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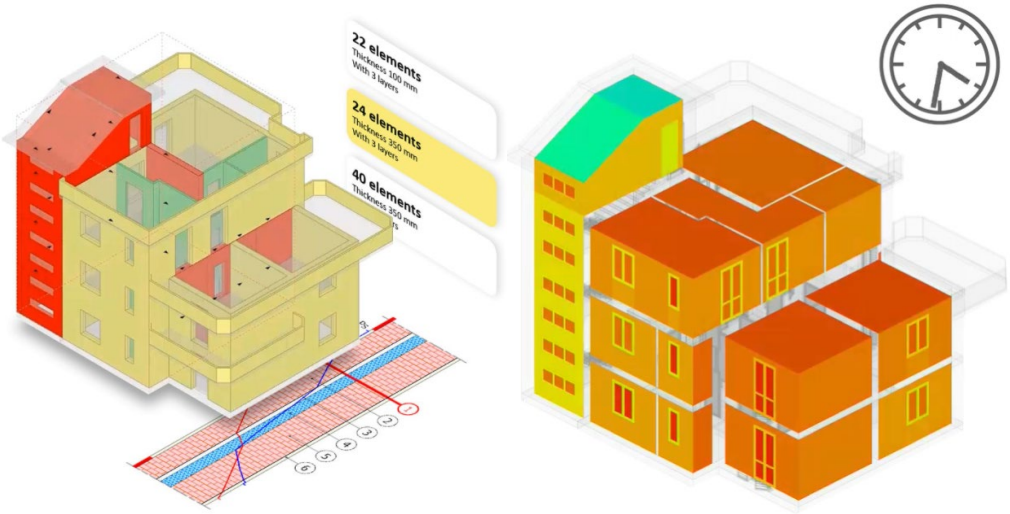
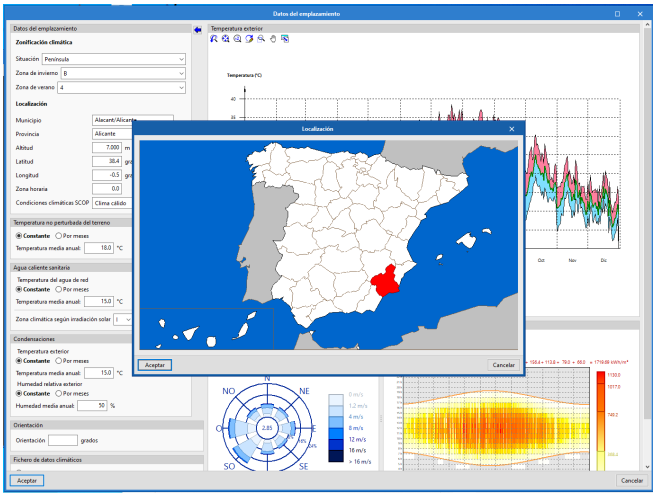
State of the Art of using BIM for Energy Analysis of Building





Summary

1-Introduction.

The BIM methodology, in its sixth dimension (BIM 6D), considers the following two processes as important for sustainability modeling. These are life cycle analysis and energy analysis.

During the life cycle analysis, various aspects are taken into account, such as the use of sustainable materials, energy efficiency during the operational phase, water and waste management, among others. Considering all these variables from the beginning of the project facilitates informed decision-making that promotes sustainability and efficiency.

In addition, energy simulations use specialized software to forecast the building's energy consumption and evaluate the performance of different systems and strategies, such as lighting, air conditioning, and building orientation. These simulations make it possible to optimize the design of the building and select the best options in terms of energy efficiency.

In this project, BIM4Energy, BIM-based tools will be used to evaluate the energy consumption of several case studies: a single-family house, a residential multistore building and an school building.

There are on the one hand several tools capable of create the building energy model (BEM) and perform the evaluation of the energy consumption of a building. From a series of energy sub-models (Building Envelope model, building space model, Heating-Ventilation-Air conditioning (HVAC) System model), and a series of climatic parameters, indoor comfort and occupation conditions (equipment starting temperatures), the BEM tools calculate the annual energy consumption of the building. Figure 1 shows an outline of a BEM [1].

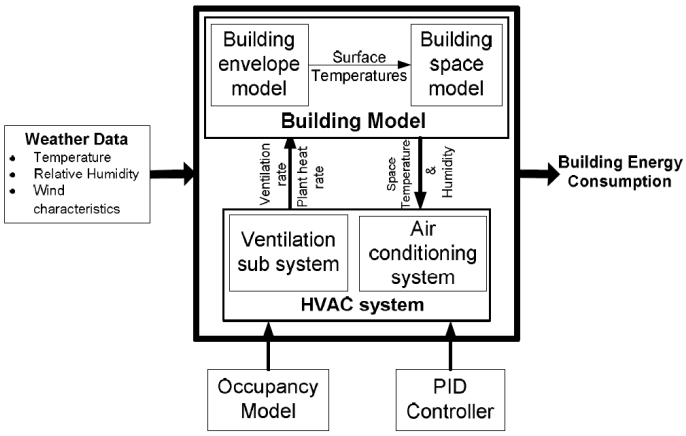


Fig.1. Overall structure of Building Energy System (BES) model [1]

Energy needs are influenced by the building geometry, equipment, and user behaviour. BIM models can store all this information. BIM can act as a basis for energy analysis software to estimate a building's energy needs [2].

2-BIM 6D in the world and Europe

Around the world, there are numerous countries and communities implementing the BIM methodology as a basis for their building projects. Whether on a larger or smaller scale, the impact and improvements that its implementation has brought is considerable.

Countries such as Dubai and the United States can be cited as examples of an early or pioneering implementation of this method, as they have had regulations and programs in place since 2003. During the

2010s, several nations alike oversaw establishing guidelines and regulations, such as Chile, Australia, Canada, South Korea, among others.

In Europe, it has been the Scandinavian countries that have taken the lead in implementing BIM in their projects, through the creation of standards, guides and advice.

In terms of energy efficiency, there is also hard work worldwide in establishing ways to evaluate and establish measures and implementations to improve constructions. Among them is the LEED (Leadership in Energy and Environmental Design) certification, by the US Green Building Council. It has a rating system divided into 5 categories (Sustainable Sites, Water Saving, Energy and Atmosphere, Materials and Resources and Environmental Quality), and has four progressive levels according to score, visible in Figure 2.

Figure 2. LEED Certificate Levels

The certificate is widely used in America, particularly in the United States, Canada and some Latin American cities.

Another important certificate is the BREEAM (Building Research Establishment Environmental Assessment Methodology), created by the Building Research Establishment in the United Kingdom. Its implementation since 1990 can be described as pioneering.

At the software level, several programs allow the generation of energy efficiency studies for certification purposes. "*According to a study by the Hochschule für Technik und Wirtschaft Berlin, many of the BIM programs, plugins and other third-party applications available on the market for building analysis and simulation can also be used as support tools in the BIM process. Some of them, such as ArchiCAD, Revit, Vectorworks, Ecotect, Hourly Analysis Program (HAP), Integrated Environmental Solutions (IES-VE) or Green Building Studio (GBS), can be used in different types of certification.*" (BIM Alliance, 2024) [3].

A possible drawback is that, despite the variety of programs, the compatibility of the program with the desired certification must be verified, since not all programs are compatible with all certificates, so some additional process would have to be incurred.

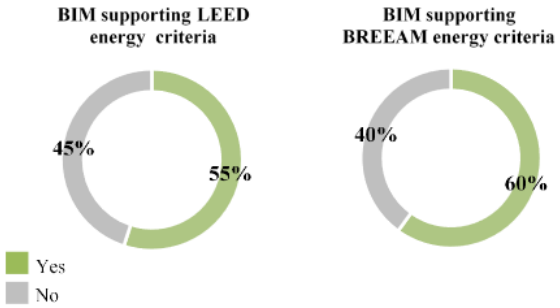


Figure 3. BIM software supporting LEED and BREAM energy criteria

3-State of the Art of using BIM for Energy Analysis of Buildings

A rapid development of BIM and BIM-related applications have provided opportunities to support green building practices, such as acoustic analysis, carbon emission, construction and demolition waste management, lighting analysis, operational energy use, and water use [4].

Although some authors [5] claim that BIM tools have several capacity limitations in interoperability and data exchange between BIM and BEM tools, the truth is that there are already Open BIM solutions for the energy

efficiency analysis in buildings. These tools read the necessary information from BIM models, perform energy analysis according to national regulations and save their results in the BIM model. For example, CypeTherm HE plus.

In addition, published works, e.g. [6], attempt to develop a BIM-based approach that can be used to assess the thermal building performance.

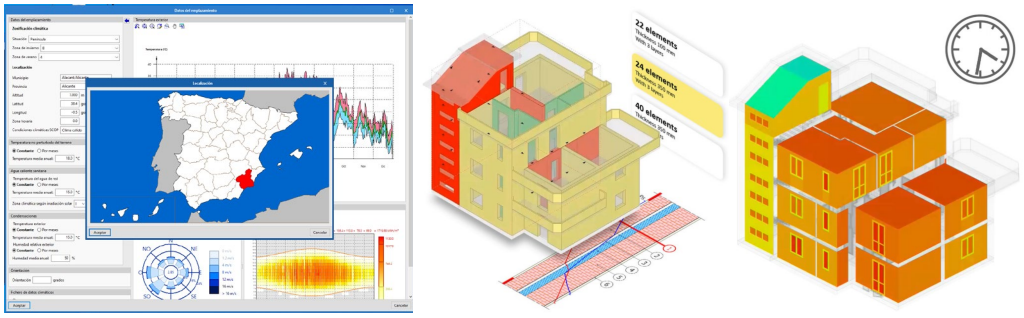


Figure 4: BIM model and BEM for energy efficiency assessment. Source Cype and ACCA software

3.1-BIM definition and BIM applications

Definition of Building Information Modeling (BIM) could be different depending on the content of the model. For example, an information model could include information about the building geometry, envelope components, materials, costs, HVAC system, electrical systems, and thermal properties of materials. The U.S. national BIM standard (NBIMS-US) defines BIM as "the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting, and many other purposes" [7]. Krygiel and Nies define BIM as "information about the entire building and a complete set of design documents stored in an integrated database" [8]. BIM is also defined by Smith and Tardif as "a mechanism to transfer from data into information to gain the knowledge that allows us to act with wisdom" [9].

The application of Building Information Modeling (BIM) in various fields is expanding as researchers recognize the potential benefits it offers. While BIM is reported to be used for structural and energy analysis with frequencies of 27% and 25%, respectively, its primary use remains the rapid development of 3D geometric models and 3D coordination, with a usage frequency of 60% [10]. The application of BIM is not limited to architects and engineers.

There are also reasons for homeowners, facility managers, contractors, and fabricators to use BIM [11]. The key factors driving the adoption of BIM in projects include the automation of the modeling process, improved accuracy of construction documents, enhanced communication among parties in the design and construction process, automatic reflection of changes across all views after modifying one view, and the reduction of field coordination problems [11–14]. While most BIM applications are dedicated to building design, equivalent emphasis has not been placed on other areas such as energy modeling, which can be referred to as BIM-to-BEM interoperability process (BBIP).

3.2-Aplication of BIM in BEM

The integration of Building Information Modeling (BIM) within Building Energy Modeling (BEM) presents numerous advantages [5]:

- Automation of energy modeling processes.
- Efficient storage and organization of building data (e.g., real-time data).

- Enhancement of existing libraries (e.g., incorporating additional attributes to materials).
- Improved presentation of energy-related outputs.

The primary contributions of BIM to energy-related modeling, simulations, and information management revolve around the facilitation of data handling. This can lead to the automation of energy modeling, enhanced presentation of outputs, the ability to store and organize new building data—particularly real-time information to maintain an up-to-date energy model—and the enhancement of existing libraries by adding new attributes to the standard energy simulation process [5].

One of the significant benefits of applying BIM in the energy simulation of buildings is the automation of the modeling process [14,15]. This automation can save time, reduce costs, and minimize human error compared to traditional energy modeling methods, which involve developing a graphical model in a BEM tool using data related to geometry, material properties, equipment, and schedules. For instance, integrating an add-on to an energy simulation tool such as OpenStudio provides an opportunity to connect a BIMserver to the energy simulation tool, allowing the importation of data related to geometry, materials, window types, and thermal properties from an IFC file [14].

3.3-BIM-to-BEM interoperability process and components

To gain a comprehensive understanding of the challenges and issues within the BIM-to-BEM interoperability process (BBIP), it is beneficial to classify the various components involved, as illustrated in Figure 5. The interactions among these components can contribute to potential issues and challenges, which are identified and explained as follows [5]:

1. BIM tools: Examples include Revit and ArchiCAD.
2. Mapping building information to a BIM file: This process involves translating building data into a BIM-compatible format.
3. BIM file standards: These include formats such as gbXML or IFC.
4. Graphical User Interface (GUI) in BEM tools: Examples include OpenStudio and DesignBuilder.
5. Mapping data from BIM file to a BEM-readable file: This step involves converting BIM data into a format that can be read by BEM tools.
6. Mapping data from GUI to a simulation engine-readable file: This process involves translating data from the GUI into a format suitable for simulation engines like EnergyPlus or DOE2.

Interoperability issues often arise from the processes numbered 2, 5, and 6. These steps are critical points where data translation and compatibility challenges can occur, leading to potential inefficiencies and errors in the BBIP workflow.

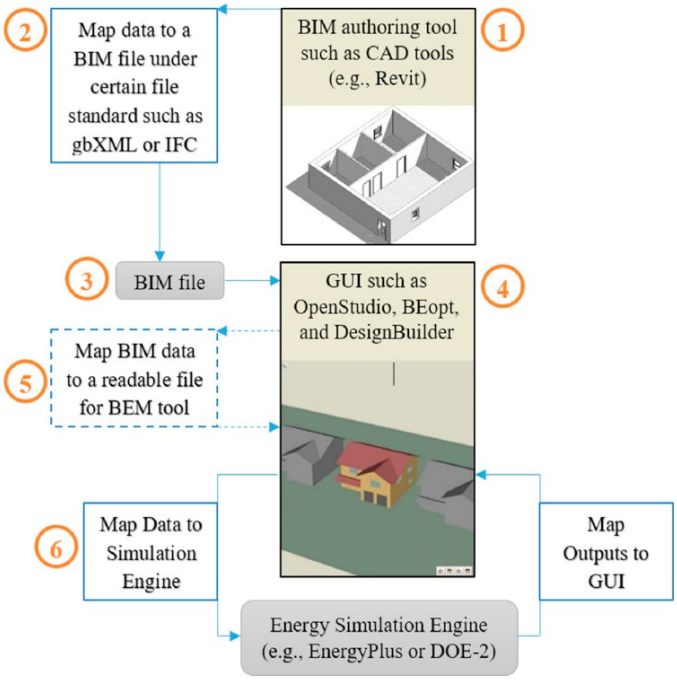


Figure 5: BIM-to-BEM interoperability process and component. Source: [5]

3.4-Research studies on using BIM in energy simulation

The summary of the reviewed research studies on the application of Building Information Modeling (BIM) in energy simulation is presented in Table 1. It is evident that ArchiCAD and Revit are the predominant BIM authoring tools utilized in these studies. Depending on the research focus, either the Industry Foundation Classes (IFC) or Green Building XML (gbXML) BIM file schemas are employed. Conventional energy tools in the United States include OpenStudio, EnergyPlus, Green Building Studio (GBS), and eQuest, while international tools such as Modelica, COMETH, and EnergyBuild are also available.

It is observed that the majority of identified challenges and issues arise during the mapping process, which can be categorized under interoperability issues. Examples of such challenges include: the BIM tool may not transfer all the information in a model, the BIM file may not save all the information correctly, the Building Energy Modeling (BEM) tool may not read all the information from the BIM file, and the information may not be mapped and transferred properly to the BEM and energy simulation engine's file format. However, the process of mapping data to the energy simulation engine, as indicated by component 6 in Figure 5, is not thoroughly discussed in the literature and represents an area requiring further research.

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Table 1: Research studies on using BIM in Energy simulations. Source [5].

Reference	BIM CAD tool	BIM file schema	Energy tool	Description of the study and adopted solutions
Epstein [16]	ArchiCAD	IFC	EnergyBuild	A case study in Greece adopted BIM to BEM process as part of the project
Ramaji et al. [14]	–	IFC	OpenStudio	Development of an add-on to import the data related to geometry, materials, windows types, and thermal properties from IFC file.
Yu [17]	Revit	IFC	OpenStudio	Development of a middleware, which use BIMserver and Query Generator to extract required data from IFC file. Users add missing data manually and a python script convert the file to a proper format for CONTAM for air distribution analysis.
Salakij et al. [18]	–	gbXML	Building Energy Analysis Model (BEAM) developed by Matlab	Developed an energy simulation tool using Matlab, which is capable of reading gbXML file to perform the energy analysis.
Krygiel and Nies [19]	Revit	gbXML	GBS	Energy analysis using BIM is performed to evaluate two façade systems.
Kim et al. [20] & Jeong et al. [21]	–	–	Modelica	The study is based on integration of Modelica to perform energy analysis, ModelicaBIM library to provide required data needed from BIM file, and using BIM API to retrieve data from conventional BIM tools such as Revit and ArchiCAD.
O'Donnell et al. [23] & Bazjanac [24]	ArchiCAD	IFC	EnergyPlus	A semi-automated method is adopted to add the required data for energy simulation to the IDF file generated from IFC file, prior to the energy analysis in EnergyPlus.
El Asmi et al. [22]	–	IFC	COMETH	The study is focused on application of MVD in obtaining the required data for energy simulation (e.g., HVAC system data), which are missing through the process and using IfcPropertySet to add the data to the IFC file
Santos et al. [25]	–	–	EnergyPlus	Adopting mesh planarization algorithm to divide the curved surfaces into flat panels and exporting the required data from CAD tool to EnergyPlus.
Karen and Douglas [26]	Revit	IFC	EnergyPlus	Generation of thermal zones is automated using the data obtained from Revit, provided in IFC file and the outputs obtained from EnergyPlus are visualized.
Dimitriou et al. [27]	Revit	gbXML	EnergyPlus	Development of a gbXML editing tool to provide the data, which lacks for energy simulation in EnergyPlus prior to generating the IDF file.
Garcia and Zhu [28] Egwunatum et al. [29]	–	gbXML	eQuest	Development of a corrective tool for modifying the gbXML file and converting it to DOE-INP file for use in eQuest.
	–	IFC	IES VE	A case study to review the feasibility of optimization in design by linking BIM to energy simulation tool. Faster, more accurate, and detailed outputs concerning energy consumption, airflow analysis, visualization, and daylight analysis were among the benefits observed in the study.
Somboonwit et al. [15]	Revit & Dynamo	gbXML	GBS, DOE2, eQuest	Automation of Building Performance Simulation (BPS) is studied using different tools in order to investigate the interoperability between them. Kinetic PV façade (KPVF) is modeled and issues such as misplaced and distorted geometry are observed.

3.5 BIM to BEM Cype solutions

The software company Cype Ingenieros offers several Open BIM solutions to carry out the energy simulation of a building.

Cype has a common data environment (CDE), called BIMServer.center, where you can share the IFC models of the same building project. The design Cype software of each building discipline are connected to the Building Project in BIMServer.Center, so that users can share the work done through IFC models. In this way, the agents (developers, structural engineers, facilities engineers and architects) working on the same project, in the different disciplines, can see the progress of the work carried out by the rest of the participants.

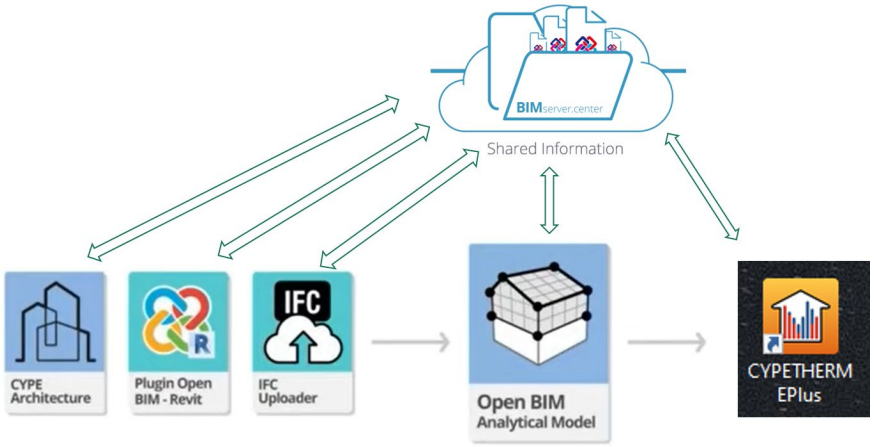

Figure 6 Open BIM Energy Simulation Workflow.

The workflow to carry out the energy simulation of a building using Cype's Open BIM programs consists of using at least 3 different programs sequentially (Figure. 6):

- The first is *Cype Arquitecture*, with which to build the BIM Architectural model
- The second is the *Open BIM Analytical Model*, which calculates the geometric parameters of the different building spaces to be studied.
- And the third is *CypeTherm EPlus* that performs the energy simulation.

To characterize the construction elements as well as the thermal properties of the materials, you can use the *Open BIM Construction System* program or perform this work within *CypeTherm EPlus*, before the energy simulation.

To create the BIM model of the building in IFC format, there are two alternatives to Cype Arquitecture. You can use Revit and the Open BIM plugin to create the IFC and submit it to BIMServer.Center. Or make the BIM model in IFC format with any other program and upload it to BIMServer.Center using IFC Uploader.

CypeTherm EPlus perform the thermal analysis, after building the BEM, using EnergyPlus as engine of the calculations. The results reports are:

a) Energy Demand Report

b) Report on energy consumption and CO2 equivalent emissions produced.

c) Obtaining the building's energy rating.

With the proposal of Cype Ingenieros to perform energy simulation of building using BIM models, the interoperability between the different components of the BBIP is very good since all the components are solved by programs of the same software company (CYPE)

4-Conclusions

- The integration of Building Information Modeling (BIM) within Building Energy Modeling (BEM) presents numerous advantages: a) automation of energy modeling processes: b) efficient storage and organization of building data (e.g., real-time data); c) enhancement of existing libraries (e.g., incorporating additional attributes to materials); d) Improved presentation of energy-related outputs.

- Several problems have been detected in the BIM to BEM interoperability process: The BIM tool may not transfer all the information in a model; the BIM file may not save all the information correctly; the Building Energy Modeling (BEM) tool may not read all the information from the BIM file; and the information may not be mapped and transferred properly to the BEM and energy simulation engine's file format.

- Cype OpenBIM solutions for Energy simulations of Buildings solve interoperability problems.

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