Interoperability between BIM and building energy modelling – a case study

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Abstract
As Building Energy Modelling (BIM) is spreading in recent years, some interoperability issues between BIM and dynamic Building Energy Modelling (BEM) are raising. This study performs an investigation considering as a case study two terraced buildings located in Rome. During their early design stage, the tools used for modelling were Revit (BIM platform) and Design Builder (Energy Plus engine). The main difficulties and limitations found in the interface between the two programs are discussed. Some suggestions are proposed in order to improve the interoperability between BIM and BEM models.

Introduction
Building Information Modelling (BIM) is a shared digital representation of a building, that usually employs a 3D representation and whose physical and functional characteristics are based on open standards for software interoperability. The use of BIM is spreading in the construction industry and it is also considered as one of the core concepts in the Industry 4.0. The European Directive 2014/24/EU (European Parliament and Council, 2014) introduced some guidelines about the use of BIM in the design and realization of public works. The application of BIM is strongly recommended to increase the effectiveness and the transparency of public procurements.

BEM is a physics-based software that aims at evaluating the energy use of buildings. The inputs are generally the building geometry, the construction materials, lighting, HVAC, domestic hot water and renewable generation system configurations and control strategies, schedules of occupancy, thermostat settings and local weather. Within the BEM model some physical equations are implemented to calculate thermal loads and resulting final and primary energy use, along with occupant comfort indexes or energy costs. The models can be distinguished in stationary (monthly average data inputs are employed) and dynamic performing simulations, on hourly or shorter basis.

The integration of BIM with BEM is expected to play a key role for energy simulation in construction projects (Kamel and Memari, 2019). The detailed simulation of buildings energy consumption, along with the evaluation of their embodied environmental impacts is, in fact, fundamental in the design of low-energy constructions or in the retrofit of the existing stock (Asdrubali and Grazieschi, 2020; Asdrubali et al. 2020). However, the interoperability between the two platforms is still a research domain. It is because the interface between programs is not properly solved yet and this often leads to time consuming efforts and frustration among modellers.

The investigation of this work is performed considering as a case study the design of a new residential complex composed of two terraced buildings located in the eastern belt of Rome. The two buildings are very similar and are designed following the most updated regulations about energy efficiency in Italy: they aim at the nearly zero energy standard. During their early design stage, the buildings were modelled using Revit as a BIM platform. The BIM model was then exported in DesignBuilder (DB) in order to perform a dynamic simulation of the energy consumptions in an optimization perspective. The work is organized as follows: a review about the state of the art is provided in the first section; then, the case study and the methodology adopted are introduced; the results are shown in the third section; finally, a discussion about the future perspectives is deployed before the conclusions.

State of the art
The integration of different simulation environments is a challenge that has been supported by industry and specialized practitioners because of its potential to reduce modelling time deriving from the necessity of a continuous manual creation of buildings data. An automatic exchange of the data could be useful and time saving for users, but few software environments support an adequate and robust translation process.

BIM offers the potential of data exchange between different simulation environments. Two data formats usually facilitate the translation of data between BIM and BEM programs:
- Green Building XML Schema (gbXML)
- Industry Foundation Class (IFC)

The gbXML is an open format developed to facilitate the exchange of building data stored in Building Information Models (BIMs) to building performance simulation tools. The gbXML is integrated into a range of Computer-aided design programs and engineering analysis tools (Green
Building XML Schema, 2021) allowing them to communicate with each other: this schema is integrated both in Revit and in DesingBuilder.

IFC is developed by buildingSMART, a worldwide industry body. The aim of the project is to overcome the barriers to the interoperability of data, making the cooperation between users employing different software possible. IFC is able to share geometry information, internal loads and HVAC schedules and specifications (Hitchcock and Wong, 2011; Bazjanac and Maile, 2004). IFC files contain geometric configurations and material properties, but in a form that might not be directly usable for a thermal simulation engine due to the absence of 2nd-level space boundary information.

Lilis et al. (2017) introduced an algorithm (CBIP) that extracts geometrical information from a IFC file and transforms it into 2nd-level space boundary data. In order to be suitable for CBIP processing, the IFC should however respect some quality rules that include completeness and correctness criteria (Katsiagarakis et al., 2019). Revit is IFC certified but not DesingBuilder so it was not considered for this work (buildingSMART, 2020).

IFC format can however exchange data with EnergyPlus using the IDF Generator (Bazjanac, 2009), developed at the Lawrence Berkeley National Laboratory: it transforms IFC file into an EnergyPlus input-data file (IDF) after the Geometry Simplification Tool (GST) has simplified the original building geometry.

Ever if the interoperability seems to be guaranteed, different authors have already complained about its limitations showing that it remains unsolved even if a strong adoption of IFC and collaborative web-based platforms are developing (Sattler et al., 2019).

Kamel and Memari (2019) showed that not all the data required for energy simulation were exported properly using the gbXML method and proposed a corrective tool that was developed using Python.

El Asmi et al. (2015) showed that even the most advanced data framework failed to generate reliable BEM models from BIM exportations and that not all the information required were exchanged.

BIM models usually contain a high amount of information that is not necessary for energy analyses. The Level of Development of some BIM models is sometimes too high and a reduction of the information to the required extent is proposed by some authors (Georgescu and Mezić, 2015).

Gourlis and Kovacic (2017) showed that a simplification of the architectural models, and a re-definition of the boundaries is essential for the proper definition of the thermal zones when a BIM model is exported via gbXML format in the OpenStudio Plug-in for SketchUp.

Fernald et al. (2018) analysed the translation process of BIM models into BEM programs considering different tools and workflows: it was shown that the process is still not automated and quite time consuming since it requires the users’ intervention. The different cons in using the available tools and methodologies are highlighted: disjointed geometries, values for simulation that cannot be accessed, values that are incorrectly imported, necessity of simplifications, necessity of reduction of the level of detail in the BIM file, human-based errors.

Pezeshki et al. (2019) showed that the information delivered through gbXML and IFC formats is often not interpretable by the BEM tool since it is not accurately exported by the BIM tool. The lack of an adequate interoperability is perceived by the building operators as an increase in costs and it contributes to hinder the diffusion of BIM technologies.

Methodology

In order to evaluate the interoperability issues between the BIM and BEM programs, a residential complex was chosen as a case study. It was firstly modelled in a BIM environment and then exported into a dynamic BEM program. The following sections detail the procedure adopted.

Case study

The case study is a residential complex located in Palestrina, a city that is twenty-five kilometers far from Rome, in the south-eastern belt of the capital of Italy. Palestrina has a colder climate in comparison with Rome since it is farther from the seacoast: the degree days are 2141 (which implies the classification in climatic zone E) while central Rome has 1415 degree-days (climatic zone D).

The residential complex selected as case study is characterized by two buildings (called unit A and unit B) that are composed by terraced houses. Unit A has a gross internal surface of 83 m² while unit B has a gross internal surface of 166 m². The two units are composed by two apartments arranged in two levels: the living area is on the ground level while the sleeping area is on the first floor.

The thermal properties of the components of the two residential units are designed following the most updated legislation about energy efficiency in force in Italy (Italian Ministry of Economic Development, 2015) while the load bearing structure is framed and realized in reinforced concrete. The opaque walls are composed by sandwich hollow-brick layers with a thermal insulation layer of 8 cm interposed. The ground floor is characterized by a 12 cm insulation layer separated from the ground by a vapor barrier and overcome by the paving.

The first floor is built with a concrete structure lightened by hollow brick blocks: the underfloor heating system guarantees insulation too. The roof is realized with a wooden structure with an 8 cm insulation layer located before the ventilation chamber and the tiles. The windows are PVC framed and gifted by a double 4-20-4 low-E glass filled with argon.

A thermal zone was defined for every room of the four apartments. The U-values of every building component and the respective minimum value recommended by the
Italian legislation for new buildings are reported in Table 1.

**Table 1: U-value of the building components and Italian limits (Italian Ministry of Economic Development, 2015).**

<table>
<thead>
<tr>
<th>Component</th>
<th>U-value [W/m²K]</th>
<th>Min U-value [W/m²K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque walls</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Ground floor</td>
<td>0.22</td>
<td>0.29</td>
</tr>
<tr>
<td>First floor</td>
<td>2.22</td>
<td>-</td>
</tr>
<tr>
<td>Roof</td>
<td>0.22</td>
<td>0.26</td>
</tr>
<tr>
<td>Windows</td>
<td>1.54</td>
<td>1.80</td>
</tr>
</tbody>
</table>

The four apartments are equipped with an air-to-water heat pump that guarantees heating, domestic hot water (DHW) and cooling. An underfloor heating system is provided for heating while fan coils are installed as emission systems for cooling. Finally, in order to reach the minimum renewable energy coverage established by the Italian law (President of Italian Republic, 2011), a roof-mounted photovoltaic system of 6 kWp is planned for Unit A and of 9 kWp for Unit B.

**Methodology**

This study was developed in six steps:
- Data Collection;
- Creation of a Building Information Model (BIM);
- Creation of an Energy Analysis Model (EAM);
- Data quality checking and exportation of the EAM data in gbXML format;
- Creation of the Building Energy Model (BEM);
- Addition of the information still missing to run a detailed dynamic simulation in the BEM environment.

After the definition of the characteristics of the buildings components it was possible to create the BIM model within the software Autodesk Revit (see Figure 1 and Figure 2).

Revit was chosen because it is the most common software in construction and design companies worldwide, increasing the significance and reproductibility of this investigation.

All the information already described in the previous section was inserted in the BIM model as input and included in the EAM.

Following the shortcuts menus recommendations, HVAC typologies and efficiency were specified in the BIM model: a residential 14 SEER/8.3 HSPF split/packaged heat pump was selected. The schedule of the systems is set to 12 hours/7 days.

Lighting characteristics were also defined in the BIM environment: a power density of 1.66 W/m²-100 lux was defined.

On the contrary, BIM program did not permit to define the occupancy density and the schedule for every thermal zone.

The Level of detail reached in the BIM model was equal to LOD 300.

Before the creation of the exportation file, an EAM was developed in the BIM interface (see Figure 3).

Some modifications were necessary in the original BIM model to remove the data that were not necessary for an energy analysis (e.g. removal of the load bearing structure): this step can be considered a preparation of the BIM to facilitate the exportation.

After that, in order to export the model into DB, a gbXML file was created: a data quality checking of the file was performed using the tool already integrated in Revit. DesignBuilder (DesignBuilder Software Ltd, 2020) is a powerful interface of Energy Plus simulation engine that is very used for dynamic energy simulation both in the scientific literature and in the professional world.

Once the gbXML file was opened in DB (see Figure 4), the BEM software capability of reading correctly the input file was checked.

As not all the input data necessary for a detailed dynamic energy simulation were included after the importation, the intervention of the user in the BEM environment was necessary. The different levels of user’s intervention are detailed in the following sections.

The results about the primary energy consumptions of the two residential units that were obtained with or without the user’s intervention were compared with reference values in order to determine the influence of this final step.
definition. Moreover, the data quality checking performed by Revit during the creation of the gbXML file did not show any error.

**Interventions within BEM**

Important interventions of the modeller were necessary after the importation of the BIM data in the BEM environment. It regarded the verification of the data exchanged and the addition of the missing input. The importation of thermal properties and the definition of construction materials were successful but they were not automatically assigned to the related envelope elements (external walls, roofs, ground floors, windows, ...). The user so was requested to assign them manually. The translation of the geometry of the buildings was trickier. The geometry of the two residential units is quite simple since they are characterized by planar surfaces and extruded volumes. The BEM software was able to recognize the thermal zones already defined in the BIM model. The recognition of planar geometries proved to be solved. The difficulties were found in the recognition of the balconies: as it can be noted from Figure 3 and Figure 4, they were not included in the EAM and so imported in DB. Similarly, also the shutters were not recognized in the energy modelling program.

As regards the HVAC, DHW and lighting specifications, it was not possible to exchange data about generation typologies, efficiencies, and schedules. Also control systems, such as the setpoint temperatures, were manually inserted in the BEM environment. In the same way, also the information regarding renewable energy generation was manually fixed within the energy simulation environment since data were not conveyed by the gbXML file.

Finally, it was not possible to exchange the information about internal gains, ground or neighbor buildings reflection properties and appliances loads.

Table 2 summarizes the information that was exchanged, and the limitations found during the process. Different scenarios involving variable level of intervention of the user were supposed. The “Automated” scenario excluded any intervention of the user in the energy simulation model except for:

- Selection of the right wall stratigraphies and not the default settings in DB;
- Selection of the windows imported from the BIM model and not the default ones.

A minimum intervention of the user was then supposed (this scenario is called “Preliminary”). It involves the:

- Definition of HVAC specifications that are equivalent to the ones already set in the BIM model;
- Definition of real HVAC schedules;
- Insertion of real setpoint temperatures (20°C for heating and 26°C for cooling);
- Definition of real DHW consumption parameters in DB;
- Definition of real lighting properties in DB.

**User’s interventions**

The experience proposed about the interoperability between the two programs implied the necessity of a certain level of intervention of the modeller. For this reason, the interface between BIM and BEM cannot be considered automated in this study. This section describes the two main areas of intervention that were requested by the user: checking of the data quality, and manual adjustment of the BEM model.

**Data quality checking**

The first significant intervention of the modeller regarded the adjustment of the BIM in order to prepare it for the exportation. In this phase the capability of the modeller in simplifying the BIM without loosing the information required for the energy analysis is directly involved. The checking, instead, regarded the completeness and correctness of the information contained in the BIM file. As regards the completeness, conditioned spaces, ground boundary conditions and material properties were properly defined; at the same time, the predefined template, based on the building and space types, was used for internal gains (schedules and densities). Concerning correctness, no geometric errors were detected in space
The “Final” model considered also the insertion of the photovoltaic systems in DesingBuilder.

Table 2: Data exchanged between BIM and BEM and corresponding limitations.

<table>
<thead>
<tr>
<th>Permitted</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>✓ Errors occurred in the balconies that were not considered by the EAM. Trees were also not considered.</td>
</tr>
<tr>
<td>Thermal properties</td>
<td>✓ They were not automatically assigned.</td>
</tr>
<tr>
<td>Windows</td>
<td>✓ Thermal characteristics were correctly imported but it was not possible to exchange information about shutters.</td>
</tr>
<tr>
<td>HVAC</td>
<td>X The settings of the BIM were not exchanged. Moreover, the DHW consumption rate (l/m²) was directly set in DB.</td>
</tr>
<tr>
<td>Schedules</td>
<td>X The schedule defined in the BIM was 12/7 but the information was not exported.</td>
</tr>
<tr>
<td>Renewable energy systems</td>
<td>X The data were not exchanged (e.g. panel surface, tilt, orientation, …)</td>
</tr>
<tr>
<td>Lighting</td>
<td>X The information inserted in Revit was not imported: the consumption parameter (W/m²-100 lux) was reinserted in DB considering an efficiency of LED lamps of 60 lumen/W.</td>
</tr>
<tr>
<td>Internal gains</td>
<td>X Revit did not permit to define occupation profiles and internal gains: e.g. a density of 0.070 people/m² was defined in DB also customizing hours of occupancy.</td>
</tr>
<tr>
<td>Loads</td>
<td>X They were not set in the BIM and so not exported in the BEM: e.g. the metabolic rate was directly defined in DB.</td>
</tr>
<tr>
<td>Ground/neighbour reflections</td>
<td>X They were not considered in the BIM modelling. Materials optical properties were defined in DB.</td>
</tr>
</tbody>
</table>

Successively, further specifications were added in the BEM to obtain a more “Detailed” model. The following manual interventions were undertaken:
• Insertion of balconies;
• Insertion of shadings in windows;
• Definition of occupancy schedules;
• Definition of internal loads (occupancy, electrical appliances, …); 
• Definition of ground and neighbour buildings reflection properties.

The “Final” model considered the insertion of the photovoltaic systems in DesingBuilder.

Table 3 summarises the data inserted, checked or specified by the modeller in the BEM program for every scenario supposed.

Table 3: Data inserted/specifed (✓), not simulated (x) or left to default values for every scenario of the modeller’s intervention.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Automated</th>
<th>Preliminary</th>
<th>Detailed</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Windows</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>HVAC</td>
<td>Default</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Setpoints</td>
<td>Default</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DHW</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lighting</td>
<td>Default</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Balconies</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Shadings in windows</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Internal gains/loads</td>
<td>Default</td>
<td>Default</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Reflections</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Renewable generation</td>
<td>X</td>
<td>X</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

Results
The results about the non-renewable energy consumption of the building with and without manual adjustments of the user are shown in Figure 5 for Unit A and Figure 6 for Unit B. The results are compared with the reference values of non-renewable primary energy consumptions calculated within DB software and with input values established by the Italian legislation (President of Italian Republic, 2011; Italian Ministry of Economic Development, 2015): they represent the reference for the energy design of new buildings in Italy.

As it can be noted, the intervention of the modeller is necessary: the “Automated” scenario, in fact, is not able to simulate the consumption for cooling and DHW of the two residential units and adopts default values for a lot of the inputs.

The inclusion of renewable energy generation information in the interoperable data is important since it can have a sensible influence on results, principally in case of low-energy or net zero energy buildings. In particular, the inclusion of the renewable energy generation in the calculations permits to correctly approximate the non-renewable energy demand of the reference building.

Discussion and future perspectives
This experience on the interoperability between BIM and BEM showed the necessity of a series of precautions to be adopted by the modeller that underline how the process needs to be refined. During the exportation process, in fact, a lot of information that had already been defined within the BIM environment was lost.

Table 3: Data inserted/specifed (✓), not simulated (x) or left to default values for every scenario of the modeller’s intervention.
This fact limits the real potential of BIM. As already stated, for example, the gbXML file exported from Revit does not contain data about the temperature setpoints, the occupation profiles of the building, the activities done in thermal zones, the characteristics and performances of energy systems. All this information must be set directly in the energy simulation program. Even if the right importation of the geometry and thermal properties permitted a consistent time saving avoiding the recreation of a completely new 3D model, the lack of data transfer about the energy systems represents a strong limitation in the interface between the considered BIM and BEM programs.

Another real gap in the interoperability between the two modelling environments is also the lack of bidirectionality: even if it is somehow possible to exchange data from BIM to BEM, maintaining a lot of relevant information, it is not possible to do the inverse. The modifications added to the imported model in DB are not useful to update the BIM file.

The improvement of the interoperability conditions could represent a significant reduction in modelling time and costs. This is surely the most important benefit since the traditional method would foresee the creation of a new 3D model in the energy simulation program containing the largest part of the data already defined in the BIM file. The data and graphical drawings already produced would be used only as background reference. The production of the BIM would be finalized only to the graphical representation, but its real potential is in the exchange of the information that guarantees the management of the project. The integration design between the architectural representation and engineering aspects can improve the quality of the projects and reduce time and costs spent for the transmission of contents.

Conclusions

The interoperability issues between BIM and BEM software are not perfectly solved yet. The data transfer can be considered accurate for very simple geometries and thermal zones such as the ones defined in the case study selected. However, the interpretation of balconies and shading systems (e.g., shutters in windows) by the BEM software caused the trickiest issues. Moreover, it was not possible to exchange the information regarding the HVAC systems and the renewable energy generation.

The limits experimented in this case study make the building energy simulation possible only after the intervention of the modeller in the BEM environment. The transformation of the BIM model into Design Builder so involved different types of limitations and it implied the necessity of manual intervention of the modeller; the process of adjustment of the BIM file and of data tracking and revision was time consuming and required a certain level expertise. The process, in fact, forces the user to check for the interoperability issues and, in some cases, to fix them manually after the importation. The interpretation of BIM-exported data is so prone to the user’s capability and experience that are called to act to obtain a reliable automated energy model.

References


