

Guidelines for analysing the building energy efficiency using BIM

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Abstract

Introduction

The benefits of Building Information Modelling (BIM) for the construction industry are already known and proved. One of the applications of BIM is to estimate buildings energy demand and foster the introduction of more efficient design alternatives. BIM creates information to support designers' decision-making and to allow them to compare and select the best options, enhancing buildings energy efficiency. With the increasing use of BIM and energy simulation tools, there is a need to establish a common and valid procedure for buildings energy assessment.

Material and Methods

By carrying out a building simulation with BIM, this paper identifies and describes the fundamental stages and requirements to perform a reliable, concise and fast energy assessment. These guidelines will consider Autodesk Revit as a BIM platform to create and prepare the building 3D model.

Results

The proposed guidelines cover all the required tasks for a BIM energy assessment, as the building modulation details and requirements, the software interoperability modes and restrictions and the comparison and selection of improvement measures. Inputs and advice are given regarding the use of some of the existing energy simulation BIM tools.

Conclusions

With the increasing number of studies addressing energy simulations with BIM, it is essential to define a set of requisites to precisely perform them. By identifying the minimum requirements and tasks, the proposed guidelines will support future studies in achieving more reliable and comparable results.

The possibility to estimate and improve the energy demand of a building during the initial project stages allows for the opportunity to build high performance and more sustainable buildings. BIM capabilities might be an essential support to effectively improve the built environment energy efficiency and accomplish environmental goals.

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1. Introduction

Facing the increasing concern about the environmental impacts, the society has been looking for more efficient and sustainable processes and buildings, since the relation between those impacts and the construction industry has already been accepted by the scientific community [1]. With the introduction of Information Technologies in the Architectural, Engineering and Construction (AEC) industry, several methods to support project teams have been developed. Among them is the Building Information Modelling (BIM) method, which aims at supporting designers in managing all the project data [2]. Nevertheless, BIM applications and benefits are far beyond information management, and therefore, the use of BIM has been increasing in the past years. BIM is a set of policies, methods and techniques, which conceive a work methodology that is capable of managing all the project data and design, in a virtual model, during all the building life cycle [3]. BIM applications involve several dimensions from visualisation, scheduling, cost estimation, maintenance, sustainability or safety. It will lead to several advantages, as better buildings and constructions, which require fewer resources [4]. The inherent information share associated with the BIM process, allows stakeholders to work individually with real-time updates, enabling the identification of errors, incompatibilities and interferences.

BIM and sustainability are focused on efficient proposals for new architecture and engineering forms, preserving the natural environment and ecosystems. BIM provides the opportunity to introduce sustainable measures throughout the project, as it allows to overlay and group multi-disciplinary information into a single model [5]. The opportunity to simulate and analyse the building performance before the construction itself, allows the efficient development of high-performance buildings [6]. Among some of BIM sustainable applications, are the water use prediction, sustainable materials selection (through life cycle analysis), building acoustics improvement or even the sustainability assessment through the implementation of Building Sustainability Assessment methods. However, the most common application of BIM among researchers on the sustainability field, is the building energy efficiency improvement, through Building Energy Modelling (BEM) – which includes building orientation, daylight, renewable energy and performance analysis. By combining BIM with an energy assessment, designers can validate their designs and improve the efficiency of their buildings with a fast-iterative process. BEM can be used during the building life cycle to support the designer's decision making, from the early design to the operation phases. The use of BEM tools allows for more accurate and complete energy analysis, improved lifecycle cost analysis and more opportunities to monitor the building performance during the operation phase [7].

Several authors have already performed several comparisons and assessments with different BEM tools and processes [7–9]. Generally, they have pointed out IES VE as the most embracing, versatile, accurate and powerful in terms of energy analysis capabilities. Some notes were also given for Green Building Studio (GBS), about the analysis capabilities and the faster output to compare different design iterations, as it quickly performs the energy analysis. With regards to the building energy consumption optimisation, Abanda et al. [6] have reached savings of 1000€ in a 30-year period only by proper orientating the building through daylight simulations. On a own previous study [10], an energy renovation of a residential dwelling was performed. By exporting the BIM model from Autodesk Revit to DesignBuilder (DB) and Green Building Studio, different design solutions were compared, as well as the results from both BEM tools. BEM approach has facilitated and foster the performance comparison of different solutions and insulation thickness, allowing to achieve the most suitable building renovation design. Goullis and Kovacic [11] have assessed and optimised the energy performance of an industrial building by carrying out a set of energy simulations in EnergyPlus. They argue that BEM approach is still not mature enough, requiring a significant amount of time, assumptions and remodelling [12,13]. These findings are in line with other authors conclusions, stressing out the existence of several problems when performing energy analysis.

The most common limitations are related to the interoperability between BIM platforms and tools, where geometry flaws usually occur, requiring time for double-checking and geometry correction [14]. There is a need to further develop the existing exchange file formats, as Industry Foundation Class (IFC) and green building XML (gbXML). Most of the existing BEM tools force designers to assume a set of parameters for the simulations and treat the human behaviour as "robots" (same activities at the same time, every day) [15]. Furthermore, researchers usually use different methods, software, simulation parameters and energy settings [7], making unfeasible any results comparison with other buildings. Some researchers as Reeves et al. [7], have already started to establish a common understating about BIM for energy analysis, but the focus was given on the selection and comparison of different BEM simulation tools and not on the simulation process itself. The results have provided an evaluation guide for designers to select the most suitable BEM tool for their projects. Both Reeve et al. and Bambardekar et al. [7,16], argue that such kind of study was in need, as designers faced several challenges to evaluate, select and use some of the BEM tools, especially when they have little knowledge on the topic.

Despite the initial developments, there is still a need to establish a standard procedure to carry out reliable energy analysis with BIM. It is necessary to define a common practice [7], to recognise validated methods and to provide a guide for project teams to perform concise energy assessments. A common procedure will ensure that standard simulation requirements are accomplished, misleading results are avoided, and energy comparisons between buildings from different locations are possible. Thus, the present study aims to define a set of guidelines to support designers in achieving reliable results when performing building energy assessments with BIM. As several simulation tools and parameters are used, results are often different, and comparisons unfeasible, highlighting the need for specific common guidelines. By describing the essential tasks and requirements to perform an energy analysis with BIM, this research provides specific know-how for designers to select and carry out a suitable and reliable assessment method to be applied during the design stage. The outcomes of this study can also provide insights for the development of a common requirement for energy performance simulation analysis.

2. Materials and Methods

This paper aims to establish a set of guidelines to support researchers and practitioners in performing a reliable energy analysis, as well as introducing energy-improvement measures in their projects. The objective is to provide valuable insights and establish a common and consistent procedure to support project teams when analysing buildings energy efficiency. The guidelines were developed based on the authors' experience in performing energy simulations with BIM and describes the essential steps, recommendations and limitations when such analysis is carried out. Despite the guidelines mention some BIM tools, they are generic and replicable, and they can be applied with different BIM software and in different locations.

In the development of the guidelines, a hypothetical case study was adopted, to describe all the simulation process, from the building modelling phase to the interpretation of results. Since Autodesk Revit is one of the most used BIM platforms among researchers [17], this study considers this software for the creation of the BIM model. All the required actions in Autodesk Revit are described, as well as the existing interoperability methods and the following steps in specific BIM simulation tools.

It is necessary to highlight that other reliable processes to perform energy simulations may exist, depending on the analysis objective, building location and specific regulation. The presented guidelines must be adapted to the particular condition of each case.

3. Energy simulation guidelines

The fundamental tasks of the process were identified and described to establish general guidelines to perform a reliable energy assessment. The following sections present those guidelines across the main six tasks of the process: Objective and software selection; Modelling; Interoperability; Before simulation; Simulation results; and Improvement measures.

3.1. Objective and software selection

The first step when performing an energy assessment is to establish the type of analysis and results that are intended. Depending on the analysis – energy performance, daylight/orientation analysis, electrical consumption or renewable energy production – different approaches and software should be selected. According to Reeves [7], the BEM tool selection is "*dependent on how the user intends to apply BEM and how BEM is incorporated into a design, construction and facility management workflow*". Furthermore, depending on the study location and building type, specific BEM tools may be available to perform energy analysis, according to the local conditions. As an example, the software development company *Cype*, has created a specific BEM tool for Portuguese residential buildings, which considers the Portuguese energy regulation.

Reeves et al. [7] have already defined the essential steps when selecting the most suitable BEM tool for the analysis. General criteria to choose a BEM tool are the following:

- Usability, Input/Outputs, Speed and Accuracy:
 - Analysis type, detail and accuracy – depending on the analysis type and level of detail, different BEM tools should be selected. Some tools are focused on the building performance simulation or in the orientation optimisation. In contrast, others are proper for a broader analysis, embracing renewable energy production or the overall electricity consumption. Tools as Integrated Environmental Solution – Virtual Environment (IES VE) or EnergyPlus require in-depth knowledge about the simulation parameters and the provided results are carefully detailed, comprehensive and extensive. On the other hand, BEM tool GBS, has a couple of pre-defined settings, allowing to perform faster energy analysis. Nevertheless, results are often different from the reality and designers have little control over the simulation;
 - Software calculation engine – facing the diversity of BEM tools, they usually have different calculation methods. Some BEM tools are based on dynamic calculation, while others are based on static or semi-static methods. The most common accepted methods are the DOE (and DOE-2) engines, which are presented in eQuest, EnergyPlus or GBS software.
- Interoperability – The software interoperability is also a key aspect when selecting the BEM tool. It is essential that the selected BEM tool can read files from the BIM modelling platform, usually in IFC or gbXML formats. Some BEM tools have already developed plug-ins for BIM platforms to speed up and optimise the model interoperability. However, it is still prevalent to find errors on the geometry transference and, therefore, it is essential to check if the model transmission runs smoothly. Depending on the analysis purposes, some BEM tools are also able to export the simulation results in different file formats;
- Software licenses – Most of the existing software requires the purchase of activation licenses. Designers must carefully examine the BEM tools capabilities before acquiring any license. Still, several developers made available trial or academic licenses, creating the opportunity to test the BEM tool before the purchase itself.

3.2. Modelling

Building modelling is an essential feature for a consistent energy assessment. Only a adequately made model will provide enough data for the BIM tool to perform a reliable simulation. BIM models are created and edited in BIM platforms, such as Autodesk Revit or ArchiCAD.

Before the modelling process, designers must assign the building location and orientation. Then, at least, the architectural model must be created for energy analysis. However, if more models (structural and MEP) are made, more concise will be the energy simulation results. After checking the model interferences, materials must be characterised (at least, density and thermal conductivity) and assigned to building elements (Figure 1, left). These building elements should be correctly defined, in terms of layers (as slabs, bricks, insulation, air cavity, finishing materials, etc.) thickness, position and connections (Figure 1, right).

The following step is to assign characteristics to the interior spaces of the model, by creating "rooms" or "spaces". The *room* function only allows defining the internal space identity and dimensional data. The *space* function allows to input, among others, lightning, mechanical and energy analysis data, as occupancy, space type and electric loads. When using the *room* function, the input data for the energy assessment is defined in the BEM tool. Using the *space* function, most of the model energy data can be controlled in the BIM platform. *Space* or *room* data is included in the analytical model of the building, which will be exported to the BEM tool for the analysis. Just before the model exportation, the model energy settings should be also defined in the BIM platform, including, building type, export category (*room/space*), operation schedule, HVAC system, among others. To choose the kind of data to export, it is highly recommended to check the suggested method by the selected BEM tool developer.

The model Level of Development (LOD) should be adopted according to the intended analysis. If an energy assessment is required, the model should be a LOD 300, containing all data described above. However, if it is only intended a solar exposure and shading analysis, the model does not require the materials proprieties and interior spaces characteristics (LOD 200). For a solar/shading analysis, the surrounding buildings and obstacles only need to have a LOD 100, with form and massing data [18].

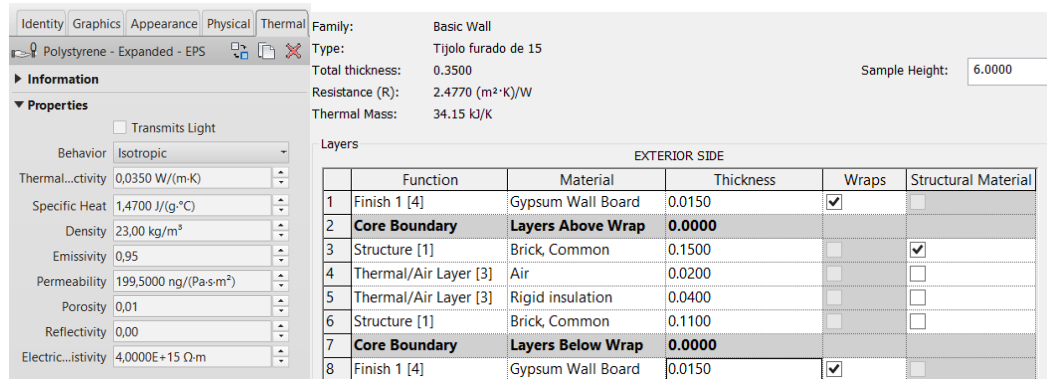


Figure 1 – Material properties (left); Element layers (right)

3.3. Interoperability

Software interoperability is a critical aspect of the BIM method. Existing BIM platforms allows exporting models using IFC file format, which can be readable by BEM tools. However, when the objective is to perform a sort of sustainable analysis, as an energy assessment, gbXML file format may have more advantages. This type of format has more capabilities than the IFC format to store the building thermal data. Nevertheless, as stated before, some BEM tools have already created plug-ins to improve the information exchange with modelling platforms. Some examples of BEM tools which already have plug-ins for the BIM platform Autodesk Revit are GBS, DB and IES VE.

Despite the interoperability improvement, researchers are still arguing with some restrictions and problems. The most common challenge concerns the geometry data transference, with lost or misled information, requiring a full check of the model characteristics before the simulation. It is also common to have issues with other building data as, for example, the building location and orientation.

Whenever possible and if necessary, the BIM platform library must also be exported for the BEM tool, to avoid information loss and double work.

3.4. Before simulation

After the BIM model upload in the BEM tool, it is time to check if all the model geometry, information and characteristics were correctly imported. If not, designers must try to correct the model file first in the modelling platform. If the problems persist and the BIM tool allows it, the model must be adjusted

directly in the BEM tool. Parameters as room areas and volumes, materials thermal characteristics, envelope configuration, spaces occupancy data or project location must always be reviewed.

The following step is to define all the simulation parameters that were not specified in the modelling platform. In the case of Autodesk Revit, if "spaces" are exported, usually BEM tools recognise and use all the data about the room characteristics and occupancy. If "rooms" are exported, only the room geometry data is transferred, and parameters as occupants, equipment's, HVAC system, lights or air change rates must be defined in the BEM tool. The utilities (electricity or fuel) costs and the weather station must be specified according to the location.

Finally, the type of intended analysis must be selected and the simulation method and period (if available) defined.

3.5. *Simulation results*

Results may be presented in different formats, from numerical tables to circular or bar charts. Data as the energy consumption, electricity and fuel needs, renewable energy production, light intensity, costs, savings or CO₂ emissions can be easily assessed. Some existing BEM tools also provide another kind of results, as the energy certification paperwork or the assessment of some criteria from sustainability assessment methods. Nevertheless, the most critical aspect is the validation of results. After performing an energy simulation, results must be validated against a recognised calculation method. Furthermore, simulation results tend to present disparities with reality and, whenever possible, simulation methods must be calibrated by comparison with real buildings. With the development of guidelines, this task can be avoided by certifying the calculation method or by creating a sort of benchmarks, to frame the energy consumption of typical buildings from a specific region.

The majority of the existing BEM tools allows to export the simulation results in several format files, as gbXML or Virtual Reality Modeling Language (VRML) and, even export the results to other BEM tools. The possibility to export simulation results allows designers to process and handle the simulation data, creating the opportunity to present results according to their needs. Moreover, the possibility to export simulation results to other BEM tools may allow the comparison between different simulation tools or even validate results (if both BEM tools have the same calculation engine). As an example, GBS allows exporting the results to EnergyPlus, which performs many reliable simulations or to eQUEST for more advanced analysis.

3.6. *Improvement measures*

When performing the energy simulation, some BEM tools automatically analyse potential improvement measures. As an example, GBS automatically analyses different building orientations or the building potential to reduce the carbon footprint during the energy assessment. Thus, project teams can quickly identify possible energy savings resulting from the adoption of different solutions.

Some of the existing BEM tools allow to directly introduce improvement measures and/or edit the BIM model, providing a comparison of the energy consumption with the initial model scenario. The comparison interface may also influence on the BEM tool selection, as it can provide better visual appearance or present a more comprehensive analysis. Other BEM tools, incorporated in BIM environments, contains direct links to other specific BIM tools, where improvement actions are suggested (as GBS and Insight). When the BEM tool does not allow to introduce a new scenario, it may have the possibility to update the BIM model (from the BIM platform) if connected to a central model.

It is necessary to highlight that if a BIM collaborative process is used, project teams must guarantee that the improvements measures reach the central model so that they can be available to all the stakeholders.

4. **Conclusions**

The increased concern about the environment will enforce project teams to develop high-performance buildings. The use of BIM will allow designers to improve the sustainability of buildings, based on the comparison of the energy savings resulting from the implementation of different design scenarios, since

the early design stages and with fewer resources. This study has presented general guidelines and recommendations for designers to perform a reliable energy assessment using BIM, by describing the essential tasks of whole the assessment process.

Most of the efforts must be made before the beginning of any simulation. Project teams must be aware of their objectives and limitations so that they can run a smooth process without possible errors and troubles. A proper selection of their methods can save a considerable amount of time during the simulation process and provide the intended results. Some existing limitations can still be found in the energy assessments as interoperability issues between different software. It is necessary to improve standard transfer files formats to tackle some geometry and identity transference errors. There is also a need to establish a process to validate the simulation methods and results, which needs to be in accordance with region-specific factors. The existence of several BEM tools and BIM platforms, allows designers to choose different simulation options and procedures, making it difficult to establish common standards for simulations and comparisons. Thus, it is essential to develop, recognise and validate common methods to achieve more reliable and comparable results.

The outcomes of this study are a source of knowledge to support designers when performing energy analysis using the BIM method. Furthermore, it can also provide valuable insights for a future definition of a standard process to assess buildings energy performance.

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