# Building Information Modeling (BIM) and Building Energy Modeling (BEM): Interoperability and Interactive Data Representation for the Energy Management of the Existing Buildings

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## Abstract

The text discusses the potential for energy efficiency improvements in existing buildings, emphasizing the importance of digital modeling and Building Performance Simulation (BPS) methods to achieve Net Zero Energy Building (NZEB) standards. The integration of Building Information Modeling (BIM) and Building Energy Modeling (BEM) approaches is highlighted as crucial for enhancing energy efficiency. The proposed workflow involves four steps: i) collection of building data through documental analysis and on-site surveys; ii) the construction of a BIM model and its production in Industry Foundation Classes (IFC) standards, including thermo-physical parameters; iii) the developing the BEM model; iv) the creation of a Virtual Reality (VR) interactive environment. The methodology is tested on an office building at the University of Rome Tor Vergata, built in the 1980s. Key outcomes include verifying data interoperability, optimizing energy simulation processes, and enabling interactive exploration of energy data through VR techniques. This integrated approach reduces errors, time, and costs, while also serving as a decision-making support tool for building managers and an educational tool for energy design awareness. The study presents a scalable workflow for energy building management and lays the groundwork for innovative digital twin development for buildings and structure.

## 1. Introduction

In Europe, the 20th Century existing building stock, constructed using industrial-derived techniques and materials, needs to undertake massive assessment of its energetic performances. Looking to Italy, 75% of residential sector building stock was constructed before 2000, avoiding detailed consideration about energy consumptions, and only 2% was built after 2010, according to recent environmental criteria (Gevorgian et. al, 2021). The enhancement of the energy performance of this building stock – achieving Net Zero Energy Building (NZEB) standards (European Commission, 2020) – can significantly contribute to global efforts to mitigate climate change (Arenas, 2024).

This pursuit represents a significant research endeavor and requires a multidisciplinary approach and a continuous updating of research tools.

In particular, the process benefits from the combination of a solid knowledge base of the building, obtained through documental analysis and on-site surveys, with advanced digital modelling, to organize information, to support Building Performance Simulation (BPS), and to facilitate the visualization of data. In this field, one promising approach is the integration of Building Information Modeling (BIM) and Building Energy Modeling (BEM) methodologies (Spiridigliozzi, 2019). By combining these approaches, we can leverage the wealth of building technology data provided by BIM with the detailed energy simulation capabilities of BEM. This integration allows for a holistic assessment of a building's energy performance and facilitates informed decision-making throughout the design, construction,

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and operation phases. However, despite the significant advancements and widespread application of both BIM and BEM in recent years, challenges remain in establishing an efficient workflow that enables seamless interoperability and interactive visualization of energy data. In this framework the interoperability workflows support the integration of sensors-acquisition data, to be exploited for both the calibration and validation of the BEM model and the active monitoring of the building.
Leveraging Virtual Reality (VR) techniques presents an exciting opportunity to enhance the representation and understanding of energy-related information (Pan, 2023). By immersing stakeholders in virtual environments, VR enables more intuitive exploration and analysis of complex energy data. However, developing effective VR-based tools for energy analysis and decision-making requires interdisciplinary collaboration and innovative approaches (Panya, 2023).

## 2. Methods

The proposed workflow consists of five steps: i) construction of a philological BIM model based on the original project documentation and photogrammetric surveys of the actual state of the building; ii) production of the geometric model exploiting IFC standards; iii) informative enrichment of the IFC databases embedding the thermo-physical parameters of the building elements; iv) development of the BEM model based on the IFCs; v) development of a VR interactive environment including geometries, graphical elements and data panels, based on the IFC (Elagiry, 2020).
The workflow is based on combining different software platforms and codes. In particular, Autodesk Revit 2023 is used for the BIM's first development while the informative customization of the model, in terms of thermophysical parameters, is performed by exploiting the 'IfcOpenShell Phyton' open-source Toolkit. On the basis of the customized IFC, the energy simulation is developed exploiting the IDA-ICE environment (Sahlin, 2004), while the VR interactive environment, embedding the energy data – concerning thermophysical parameters of the building elements and main results of the analyses – is built using the Unity platform with the Unity XR Interaction Toolkit by Unity Technologies (San Francisco, CA, US) and then tested using different head-mounted displays (HTC Vive Pro, HTC XR Elite and Meta Quest Pro).

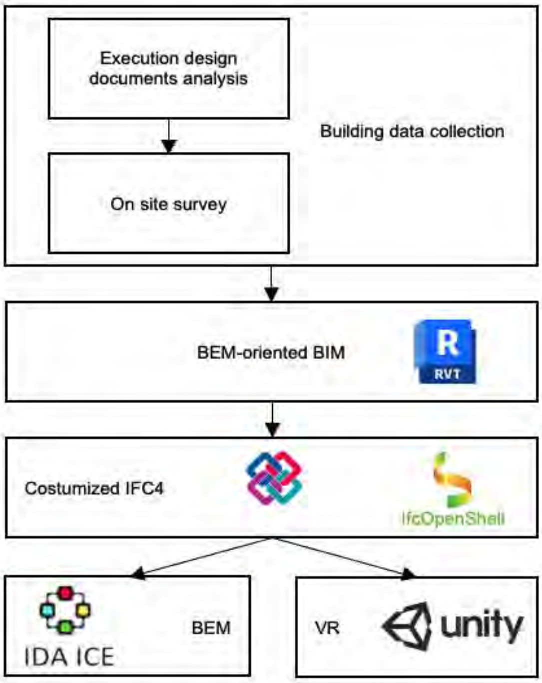

Fig. 1 – Workflow diagram

## 3. Results

The proposed methodology is tested on the case study of an office building of the University of Rome Tor Vergata, considered a sample of the late 20th century existing building stock featuring a complex building system composed of a steel load-bearing frame, reinforced concrete slabs, and precast concrete panels for the envelope. A single room of the building, with two windows, was considered as a sample to test the interoperability procedure within the VR data visualization.

### 3.1 From Building Data to IFC

For the collection of building data intended for integration into a Building Information Modeling (BIM) system, the principal source considered is the repository of building execution design documents preserved within the University's technical archive. These documents contain significant building data relating to geometry, detailed building elements, and construction materials. Specifically, the execution drawings include precise specifications regarding the composition of the building envelope, encompassing the layering of façade panels and the classification of window frames.

To ensure the accuracy and comprehensiveness of the data, information extracted from the original design drawings undergoes cross-validation with on-site survey data. This process facilitates the precise characterization of the "as-built" condition of the structure. The amalgamation of data derived from building execution design and on-site surveys serves as the foundational input for subsequent BIM processes. Within the BIM Authoring platform, Revit 2023, a conventional modeling approach is adopted, making use of the platform's standard native functionalities. For instance, geometric modeling of the building envelope relies on the "architectural wall" system library, while structural components are represented using standard steel component libraries. Concurrently, the informative modeling phase follows a highly customized procedure tailored to project-specific requirements. This involves extensive utilization of Revit's native take-off sheet function and the enrichment of the Industry Foundation Classes (IFC4) open standard. The IFC enrichment entails associating specific Property set data with building elements, encompassing thermal and physical properties of materials. The considered thermal and physical parameters are specific heat capacity, thermal conductivity, and mass density. They are associated to the IFC4 Ifc Materials category with specific names presented in Table 1.

Table 1 – IFC4 names of the thermal-physical parameters

| **Parameter name** | **Ifc name** |
|---|---|
| Specific Heat Capacity | IfcSpecificHeatCapacityMeasure |
| Thermal Conductivity | IfcThermalConductivityMeasure |
| Mass Density | IfcMassDensityMeasure |

In particular, the native take-off sheet function was used for the labelling of the building areas depending on their intended use, numbering, level and exposure to map the results of IDA-ICE energy simulation to each thermal zone. The native take-off sheet function was further used to prepare the IFC for the VR. In this case the sample, composed of a room with two windows, was considered. The take-off sheet elaboration focuses on the association of building properties, such as geometric features and thermal parameters to the single building component.

## 3.2 From IFC to BEM

The enrichment of IFC with Building Energy Modeling (BEM)-oriented Property Sets, which include thermal and physical properties of materials, significantly reduces data loss during the interoperability process. This enrichment is achieved through the utilization of a Python script that leverages the IFC Open Shell library. The script is designed to automatically parse a simple text file containing thermal and physical properties of materials and populate specific BEM-oriented Property Sets of each material, embedding the corresponding values of these parameters. The script considers the association between thermal and physical parameters and the categories of the ICFx4 open standard, presented in Table 1. Fig. 2 illustrates the main step of the script.

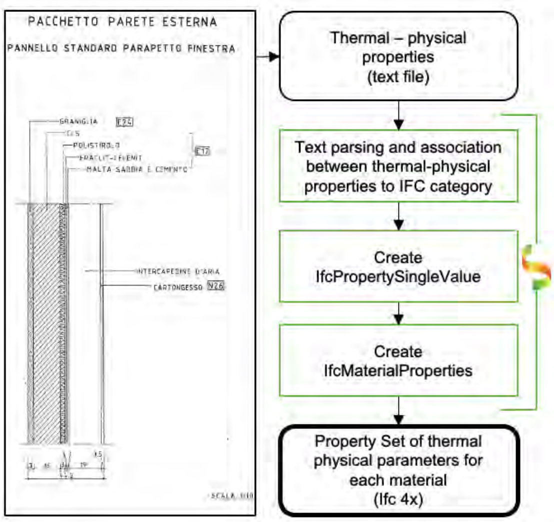


Fig. 2 – The algorithm to generate Property Set of thermal and physical parameters of the building materials in IFC4

The IFC file also contained informative data regarding the labeling of building areas and all geometric features of the building. Fig. 3 displays an image of the IFC model embedding the thermal and physical parameters, while Table 2 provides a concise overview of the parameters that can be read by the BEM.

Table 2 – Interoperability check

| BIM data | IFC4 | IDA-ICE 4.8 |
|---|---|---|
| Geometry | x | x |
| Envelope stratigraphy | x | x |
| Wall | x | x |
| Windows | x | x |
| Thermal Zone | x | x |
| Thermal Properties | x | - |

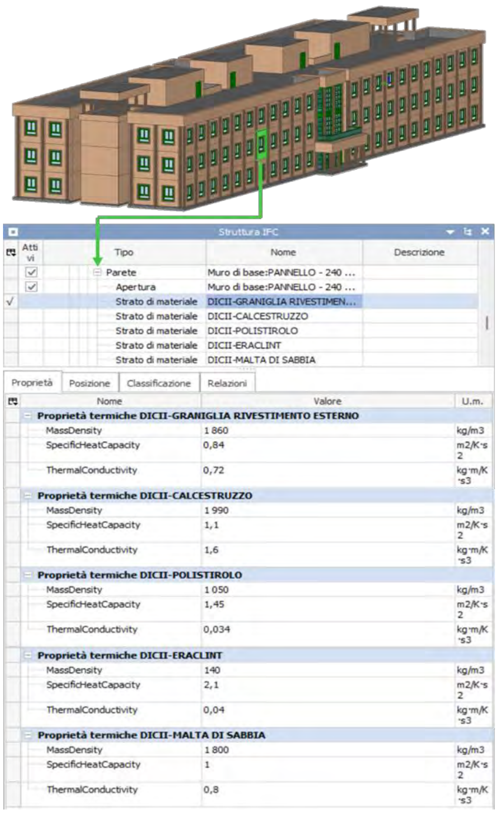


Fig. 3 – The algorithm to generate Property Set of thermal and physical parameters of the building materials in IFC4

All the geometric and informative data contained in the IFC file were correctly read by the IDA-ICE model: Fig. 4 shows two examples of mapping to imported IFC resources in the IDA-ICE model: first, the external wall and then of the thermal zones. To associate thermal properties of each material embedded in the envelope stratigraphy, a manual mapping is required by the actual version of the software IDA-ICE 5.0.

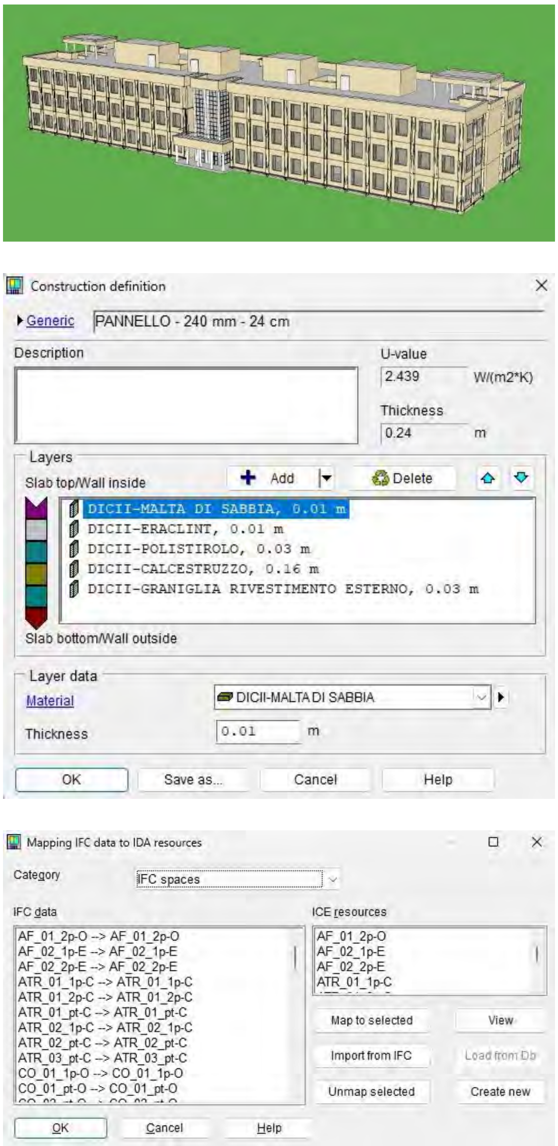


Fig. 4 – 3D representation of the BEM model in IDA ICE 4.8 showing the wall stratigraphy and thermal zones parameters

## 3.3 From IFC to VR

With the aim of making the geometric model of the building usable, navigable, and interactively interrogable, a methodology for the integration of the BIM model in a generic virtual reality environment has been designed and implemented. The environment was built using the Unity platform by Unity Technologies, which represents the state of the art for the development of virtual and augmented reality environments. Version 2023.1 has been used. The main challenge in the integration is the ability to manage the correct importing of the model within a scene, including the transfer of the VR Property Set of the various geometrical objects (walls, windows, floors, etc.). In fact, commonly used import systems limit the transfer to geometrical features and texture properties only. Other properties, such as structural or energy variables or even simulation results, may be of interest for a comprehensive exploration of the building. They can be recalled, queried, and inspected by the user in the virtual scene. For this purpose, a C# script has been implemented and attached as a *Component* to an empty *Game Object* in Unity. The script allows for the reading of a generic IFC4 format file, extracts the names and values of the variables of the VR Property Set, and associates them with their respective bodies as additional user-defined variables. By assigning these variables as global, it is possible to recall them at any time during the acts of interaction and navigation. The reading of the file, parsing of strings and matching for names are performed using *Microsoft Regex* class methods for extended compatibility. After the importing, it is possible to make an object of the model interactable, providing that a user selection corresponds to the popup of an informative panel summarizing the specific properties. This is made possible thanks to the use of the XR Interaction Toolkit, which is a third-party library fully integrated into the Unity environment. It allows the simplified management of user tracking, including the interaction with virtual objects using gestures and controllers. It has been successfully used in many engineering applications for both virtual and augmented reality (Cellupica et al., 2024; Cirelli et al., 2024).

Fig. 5 summarizes the algorithm implemented in the VR Property Set import script.

Fig. 6, on the other hand, shows an image of the immersive navigation experience in which the user is inside the BIM geometric model and interacts by selecting one of the walls, obtaining the appearance of a panel summarizing the remarkable properties.

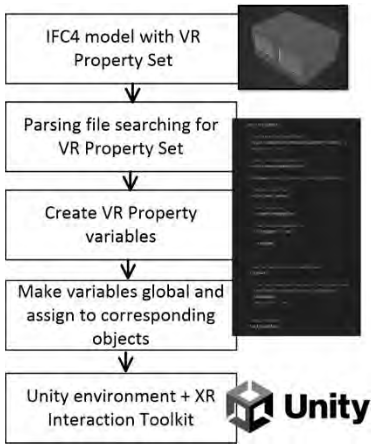


Fig. 5 – The algorithm for importing VR Property Set into Unity

Fig. 6 – The implemented virtual reality environment for testing the proposed procedure. The user is wearing a HTC Vive Pro 2 helmet

The complete navigation and interaction methodology has been tested in the Joint Laboratory of Virtual and Augmented Reality using the most popular virtual reality systems: HTC Vive Pro, HTC XR Elite, Meta Quest Pro and Meta Quest 3. Navigation and interaction using the HTC Vive Pro system have proven to be the most stable and accurate. However, the resolution performance is comparable between the four headsets. Meta Quest Pro has proven to be the most comfortable to wear, considering both the helmet and the controllers.

## 4. Conclusions

Among the main results of the work, the analyzed case study presents: i) the verification of data interoperability between the BIM and BEM models, taking advantage of the customization of the IFC open standards; ii) the optimization of the energy simulation process, in terms of modeling time and cost, fully fruiting the organization of the database, in both geometric and informative terms, of the BIM model and minimizing data loss; iii) the effectiveness of the interactive exploration and interrogation of the energy data, exploiting the VR techniques, for both the knowledge and the energy management of the existing buildings.

In this sense, as a further step, the workflows will enclose even the sensors-acquisition data for microclimatic measurements – already deployed in the considered case study – to be exploited for the both the calibration and validation the BEM model, and to the potentiality of the VR representation.

From a broad perspective, the present paper remarks that the use of a unified BIM-BEM database limits the possibility of error caused by the development of different simulation models and, as a result, reduces costs and time; on the other hand, the integration with interactive visualization enabled by VR expands the scope of application of integrated BIM and BEM models as building management support tools dedicated to multiple levels of users, without specific modeling skills.

At the operational level, the proposed workflow can be adopted as a tool for the energy management of the existing building stock, enabling at the same the fruition of organized building data and the results of the BEM, supporting the planning of maintenance and energy retrofit solutions.

In this sense, the development of VR visualizations of the energy data allows, on the one hand, access to rapid preliminary energetic analyses of the buildings, providing a practical "decision-making" support tool for building managers and, on the other hand, a robust dissemination and educational tool to raise awareness of the importance of the energy design process.

## Acknowledgement

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