analysis tools. This paper discusses the design and implementation of the test bed. The test bed consists of three major parts: (1) the repository of the BIM model of the test-case building with measured energy data; (2) user interfaces for users to upload and retrieve test-case information and model data in an organized and convenient way; and (3) utilities for users to convert data between different formats used by different energy analysis tools and to evaluate the energy analysis tools based on comparisons of analysis results with actual measurement data.

INTRODUCTION

The building industry is one of the most carbon emission–intensive industries. The emissions of carbon from the life cycles of buildings account for 40% of global carbon emissions (Schlueter and Thesseling 2009). Because of the huge impact on environmental transition, governments have begun to take energy reduction seriously. UK first released regulations related to green building, and other countries have launched similar regulations (Building Research Establishment 2013). With climate change receiving growing attention from the public, more researchers have committed themselves to different kinds of energy analysis, such as computational fluid dynamics, HVAC simulation, daylight analysis, *etc*. There have been many research efforts that take energy reduction into account during the design stage. Zeng (2012) recommended that the early design stage is the best time to work on energy analysis. Because designers have the most flexibility to change the building design in the conceptual design stage, results of energy analysis can be used to determine the best energy-saving design. In contrast, in the detailed design stage, energy experts must spend a great deal of effort to modify and simplify the model to meet the needs of energy analysis tools with less flexibility to change the whole design. Jahnkassim *et al*. (2013) presented a good example to demonstrate that integrated simulation and visualization in the design stage can greatly benefit energy efficiency. In this example, visitors could feel cool without the use of air-conditioning in an indoor public space. Due to the success of energy reduction, increasingly many researchers are engaging in the field of building energy simulation and more research is implemented to improve simulation software.

Nowadays, building information modeling (BIM) based building design can improve the effectiveness and efficiency of energy analyses of a building. BIM (Eastman *et al.* 2011) is a revolutionary technology for the construction industry and can be used to improve the performance and quality of construction. With the development of BIM technology, there are numerous BIM modeling software and analysis tools for use in building design. Kuo *et al.* (2011) used the Autodesk BIM software series to validate the electricity production efficiency of a building with building-integrated photovoltaic (BIPV). The authors compared the actual measurement data of a BIPV building with the analysis results and used the results as feedback for the following designs. Kim and Anderson (2013) developed a method to convert BIM models into energy analysis software, i.e. EnergyPlus and Green Building Studio, and compared their results. The procedures for generating and managing digital BIM model information for better design, construction, operation, and maintenance are the important issues of BIM. Hsieh *et al.* (2013) proposed that BIM can be enhanced by user experiences to deal with complicated decision making and to facilitate feedback of user experiences to the design and construction.

Although there are increasing numbers of research efforts devoted to improving energy analysis tools and implementing them into the design stage, there is no effective way for researchers to acquire the data and results from previous research and cases for assessment of different analysis algorithms and tools. Researchers who wish to improve the accuracy of energy analysis tools require models with actual measurement data in order to enhance the algorithms of the energy analysis tools. Gupta *et al.* (2014) developed a BIM-based conceptual framework for photovoltaic simulation. In this study, the results of a developed simulation tool were compared with measurement data and results of three other simulation tools for a whole year's worth of data. It showed that researchers who wish to promote the benefits of implementing energy analysis during the design stage require models with actual measurement data and results of analysis. By comparing the differences between the measurement data and the analysis results, researchers can study the reasons behind to improve the efficiency and accuracy of energy analysis during the design stage. The researchers of this paper conducted in-depth interview with some industry experts in Taiwan to confirm the demand of measurement data for comparing with analysis outputs. The interviewees said that they would really like to use the test bed, and energy experts wish to know if the energy analysis would be accurate. Via the verification process, an energy expert can check the configuration of parameters and improve the analysis procedure.

For the above reasons, this paper aims to develop a test bed for researchers to share models, data, and analysis results. The test bed adopts BIM technology for dealing with the integration of models and data. In a report from the Architecture and Building Research Institute of the Ministry of the Interior in Taiwan (Chen 2013), analysis of sunlight and energy savings of the building envelope are regarded two of the most important tasks in the design stage. Therefore, this study decides to focus on analysis of sunlight analysis and energy savings in the building envelope for developing a prototype test bed. The researchers can obtain required information from the test bed in a convenient way to support further research.

APPLICATION SCENARIO

The main purpose of this paper is to provide a convenient way for researchers to share models, measurement data, and, in particular, results from previous studies. Researchers can obtain necessary information to verify results found with actual measurement data and results from other researchers in order to improve energy analysis. In the beginning, this test bed will first focus on analysis of sunlight and energy savings from the building envelope, as these two analyses are frequently conducted in the design stage. During the design stage, researchers do not need to perform much modification to their models. The test bed will have other functions to help attract more researchers to use it.

The application workflow is shown in Figure 1. All users of the test bed are information providers of two kinds. One is test case provider and the other one is analysis results provider. Initially, there will be a test case provider to supply one research case with data needed for case study, such as models, climate data and measurement data for energy analysis. The test case provider can also provide existing analysis results for the case. Then, after downloading the data of a case and analyzing the case by their own algorithm or analysis tools, the analysis results provider publishes and shares their results on the test bed for others to conduct verification and comparison study in the future.

The following strategies may be used to operate test bed. First, the users must upload their analysis results to get the authority for accessing existing analysis results on the same test model in the test bed. This regulation is to prevent the users from using more than their fair share of the resources of the test bed. Second, the analysis results will be sorted by their accuracy when compared to the measured data. The more accurate the results are, the higher rank and visibility the algorithm or tool will become. Third, the cases most discussed on the test bed will become benchmarks in the long run. Every result created by the future algorithm has to be tested against the benchmark and reach a certain level of accuracy in order to be recognized as a feasible algorithm.

DESIGN OF THE TEST BED

The development of BIM is not only in the creation of more tools but also in gradually developing BIM services into cloud computing. Some research efforts have analyzed the benefits of combining BIM with cloud technology. Amor and Dimyadi (2010) created a website that lets users share BIM models via IFC files. Chen *et al.* (2013) created a web-based BIM system to provide shared storage and visualization of BIM models though cloud technology. Following on from previous studies, which demonstrated the many advantages of combining BIM with cloud technology, this paper aims to create a web-based platform to accomplish the goal of sharing models and data via a repository in a cloud computing environment.

Figure 2 shows the data flow diagram for the test bed. In the data flow diagram, the first stage is data input. The most important part of this stage is the formats of the BIM authoring tools. With the development of BIM technology, there are numerous types of BIM modeling software and energy analysis tools to be deployed in building design. The issue of transferring data between BIM modeling software and analysis tools is an important one. The IFC file format is commonly used to fulfill the demand for interoperability in BIM. There are two advantages of IFC. First, the IFC file format is an open standard. Even though every BIM software has its own file formats, almost every one allows users to export BIM models in the IFC format. Second, IFC files describe the geometry of and information about every component in the BIM model. For the purposes of interoperability, the test bed accepts IFC files exported from BIM authoring tools.

The second stage is the data process. This is the most advanced component of the test bed and involves two procedures. One is to extract essential data from the IFC and convert them into energy analysis files. The other one is to extract essential data for the model to be viewed online. The main purpose of creating these two procedures is to incorporate convenient functions to attract more users. First, many people model using BIM authoring tools, but few models using energy analysis software. For the test bed to be convenient to users, it should allow them to convert files if they only have BIM models instead of energy analysis models. Second, it would be convenient and useful for BIM models to be visualized in web-based viewers. Therefore, it is desirable that this test bed provides a web-based IFC viewer that will allow users to view the models in advance and examine whether the model is suitable for their needs or not. Also, this stage requires a stable IFC parser to rapidly extract the essential geometry and material information in IFC files, convert it to different file formats, and extract the essential information for online visualization.

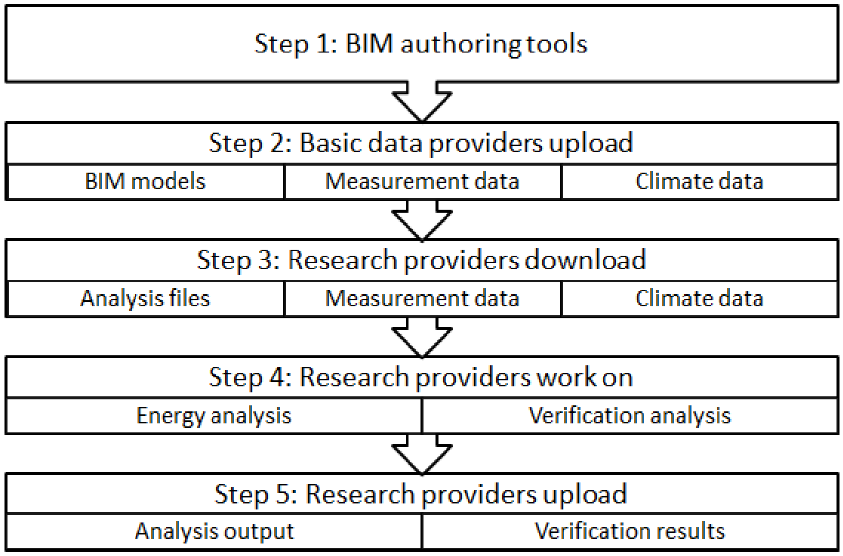

Figure 1. The application flow of the test bed.

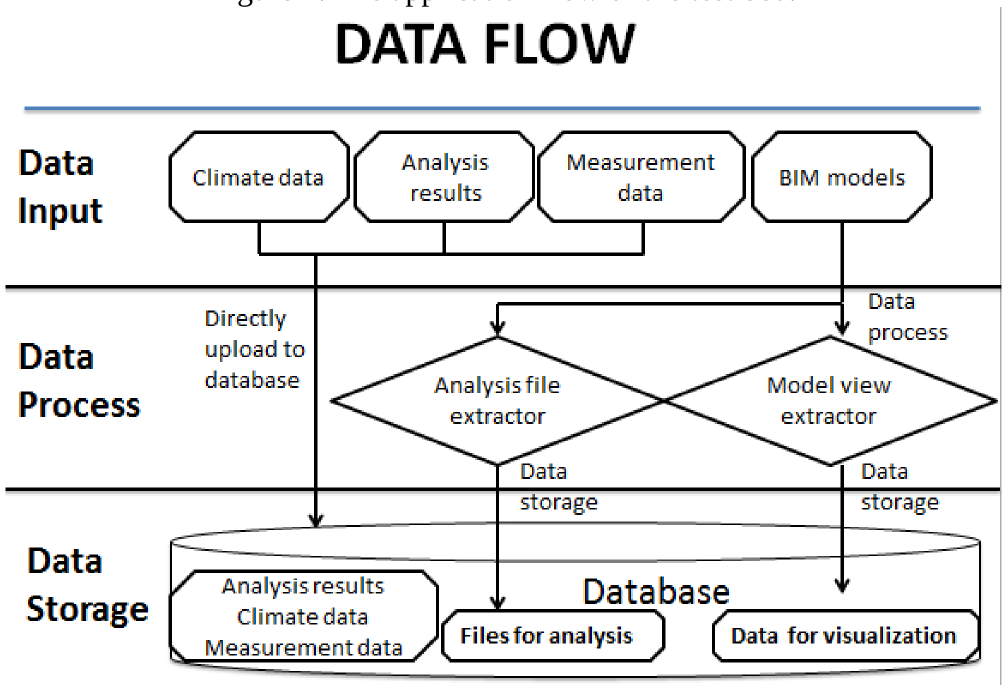

Figure 2. The data flow diagram of the test bed.

The third stage is data storage. The aim of this stage is to maintain the stability and efficiency of the test bed. Therefore, this research uses a NoSQL database to implement the repository of models and data because the NoSQL database has the advantage of being faster in data access than a standard SQL database. The test bed needs to address the storage issue, in that the IFC file is too big for online visualization. This may be solved by adopting some open-source web-based IFC viewers that convert the IFC files into smaller files in another format to accelerate the speed of online visualization.

To fulfill the aims of the test bed, four major modules are designed: an upload module, a download module, a conversion module, and a visualization module. The next section will outline these four modules.

IMPLEMENTATION OF THE TEST BED

The most difficult task in developing the test bed is to integrate all the modules together. Each of the modules is developed with the best tools available. However, it is not an easy task to integrate them together.

Several programming tools considered for implementing the four modules are introduced here. The better choices for the upload and download modules are using PHP or Node.js, which are rich in resources on the Internet. For the conversion module, the best choice is using an application programming interface (API) and several open–source APIs for extracting essential information from an IFC file have been released on the Internet. There are many APIs for IFC parsers that have been created based on C++ or Java. Finally, for the visualization module, a WebGL such as BIMsurfer (2011) is a good choice for implementing online visualization.

The programming tools that this test bed adopts are discussed further below. According to the above discussions, the API of the IFCTOOLPROJECT (IFCTOOLPROJECT 2013) was selected as an IFC parser to extract essential information for creating the conversion module. The API of IFCTOOLPROJECT is based on the Java programming language. Java is a useful language for dealing with cross-platform computing, and can also be used to create a website, hence it was chosen as the development tool. Thus far, the IFCTOOLPROJECT API has successfully extracted the geometry of the walls and slabs of a building in the test examples conducted.

Next are the upload and download modules; these are the core modules of the test bed. These two modules allow researchers to upload models, measurement data, and analysis results. Researchers can also download information necessary for conducting further research. Because this research has already decided to use Java to develop the test bed, the Playframework (2007) API is chosen for creating the upload and download modules, as it is also based on Java. In addition, Playframework provides several packages for interfacing with different kinds of database. It also provides a convenient means of creating the core component of the website.

The last module to be developed is the visualization module. This research will create this module by using WebGL because of two reasons: (1) there are a plenty of resources of WebGL in the Internet; (2) some plugins may not be required for users of this test bed.

CONCLUSION

In this research, a test bed is proposed for sharing sets of models, measurement data, and analysis results from previous building energy related studies. Although the development of the test bed is still ongoing, the needs and benefits of such a test bed in advancing the research and application of building energy simulations should be clear. The design and the implementation issues of the proposed test bed have been discussed in this paper. The platform will be tested by several researchers from different fields. It is hoped that researchers in sustainable building design and building energy analysis will support the effort and share their information on the test bed.

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