# BIM Tools Interoperability For Designing Energy-Efficient Buildings

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**Abstract.** The constructive complexity of the building envelope, together with the high degree of performance required in new dwellings, entails the application of computer-based modelling tools over the design processes. Furthermore, to achieve the NZEB (net zero energy building) qualification, the use of BPS (building performance simulation) tools during the early design stage becomes indispensable. In this context, the present research aims to analyse the interoperability potential offered by BIM-based (Building Information Modelling) software to optimize the modelling phase and to improve simulation results. The research shows advantages and drawbacks related to a workflow adoption based on 3D BIM implemented in Autodesk Revit, and on energy simulation in IDA-ICE environment, by means of a visual algorithmic programming tool. The Bestest ASHRAE case study has been considered as reference system to test and verify the actual process optimization. The outcomes identify what is the correct information set which is needed for the energy analysis to get suitable energy simulation result with the minimum data losses.

## INTRODUCTION

According to the Energy Performance of Building Directive 2010/31/UE (EPBD) [1] recast, new and existing buildings have the aim to achieve the Nearly Zero Energy Buildings (nZEBs) and Zero Energy Buildings (ZEBs) requirements, in order to reduce the emission and the energy demand of the entire building sector [2,3]. To comply with the nZEB requirements, the use of well-performing materials and efficient technical systems become fundamental, with the consequence of increasing the entire building process costs. Therefore, many researches highlight the necessity to identify new methodologies optimizing the ZEB development during the design process, reducing delays and costs increase. New technological methodologies allow to reach objectives never reached before, including the historic buildings cataloging, creating innovative and integrated territorial models [4], or improving the cultural heritage energy performance [5-7]. In this context, the Building Information Modeling (BIM) technology could have a wide application by the use of an integrated model, which includes all the building information in a unique database. While the use of traditional design methods leads to limitations in terms of analysis and research, this new workflow allows to use a central database for data exchange and integration, based on the Industry Foundation Classes (IFC) [8,11]. Building sustainability is a critical design issue, as the decisions taken in the project conception significantly influence the environmental impact and future energy efficiency of the building. [8-10]. The hardline goal is to illustrate the suitability of Building Performance Simulation (BPS) tool in early design stages and presenting the enhanced benefits and time-saving aspects. Additionally, that is very often a complex assignment due to a large number of parameters involved in the energy buildings performance. BIM makes it possible to create a building 3D model, by overlapping multi-disciplinary information. In so doing, it is possible to share information about architecture, materials, sustainability, structure, facilities, and context [12,13] between architects and engineers. Heap-Yih Chong et al. [14] by reviewing BIM standards and guidelines concludes how Bim adoption in the AEC industry can improve a collaborative environment work and social sustainability. In this completely innovative way, sustainability analysis is perfectly integrated from the beginning of the design process [15]. Hence, it is clear the importance of finding optimal energy solutions in the decision-making phase of the building process, and therefore highlight the strong impact of design decisions on energy performance and costs [16]. BIM software offers clear advantages in terms of efficiency because it guarantees interoperability, costs optimization, times and operational flows, integration, sharing, transparency of information and, sustainability. [20] To achieve full interoperability without error or data losses, there is still work to be done, as investigated by Jeong et al. [17] and confirmed by Grilo and Jardim-Goncalves [18]. Two data formats were developed by the AEC industry to facilitate interoperability between different software. On one hand, there is the gbXML format developed by Green Building Studio [19]; on the other hand, the IFC, which is an object-based open file format, is the format developed by buildingSMART [20]. The gbXML format reads the geometrical shapes and the information data from the 3D model and saves it in a text format under pre-defined notation for the strict purpose of energy analysis. The IFC is an open file registered with the International Standardization Organization (ISO 16739) and it is the most common used by the AEC industry. Ira Ivanova et al. [20] shows how both gbXML and IFC have a reasonable performance in extracting and storing building geometry data and non-geometric conditions. In this study, the building information model has been exported to an IFC file format and then is imported into an energy analysis tool that supports IFC files. In the research, a workflow along with a supporting visual programming tool add-on for generating energy analysis models in IDA-ICE [22] from a BIM has been investigated. In the following sections, the implementation of the workflow is explained, followed by a discussion on the information extraction and model transformation processes. It also describes how all the information are mapped between the data models of the input and output files, which are, respectively, IFC and IDM file. Finally, considering the challenges and limitations associated with this design process, information exchange from BIM to energy analysis models have been discussed.

## METHODOLOGY

This study aims to implement BIM-Building Energy Model (BEM) interoperability process, in order to facilitate the achievement of ZEB targets. Due to the substantial impact of buildings energy consumption, it is important that designers pinpoint where improve the design phase optimizing energy performance [23]. Current research shows that the building performance arrangements with the BPS aid can improve the nZEB design process, during the early design stages. In order to guarantee the quality and to reduce errors, the BIM workflow allows the design data sharing, ensuring export speed. With BIM and by integrating parametric modelling into it, the designers get great benefits to create sustainable building designs by the possibilities to variate information parameters. A BIM model may contain most of the data needed to run energy simulations and the risk of errors and time consumption are sensibility reduced. In this work, the reported workflow involves the use of BIM models for physical and thermal building management, and the use of IDA-ICE as an energy simulator. In detail, the paper shows how an integrated building model can export all the required information for a performance simulator as IDA-ICE. Methodology workflow is shown in Figure 1.

- In the first step, the Revit architectural model has been created, including all its geometric, spatial and thermal characteristics. The Bestest ASHRAE case study has been considered as a reference system for testing the actual process optimization while a visual programming tool is utilized to perform the 3D model and to prepare the IFC file for the energy simulation tool;
- the second step includes the IFC check, export and the IDA-ICE import for running the energy simulation.

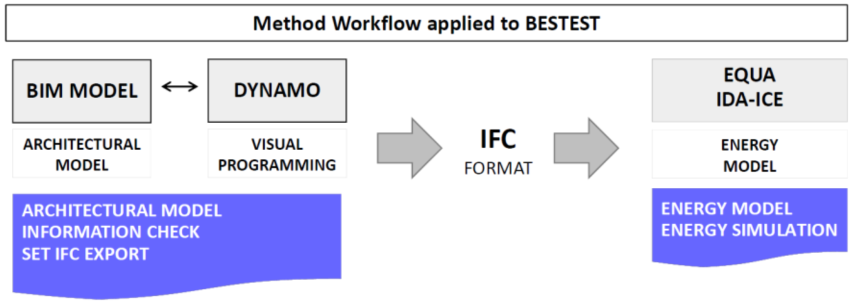
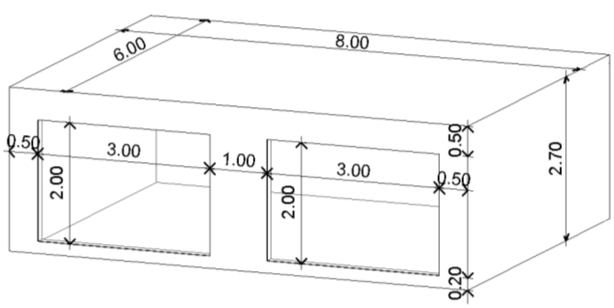



**FIGURE 1.** Workflow applied to BESTEST

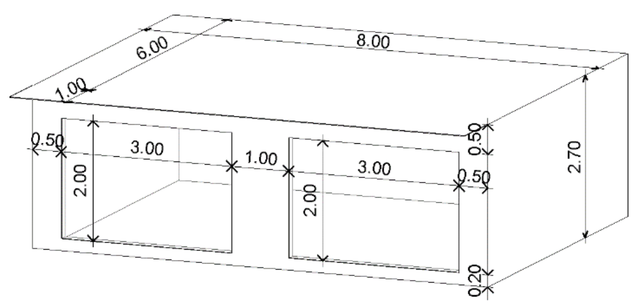
In one hand, Autodesk Revit is chosen as BIM software, in the other hand IDA-ICE, developed by EQUA Simulation AB (Equa Simulations), is chosen as energy software due to the easy import of the IFC models. IDA-ICE (IDA Indoor Climate and Energy) is a year-round multi-zone simulation application for building thermal load and energy consumption. It is an independent tool with both a graphical interface and a simulation engine, and the BIM import command allows to use directly 3D buildings model hailing from the IFC format [48]. In the present paper, a visual programming tool, Autodesk Dynamo, has been also used to perform BIM export files and convert them to input files for energy simulation. Dynamo is an open-source visual scripting platform for computational design and is integrated support inside the BIM tool Revit. The IFC file is selected as the input building information model file format because it is the most widely accepted data schema for BIM and it is ISO standard 16739-1:2018. There are several challenges associated with the transformation of IFC models. These challenges are mostly related to 1) physical models with analytical models representation differences; 2) progressing changes in the IFC standards, and 3) problems associated with their implementation in the energy simulation tool. In this section, some of the challenges have been discussed. The open exchange of BIM information regulated by the UNI standard is the IFC format; therefore, the implementation of this specific format is the priority of BIM authoring tools. That has a significant impact on the implementation of new workflows based on integrated interoperability by means of IFC schemes. For that reason, the workflow examined in this paper involves the use of an energy simulation tool such as IDA-ICE established with the ability to import BIM formats exclusively in IFC format.

## The case study

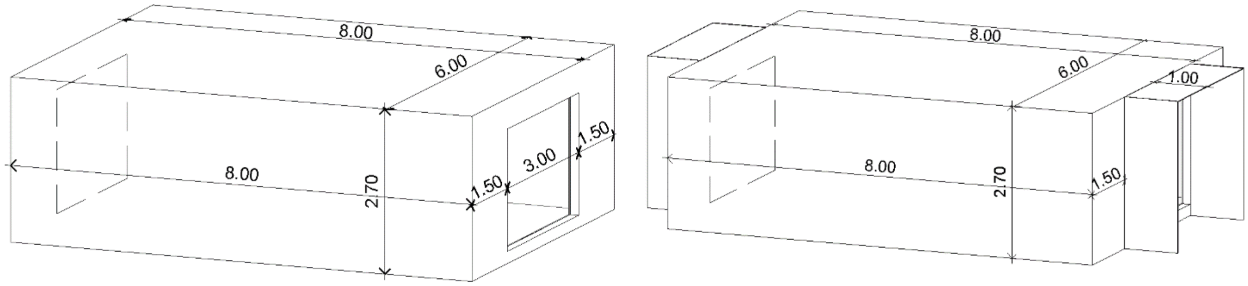
In the present study, some BESTEST cases are used to evaluate the accuracy of the workflow presented by the Validation of IDA Indoor Climate and Energy Test respect to ANSI/ASHRAE Standard 140-2004. The main reason for performing the tests is to ascertain that the computational models give reasonable values compared to other software programs and by the BIM import tool as well. This section focuses on the ASHRAE standard describing four experiments, which attempt to investigate on the different building geometry parameters. The selected cases are shown in Figure 2.




(a) CASE 900 - Base Case




(b) CASE 910 - South Shading




(c) CASE 920 - East/West Window Orientation (d) CASE 930 - East/West Shading

**FIGURE 2.** BESTEST Cases

The four BESTESTs are based on a single rectangular area (8m wide x 6m long x 2.7m high) without internal partitions and with two windows (3m long x 2m high) on the southern or east, west exposure. The building is a heavy mass construction and contains basic geometry information as for walls, floor, and roof (Table 1). The four examples show small differences in terms of exposure and shading, while the thermal specifications are defined and assigned to the reference thermal zone.

**TABLE 1.** Thermal properties of Construction Elements

| Wall Construction | Floor Construction | Roof Construction |
|---|---|---|
| Concrete Block | Concrete SlaB | Plasterboard |
| Foam Insulation | Insulation | Fiberglass Quilt |
| WoodSiding | | Roof Deck |
| **U = 0.512 (W/m2-K)** | **U = 0.039 (W/m2-K)** | **U = 0.318 (W/m2-K)** |

The use of Dynamo lead to personalize the workflow relating to BESTETs information, making possible to automate construction and export processes. The programming application can be independently used, but it is also capable of interfacing with Autodesk Revit, being it an open source add-on module, constantly updated and linked to active communities. Its use is spreading rapidly, becoming indispensable for the BIM parametric modelling. Visual programming allows to replace conventional elaborate coding with the connecting visual scripting blocks. An example is shown in Figure 3.

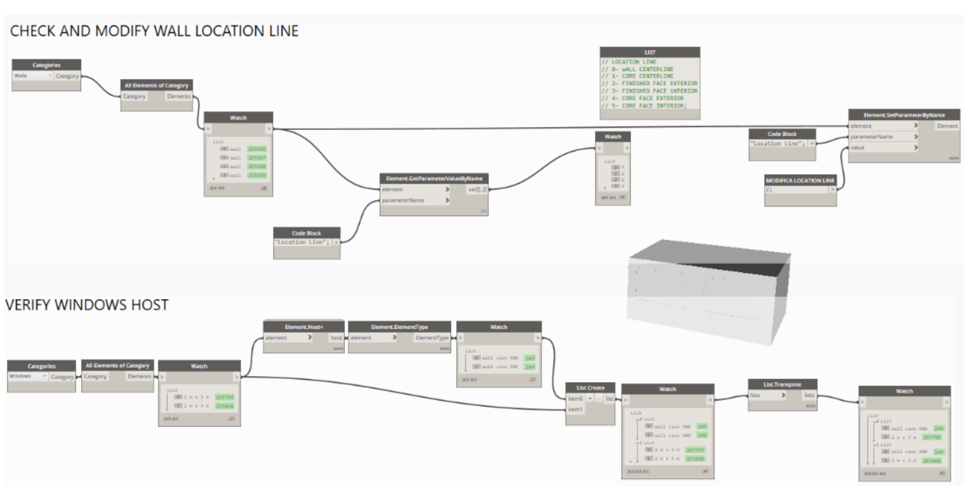



**FIGURE 3.–** Visual programming tool Autodesk Dynamo

Thanks to the use of calculation codes, it is easy to manage a large amount of data, also called BIGDATA, creating a real identification, control, and archiving system. In detail, dynamo made it possible to verify the data completeness necessary for the energy model creation. Once the IFC file is performed, it is imported into IDA-ICE simulation tools. Therefore, inside IDA-ICE, the geometry is correctly imported by the IFC import, while thermal characteristics are set. The heat transfer coefficient is given as a constant value. IDA-ICE calculates the variability of the heat transfer coefficients, depending on wind speed and direction, solar radiation, and outside weather conditions. The ventilation rate owing to infiltration is about 0.5 Vol/hour, while the internal load is 200 W continuous, 60% radiative, 40% convective and, 100% sensible. The mechanical system is 100% convective air system, with no duct losses, heating <20°C, cooling >27°C and soil Temperature of 10 °C continuous. Material thermal properties and Construction element types are set inside Revit BIM tool and revised in IDA-ICE. The transmission process has been thus evaluated. Specifically, eight essential aspects have been considered during data transmission:

1. Orientation and site information
2. Geometry as a whole
3. Construction elements
4. Layers of construction elements
5. Thermal properties of layer materials
6. Glass surfaces
7. Shading
8. Thermal Zones

# RESULTS

This paper aims to improve the energy simulation processes by focusing on the interoperability issues between BIM and BEM tools, in order to promote sustainable and integrated design for the nZEB objectives. Therefore, the results of this research focus on the problems encountered in the information exchange deriving from the use of Revit and IDA-ICE. The information transfer creates a considerable time saving in the building's energy process, so confirming or refuting the transmission success is an essential priority. Eight characteristics have to be assessed to get the correct building energy performance. Those factors have been implemented and verified in the BIM and subsequently, they have been evaluated in the BEM. The IDA-ICE's response to the transmission process is almost reliable, although some elements require mapping to work properly. The mapping takes place between the imported elements and the elements created in the energy software, as it happens for the construction elements. These elements are correctly read as surfaces but need a thermal association for the energy simulation. Table 2 summarizes the results.

**TABLE 2.** Results of the energy data transmission process

| **Energy data information** | **Creation in Revit** | **Reading in IDA-ICE** | **Creation in IDA-ICE** |
|---|---|---|---|
| Orientation and site information | x | x/- | x |
| Geometry | x | x | - |
| Construction elements | x | x | Only needs mapping |
| Layers of construction elements | x | x | Only needs mapping |
| Thermal properties | exported not to the right IFC classes | - | x |
| Windows | x | x | Only needs mapping |
| Shading | - | - | x |
| Thermal Zones | x | x | Only needs mapping |

The first issue includes the orientation and the information site, both implemented in BIM. IDA-ICE can read the model rotation but cannot insert it in a geographic position. This means that global data of location, climate, and wind profile must be set once inside IDA-ICE. The second issue is the geometry as a whole, which is perfectly read by the simulation tool. All the building surfaces are recognized in their spatial dimensions. This step is not completed until the construction elements and construction layers are not correctly associated. The construction category needs to be mapped to selected ICE resources. To do so, materials construction have to be created or loaded from the database and then associated with the IFC data. Revit can only export thermal characteristics of elements in the form of IfcPropertySingleValue class and not in IfcWall, which means that they are not exported to the right IFC classes and consequently not read in IDA-ICE. That happens because different software tools cannot well interpret several building properties due to the difference in domain knowledge. Figure 4 is an IFC extract which explains where the thermal characteristics of BIM materials are exported. This become a limit for the transmission process because can generate human-error during the mapping process. Only when all the materials are mapped, it is possible to link the construction IFC category to the construction ICE resources.

```
#493= IFCPROPERTYSINGLEVALUE('Family',$,IFCLABEL('Basic Wall: Wall Construction - Case 900'),$);
#494= IFCPROPERTYSINGLEVALUE('Family and Type',$,IFCLABEL('Basic Wall: Wall Construction - Case 900'),$);
#495= IFCPROPERTYSINGLEVALUE('Type',$,IFCLABEL('Basic Wall: Wall Con            Case 900'),$);
#496= IFCPROPERTYSINGLEVALUE('Type Id',$,IFCLABEL('Basic Wall: Wall Construction - Case 900'),$);
#497= IFCPROPERTYSINGLEVALUE('Absorptance',$,IFCREAL(0.7),$);
#498= IFCPROPERTYSINGLEVALUE('Heat Transfer Coefficient (U)',$,IFCREAL(0.556215553002123),$);
#499= IFCPROPERTYSINGLEVALUE('Roughness',$,IFCINTEGER(3),$);
#500= IFCPROPERTYSINGLEVALUE('Thermal mass',$,IFCREAL(144293.),$);
#501= IFCPROPERTYSINGLEVALUE('Thermal Resistance (R)',$,IFCREAL(1.79786414565826),$);
#502= IFCPROPERTYSINGLEVALUE('Structural Material',$,IFCLABEL('Isolamento'),$);
#503= IFCPROPERTYSINGLEVALUE('Coarse Scale Fill Color',$,IFCINTEGER(0),$);
#504= IFCPROPERTYSINGLEVALUE('Function',$,IFCIDENTIFIER('Exterior'),$);
#505= IFCPROPERTYSINGLEVALUE('Width',$,IFCLENGTHMEASURE(0.1705),$);
#506= IFCPROPERTYSINGLEVALUE('Wrapping at Ends',$,IFCIDENTIFIER('None'),$);
#507= IFCPROPERTYSINGLEVALUE('Wrapping at Inserts',$,IFCIDENTIFIER('Do not wrap'),$);
#508= IFCPROPERTYSINGLEVALUE('Assembly Code',$,IFCTEXT(''),$);
#509= IFCPROPERTYSINGLEVALUE('Assembly Description',$,IFCTEXT(''),$);
```

**FIGURE 4.** Extract of IFC Scheme

As for all building elements, analytical properties of windows or glazing type are not imported in IDA-ICE. The information about the window dimensions and geometry are correctly read because they are exported to the IfcWindow class. All the other thermal values are exported in IfcPropertySingleValue class, for that reason, they cannot be read in IDA-ICE tool. The result is to map the IFC window type to the thermal properties created in IDA-ICE. Passing to the shading issue, no shading category are present in Autodesk Revit, for this reason, different solutions have been investigated. First of all, the use of a thin wall has been considered. In the IFC scheme structure, each element category has an IFC class name, as shown before for the ifcWall, IfcWindow, and the IfcPropertySingleValue. Therefore, creating shading by the wall tool means having a new wall analysed in the energy model, which could create simulation errors. A second way investigates has been using the "generic model" in place, which presents different results. In this case, IDA-ICE can recognize the geometry but not the shading category. Because of the IFC class is not automatically accepted in IDA-ICE, the solution requires users to create it manually. The last issue is the thermal zones. As specify for wall, windows, and floors, IDA-ICE can read thermal zone names and geometry, but not the associated properties value. Finally, for all of the above-analysed points, the mapping process is extremely simple, and in spite of the extra steps to be taken, it is still timesaving. Even the results in terms of energy do not differ much, so the result can be defined as successful. Table 3 shows in detail the elements analysed during the transmission process and the response of each case study. The four buildings analysed respond in a very similar way as the studied geometry are almost the same. An interesting future work would be to investigate complex cases in order to read the answer of larger geometries.

**TABLE 3.** The response of all the case studies

| | Orientation | Site Location | Weather Data | Wall Geometry | Window Geometry | South Exposition | East-West Exposition | Floor Geometry | Roof Geometry | Shading Element | Shading Properties | Thermal properties | Material Name | Construction Type | Spaces Name | Spaces thermal properties | Thermal Loads |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CASE 900 | | x | x | | | | x | | | x | x | x | | | | x | x |
| CASE 910 | | x | x | | | x | | | | | x | x | | | | x | x |
| CASE 920 | | x | x | | | | x | | | x | x | x | | | | x | x |
| CASE 930 | | x | x | | | x | | | | | x | x | | | | x | x |

## CONCLUSIONS

Two aspects emerged as priorities for engineers and architects in the development of zero-energy buildings: the detailed energy assessment and the reduction of time and construction costs. In this framework, BIM could be a potential instrument for reducing costs and time during the building-design stage, providing a unique integrated file which contains architectural and energy information. Due to the well-known difficulties in the BIM-BEM interoperability, the goal of this work is to develop and verify a new methodology for overcoming the gap between BIM and energy models and facilitating the use of BIM within the ZEB construction process. In the effort of designing performing buildings with the aid of design tools, scripting, and building performance simulations, several studies have been conducted. However, integrated dynamic models lack common interoperability procedures or standardized codes. For these reasons, the combination of a BIM design tool and a BPS tool still creates interoperability problems on which the research community is investigating.

In this study, the flow of information from BIM to BEM is not automatic because of the mapping process, which is time-consuming and made possible human oversights. The use of visual scripting Autodesk Dynamo has facilitated the modelling and verification of 3D information modelling but has been used exclusively during the first part of the workflow, in Revit. To automatically create the energy model and thus have an automatic interoperability, all IFC information should be read in IDA-ICE without the creation of new parameters. Overall, the transmissions result it is considered acceptable despite some clarifications to be corrected. In case of an automated BIM to BEM fewer time resources and efforts would be necessary and the optimisation would become a part of a standardised design process. Finally, the use of BIM in Italy is still poorly widespread It is considered an innovative solution but its straightforward application is still remote, apart from regulatory obligations. The first one, reducing data transfer errors and studying the use of other energy software associated with BIM. The second, continuing to investigate IDA-ICE data transmission by a complex case study, inserting special plant systems, in order to simplify and facilitate the achievement of the ZEB objectives. IDA-ICE has in fact the possibility to be integrated by MATLAB codes, future research will focus on these aspects.

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