ISBN: 978-85-67169-04-0

SIBRAGEC ELAGEC 2015

São Carlos / SP - Brasil - 7 a 9 de outubro

INTEROPERABILITY OF BUILDING ENERGY MODELING (BEM) WITH BUILDING INFORMATION MODELING (BIM)

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ABSTRACT

Several authors have recognized the importance of an interoperability of Building Energy Modelling (BEM) software with Building Information Modeling (BIM) since the 90s. The present study evaluates the current state of the interoperability of BEM with detailed designs of building projects in BIM. The authors performed an experimental assessment, based on tests with software related to the design of an office building in Colombia. The assessment is divided in two steps, a preparatory and a final experiment, and evaluates the results for the transfer of the building geometry from BIM to BEM. It can be concluded that BEM software is not interoperable with BIM currently, the opposite of what many companies and authors ensure. The geometry transfer is inaccurate, which is the most elemental input parameter for BEM. This lack of interoperability between BEM and BIM causes the projects, aiming to be sustainable and with good energy performance, to have difficulties on being delivered in an integrated way (through IPD) by the main stakeholders.

Keywords: *Building Energy Modeling, BEM, BIM, Interoperability, data models for construction products.*

RESÚMEN

Varios autores han reconocido la importancia de la interoperabilidad entre los software de Modelación Energética de Edificaciones (BEM) y de Modelado de Información de Construcción (BIM) desde los años 90. El presente estudio evalúa el estado actual de la interoperabilidad del software BIM con el diseño detallado de los proyectos de construcción en BIM. El artículo presenta un análisis experimental a partir de pruebas realizadas a paquetes de software relacionados con el diseño de un edificio de oficinas en Colombia. Este análisis está dividido en dos etapas, un experimento preparatorio y uno final, y evalúa la transferencia de la geometría de la edificación de BIM a BEM. Se puede concluir que BEM y BIM no son interoperables entre sí actualmente, a diferencia de lo que varias compañías y autores anuncian. La transferencia de la geometría, que es el parámetro de entrada más elemental de BEM, es aún imprecisa. Esta falta interoperabilidad entre BIM y BEM ocasiona que los proyectos que buscan ser sostenibles, eficientes y con un buen comportamiento energético tengan dificultad para ser desarrollados y entregados de forma integrada (a través de IPD) por los distintos actores del proyecto.

Palabras-clave: Modelación energética de edificaciones, BEM, BIM, Interoperabilidad, Modelos de datos para los productos de construcción.

1 INTRODUCTION

Building Information Modeling (BIM) has been developed as a technologic tool that allows the exchange of information among the stakeholders involved in a project, following the Integrated Project Delivery (IPD) approach. One of the problematic aspects of BIM has always been the interoperability among the diverse software specialized in the different aspects of a design. That is the reason why open data models were created to be used as standards for BIM software, as the International Alliance for Interoperability (IAI, today buildingSMART) in 1995, as (BAZJANAC; CRAWLEY, 1999).

Building Energy Modeling (BEM) software has been used for the design of sustainable and efficient buildings. Since the 90´s, Crawley, et al. (1997) stated that the priority of BEM users was its interoperability with common software for buildings analyses, CAD at the time. Hitchcock; Wong (2011) concluded that "the interoperability between BIM and BEM was a goal yet hard to achieve". Several authors have started to develop new data models to be used by BEM software, although this practice goes against the standardization aimed with the IAI creation.

To assess the current state of the interoperability between BIM and BEM software in the detailed design phase of construction projects, an experimental analysis is performed through the use of different software packages. The analysis is divided into two stages, a preparatory experiment, using the BIM model of an elementary building, and a final one, using a more robust and complex BIM model of an office building in Colombia. The transfer of the building geometry is evaluated then.

2 LITERATURE REVIEW

2.1 Building Energy Modeling (BEM)

BEM software estimates energy consumption of buildings based on simulations of energy and mass flows (CRAWLEY, et al., 2001), contributing to decision making in early stages of a project. These simulations take into account equations, thermodynamic principles, and complex assumptions. They are based on elemental input parameters like the building geometry and complex input parameters like the information related to HVAC (Heating, Ventilation, and Air Conditioning) systems and components, weather, operation conditions, among others (BAZJANAC; CRAWLEY, 1999).

Major BEM software packages can be divided into two groups, those using the calculation engine developed by the US Department of Energy (DOE) and those using their own calculation engine. Examples of software in the first group are: eQUEST®, DesignBuilder®, EnergyPlus®, and Autodesk® Green Building Studio® (GBS). IES Virtual Environment (IESVE) and Trace 700 are examples of the second group.

BEM software is subject to approval by certification systems for sustainable buildings as LEED, BREAM, etc., they are the main market for BEM products (WINKELMANN, et al., 1993) and, given that, hold a great influence on them.

2.2 Building Information Modeling (BIM)

Eastman, et al. (2008) defined BIM as the parametric modeling technique and processes associated to produce, communicate, and analyse digital construction models. Given that BIM focuses in handling information related to the entire lifecycle of a construction project, interoperability is very useful for a collaborative and integrated work among all stakeholders through an Integrated Project Delivery (IPD) approach. Bazjanac (2001) remarked the importance for BIM software to be interoperable, which means to be able to share information in a perfect way.

2.3 Data models for construction products

To ensure interoperability among different software, the IAI (now called buildingSMART) developed a neutral object-oriented data model called Industry Foundation Classes -IFC- that facilitates the exchange of information among compatible software (BAZJANAC; CRAWLEY, D. B., 1999). Some authors have found various limitations on the IFC model. Dong, et al. (2007) recognized that buildingSMART has focused its efforts on architectural representation of a building but other domains, such as energy modeling BEM, are still to be developed. Therefore, the Green Building XML (gbXML) data model is the most widely used by BEM simulation tools, as it allows to include information about isolation, thermic areas, and mechanical equipment. This data model presents many problems though. Hijazi (2015) developed a Data Transparency Tool (DTT) to allow the user to verify the data in the gbXML files and then correct their inaccuracies.

2.4 Data models for construction products

Crawley, et al. (1997) showed that the priority of BEM users was its interoperability with building modeling tools, such as CAD at the time. Bazjanac; Crawley (1999) proposed that the solution to this need was to make BEM software compatible with the IFC model. They conducted an experiment consisting in the design of a small building using various IFC compatible software and the results comparison. At that time, there was not an interactive interface available to analyse a building geometry on IFC.

Maile, et al. (2007) tested the interoperability of different BEM software packages: Equest, DesignBuilder and EnergyPlus, and found that there are significant differences between the BIM model (architectural model of a building) and the analytical model (model required for an energy simulation). The tested software had problems importing the building geometry like omission of slabs, windows, walls, and surfaces generating shadows. Hitchcock; Wong (2011) found that interoperability between BIM and BEM was an elusive goal and that it was imperative to work on a stricter standardization data model for construction products. Kim, et al. (2015) developed a new interface for semi-automatic translation from BIM to BEM models called ModelicaBIM library. But, this does not use objects, unlike IFC. Likewise, Cemesova, et al. (2015) created an IFC extension with an energy domain to export data to the Passive House Planning Package (PHPP), a system commonly used in Europe but not in America.

3 METHODOLOGY

In order to study the interoperability between BIM and BEM at the detailed design stage, an experimental analysis is conducted with BIM and BEM software packages associated to the design of a construction project. This analysis is divided into two stages: a preparatory experiment and a final experiment.

3.1 Preparatory experiment

This first experiment immediately identifies the main problems of interoperability between BIM and BEM, using a BIM model of an elementary building. This experiment is conducted in four iterative steps until satisfactory results are obtained: (1) Select the BIM and BEM software packages as well as the data models to use; (2) Import the BIM elementary model to the BEM software, using the corresponding data model; (3) Identify limitations and document the resultant geometry obtained. (4) Finally, if results are not reliable (information required to perform energy modeling, such as geometry, has not good quality), changes must be made to the original BIM model and return to step 2. If the results are reliable, continue to the final experiment.

3.2 Final experiment

This experiment consists of the identification of main interoperability problems using a real, more robust and complex, BIM model. This final experiment must be performed after the preparatory experiment is finished. The methodology followed is the same as the one used for the preparatory experiment, but with two fundamental differences. The first one is that, if results are not reliable in the first iteration, the changes documented during the preparatory experiments must be implemented in the new BIM model. The second is that, since changes take longer in a more complex building model, it is suggested to make several changes to the model in each iteration. As in the preparatory experiment, this process ends after some iterations (from step 2 to 4).

4 CASE STUDY

As the elemental model for the preparatory experiment, the authors chose a residential multi-story building. First column of Table 1 shows the BIM model of the building in Revit® and its surrounding environment. The model has an angular shape with two floors and two basements. Its vertical distribution consists of a ladder. This building has 14 thermal zones.

As the complex model used for the final experiment, the authors choose a mixed-use (63% offices, 35% parking, 2% commerce) multi-story building in Bogotá. This building was under construction during the making of this paper. The building consists of 19 floors (3 basements), 11 elevators, 3 stairways, and a total of 63.653 m2 of built area. This model has more than 250 thermal zones. The foundation and structure of the building consists of reinforced concrete. First row of Table 2 shows the BIM model of this building using Revit®.

5 RESULTS

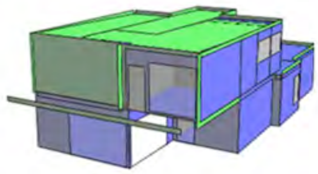
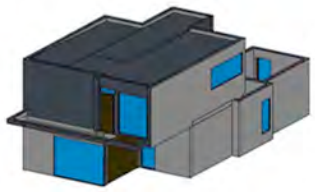
5.1 Preparatory experiment

The authors chose Revit® from Autodesk as the BIM software to be used, because it is the most common software in construction and design companies worldwide, favouring the repetition potential of this investigation.

On the other hand, the authors chose IES Virtual Environment (IESVE) and eQUEST as BEM software because they are approved by the Green Building Council and are also the most commonly used in America. Additionally, Autodesk® Green Building Studio (GBS) was used as an intermediary between Revit® software and eQUEST, as this software is part of the complicated information flow of that exists between these BIM and BEM software (LOBOS, et al., 2015).

Finally, the .INP and gbXML data models were used. The first because it the most frequently used by BEM software. The second model because it is used by the popular calculation engine DOE, and therefore by eQuest, despite not being a data model for BIM. Following the specified data flow process, the basic model for the preparatory experiment was imported to the two BEM software, as presented in Table 1.

Table 1 – First importation of the BIM model to the corresponding BEM software

Original BIM model in Revit®	Analytical model in IESVE	Analytical model in eQuest
		

Source: The authors (2015)

The main inconsistencies on the geometry information of the analytical models correspond to missing slabs, flooring, boards, window frames, basements, doors, windows (or types of walls), and surfaces generating shades. The fact that BEM have not imported furniture, topography, stairs, railings, and sanitary equipment is not considered relevant because their absence does not greatly affect the results of energy analysis. In the generated report IESVE particularly found 11 spaces instead of the original 14 thermal zones.

To solve these first identified limitations, several iterations were performed: the first change was to allow for modifications so "Detach central file" Revit® MEP tool was applied. Then, to speed the BEM model generation time, all elements not related to the energy analysis were deleted (e.g. Furniture, elevators, sanitary equipment). Next, spaces and thermal areas were defined with "Place space" Revit® MEP tool, resulting on the appearance of some of the missing windows and doors, and one more thermal space, so 12 spaces were counted.

The authors tried to solve the absence of basement levels by defining level zero of the BIM model as the last basement. Results did not change with this variation, showing that importation is not sensitive to level variations. Then, object families to model the basements instead of the "building path" option, obtaining one sole big basement without a division slab between floors. Finally, the two basements were defined as spaces and thermal zones with the "Place Space" tool of Revit® MEP. When imported again, the model shows the slab separating both basement levels and the total of 14 thermal spaces.

A total of six iterations of importation into the BEM software were made in order to solve the geometry issues. It was found that, in this specific example, there is no difference between the results of the simulation made with eQuest and IESVE.

5.2 Final experiment

For this experiment, authors adopted the same software and data models. The main limitation found in the first iteration was that the model could not be imported to GBS and therefore could not be displayed on the eQuest software (Table 2). Regarding the IESVE software, the main limitation is the absence of the 3 basement floors, which are of great importance as they are spaces that usually have mechanical ventilation. In the subsequent iterations the same modifications as with the preparatory experiment were applied: Using the "Detach central file" tool and deleting all elements not related to the energy analysis.

To solve the IESVE importation issue, a great number of modifications were implemented in one sole iteration. Object families were used to model the basements. It was ensured that all rooms were set in their upper and lower limits. The size of the bounding box containing the model was reduced. Plates and other external elements were removed by disabling the "room bounding" option and using the "hide in view" option. It was ensured that all halls and rooms were assigned to a thermal zone. The "calculate areas and volumes" and the "calculate room area finished wall" options were activated. Missing elements were located and corrected by turning the 3D model with the "edit boundary" option like eliminating voids in the plates. After all these changes, the IESVE model showed a hole-free structure, lighter, without all the unnecessary elements, and with 3 more thermal spaces (the basements). The model could not been seen in eQuest.

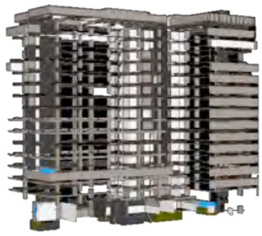
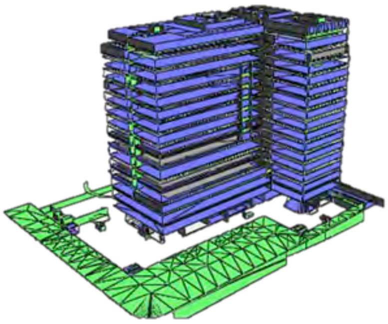
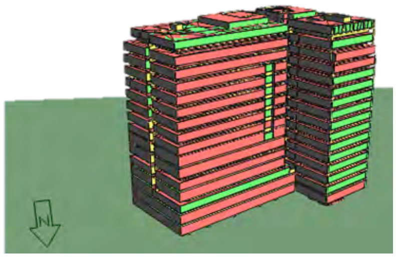
To solve the problem with GBS and with eQuest as a consequence, the origin (0,0,0) of the Revit® model was re-established to a point closer to the building. This last change helped to eliminate the “Openings have duplicate vertices defined” error on GBS, but the IESVE model did not show any changes. Then, in the display control of Revit®, categories such as gutters, raster images, landscapes and others that are not relevant for the energy analyses were turned off. This change made it easier to import the model into the BEM software. Finally, the resolution of the model was increased with the "analytical resolution" option in Revit®, in order to avoid the presence of numerous small surfaces. After a process of 12 changes, the GBS model could be imported into eQuest, but it presented a very bad view since it took off several walls, slabs, and columns, and basements did not appear. The IESVE model remained the same.

5.3 Discussion

Table 2 presents results obtained after a final experiment with 4 iterations and 12 changes made to the BIM model used to generate a BEM analytical model with a correct geometry.

Results obtained in the preparatory experiment showed the same solution documentation for eQuest and IESVE. But, results obtained in the final experiment showed a very different software documentation for both BEM models. It was difficult to display the model in eQuest. After 12 changes in Revit®, it was possible to import a model with missing walls, slabs, columns, basements, and other elements. In IESVE, the model could be viewed since the first iteration and presented a precise geometry after the third iteration with 10 amendments made to the BIM model. Despite the success in the translation of the model to IESVE, the process is tedious. A trial and error process has to be made, demonstrating that the interoperability presented by a software BEM is affected not only by the size of the BIM model but also by the type of data model used and the sequence of implemented changes.

Table 2 – Results obtained after the iteration process

Software	Analytical model in IESVE	Analytical model in eQuest
Revit®		
eQUEST	Did not display a model. In the Autodesk® Green Building Studio (GBS) software, the error “Invalid gbXML file” appears with: “Openings have duplicate vertices defined” and “Surfaces have duplicate vertices defined”.	
IESVE		

Source: The authors (2015)

6 CONCLUSIONS

It can be concluded that BIM and BEM software are not currently interoperable, in contrast to what it is wrongly stated by several software development companies. The transfer of the building geometry, which is the basic input parameter for BEM, is still deficient. The views of analytical models of a building in BEM are not updated automatically with changes in the BIM model. Therefore, several iterations of changing, importing, and exporting the BIM model have to be done in order to ensure that the geometry is correctly transferred. As well as geometry (basic input parameter BEM) is not correctly read by the BEM software, families of objects cannot be translated properly in some other variables analysed by the BEM software.

This lack of interoperability between BIM and BEM causes difficulties in the development and delivery of projects that are seeking sustainable, efficient, and good energy performance throughout its life cycle.

In future research, it is recommendable explore about the causes of this lack of interoperability through a detailed analysis of the operation and the processes of data models exchange for construction products. It is necessary to improve existing data models before starting to develop new models, in order to promote standardization sought with the creation of the International Alliance for Interoperability in the 90s. Finally, the authors propose that the first step of the solution is to make a protocol in which the families of objects managed by BIM are related with the input parameters handled by BEM.

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