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METHODOLOGY FOR OPTIMIZING THE INTEROPERABILITY BETWEEN BIM AND BEM SOFTWARE

TESI DI LAUREA MAGISTRALE IN
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Abstract

The "Global Status Report 2019 for Building and Construction" published by the "Global Alliance for Buildings and Construction (Global ABC)", shows that the CO₂ emissions of the world's buildings and their construction are around 39% of the total carbon dioxide emissions. Today the challenge in being able to balance the demand and supply of energy is also increasing due to the diversification of technologies and energy resources. Fortunately, the construction sector can make use of methodologies and tools capable of simplifying and speeding up the energy analysis process by taking advantage of the integrative design methodology with the related software now commonly called BIM methodology. BIM (Building Information Modeling) has significant benefits for the professionals involved, minimizing what may be design errors and improving the communication of project information. BIM modelling is also able to interface with the architectural, structural, energy and plant design process. This thesis aims to analyse the criticalities of data transfer from the BIM model to the energy design software for the creation of an energy model commonly called BEM (Building Energy Model). The objective is to optimize the interoperability between BIM and BEM. The work is divided into:

- Introduction on what are BIM and BEM
- BEM model design software
- Data entry on the BIM model for energy calculation purposes
- IFC/gbXML settings for energy analysis export
- BIM-BEM interoperability analysis
- Analysis of Revit - Termolog interoperability via IFC format
- Conclusions

Abstract in italiano

Il “Global Status Report 2019 for Building and Construction” pubblicato dalla “Global Alliance for Buildings and Construction (Global ABC)”, mostra che le emissioni di CO₂ degli edifici del mondo e della loro costruzione sono intorno al 39% delle emissioni di diossido di carbonio mondiali. Oggigiorno la sfida nel riuscire a bilanciare la domanda e l’offerta di energia è in aumento anche a causa della diversificazione di tecnologie e risorse energetiche. Fortunatamente il settore edilizio può avvalersi di metodologie e strumenti in grado di semplificare e velocizzare il processo di analisi energetica usufruendo della metodologia di progettazione integrativa ormai comunemente denominata metodologia BIM. Il BIM (Building Information Modeling) comporta notevoli benefici per i professionisti coinvolti, minimizzando quelli che possono essere gli errori di progettazione e migliorando la comunicazione delle informazioni di progetto. La modellazione BIM è inoltre in grado di interfacciarsi con il processo di progettazione architettonica, strutturale, energetica ed impiantistica. La presente tesi si propone lo scopo di analizzare le criticità di trasferimento dati dal modello BIM ai software di progettazione energetica per la creazione di un modello energetico comunemente chiamato BEM (Building Energy Model). L’obiettivo è ottimizzare l’interoperabilità tra BIM e BEM. Il lavoro si articola in:

- Introduzione su cosa sono il BIM e il BEM
- Software per la progettazione dei modelli BEM
- Inserimento dati su modello BIM ai fini del calcolo energetico
- Settaggi IFC/gbXML ai fini dell’esportazione per l’analisi energetica
- Analisi dell’interoperabilità BIM - BEM
- Analisi dell’interoperabilità Revit – Termolog tramite formato IFC
- Conclusioni

Contents

Abstract	iii
Abstract in italiano	iv
Contents	5
1 Introduction	7
1.1. Building Information Model	7
1.1.1. The Concept of BIM	7
1.1.2. Introduction to BIM	9
1.1.3. Dimension of BIM	10
1.2. Why BIM?	12
1.2.1. BIM - Italian regulatory requirements	12
1.2.2. BIM - Opportunities	13
1.3. Building Energy Model	14
1.3.1. gbXML	15
1.3.2. IFC	16
1.3.3. Optimal Workflow	17
1.4. BEM software	19
1.4.1. Steady state calculation method	21
1.4.2. Dynamic calculation method	23
2 Methodology	25
2.1. BIM to BEM	26
2.2. Revit model setup for ES	28
2.2.1. Weather data	29
2.2.2. Building geometry	30
2.2.3. Thermo-physical characteristics of the envelope materials	31
2.2.4. Thermal zones characteristics	32
2.2.5. HVAC system characteristics	33
2.3. IFC export settings	34
2.3.1. Assignment of IFC export classes	35
2.3.2. Assignment of IFC project parameters and property sets	36

2.3.3.	IFC export setup tab	38
2.4.	gbXML export setting	53
2.5.	Import to BEM softwares.....	63
3	Case study	66
3.1.	Example project.....	67
3.2.	Encountered errors – IFC into Termolog	68
3.2.1.	Roof	69
3.2.2.	Window Dimensions	70
3.2.3.	Window Thermal Transmittance.....	71
3.2.4.	Environments	74
3.2.5.	Thermal Zones.....	75
3.2.6.	Door Thermal Transmittance	76
3.2.7.	Project Location.....	77
3.2.8.	Double Heights.....	78
3.2.9.	Elements that cross levels	78
3.3.	Interoperability assessment.....	79
3.4.	Application of the interoperability methodology	82
4	Conclusions.....	84
5	Bibliography	86
6	List of Figures	89
7	List of Table	91
8	Acknowledgments.....	92

1 Introduction

1.1. Building Information Model

1.1.1. The Concept of BIM

The concept of BIM comes from Charles Eastman, who in 1974 published a document titled “An Outline of the Building Description System”, in which stands the definition of Building Description System or BDS. The BDS is a database capable of describing buildings at a detail allowing design and construction. Eastman idea was to build a software that manages individual library elements that can be aggregated to generate a complete building model, through a graphical interface that works for orthogonal and axonometric projections. Each object contains its own geometric description and some information relevant to the material it is made of the contact details of the suppliers and its own technical characteristics [1]. After one year Charles Eastman will introduce the concept of BIM or Building Information Modeling. The NBIMS (National Building Information Model Standard), an U.S. code that provides consensus-based standards through referencing existing ones, defines BIM (Building Information Modeling) as a digital representation of physical and functional characteristics of a facility, which serves as a shared knowledge resource for information, determining a reliable basis for decisions during its whole life cycle, from inception onward [2].

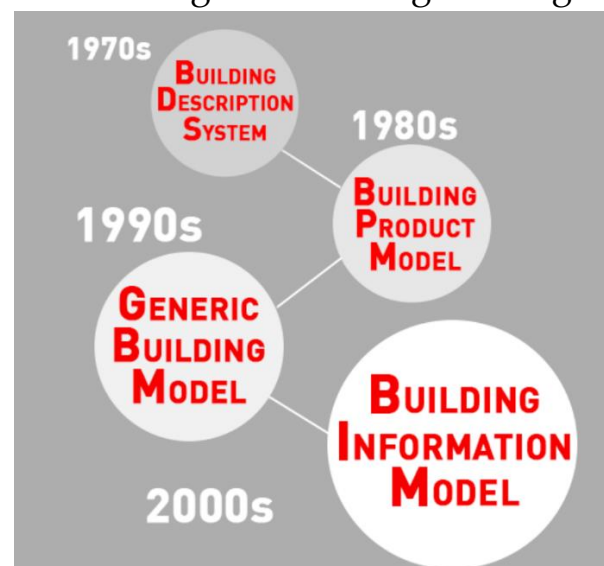


Figure 1-1 The development of BIM

Fast forward to 1989, and a new program called Building Product Model (BPM) was developed which covered design, estimation and construction processes –comprising information from projects from planning to completion. It acted as an archive and framework of concepts, technologies and standards. However, BPM only focused on product information instead of integrating information that was useful for design and construction management in the AEC industry- further development was needed.

Enter 1995 and the Generic Building Model (GBM) was introduced to expand and integrate information from current and future design that could be used throughout a project life cycle – allowing multiple collaboration points amongst a project’s stakeholders. Then, we welcomed the new millennia and if you recall, the exponential technological advancements coming into play greatly impacted and transformed the way literally everything worked. The AEC industry, no different, scurried to adopt and expand their usage of technology for enhanced project management and delivery.

Only in the 2000s Building Information Modelling (BIM) was introduced in advent of the technological revolution. It is vital to recognise that BIM is not a program or software, but a set of practices built upon prior research to utilise best available technologies, improving information flow, reducing errors and therefore increasing efficiency though collaborative construction. Currently, no single software delivers a complete BIM solution; instead, an assortment of software is utilised simultaneously throughout the Appraisal, Design, Pre-Construction, Construction and In-Use phases [3].

1.1.2. Introduction to BIM

BIM (Building Information Modeling) can be treated as advanced evolution of CAD (Computer-Aided Design) and implementation of BIM technology will contribute to greater construction industry efficiencies through increased collaboration between different project participants, less collisions and repeat work on corrections and adjustments. The BIM has become the standard definition of information modelling technology in construction industry when achieving maximum integration between different disciplines, creating a model of intelligent parametric objects and the first mass implementation.

BIM may be described as the way:

- to develop the strategy of building project design, construction, and facility management based on the computer-aided modelling and simulation technologies of the object and its development processes.
- to ensure the integrated management of graphical and information data flows combined with descriptions of process, all this performing under the integrated software environment.
- to transform individual executors into teams and decentralized tools into complex solutions, to integrate individual tasks into processes.
- to perform life cycle operations of a construction project faster, more effective, and with lower costs.

1.1.3. Dimension of BIM

Over the past years, consistent effort has been made to provide traditional three-dimensional BIM with "fourth" (4D), "fifth" (5D) "sixth" (6D) and even "seventh" (7D) dimensions [4]:



Figure 1-2 BIM Dimensions

- **Modeling (3D):** the digital model is very accurate in terms of graphics, an aspect that has become relevant in all disciplines involved in the project. Thanks to a 3D model faithful to the geometry of the real building, it is possible to evaluate in advance problems related to code checking, i.e. the control of the adequacy of the project to planning and regulatory requests and to clash detection or conflict control between the various parts making up the model.
- **Time analysis (4D):** monitor the progress of the work using one efficient tool that allows a precise organization between the interested parties. It is a duty nowadays. BIM allows you to plan the actions and times of execution necessary for the progressive progress of the work, from design to construction.

- Cost analysis (5D): the possibility of obtaining the quantities of materials required directly from the BIM model allows professionals to make calculations accurate metrics, avoiding waste of materials with a consequent increase in costs. The automatic updating of the quantities during the design makes the drafting of new metric calculations much faster than traditional methods.
- Sustainability (6D): the exploitation of natural, economic and social resources is an aspect that is now impossible to overlook in the design of new buildings. Use of BIM as a solution to the integration of sustainability in the design from la opportunity for professionals to use new and performing solutions that hold account of a quantity of data that would otherwise be unlikely to be considered.
- Building management (7D): an information model faithful to what was built (called As Built) turns out to be extremely useful even after the construction of the building itself, as it has the necessary information for maintenance and future disposal of the building.

1.2. Why BIM?

The transition to the BIM methodology is becoming more and more widespread, and the reasons why this methodology is becoming more and more widespread are very simple. The local legislation drives, year after year, to use more advanced BIM methodologies, moreover the BIM methodology offers very useful management solutions especially for large-scale projects. One of the prerequisites of any BIM protocol is to guarantee the exchange of BIM information. Clients should be the major beneficiaries of this exchange, because in this way they are able to express and monitor compliance with their needs [5].

1.2.1. BIM - Italian regulatory requirements

BIM modelling is becoming a fundamental requirement for new buildings today. In Italy, for public administration, the Ministerial Decree 1 December 2017, n. 560, establishes that all the contracting authorities require, for new construction works and interventions on existing buildings, the use of the methods and electronic tools referred to in article 23, paragraph 1, letter h), of the Public Contracts Code, following the following deadlines:

- January 1, 2022, except for ordinary maintenance works for a tender amount equal to or greater than 15 million euros.
- January 1, 2023, except for ordinary and extraordinary maintenance works for a tender amount equal to or greater than the threshold referred to in Article 35 of the Public Contracts Code (5,35 million euros for public works contracts and concessions).
- January 1, 2025, except for ordinary and extraordinary maintenance works for a tender amount equal to or greater than 1 million euros.

1.2.2. BIM - Opportunities

BIM modelling has significant benefits for the professionals involved, minimizing what may be design errors and improving the communication and control of project information. BIM can interface with the architectural, structural, energy and plant design process. It can improve the automation of the whole construction cycle, saving time and removing the probability of human errors. With BIM methodology is possible to have a better presentation of outputs, facilitating the reading of information in the management system. The real potential is the capability to store and the organize all the data of a building with the possibility to improve also existing libraries and tools. Every object of a model will so contain all the information that the user wants to define for that particular object.

Thanks to its ability to interface with the various building disciplines, BIM is nowadays able to exploit some interchange formats to export models and import them into energy or structural calculation programs.

The interchange formats contain within them the geometry but also all the information necessary for the structural or energy calculation. The most common interchange formats are:

- IFC, used as an interchange format for the structural and the energy analysis.
- gbXML, used as an interchange format for the energy analysis.

BIM technology offers the opportunity to better store and organize data but also the opportunity to minimize the time spent in the design process for energy and structural disciplines.

1.3. Building Energy Model

The energy performance of a building expresses the amount of energy necessary to meet the energy needs connected to a standard use of the building and includes the energy used for space heating, domestic hot water heating, cooling, ventilation and possibly artificial lighting and the transport of people or things [6].

Building energy simulation means using a software to predict energy consumption of a building. Simulation software can define key parameters for different parts and components of a building. This simulation should be based on virtual displays, for example, a model of a building and models that interact with energy variables, such as energy simulations. Energy Modeling means simulating energy models with an energy simulation software. This simulation software, in accordance with needs of a building, can predict monthly energy consumption, annual energy costs, annual carbon emissions, compare different efficiency measures and plan on cost savings [7]. The most important data required to study an energy model case study of a building, are:

- weather data
- building geometry
- thermo-physical characteristics of the envelope materials
- thermal zones characteristics
- HVAC system characteristics

Building Energy Modeling (BEM) intends to quantify buildings' energy performance to help designers and architects better understand the environmental impacts of their decisions [8]. Current tools allow you to import models exported from BIM software into energy calculation software. The main interchange formats are the IFC and the gbXML format. Particular attention when creating a gbXML or IFC file from a BIM model must be made on the modelling of rooms and thermal zones.

1.3.1. gbXML

The Green Building XML (gbXML) schema, developed by Green Building Studio Inc., is focused on environmental data. It was originally developed to enable interoperability between the building design in CAD software and energy analysis tools [9]. However, gbXML also attends to exchange data among diverse simulation instruments. In its format, the geometric and weather data, user profiles, and energy information are exchanged. gbXML is a bottom-up structure and is easy to comprehend. gbXML structure was created to optimize the exchange of information from a BIM model to energy calculation software. It seems to be the most suitable interchange format for energy simulation. It is more comprehensive than IFC when it comes to energy modelling where it can transfer the required data such as weather data and

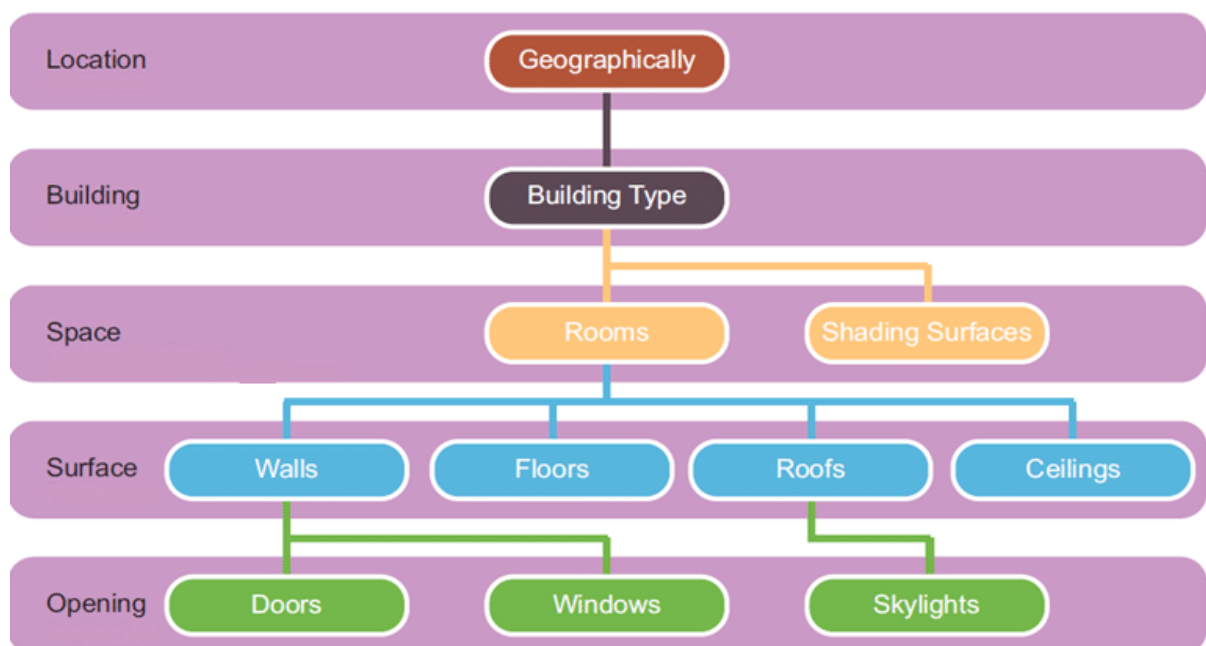


Figure 1-3 gbXML bottom-up structure

ventilation. gbXML identifies spaces similar to that of an energy model, only considering the thermal properties of virtual thickness as numerical figures.

Despite its simplified structure, the gbXML format can lead to errors when no attention is paid to the export procedure. The main causes of

errors in modelling can be the air gaps, generated by variation of the height of the room, structural columns, multiple slopes roofs, thickness variations, wall-floor joint, not perfectly adjacency of the thermal zones

Furthermore, problems related to the complexity of geometric shapes are identified, forcing to have a reference model with thermal zones similar to parallelepipeds.

1.3.2. IFC

The industry foundation classes (IFC) were developed by international association interoperability (IAI) but are now administrated by the buildingSMART alliance. They are the only 3D object-oriented open standards that use BIM. In contrast to gbXML, the aim of the IFC format is to provide a single basis for the exchange of information in the field of construction and facility management [10].

The IFC schema is more extensive and complex than the gbXML format, and supports, in addition to a good geometric representation, semantic data enrichment with a top-down structure [11]. IFC is a data schema that is used to digitally describe an element. The hierarchical setting of this scheme gives a logical order and relate the elements to each other. IFC format, unlike the gbXML, identifies spaces similar to that of an architectural model rather than an energy model, considering the thickness of the elements.

The key elements to understand how the hierarchy is organized are the following [12]:

- IfcProject: establishes the context in which to exchange or share information.
- IfcSite: is the entity that represents the project site.
- IfcBuilding: identifies the building or buildings on the site.
- IfcBuildingStorey: represents the levels (or more commonly the floors) into which a building is divided.
- IfcSpace: these are the rooms belonging to the various floors of the building.

- `IfcBuildingElement`: represent the construction elements that make up a building and are generally associated with a level.

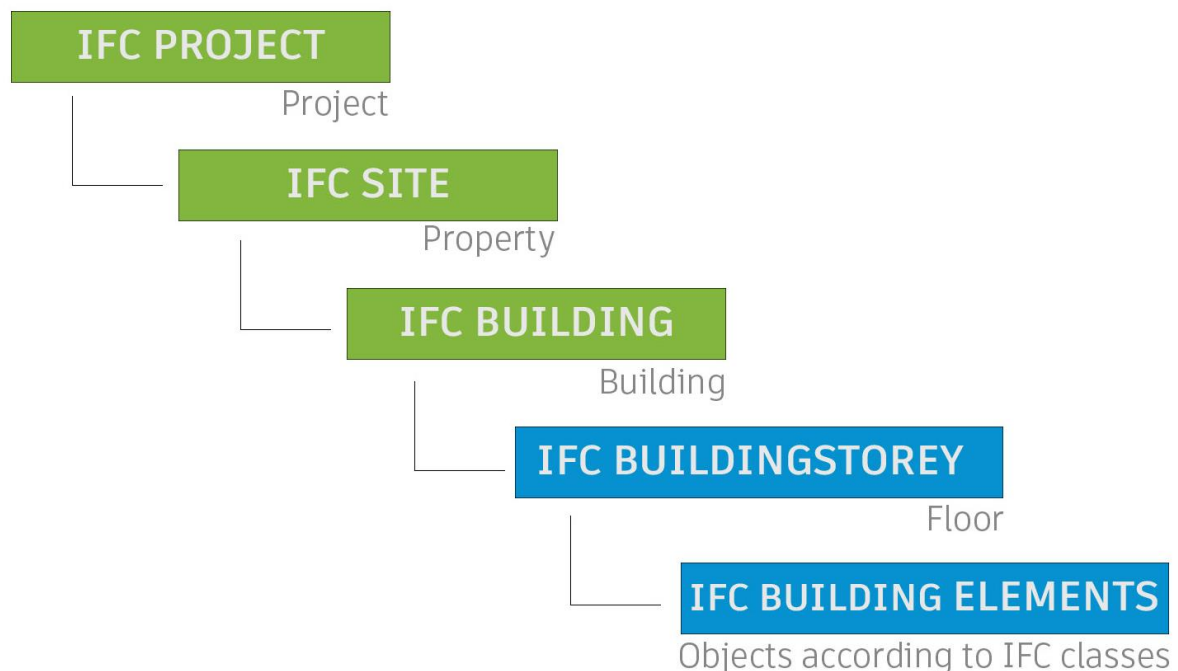


Figure 1-4 IFC top-down structure

As the gbXML format, also the complex structure of the IFC can lead to errors. Particular attention needs to be paid to the assignment of parameters and IFC classes for every object of the model [13].

1.3.3. Optimal Workflow

For BIM-BEM projects, the architectural BIM model is shared in the early design phases when the model contains only basic geometry and room. This because once additional elements such as furniture and casework are added, the file becomes larger, and the external programs have difficulty distinguishing all the data in the file.

Sharing the model in the early design phases, to create the BEM and complete the energy simulation, helps to reduce the risks of model divergence, errors, and misunderstandings [14]. However, BIM-BEM is still characterized by issues and challenges pertaining to the prevailing design processes and available technological approaches [15].

The optimal workflow involves three main steps. First, BIM model is simplified within the BIM authoring software, removing unnecessary information and streamlining the building geometry, internal loads and equipment systems. Second, the simplified model is exported in interoperable-friendly formats, such as gbXML and IFC. Third, these BIM files are imported into the modeler GUIs of most BPS tools (Termus, Termolog, MC4, TRNSYS...) which convert building information into data usable by the respective simulation engines. Both gbXML and IFC formats are suitable for BEM as they provide material properties and thermal zone data [16].

The IFC interchange format, despite not being carefully thought for energy design (as was the gbXML interchange format), seems to be the one that gives the best results. In many academic articles it is possible to appreciate how much the IFC interchange format gives better results than gbXML. The peculiarity of the IFC format can be found also in the numerous export properties of the format. For the gbXML formats there are few export settings, while for the IFC format it is possible to customize by the user several options and characteristics of every object of the model.

The variety of export settings can also cause a lot of errors if you are not careful about the logic with which the information is exported. Therefore, is very important to understand how the information is exported and imported.

1.4. BEM software

Building Energy Modeling (BEM) is physics-based software simulation of building energy use [17]. It is a multi-purpose tool for building energy efficiency supporting projects at the level of individual buildings. The major uses of BEM applications are related to HVAC and control Design, Environmental Protocols (as LEED, BREEAM, WELL), Financial Incentives, Architectural Design, Policy Analysis, Building Stock Analysis...New application for using BEM software are discovered every year, as BEM becomes easier to use.

Nowadays almost all software are able to perform dynamic energy simulations, while not all of them are able to interface with exchange formats such as IFC and gbXML. Some of them are also set for Italian regulatory standards. There is many software we can take in consideration for ES. A view on the most widespread software for energy simulation in Italy is shown below [18].



Figure 1-5 Energy Simulation Software

Insight 360: Revit internal plug-in that uses the Autodesk simulation engine called Green Building Studio. The file is transformed into gbXML format and brought into GBS which uses the DOE-2.2 calculation engine. Insight 360 is nothing more than a new web interface that Autodesk has made available to interact with the results produced by GBS, whose interface remains accessible.

Termolog: Italian software that performs simulations based on graphic modelling or tabular method. It is possible to import files in IFC and gbXML format.

EnergyPlus+: The simulations take place through tabular compilation. The results are very detailed however there is no graphical input method. Being a widely studied calculation engine, the results obtained are very precise; however, each required variable must be filled in. It's not possible to import IFC or gbXML files without the use of the GUI, named DesignBuildier.

DesignBuildier: GUI of Energy Plus. It is possible to import files in gbXML format and evaluate them. Shortcuts to CasaClima, Energy Plus and Revit.

MC4 Suite: Italian software developed in AutoCAD environment, for integrated thermomechanical and energy, acoustic and fire protection design. It is possible to import IFC files.

EdilClima: performs simulations based on IFC modelling or import. There is a shortcut for direct connection with Revit.

TRNSYS: graphically based software environment used to simulate the behaviour of transient systems. While most simulations are focused on assessing the performance of thermal and electrical energy systems, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes. There is a plugin for SketchUp that allows the user to draw multizone buildings and import the geometry (including building self-shading and internal view factors for radiation exchange) directly from the powerful SketchUp interface into the TRNSYS Building environment (TRNBuild). No possibility to import IFC and gbXML files.

Termus (ACCA Software): software for energy certification, verification of the energy performance of buildings and the design of energy efficiency interventions. Can import files in IFC format only.

IES-VE: is a fast, accurate, sub-hourly, thermal simulation suite that can model new and existing buildings of any size and complexity. Its power embeds energy and performance assessment across the entire building lifecycle. It's possible to import both IFC and gbXML files.

Blumatica Energy: software for energy certification, interesting function that automatically suggests changes to be made to the project to comply with regulatory requirements, unfortunately data import is only possible with technical formats such as dwg and dxf or png and pdf images. It is not possible to import files in IFC or gbXML format.

A BEM program can combine all the inputs data required for energy simulation, to calculate thermal loads, energy usage and the response of the systems to supply the needs.

However, there are different calculation methods for energy simulation. The main methods are divided into steady state evaluation and dynamic evaluation.

In both simulations, the main necessary data are almost the same, the main difference consists in the time frame over which the evaluation is carried out.

1.4.1. Steady state calculation method

In the steady state analysis, the simulation is performed in a time interval that coincides with the heating average monthly value. The temperatures, the internal inputs, the expected consumption are therefore reduced to average values and the calculation is simplified. Considering the average external climatic values and the constant internal and operating conditions of the system, the simulation it's not very reliable.

1.4.1.1. Steady state calculation method – Italian legislation

Steady state energy calculation, in Italy, is regulated by the UNI TS 11300, and is divided into 4 main parts [19]:

UNI TS 11300-1: 2014 "Determination of the building's thermal energy needs for summer and winter air conditioning". Defines the procedures for the national application of UNI EN ISO 13790: 2008, with reference to the monthly method for calculating the envelope needs for summer and winter air conditioning, including humidification and dehumidification.

It is aimed at all possible applications foreseen by UNI EN ISO 13790: 2008:

- design calculation (design rating)
- energy assessment of buildings through calculation under standard conditions (asset rating)
- energy assessment of buildings through the calculation in particular climatic and operating conditions (tailored rating)

UNI TS 11300-2: 2014 "Determination of primary energy needs and yields for winter air conditioning, for the production of domestic hot water, for ventilation and for lighting in non-residential buildings". Provides data and calculation methods for determining the needs of domestic hot water and for evaluating the losses and efficiency of systems for winter air conditioning (hydraulic and aeraulic).

It also provides the calculation method for determining the energy needs for the mechanical ventilation service and the indications and national data for determining the energy needs associated with the artificial lighting service, in accordance with UNI EN 15193.

Data and methods are provided for calculating the yields and losses of generation subsystems powered by electricity or liquid or gaseous fossil fuels.

UNI TS 11300-3: 2010 "Determination of primary energy needs and yields for summer air conditioning". Provides methods for the determination of:

- efficiency and energy need of summer air conditioning systems
- primary energy requirements for summer air conditioning

UNI TS 11300-4: 2012 " Use of renewable energy and other generation methods for winter air conditioning and for the production of domestic hot water". Calculates the losses and yields of generation subsystems that provide useful thermal energy from renewable energies or with generation methods other than those dealt with in UNI TS 11300-2.

The following renewable sources technologies are considered within the standard:

- solar thermal
- Solar photovoltaic
- heat pumps that use aeraulic, hydraulic or geothermal sources
- biomass
- other generation methods (cogeneration and district heating)

1.4.2. Dynamic calculation method

A dynamic simulation allows a much more precise and realistic results of the behaviour of a building, as all the variable factors that affect the behaviour of a building. Factors such as the thermal inertia of the envelope, the internal loads and the varying conditions of use of the environments, the solar gains and the change in external climatic conditions are of relevance. The behaviour of the building will be simulated every hour and will consider the different temperatures recorded in a specific place over the course of a day, including the maximum and minimum temperatures.

1.4.2.1. Dynamic calculation method – Italian legislation

The CEN (European Committee for Standardization) dealt with the drafting of the rules governing the thermal performance of buildings and its components. The work of this committee focused primarily on the development of the EN ISO 52016-1 standard (which replaces EN ISO 13790: 2008).

UNI EN ISO 52016-1: 2018 with respect to the technical device it replaces basically provides [20]:

- the revision of the monthly method for calculating the energy needs of buildings, within which the seasonal method has been eliminated (i.e., the identification of the heating and cooling periods based on a balance between energy losses and contributions from the envelope)
- the replacement of the simplified time method with a more detailed time method.
- new and more articulated criteria for thermal zoning

On an hourly and monthly basis, this regulation governs both the calculation of the sensitive thermal energy requirement for heating and cooling and the latent thermal energy requirement for dehumidification.

The substantial novelty is represented by the fact that, on an hourly basis, it also defines the methodologies for:

- the calculation of the temperature of the internal environments
- the calculation of the sensitive thermal load for heating and cooling,
- the calculation of the latent thermal load and humidity for humidification and dehumidification,
- the calculation of the sensible and latent design thermal load for heating and cooling,
- the determination of the supply air conditions to be provided for humidification and / or dehumidification.

In Italy, UNI EN ISO 52016-1: 2018 can only be used in areas such as the energy diagnosis of the building envelope and the calculation of the operating temperature in summer (as a possible alternative to the methodology described in UNI 10375 for the purposes of verifying the Minimum Environmental Criteria for public buildings) while it is not yet functional to the estimation of energy needs according to the purposes set out in the Minimum Requirements Decree of 26/06/2015.

2 Methodology

The use of Building Information Modeling (BIM) for building energy modelling (BEM) is a recent evolution in design practice [21]. The success of BIM-BEM execution relies on considering two important aspects: process and technology. Many problems prevent the data exchange between Building Information Models and Building Energy Models, such as geometry errors and missing data, which require a lot of human intervention. To better understand and evaluate the problems related to interoperability, all the necessary information needed by the energy calculation software to perform the simulations will be analysed. It will be analysed also the ways in which the BIM modelling software, in our case Revit, exports this information.

Understanding the way in which this information are exported and imported is a key element for the correct evaluation of interoperability. In the following chapters a detailed illustration of the setup in Revit for energy simulation is shown.

First, it will be illustrated how to proceed with the insertion of the essential data for the energy analysis, after that it will be illustrated how to proceed with the correct export settings for the IFC and gbXML formats. As regards the export settings of the gbXML format, the possibility of customization is restricted, while as regards the IFC format, an entire discussion will be opened.

2.1. BIM to BEM

BIM-BEM integration offers multiple benefits, unifying the data, allowing automation in the process, capability of storing and organizing new building data. Usually, in fact, more than 70% of the information needed for Building performance simulation can be already stored within the BIM model [16].

The Industry Foundation Class (IFC) and Green Building XML (gbXML) are two prevalent informational infrastructures in the architecture, engineering, and construction (AEC) industry [9]. These informational infrastructures allow the exchange of information between BIM and BEM models. There is many software that allow the import of an IFC or gbXML file, but the data transfer from one program to another is not always easy and a lot of mistakes can compromise the exported file during the design process. Some programs can import both types of files while other programs only can import one of them. Depending on the exchange format used, the ways in which information is exported and imported change.

Lot of work has been done in the literature to understand the real potential of BIM-BEM integration with IFC and gbXML files. A commonly used method for interoperability analysis is to start with small "test" models, trying to add information gradually. Multiple academic articles often show in comparison a real case study and a "basic" model, where one or at most two rooms are modelled with few doors and windows. A common result of all academic research is that, usually, complex BIM projects with a large amount of information are more likely to generate errors when importing energy files into energy calculation programs.

Testing the import compatibility of the IFC and gbXML formats within the different energy analysis software, the same result is almost always obtained [22]. Despite the simplified models, much software requires also further manual adjustments to carry out the energy analysis and

many errors are found during interoperability analysis with the two interchange formats. Some of these errors may derive from incorrect setting of the IFC/gbXML model, while others may be limited by the reading capacity of the energy calculation program. Many literature texts show the problems caused by importing from a BIM program to a BEM program, but often the ways in which the file is exported and the setting used are omitted.

Each program has its bugs for this reason it is always better to study the chosen energy analysis program and carry out some internal modelling tests of the program and have some familiarity with it before starting the analysis. Another important thing to take into consideration is the ability to read the exported code from the IFC or gbXML file. Knowing how to read the exported code is necessary to understand if the exported file is correct. Some bugs may derive from the limited reading ability of the program, others due to an incorrect setting of the model. For this reason, it is recommended to follow a workflow similar to the following flowchart. The use of a methodology is necessary for correctly exporting a BIM model in an energy simulation software.

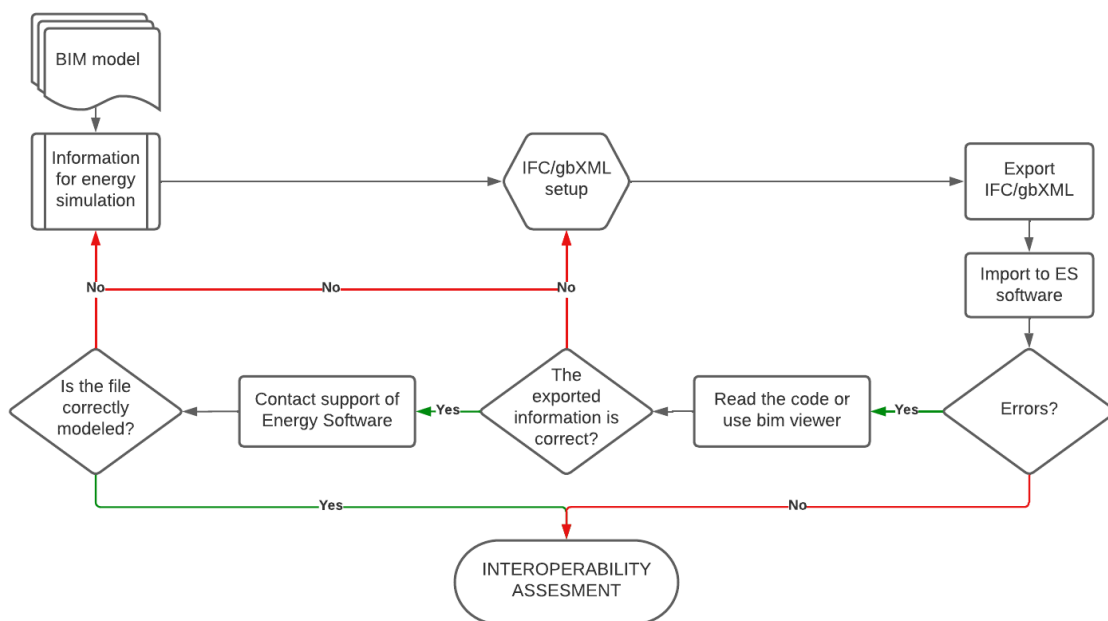


Figure 2-1 Interoperability methodology flowchart

2.2. Revit model setup for ES

As we described in the chapter of Building Energy model the information needed to do an energy simulation are:

- weather data (geographic location)
- building geometry
- thermo-physical characteristics of the envelope materials
- thermal zones characteristics
- HVAC system characteristics

In Revit is possible to model every point of the defined list. The only exception is for the HVAC system and thermal zones characteristics, which can only be exported with the gbXML interchange format (the topic will be dealt with in the paragraph “2.4 gbXML export settings”).

In the following sub-chapters, it will be shown how to correctly insert all the information needed for the energy model and it will be shown also how to properly assign the energy information to every object of our model. After that, in the next chapters, we will focus on how to proceed for IFC and gbXML exportation. For each setting its functionality will be explained in detail, arguing which is the best option to consider for energy analysis purposes. The guide and suggestions are the result of several attempts to export the BIM model in the two energy formats. The software used for the interoperability tests of this research are:

- Revit 2023 for exporting the BIM model in IFC/gbXML formats.
- Termolog 13 for importing the IFC model.
- IES-VE 2022 for importing the gbXML model.

2.2.1. Weather data

In Revit is possible to set the geographic location in the “Analyze” menu. By opening the location icon, Revit allows you to view a location search tab. By entering the project location (or the closest recorded location), Revit will export the degrees of latitude and longitude of the model site.

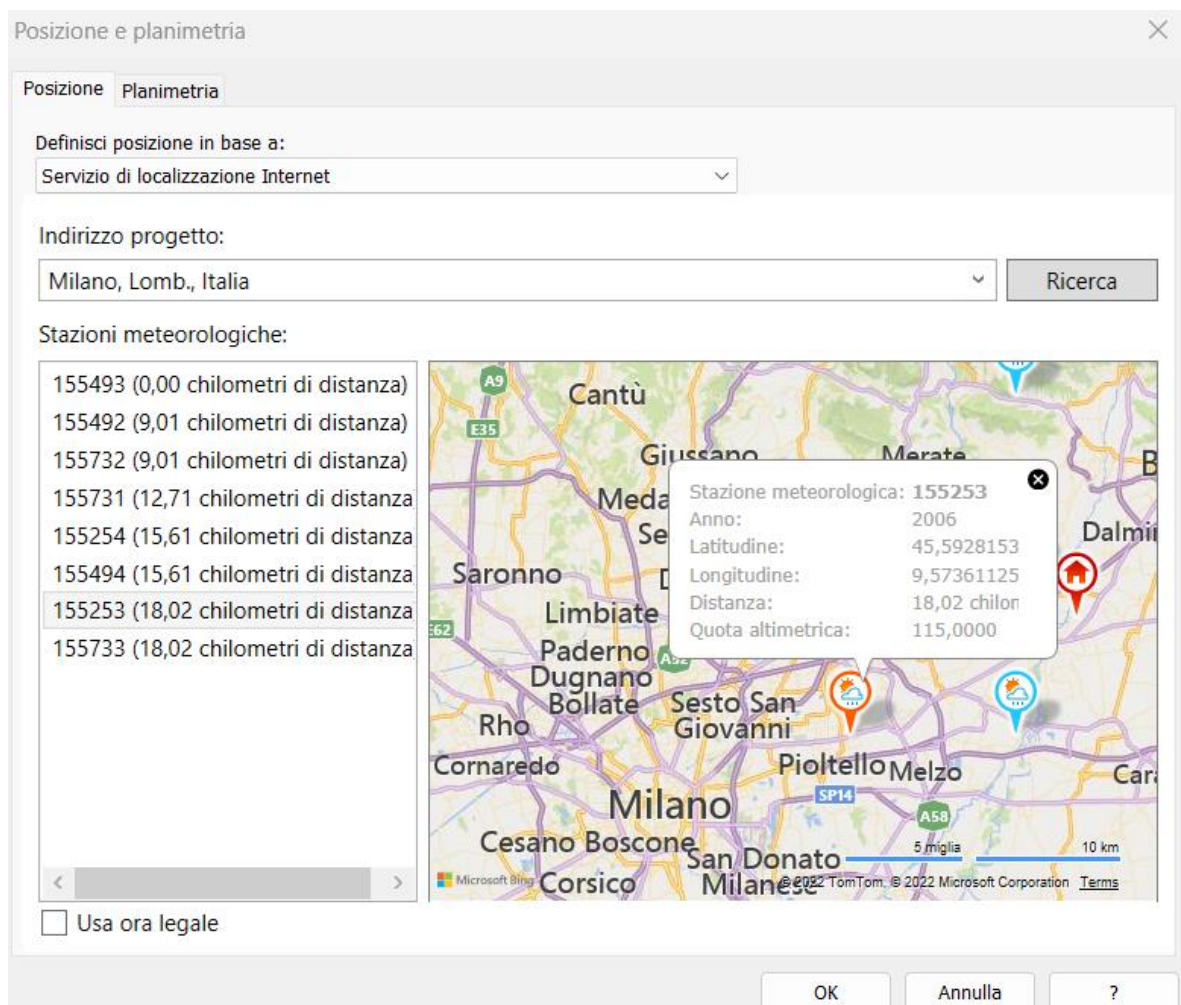


Figure 2-2 Weather data input inside Revit

2.2.2. Building geometry

The geometry of a building can be drawn easily, with accuracy and precision and with the help of parametric 3D objects to automate the drawing process. It is also possible to group objects (instances) by family and type. The family represents the group of the object (e.g., wall, curtain wall, window...) and the type represents the typology of that object (e.g., two door window, concrete wall, thickness...). Finally, the instance represents the single object.

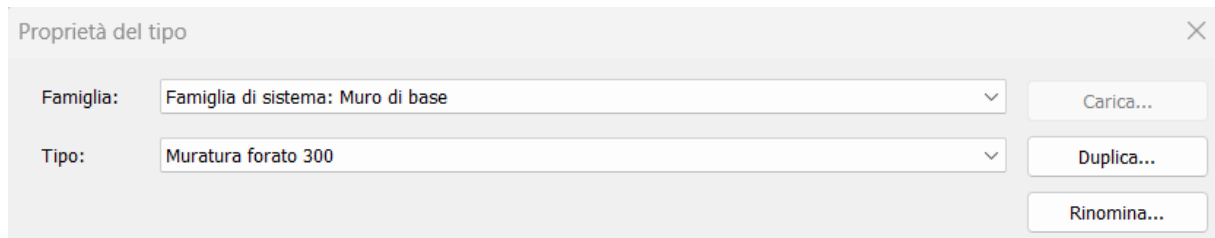


Figure 2-3 Building geometry input inside Revit

2.2.3. Thermo-physical characteristics of the envelope materials

For opaque element of construction, the characteristic of the materials can be inserted by selecting the object and entering the "Edit type" tab. Then under the "Construction" menu you can click on "Edit" in the row relating to the structure. Within this tab it is possible to insert the elements concerning the stratigraphy drawing from the existing Revit library or creating new ones. Pay attention in this step to enter the thermal properties as they are necessary for the energy calculation.

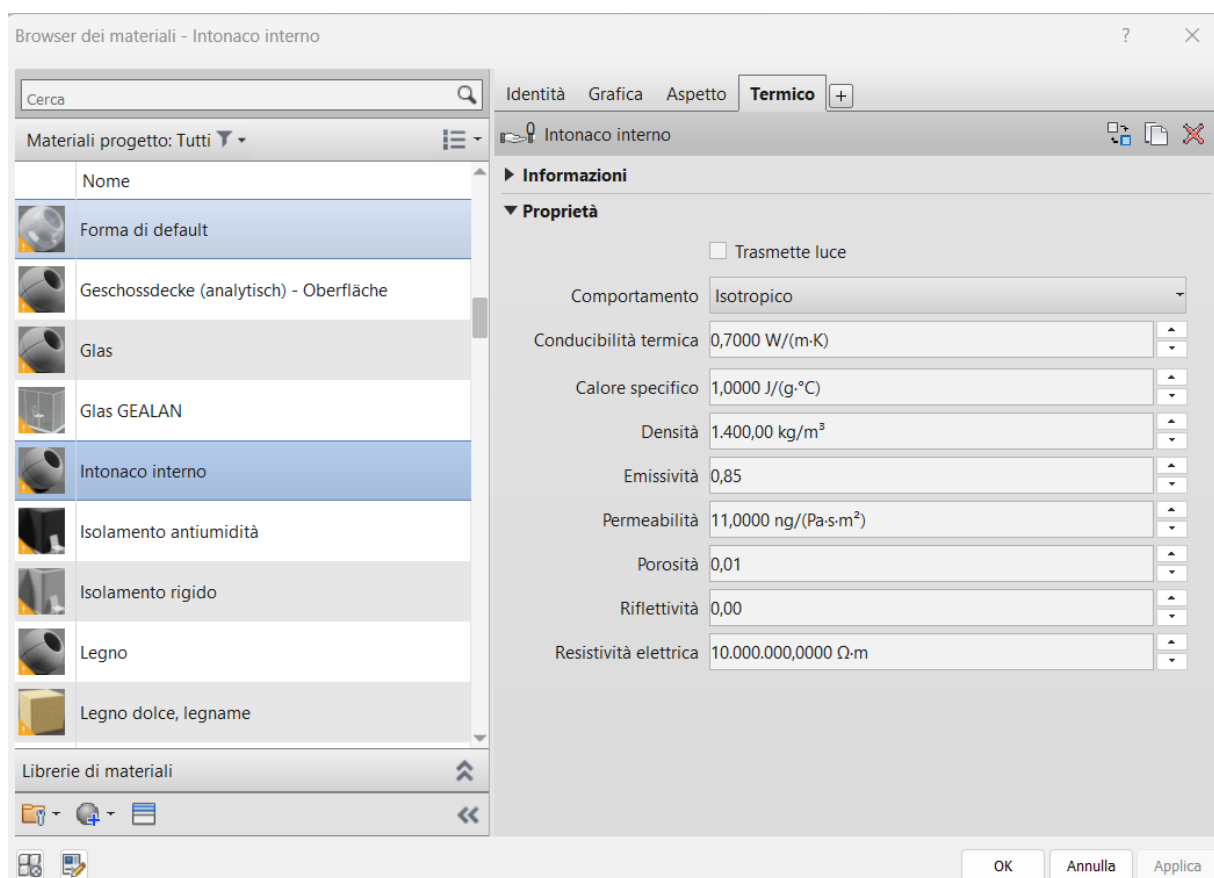
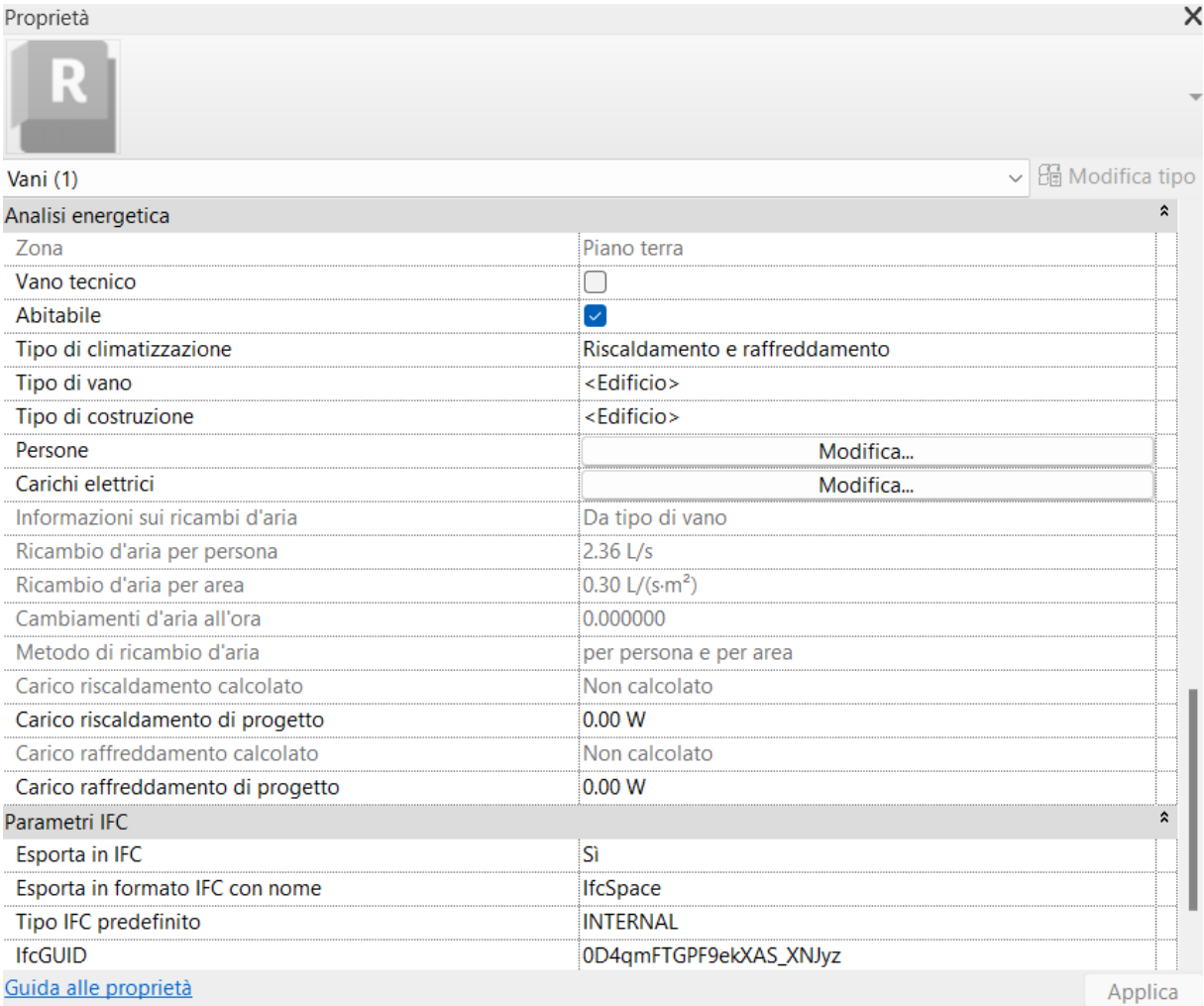


Figure 2-4 Thermo-physical characteristics of the materials input inside Revit

2.2.4. Thermal zones characteristics

It is possible to model spaces and thermal zones within Revit, by modelling the spaces through the "Analyze" tab, and group them by thermal zones with the "Zone" tab. Furthermore, for each room it is possible to insert the type of space and its possible model the characteristics of the internal loads regarding lighting, ventilation, occupancy, heating and cooling.



Proprietà

Vani (1) Modifica tipo

Analisi energetica	
Zona	Piano terra
Vano tecnico	<input type="checkbox"/>
Abitabile	<input checked="" type="checkbox"/>
Tipo di climatizzazione	Riscaldamento e raffreddamento
Tipo di vano	<Edificio>
Tipo di costruzione	<Edificio>
Persone	Modifica...
Carichi elettrici	Modifica...
Informazioni sui ricambi d'aria	Da tipo di vano
Ricambio d'aria per persona	2.36 L/s
Ricambio d'aria per area	0.30 L/(s·m ²)
Cambiamenti d'aria all'ora	0.000000
Metodo di ricambio d'aria	per persona e per area
Carico riscaldamento calcolato	Non calcolato
Carico riscaldamento di progetto	0.00 W
Carico raffreddamento calcolato	Non calcolato
Carico raffreddamento di progetto	0.00 W
Parametri IFC	
Esporta in IFC	Sì
Esporta in formato IFC con nome	IfcSpace
Tipo IFC predefinito	INTERNAL
IfcGUID	0D4qmFTGPF9ekXAS_XNJyz

[Guida alle proprietà](#) Applica

Figure 2-5 Thermal zones input inside Revit

2.2.5. HVAC system characteristics

the characteristics of the HVAC systems can be modelled by entering the "Analyze" tab and then clicking "Energy settings" in the "Energy optimization" menu. In the menu "energy analysis mode" there are the export settings for the gbXML format. Looking instead in the "Advanced" menu and clicking on "Edit" in the "Other settings" line, you can open a menu where you can enter more specifically the data referring to the type of system and the heat generators. Unfortunately, Revit has a limited capacity as regards the insertion of information regarding the system, in fact, as visible from the following screen, it is only possible to choose the traditional types of systems through the drop-down menu.

Parametro	Valore
Modello dettagliato	
Percentuale superficie vetrata	0%
Altezza davanzale	750.0
La vetrata è ombreggiata	<input type="checkbox"/>
Lunghezza aggetto ombreggiante	457.2
Percentuale superficie lucernari	0%
Larghezza e profondità lucernario	914.4
Avanzata	
Complessità esportazione	Semplice con superfici ombreggiate
Tolleranza vani ridotti	304.8
Inviluppo dell'edificio	Usa parametro Funzione
Dimensioni cella griglia analitica	914.4
Impianto edificio	VAV - Condotto singolo
Classe di infiltrazione edificio	Nessuno
Dati di costruzione	
Tipo di edificio	Ufficio
Abaco utilizzo dell'edificio	Default
Sistema riscaldamento, ventilazione e aria condizionata	VAV centrale, riscaldamento acqua calda, refrigeratore 5.96 COP, caldaie 8
Informazioni sui ricambi d'aria	Modifica...
Dati locali/vani	
Categoria di esportazione	Locali
Proprietà termiche dei materiali	
Tipi concettuali	Modifica...
Tipi schematici	<Edificio>
Elementi dettagliati	<input type="checkbox"/>

Figure 2-6 HVAC input inside Revit

2.3. IFC export settings

This chapter explains the setting of export properties in IFC format by explaining its structure of the export format.

Once that all the needed information is inserted into the Revit model file, is possible to proceed with the export settings.

It's known that all the information regarding the plant are no longer available when exporting in the IFC format, the only information exported regards the mechanical and electrical systems (MEP) included in the model, which however are not compatible with reading by most energy analysis programs.

Trying to enter the MEP details for an export for energy analysis can only cause errors in reading and overlapping of information.

To correctly export the BIM model in IFC format it is necessary to assign the correct information to each object of the model. It is possible to divide the procedure into 3 main steps:

- Assignment of IFC export classes
- Assignment of IFC project parameters and property sets
- IFC export setup tab

In the following chapters the settings for the setup of the model for the purpose of energy calculation will be evaluated. All the settings will be treated and evaluated based on the experience gained from the export tests carried out in Revit.

It should be noted that all the recommended settings are the result of an interoperability analysis carried out with the most popular programs for energy simulation both nationally and internationally. The calculation software most taken into consideration are IES-VE, Termolog, Termus, MC4 and Insight. As regards BIM modelling, a single standard software was maintained (Revit 2023) to better compare interoperability with energy analysis software.

2.3.1. Assignment of IFC export classes

IFC export classes																																																																	
<div style="border: 1px solid gray; padding: 5px;"> Classi di esportazione IFC: C:\ProgramData\Autodesk\RVT 2023\exportlayers-ifc-IAI.txt <div style="float: right; text-align: right;"> <input type="button" value="Carica..."/> <input type="button" value="Standard"/> <input type="button" value="Salva con nome..."/> </div> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;">Categoria Revit</th> <th style="width: 40%;">Nome classe IFC</th> <th style="width: 30%;">Tipo IFC</th> </tr> </thead> <tbody> <tr><td>Accessori per condotti</td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td>Accessori per tubazioni</td><td>IfcValveType</td><td></td></tr> <tr><td>Allineamenti</td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td>Annotazioni generiche</td><td>Non esportato</td><td></td></tr> <tr><td>Aperture analitiche</td><td>Non esportato</td><td></td></tr> <tr><td>Apparecchi elettrici</td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td><Linee nascoste></td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td>Apparecchi idraulici</td><td>IfcFlowTerminal</td><td></td></tr> <tr><td><Linee nascoste></td><td>IfcFlowTerminal</td><td></td></tr> <tr><td>Apparecchi per illuminazion</td><td>IfcLightFixtureType</td><td></td></tr> <tr><td><Linee nascoste></td><td>IfcLightFixtureType</td><td></td></tr> <tr><td>Sorgente d'illuminazione</td><td>IfcLightFixtureType</td><td></td></tr> <tr><td>Appoggi</td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td><Linee nascoste></td><td>IfcBuildingElementProxy</td><td></td></tr> <tr><td>Aree</td><td>IfcSpace</td><td></td></tr> <tr><td>Riempimento colore</td><td>IfcSpace</td><td></td></tr> <tr><td>Riempimento interno</td><td>IfcSpace</td><td></td></tr> <tr><td>Riferimento</td><td>IfcSpace</td><td></td></tr> <tr><td>Aree di rete strutturale</td><td>IfcGroup</td><td></td></tr> <tr><td>Contorno</td><td>IfcGroup</td><td></td></tr> </tbody> </table> </div>			Categoria Revit	Nome classe IFC	Tipo IFC	Accessori per condotti	IfcBuildingElementProxy		Accessori per tubazioni	IfcValveType		Allineamenti	IfcBuildingElementProxy		Annotazioni generiche	Non esportato		Aperture analitiche	Non esportato		Apparecchi elettrici	IfcBuildingElementProxy		<Linee nascoste>	IfcBuildingElementProxy		Apparecchi idraulici	IfcFlowTerminal		<Linee nascoste>	IfcFlowTerminal		Apparecchi per illuminazion	IfcLightFixtureType		<Linee nascoste>	IfcLightFixtureType		Sorgente d'illuminazione	IfcLightFixtureType		Appoggi	IfcBuildingElementProxy		<Linee nascoste>	IfcBuildingElementProxy		Aree	IfcSpace		Riempimento colore	IfcSpace		Riempimento interno	IfcSpace		Riferimento	IfcSpace		Aree di rete strutturale	IfcGroup		Contorno	IfcGroup	
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Contorno	IfcGroup																																																																
Setup description	For energy analysis purposes																																																																
<p>Every category, type or Revit object can be assigned to an IFC class. In the “IFC Options” tab it’s possible to assign each Revit category the corresponding IFC category. It is also possible to decide not to export a particular Revit category.</p>	<p>This can be very useful for the export of an IFC used for energy model, as all those architectural elements and details that do not affect the energy analysis can be excluded from the export. Doing this, is possible to reduce the dimension of the IFC file, improving the interoperability between BIM and BEM.</p>																																																																

Table 2.3.1-1 IFC export classes

2.3.2. Assignment of IFC project parameters and property sets

IFC Project Parameters & Property Sets

Proprietà parametro

Tipo di parametro

Parametro di progetto
(Può comparire negli abachi ma non nelle etichette)

Parametro condiviso
(Può essere condiviso da più progetti e famiglie, essere esportato in ODBC e comparire negli abachi e nelle etichette)

Seleziona... Esporta...

Dati parametro

Nome: ThermalTransmittance Tipo

Disciplina: Energia Istanza

Tipo di parametro: Coefficiente di trasferimento di calore I valori vengono allineati per tipo di gruppo

Raggruppa parametro in: Parametri IFC I valori possono variare in base all'istanza del gruppo

Descrizione comandi:
<Nessuna descrizione comando. Modificare il parametro per creare una descrizione comando personalizzata. La lunghezza massima delle descrizioni comando personalizzate è di 255 caratteri.>

Modifica descrizione comandi...

Aggiungi a tutti gli elementi nelle categorie selezionate

Categorie

Ricerca nome categoria: FIN

Elenco dei filtri: <multipli>

Nascondi categorie deselezionate

- Finestre
- Planimetria
 - Confini catastali
 - Segmenti di confini catastali

Seleziona tutti Deseleziona tutti

OK Annulla ?

Setup description

The concept template Property Sets describes how sets of properties (usually defined by a name, value, unit triple) are associated to objects or object types in the IFC parameters. When a new parameter is defined inside the "Project parameters" section in the "Manage" tab, is

For energy analysis purposes

Is it possible to add parameters to the type or instance according to the IFC standard in use as the Thermal Transmittance. By way of example, the parameters that can be associated with the "window" element are shown below. It is recommended to insert the corresponding name to the property set, and then assign the right type of parameter, in order to export

possible to group new parameters inside the IFC parameters and select if it is for type or for instance. After that, is possible to bind that parameter to the selected instances or types.

the IFC model code with IFC code standards.

PropertySet Definition:

PropertySet Name	Pset_WindowCommon
Applicable Entities	IfcWindow
Applicable Type Value	
Definition	Definition from buildingSMART International: Properties common to the definition of all occurrences of Window.

Property Definitions:

Name	Property Type	Data Type	Definition
Reference	IfcPropertySingleValue	IfcIdentifier	Reference ID for this specified type in this project (e.g. type).
FireRating	IfcPropertySingleValue	IfcLabel	Fire rating for this object. It is given according to the national safety classification.
AcousticRating	IfcPropertySingleValue	IfcLabel	Acoustic rating for this object. It is given according to the national building code. It indicates the sound transmission resistance of this object by an index rating (instead of providing full sound absorption values).
SecurityRating	IfcPropertySingleValue	IfcLabel	Index based rating system indicating security level. It is given according to the national building code.
IsExternal	IfcPropertySingleValue	IfcBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element facing the outside of the building.
Infiltration	IfcPropertySingleValue	IfcVolumetricFlowRateMeasure / VOLUMETRICFLOWRATEUNIT	Infiltration flowrate of outside air for the filler object based area of the filler object at a pressure level of 50 Pascals. It is used, if the length of all joints is unknown.
ThermalTransmittance	IfcPropertySingleValue	IfcThermalTransmittanceMeasure / THERMALTRANSMITTANCEUNIT	Thermal transmittance coefficient (U-Value) of a material. Applies to the total door construction.
GlazingAreaFraction	IfcPropertySingleValue	IfcPositiveRatioMeasure	Fraction of the glazing area relative to the total area of the element. It shall be used, if the glazing area is not given separately for all panels within the filling element.
SmokeStop	IfcPropertySingleValue	IfcBoolean	Indication whether the object is designed to provide a smoke stop (TRUE) or not (FALSE).

The parameters of the IFC standard can be found at "<https://standards.buildingsmart.org/IFC/RELEASE/>".

Table 2.3.2-1 IFC Project Parameters & Property Sets

After having designed the model and set all the information for each object, it is possible to move on to the export setup tab. By clicking on Modify setup it is possible to access further settings for exporting the IFC format.

In the IFC export tab, clicking on "Modify setup..." various tabs will appear. Starting from the first one, it will be possible to set the following configurations [23] :

2.3.3. IFC export setup tab

General

General
Additional Content
Property Sets
Level of Detail
Advanced
Geographic Reference

IFC version	IFC4 Design Transfer View ▼
Exchange Requirement	 ▼
File type	IFC ▼
Phase to export	Fase 1 ▼
Space boundaries	None ▼

Split Walls, Columns, Ducts by Level
 File Header Information...

Include Steel Elements
 Project Address...

Setup description	For energy analysis purposes
<p>IFC version: the IFC versions are divided by category and by update. The IFC4 version is the latest update. There are also different categories based on the function that the IFC format must have. The “Coordination View” for example is used for clash</p>	<p>As regards the energy simulation there is not yet an IFC version, nowadays the "Design Transfer View" is the most quoted version to import the project into energy analysis software.</p>

<p>detection and managing the parameters, the “Reference View” allows design teams to refer to the correct basis and the “Design Transfer View” is an extension of the IFC4 Reference View. There are also other categories like the “Handover View”, used during the lifecycle, or also other customized categories for calculating quantities or for the construction execution.</p>	
<p>Exchange Requirement: there are 3 different exchange modes, and they are “Architectural”, “Structural” and “MEP”.</p>	<p>As far as the energy simulation, there is not yet an export mode, therefore for the purposes of energy calculation it is not necessary to define this parameter.</p>
<p>File type: export types are “IFC” format (standard), “IFC XML” format for interoperability with XML tools, and “IFC ZIP” format for a compressed format.</p>	<p>It’s recommended to check this option with large scale projects.</p>
<p>Phase to export: useful to export the reference phase, usually in the context of renovation it is necessary to analyse the energy consumption before and after the intervention.</p>	<p>For energy analysis select the phase that we want to analyse.</p>
<p>Space boundaries: is possible to choose how the space boundaries can be exported. “None” mode</p>	<p>Although "Level 2" seems to be the best setting for energy analysis export, some energy</p>

<p>does not export boundary surface information “Level 1” exports boundary surfaces for quantity and mass evaluation and “Level 2” exports boundary surfaces together with all data required for energy or thermal calculations.</p>	<p>calculation software are able to directly recognize the rooms and boundary conditions or rooms created in Revit. Sometimes using "Level 2" can cause data overlapping so it is recommended to compare the “Level 2” with “None” mode.</p>
<p>Split walls, supports, and air ducts by level: the check of this box divides elements if they have been modelled over several floors. They are divided according to the floors of the building. This setting can be determined for each floor in the Revit properties.</p>	<p>This box check is necessary for energy analysis. Usually, the levels indicate a division of a thermal zone delimited by a slab, and the software for energy simulation must necessarily divide the surface by thermal zone of belonging.</p>
<p>Include Steel Elements: the check of this box includes steel elements in the export, useful for structural analysis.</p>	<p>This option may be unchecked for energy simulation.</p>

Table 2.3.3-1 IFC export setup tab - General

Additional content	
<div style="border: 1px solid black; padding: 5px;"> <div style="display: flex; border-bottom: 1px solid black; margin-bottom: 5px;"> General Additional Content Property Sets Level of Detail Advanced Geographic Reference </div> <div style="padding-left: 10px;"> <input type="checkbox"/> Export 2D plan view elements <input checked="" type="checkbox"/> Export linked files as separate IFCs <input type="checkbox"/> Export only elements visible in view <input type="checkbox"/> Export rooms, areas and spaces in 3D views </div> </div>	
Setup description	For energy analysis purposes
<p>Export 2D plan view elements: the check of this box includes 2D plan elements as grid, text or 2D reference use for the construction of the 3D model.</p>	<p>This option may be unchecked for energy simulation. The goal is to import the entire model without further modelling.</p>
<p>Export linked files as separate IFCs: the check of this box allows to export Revit files that are currently linked within the project as separate IFC files. If this feature is left disabled, Revit links are not exported.</p>	<p>For the purposes of energy analysis, it depends on how the model has been created with or without linked files and if they are necessary for energy analysis.</p>
<p>Export only elements visible in view: the check of this box allows to include only items that are visible in the current view thanks to visibility settings, filters, and stages.</p>	<p>When exporting IFC files for energy simulation, this option may be compared with the export classes settings, as it can act as a filtering of the elements not necessary for the energy analysis.</p>

Table 2.3.3-2 IFC export setup tab - Additional content

Property Sets

In the “Property Sets” tab, there are the most important export settings, as the property sets are the real property of every object inside the IFC model. In this tab it is possible to customize the way in which property sets are exported. Being aware of how the parameters of each object are assigned and exported by the software is crucial for a correct diagnosis of interoperability. As will be discussed in the chapter “3 Case Study”, knowing how this mechanism works will help to resolve some interoperability issues.

The screenshot shows the 'Property Sets' tab in the IFC exporter software. The tab is selected among others like 'General', 'Additional Content', 'Level of Detail', 'Advanced', and 'Geographic Reference'. The 'Export Revit property sets' checkbox is unchecked. Other options include 'Export IFC common property sets', 'Export base quantities', 'Export schedules as property sets' (checked), and 'Export user defined property sets' (unchecked). A file path is shown in a text box with a 'Browse...' button. At the bottom, there is a 'Classification Settings...' button.

Setup description

Export Revit Property Sets: the check of this box allows to export all the properties of

For energy analysis purposes

It is not recommended for energy simulation, as not all the properties of a component are required.

<p>a component. It gives to the model all the information of the Revit model and thus greatly increases the file size. A data model exported using this option can be up to 70% larger than one exported using any other method.</p>	
<p>Export IFC common property sets: the check of this box allows to include the default properties defined in the IFC schema.</p>	<p>This option may not always be sufficient to include all the parameters needed, but it is always recommended to leave this box checked. Unlike Revit property sets, IFC property sets are limited to standards property.</p>
<p>Export base quantities: the check of this box includes another type of property groups defined in the IFC schema, specifically designed for quantity estimation and evaluation. It includes quantities property as height, length, width, net volume, net area, gross volume, gross footprint area and so on.</p>	<p>The check of this option is not required for energy analysis.</p>
<p>Export schedules as property sets: the check of this box allows the creation of user-defined property sets using Revit schedules. To custom property groups, is</p>	<p>The use of this method for the export of property sets can adjust some of the problems related to interoperability. During the importation, programs can read specific property sets related to the object in the IFC schema, but</p>

<p>possible to add any properties that are not part of the standard property groups defined in the IFC schema. Because Revit projects can include many schedules, this option may be limited to schedules whose title includes IFC, Pset, or Common. Properties are all collected in the schedule and on export they are in the IFC.</p>	<p>sometimes the property set can be named different from what expected from the energy software, leading to problems of incorrect reading of the information.</p>
<p>Export user defined property sets: is the equivalent of exporting schedules as property sets, except that a text file is used as the configuration file.</p>	<p>The use of this method for the export of property sets can adjust some of the problems related to interoperability. During the importation, programs can read specific property sets related to the object in the IFC schema, but sometimes the property set can be named different from what expected from the energy software, leading to problems of incorrect reading of the information.</p>

```

# User Defined PropertySet Definition File
#
# Format:
#   PropertySet: <Pset Name> I[nstance]/T[type] <element list separated by ','>
#   <Property Name 1> <Data type> <[opt] Revit parameter name, if different from IFC>
#   <Property Name 2> <Data type> <[opt] Revit parameter name, if different from IFC>
#   ...
#
# Data types supported: Area, Boolean, ClassificationReference, ColorTemperature, Count, Currency,
# ElectricalCurrent, ElectricalEfficacy, ElectricalVoltage, Force, Frequency, Identifier,
# Illuminance, Integer, Label, Length, Logical, LuminousFlux, LuminousIntensity,
# NormalisedRatio, PlaneAngle, PositiveLength, PositivePlaneAngle, PositiveRatio, Power,
# Pressure, Ratio, Real, Text, ThermalTransmittance, ThermodynamicTemperature, Volume,
# VolumetricFlowRate
#
# Example property set definition for COBie:
#
#PropertySet:      COBie_Specification      T      IfcElementType
#  NominalLength   Real  COBie.Type.NominalLength
#  NominalWidth    Real  COBie.Type.NominalWidth
#  NominalHeight   Real  COBie.Type.NominalHeight
#  Shape           Text  COBie.Type.Shape
#  Size            Text  COBie.Type.Size
#  Color           Text  COBie.Type.Color
#  Finish          Text  COBie.Type.Finish
#  Grade           Text  COBie.Type.Grade
#  Material        Text  COBie.Type.Material
#  Constituents    Text  COBie.Type.Constituents
#  Features        Text  COBie.Type.Features
#  AccessibilityPerformance Text COBie.Type.AccessibilityPerformance
#  CodePerformance Text  COBie.Type.CodePerformance
#  SustainabilityPerformance Text COBie.Type.SustainabilityPerformance

```

<Pset Name>: name of the Pset. Do not use Pset_ as a prefix because it is reserved for standard IFC Psets.

I[nstance]/T[type]: used to specify instance or type properties. Use I or T.

<element list separated by ','>: it is the position where one or more IFC classes are listed for which this Pset will be applied, for example IfcWall, IfcSlab, IfcColumn. If the Pset needs to apply to all elements, use building elements of the next higher entity (IfcBuildingElement), such as walls, doors, etc., or IfcElement to also include distribution and civil elements.

<Property Name> - Name of the property as displayed in Revit

<Data type> - Supported IFC data types are listed in the model file. The most used ones are text, integer, real, length, volume, boolean. Currently 40 IFC property types are supported in IFC export for Revit. Usually, the data types supported are written at the beginning of the text file.

<[opt] Revit parameter name, if different from IFC> is an optional field and can be omitted if the Revit property name is also to be used for the IFC property.

Table 2.3.3-3 IFC export setup tab - Property sets

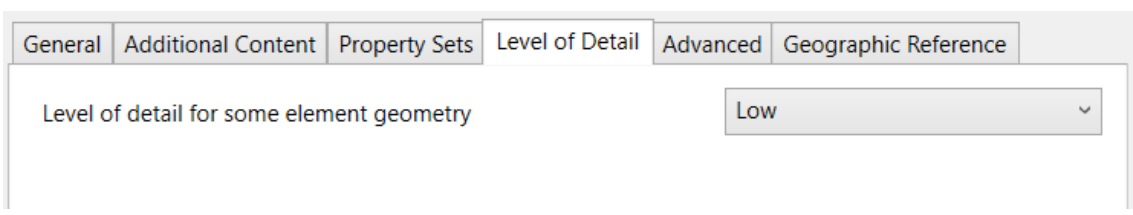
Level of Detail	
	
Setup description	For energy analysis purposes
In the “Level of Detail” tab only the Level of detail for some element geometry option is available. This option allows to set the level of detail that has a significant impact on the size of the file and its correct interpretation.	Usually, a higher detail can cause data overload. Low detail level is usually sufficient for energy analysis.

Table 2.3.3-4 IFC export setup tab - Level of Detail

Advanced

General	Additional Content	Property Sets	Level of Detail	Advanced	Geographic Reference
<input type="checkbox"/> Export parts as building elements <input type="checkbox"/> Allow use of mixed "Solid Model" representation <input type="checkbox"/> Use active view when creating geometry <input type="checkbox"/> Use family and type name for reference <input type="checkbox"/> Use 2D room boundaries for room volume <input type="checkbox"/> Include IFCSITE elevation in the site local placement origin <input type="checkbox"/> Store the IFC GUID in an element parameter after export <input type="checkbox"/> Export bounding box <input type="checkbox"/> Keep Tessellated Geometry as Triangulation <input type="checkbox"/> Use Type name only for IFCType name <input type="checkbox"/> Use visible Revit name as the IFCEntity name					
<input type="button" value="Entities to Export ..."/>					

Setup description

Export parts as building elements: refers to the exchange of IFC data when working with partial elements in the construction of walls or floor slabs. The partial elements are exported as "IfcBuildingElementPart" by default and allow the assignment of individual parts to a higher-level element within the IFC data model.

For energy analysis purposes

For energy analysis is recommended to maintain this option unchecked. Dividing a wall or a slab in partial elements can lead to an incorrect reading of the model by the energy software.

<p>Allow use of mixed “Solid Model” representation: allows export of sweep solid models together with B-rep models. In the IFC data model, a geometric object is usually generated from one or more sweep objects or only from B-rep objects. The combination of these two representation types is not enabled by default in the IFC schema and should be activate if working with complex geometry.</p>	<p>It should be noted that complex geometries can only be treated with the IFC interchange format as gbXML only works with parallelepiped geometries. Depending on the complexity of shape modelled, this can lead to geometric errors. It is always recommended to have regular shapes when possible.</p>
<p>Use active view when creating geometry: embeds the display settings for the current view into the IFC export. It was specially developed for construction equipment, such as cable piping, and built-in parts whose model geometry is different from the represented geometry.</p>	<p>Generally, this option may be unchecked for energy analysis.</p>
<p>Using family and type name for the reference: allows you to use the Revit family and type as a reference. The default setting allows you to reference a component based on the type used.</p>	<p>The activation of this option does not involve changes during the import on the energy calculation software, except that of carrying the reference name of the type or family.</p>
<p>Use 2D room boundaries for room volume: makes it easier to calculate room volume based on two-dimensional space boundaries. The Revit space geometry is used to</p>	<p>This option may be unchecked to avoid the overlapping of information of the individual environments. We remember that we have already assigned</p>

<p>determine the volume in the IFC schema by default.</p>	<p>the spaces of the model to the IfcSpace category.</p>
<p>Include IFCSITE elevation in the site local placement origin: When exporting site information, the area (Ifc site) has a height value for the project. In IFC2x3 CV2.0 this value is set to "0" by default and may not be interpreted correctly by older applications. Thanks to this export setting, the corresponding value is also provided.</p>	<p>This option may be unchecked as it is a superfluous data for energy calculation software.</p>
<p>Store the IFC GUID in an element parameter after export: The IFC specification uses an unique identifier for object instances that follows the universal unique identifier standard UUID with its implementation as a globally unique identifier GUID [24]. The compressed GUID is called "IFC-GUID" allows you to store the generated IFC GUIDs in the "IfcGUID" parameter after they have been successfully exported.</p>	<p>This simplifies subsequent coordination of the specialist model, as the components are clearly identifiable. Not necessary for energy simulation.</p>
<p>Export bounding box: Each geometric element can also be represented in simplified form using a bounding box.</p>	<p>If an object cannot be exported due to its complex geometry or if it needs to be simplified to better determine free spaces, the bounding box can be an alternative to the representation itself or it can allow the representation of the object.</p>

<p>Keep tessellated geometry as triangulation: This advanced option allows you to use a triangulation method that is compatible with older IFC 4 Reference Views.</p>	<p>This option may be checked when we don't have regular geometry to analyse. Furthermore, it can solve some problems regarding sloping roofs where many energy analysis programs recognize such surfaces by triangulation.</p>
<p>Use Type name only for IFCType name: exclude family name for IFC type name.</p>	<p>Not necessary for energy analysis purposes.</p>
<p>Use Revit visible name as IFCEntity name: affects the generation of element names in IFC</p>	<p>Not necessary for energy analysis purposes.</p>
<p>Entities to Export...: clicking on this tab is possible to filter all the entities we wanted to export.</p>	<p>This filtering option can be compared to the one of the export classes settings (chapter: IFC Export classes) and the one of the elements visible in view (chapter: IFC export setup tab).</p>

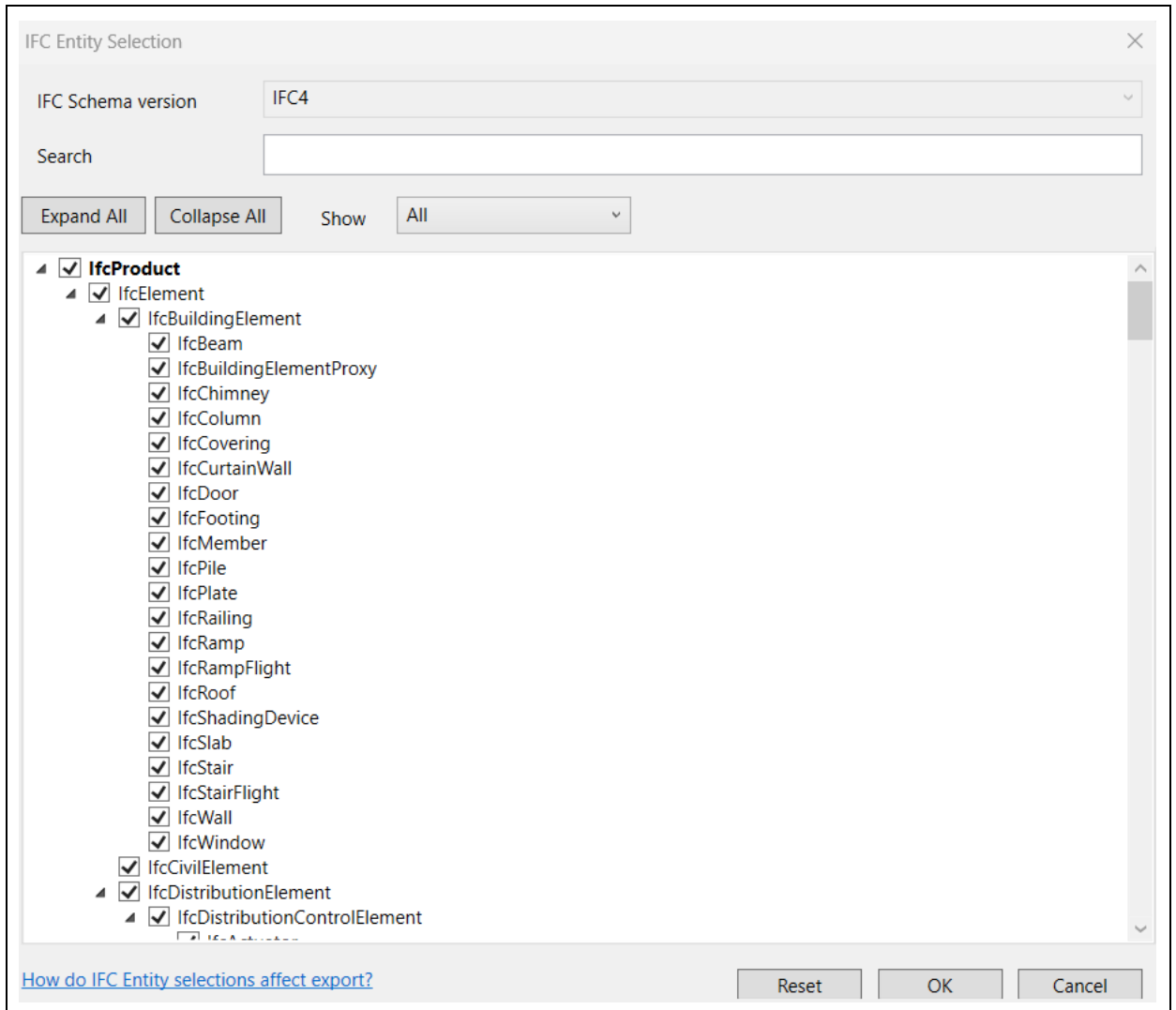


Table 2.3.3-5 IFC export setup tab - Advanced

<h2>Geographic Reference</h2>	
<div style="border: 1px solid gray; padding: 10px;"> <div style="border-bottom: 1px solid gray; display: flex; justify-content: space-between; padding-bottom: 5px;"> General Additional Content Property Sets Level of Detail Advanced Geographic Reference </div> <div style="padding: 10px 0 0 20px;"> <p>Project Site Planimetria di default ▼</p> <p>Coordinate Base Shared Coordinates ▼</p> <p>Projected Coordinate System Reference</p> <div style="border: 1px solid gray; padding: 5px; margin-top: 5px;"> <p>EPSG Code <input type="text"/></p> <p>Name</p> <p>Description</p> <p>Geodetic Datum</p> <p>Eastings</p> <p>Northings</p> <p>Elevation</p> <p>Angle from True North</p> </div> <div style="text-align: right; margin-top: 10px;"> Override Reset </div> </div> </div>	
Setup description	For energy analysis purposes
<p>This last tab it's a new feature of Revit 2023. It gives the possibility to modify the geographic reference of the model directly from the export menu, adding some more information like the geodetic datum and the angle from the True North.</p>	<p>This section is unnecessary for energy analysis. Once we set the location and the north direction this information are already insert to the IFC export files. It's recommended to leave the original setup for this tab.</p>

Table 2.3.3-6 IFC export setup tab - Geographic reference

2.4. gbXML export setting

This chapter explains the setting of export properties in gbXML format by explaining its structure of the export format.

Once that all the needed information are inserted into the Revit model file, is possible to proceed with the export settings.

Although the gbXML interchange format looks like the interchange format based on the concept of energy analysis, it can sometimes be more an impediment.

It's known that the gbXML file for energy analysis purposes should be exported early in the design stage, when the models contain only basic building geometry and spaces. Once that additional objects like furniture are added, the files become larger, and the energy analysis software have difficulty distinguishing all the data, leading to errors during the importation process. Unlike the IFC format, the gbXML format has no filtering options regarding model objects.

The energy analytical model is composed of analytical spaces and analytical surfaces, which are created based on parameters defined in the Energy Settings dialog. The exported data provides an accurate energy model for analysis. Before exporting to gbXML, define parameters in the Energy Settings dialog and create an energy analytical model. [25]

Inside the Revit tab "Analyze", it's possible to find the "Energy Settings" where it's possible to set all the information needed for the correct exportation of a gbXML file.

Revit offers three options for exporting to gbXML which correspond to the options for the analysis mode in the Energy Settings dialog [26].

Energy Settings tab - gbXML

Energy Settings	
Parameter	Value
Energy Analytical Model	
Mode	Use Building Elements
Ground Plane	Livello 1
Project Phase	Fase 3
Analytical Space Resolution	457.2
Analytical Surface Resolution	304.8
Perimeter Zone Depth	4572.0
Perimeter Zone Division	<input checked="" type="checkbox"/>
Average Vertical Void Height Threshold	1828.8
Horizontal Void/Chase Area Threshold	0.093 m ²
Reports Folder Path	\\<ProjectName>_Reports
Advanced	
Other Options	Edit...

Setup description

Use building elements: this option creates analytical spaces and surfaces from building elements. The building elements are the starting point from which the entire model is defined. Looking at the hierarchical schema of the gbXML format it's clear that the building elements as floor and walls are associated with the belonging analytical space.

For energy analysis purposes

This option is strongly discouraged when the building elements within the model that do not have the task of dividing the zones. Select this mode when you have a detailed architectural model.

Use conceptual masses and building elements: this option creates analytical spaces and surfaces from conceptual masses and building elements. The building elements and the conceptual masses are the

This option is strongly discouraged when there are additional elements inside the model, that do not have the only task of dividing the zones. Select this mode when the model contains only masses, only building elements, or a mix of the 2 types of elements, which is useful

<p>starting point from which the entire model is defined.</p>	<p>when performing energy optimization using the Mixed Design method.</p>
<p>Use rooms/spaces elements: this option creates analytical spaces and surfaces from room/space volumes. The room/spaces are the starting point from which the entire model is defined. When using this option is needed to put particular attention to the design process. Inside the model is possible to find air gaps within the room spaces and the volume generated by the Revit space element.</p>	<p>This option is the most quoted when it comes to exporting the model in gbXML format, because it takes the volumes directly from the rooms/environment elements created in the Revit files. Before using this method, add rooms or spaces to the model.</p>
<p>Ground Plane: useful to export the reference plane in order to set the ground plane, also when it's not specified.</p>	<p>For energy analysis select the reference ground plane giving the right level.</p>
<p>Project Phase: useful to export the reference phase, usually in the context of renovation it is necessary to analyse the energy consumption before and after the intervention.</p>	<p>For energy analysis select the phase that we want to analyse.</p>
<p>Analytical Space Resolution: allows to increase or decrease the resolution of a space. When</p>	<p>For energy analysis is recommended to leave the default options. Reducing these values</p>

<p>the value of the resolution decrease the processing time required to create the energy model increases significantly, giving a more precise export of the geometry.</p>	<p>does not necessarily result in a more accurate energy model. For example, while a lower Analytical Space Resolution value can result in smaller gaps between Revit elements, it can also lead to the omission of some analytical spaces due to gaps between architectural elements that were ignored at the higher setting.</p>
<p>Analytical Surface Resolution: allows to increase or decrease the resolution of a surface. When the value of the resolution decreases the processing time required to create the energy model increases significantly, giving a more precise export of the geometry.</p>	<p>For energy analysis is recommended to leave the default options.</p>
<p>Perimeter Zone Depth: specify the distance to measure inward from the exterior walls to define the perimeter zone. This setting should always be used in conjunction with the check of “Perimeter Zone Division”.</p>	<p>For energy analysis is possible to set the length of this option. It is always needed to know the distance from the external wall for which to set a different thermal zone before changing this value.</p>
<p>Average Vertical Void Height Threshold: this value is used to avoid the application of unwanted thermal loads and properties to analytical spaces like ceiling voids and small</p>	<p>For energy analysis is recommended always to analyze the whole structure in order to understand the logical value to insert here.</p>

<p>vertical spaces, such as closets and small storage spaces. When an analytical space's average height falls within this threshold, it will automatically be assigned to Unconditioned zone equipment. All analytical spaces assigned as Unconditioned are not included in any systems analyses. Analytical spaces do not have a height, so the Average Vertical Void Height Threshold is determined by dividing the volume by the area.</p>	
<p>Average Vertical Void Height Threshold: this value is similar to the Average Vertical Void Height Threshold, this value is used to avoid the application of unwanted thermal loads and properties to analytical spaces. When an analytical space's area falls within this threshold, it will also be assigned to Unconditioned zone equipment for exclusion from any systems analyses.</p>	<p>For energy analysis is recommended always to analyze the whole structure in order to understand the logical value to insert here.</p>

Table 2.3.3-1 Energy Settings tab - gbXML

At the end of this tab is possible to find the “Edit” button in which is possible to set further options.

Inside this tab is possible to find the “Advanced Energy Settings” for the export of gbXML files.

Advanced Energy Settings tab - gbXML

Advanced Energy Settings

Parameter	Value
Detailed Model	
Target Percentage Glazing	0%
Target Sill Height	750.0
Glazing is Shaded	<input type="checkbox"/>
Shade Depth	457.2
Target Percentage Skylights	0%
Skylight Width & Depth	914.4
Advanced	
Export Complexity	Simple with Shading Surfaces
Sliver Space Tolerance	304.8
Building Envelope	Use Function Parameter
Analytical Grid Cell Size	914.4
Building Service	VAV - Single Duct
Building Infiltration Class	None
Building Data	
Building Type	Ufficio
Building Operating Schedule	Default
HVAC System	Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff
Outdoor Air Information	Edit...
Room/Space Data	
Export Category	Rooms
Material Thermal Properties	
Conceptual Types	Edit...
Schematic Types	<Building>
Detailed Elements	<input type="checkbox"/>

Setup description

Export Complexity: specifies the level of detail provided for openings, and whether shading surface information is exported. Shading surfaces are surfaces that are not adjacent to any space and include surfaces that create a solar obstruction.

For energy analysis purposes

“Simple” is the most used for heating and cooling loads analysis. When the model has curtain walls as exterior walls is possible to also choose the “Complex” mode, where curtain walls are exported as multiple openings, panel by panel. It’s possible to add also shading surfaces and mullions, but usually adding this information can lead to errors when the model is imported to the energy simulation software.

<p>Sliver Space Tolerance: specifies the tolerance for areas that will be considered sliver spaces.</p>	<p>For energy analysis is recommended always to analyse the whole structure in order to understand the logical value to insert here.</p>
<p>Building Envelope: specifies the method to use to determine the building envelope. There are 2 methods for the identification of the building envelope. The first one (default) is the “Use Function Parameter”, where the function type parameter are used to determine the building envelope. The second one is the “Identify Exterior Elements”, where a combination of ray-casting and flood-fill algorithms is used to identify the building elements that are exposed to the outside of the building</p>	<p>For energy analysis is always better to maintain the default method, “Use Function Parameter”, for determine the building envelope.</p>
<p>Analytical Grid Cell Size: Specifies the cell size for the uniform cubical grid. This is the base size of the 3D grid cells, or cubes, used to divide the building shell bounding box into a uniform cubical 3D grid. This parameter is available when Building Envelope is set to Identify Exterior Elements.</p>	<p>The use of the method of “Identify Exterior Elements” for determine the building envelope is not recommended for energy analysis. Despite this, the value to insert here in case of the use of this method depends on the scale of the project. Usually, the default value is sufficient to identify correctly all the external surfaces, but it can change depending on the scale of</p>

	the objects we are taking into consideration.
Building Service: specifies the heating and cooling system for the building (central heating, VRF, radiant floor, radiator, VAV...)	Select the correct information based on your project.
Building Infiltration Class: specifies an estimate of outdoor air that enters the building through leaks in the building envelope.	<p>All the elements that interrupt the continuity of the envelope can cause air infiltration. Analyze all these elements to calculate the ratio of air infiltration.</p> <p>Loose - 0.076 cfm/sqft for tightly constructed walls.</p> <p>Medium - 0.038 cfm/sqft for tightly constructed walls.</p> <p>Tight - 0.019 cfm/sqft for tightly constructed walls</p> <p>None - infiltration is excluded from the calculation of loads.</p>
Building Type: the building type includes assumptions about the typical schedule of the building based on usage. For instance, a retail store is assumed to be open more hours per year than an office building, and so it uses more energy.	Select the correct information based on your project.
Building Operating Schedule:	This schedule can have a significant impact on the energy

<p>specify the operating schedule for the building.</p>	<p>results. Choose a schedule that most closely matches the building's assumed hours of operation.</p>
<p>HVAC System: specify an HVAC system for the project.</p>	<p>Select the correct information based on your project.</p>
<p>Outdoor Air Information: specify the outdoor air per person, outdoor air per area, and infiltration for the whole building.</p>	<p>Select the correct information based on your project. You can insert the data using the rate of new air you need to have from local legislation.</p>
<p>Room/Space Data: if the architectural model contains rooms or spaces that reside within analytical spaces of the energy model, the Export Category setting determines whether room information or space information is used in the analysis.</p>	<p>Select the correct information based on your project.</p>
<p>Material Thermal Properties: Revit offers 3 ways to specify material thermal properties of building elements for energy analysis. These methods can be used in combination with one another to suit different stages in the design process, levels of detail, and user preference.</p> <p>The “Conceptual types” are predefined materials where the</p>	<p>Select the correct information based on the level of detail of your project. When the stratigraphy is known always use the “Detailed elements” way to specify the material and thermal properties.</p>

only information you need to know is the description of the material.

The “**Schematic types**” has both described information and thermal transmittance values, and once you insert the values here, this will override the “Conceptual types”.

The “**Detailed elements**” where enabled and where material thermal properties are specified for building elements, override both conceptual types and schematic types.

Table 2.3.3-2 Advanced Energy Settings tab - gbXML

2.5. Import to BEM softwares

The use of the export settings just illustrated is necessary for a correct export of the BIM model in the IFC or gbXML formats. Despite this, every program has its bugs for this reason it is always better to study the chosen energy analysis program and carry out some tests before importing a complex energy model.

This chapter tests the export of Revit BIM models to interchange formats such as IFC and gbXML. The files exported from Revit will then be imported into energy analysis programs to test their interoperability. The Revit model files are provided by A.G.S. Project S.r.l..

First, the files will be imported without any export methodology, in order to evaluate the calculation software and their reading skills regarding the BIM models. Various tests carried out in the various literature texts will also be evaluated. All the exported models have been imported into the energy analysis software without following any methodology for the improving of the file for energy analysis purposes.

For illustrative purposes, a Revit project of a 5-storey building and subsequent imports into Termolog and IES-VE are shown below.



Figure 2-7 Revit model of residential building

As we can see, the architectural model in Revit is fulfilled with all the architectural details and the context. Most of this information are not useful for energy calculation purposes.



Figure 2-8 Residential building imported in Termolog via IFC

The import into Termolog was done using the IFC format. As it is possible to see, the model has been imported completely, dragging with it all the elements of the context which, in this case, are useless for the purposes of energy calculation. Most of the surfaces regarding the soil and the context are also incorrectly imported. It is possible to see how some windows are not imported and all the roof surfaces were not imported. Thermal zones were also incorrectly imported, and the weather data was not imported. Regarding the materials, however, these were easily read by Termolog. HVAC system information, as we previously described, cannot be exported with an IFC format.

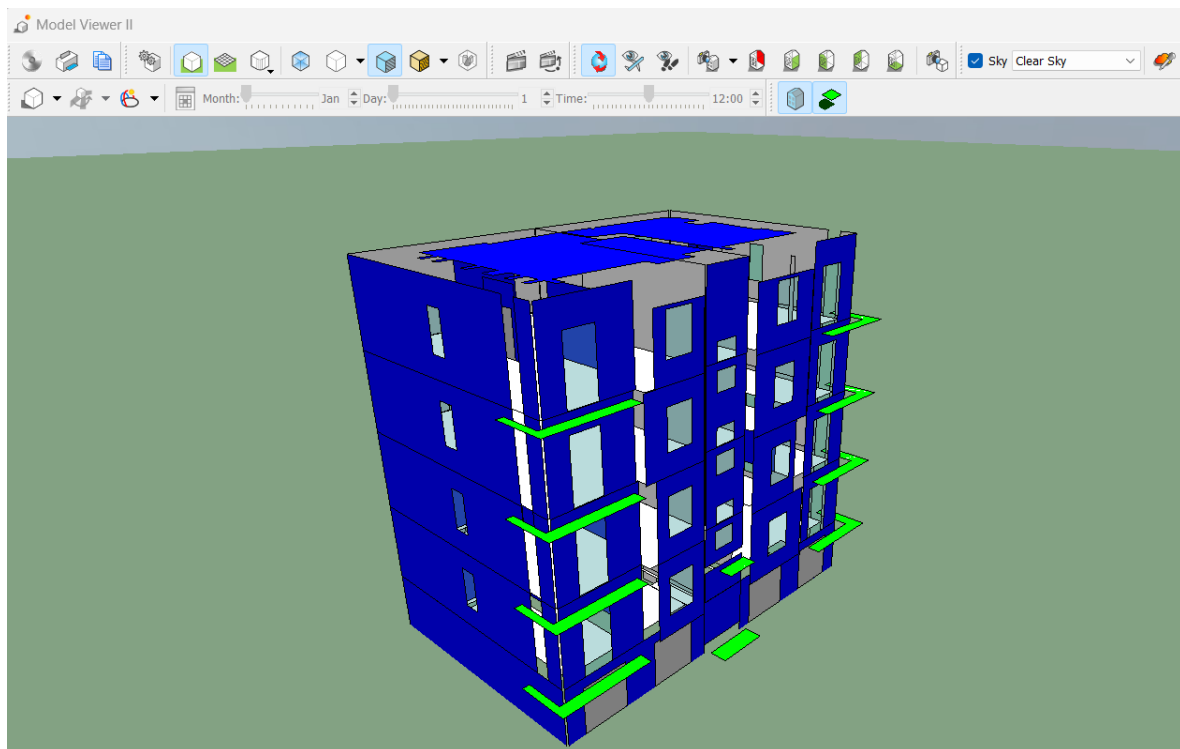


Figure 2-9 Residential building imported in IES-VE via gbXML

The import into IES-VE was done using the gbXML format. As it is possible to see, unlike the IFC format, the gbXML has the ability to read only the information limited to the envelope of the building. This is because of the gbXML bottom-up structure, where all the information are linked to the room (walls, ceilings, floors and openings). The only way in which is possible to add the background when exporting in gbXML format is by choosing the elements of the background and assign them as shading surfaces (which is the only reason to include elements of context within an energy model). In the gbXML import the zones were correctly imported, however, as we can see, the import did not work well with the surfaces of the envelope. Materials and weather data were also correctly imported. Regarding the HVAC system information, the information from the Revit file were not correctly imported.

3 Case study

This chapter analyses the imports of BIM models and the related information imported into the model. We observe the criticalities in the import phase. The precautions to be considered to improve the interoperability between the two programs are also described.

We will focus on the results of the import tests of Revit BIM models within the energy analysis program. For the energy analysis, we will use the Termolog software, which can import files in both IFC and gbXML formats. Termolog it is also capable of exporting the model in IFC format. As will be seen later, the fact that Termolog is able to export files in IFC format will also be important for understanding which are the sets of parameters used by Termolog both in the reading and writing phases. Furthermore, Termolog is certified by the local Italian legislation (CTI – Comitato Tecnico Italiano).

IFC was chosen because it is an interchange format that allows you to export the model for energy calculation purposes at any time during the design phase and not only at the beginning as for gbXML.

As described in the methodological chapter, for the export of these models we will use the "IFC4 Design Transfer View" format.

In this chapter we will focus on carrying out various tests with a simplified model in order to optimize the interoperability process and then apply it on more complex case studies, such as those analysed in the methodological chapter.

As regards the export settings, particular attention is paid to the export settings of the project parameters. In fact, some parameters are grouped and then exported thanks to the use of abacuses specifically created within the Revit model. These schedules are named according to the standard IFC nomenclature of the reference "Property Set".

3.1. Example project

We will first start by analysing a simple case. A small building model is created (few rooms divided in two levels) in order to test the effectiveness of the data transfer via IFC model between the Revit 2023 program and Termolog 13. Inside the small building model that will be called "Example Project", all the information necessary for energy calculation are described.

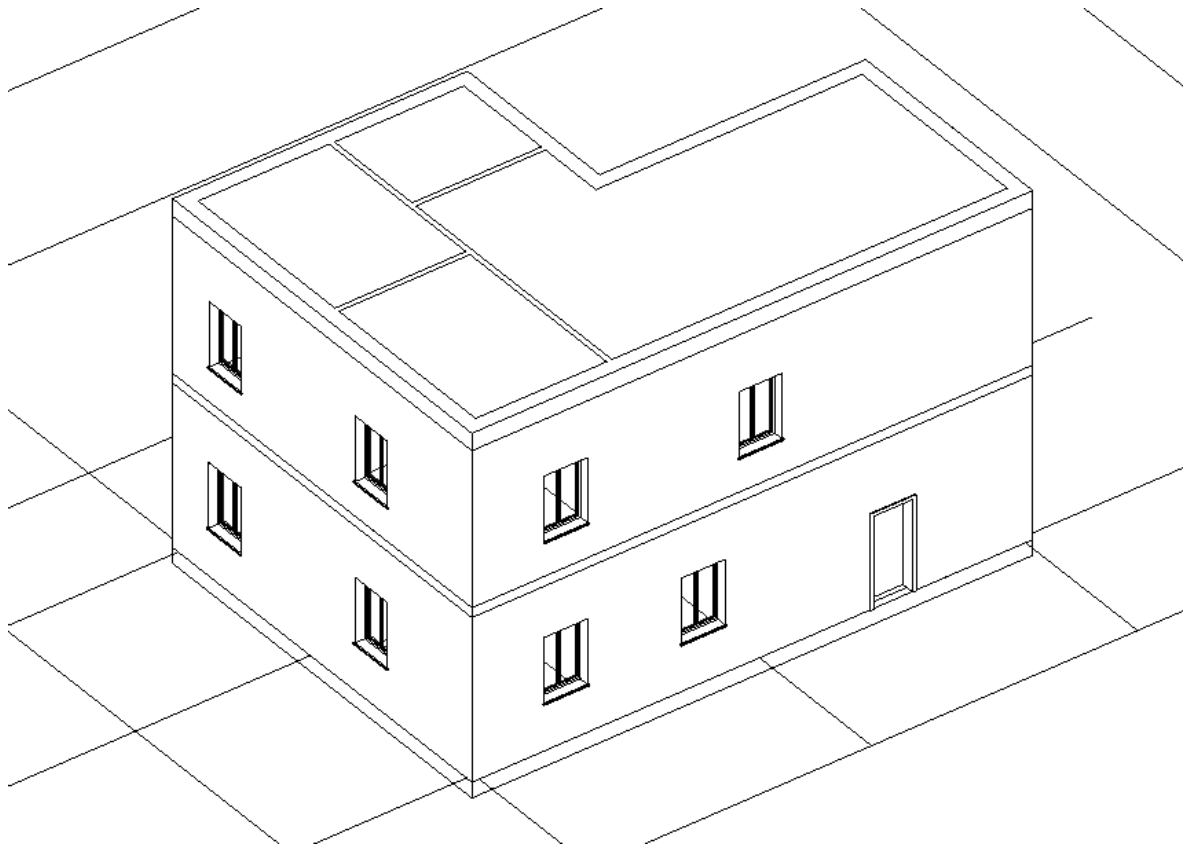


Figure 3-1 Example model in Revit

3.2. Encountered errors – IFC into Termolog

Immediately from the first import it is possible to notice geometric errors such as the roof, the thermal zones and the dimensions of the windows. In this chapter we will analyse all the encountered errors and, where possible, the solutions to overcome these problems. The following critical issues are highlighted during the import phase of the IFC model within the Termolog program.

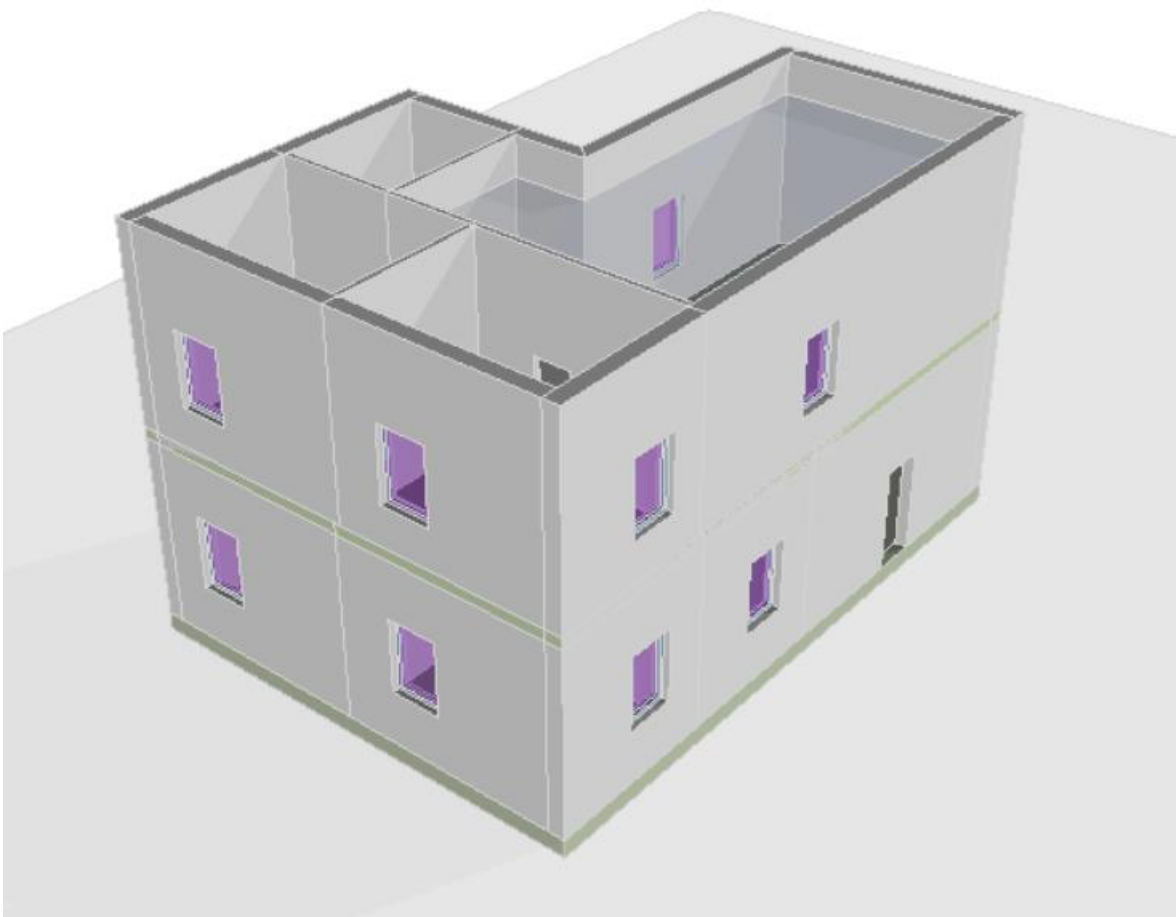


Figure 3-2 Example model imported in Termolog via IFC

3.2.1. Roof

As it possible to see the roof give us some problems when it is imported into Termolog. Checking in the BIM viewer and looking after the code we can see that the object is correctly exported from Revit. This situation leads us to believe that there is probably an error during the import phase in Termolog.

The consideration regarding the appearance of roofs is that they must be modelled within Revit on the same level as the room below. Otherwise Termolog will not read the coverage, ignoring the import of the geometric element or importing it with errors.

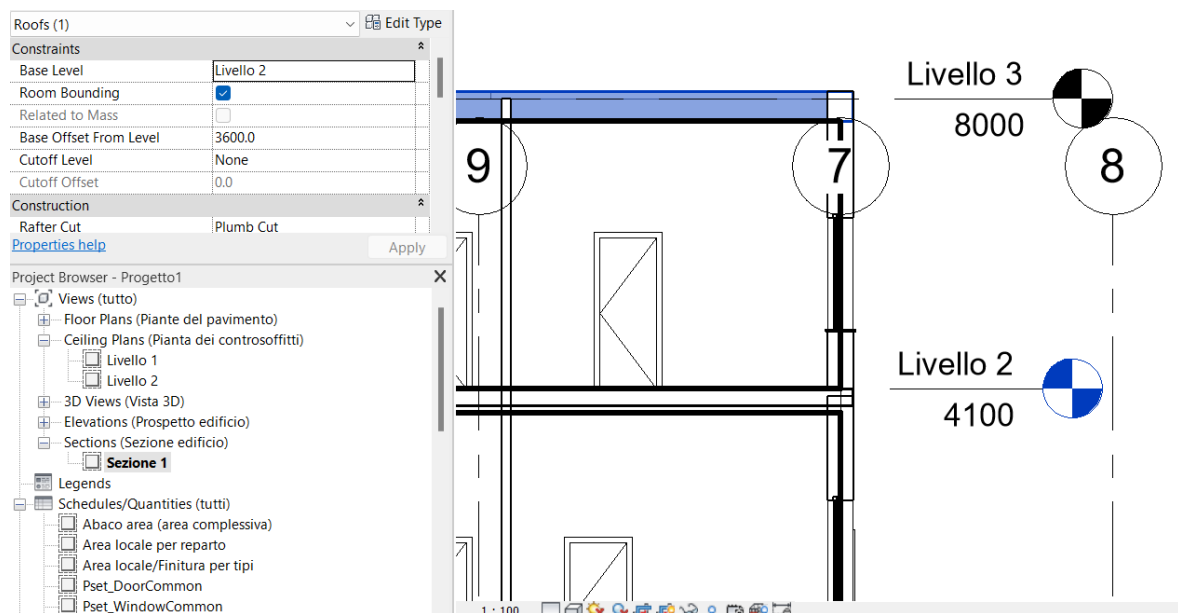


Figure 3-3 Roof modelling inside Revit

For a correct setting of the roofs, it is recommended to export the objects classified as ifcSlab (not ifcRoof). Furthermore, it is preferable that the pitches of the roofs are modelled individually. The modelling of the entire object takes place in substantially different ways depending on the BIM software used and this leads to a conversion in the IFC file which can also be very different from case to case, for this reason the modelling for single roof avoids import errors. Using triangulation drawing methodologies can improve Termolog's reading.

3.2.2. Window Dimensions

Inside the model we have created a family for the windows. The windows family has a dimension for the hole and other dimensions regarding the objects modelled inside it. Termolog reads from the IFC model only the dimensions regarding the hole.

Each window or window family must contain the architectural light inside the hole generated by Revit. By way of example, if it is decided to represent windowsills or roller shutter that penetrate the envelope, these must be represented by trying to keep the light of the hole of the same size as the architectural light. In the following image is shown how to proceed for correct modelling of the windowsills, the same logic must be followed also for roller shutters.

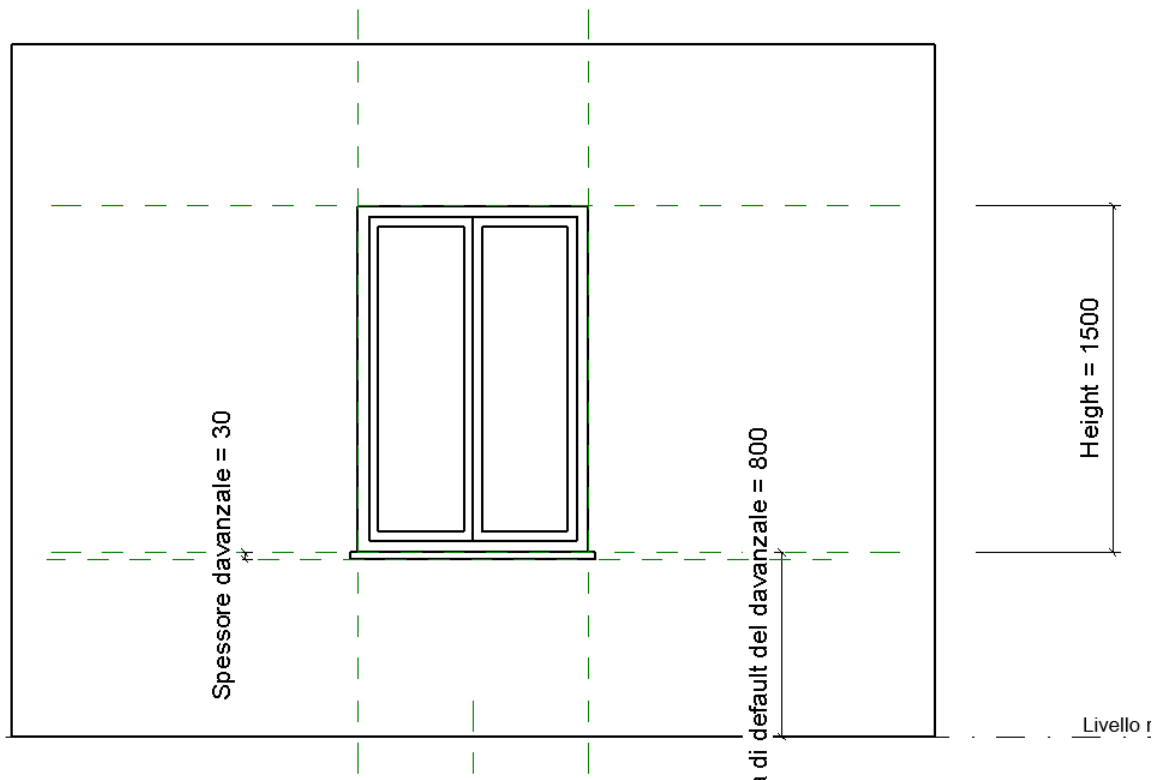


Figure 3-4 Window family modelling inside Revit

As it is possible to see, the height of the window has to be the same dimension of the architectural light. This means that we need to model roller shutters and windowsills outside the represented height.

3.2.3. Window Thermal Transmittance

Windows transmittance is inserted inside the IFC parameters. As we can see from the BIM viewer and the related code, the Thermal Transmittance parameter is correctly exported from Revit inside a set called "Analytical properties".

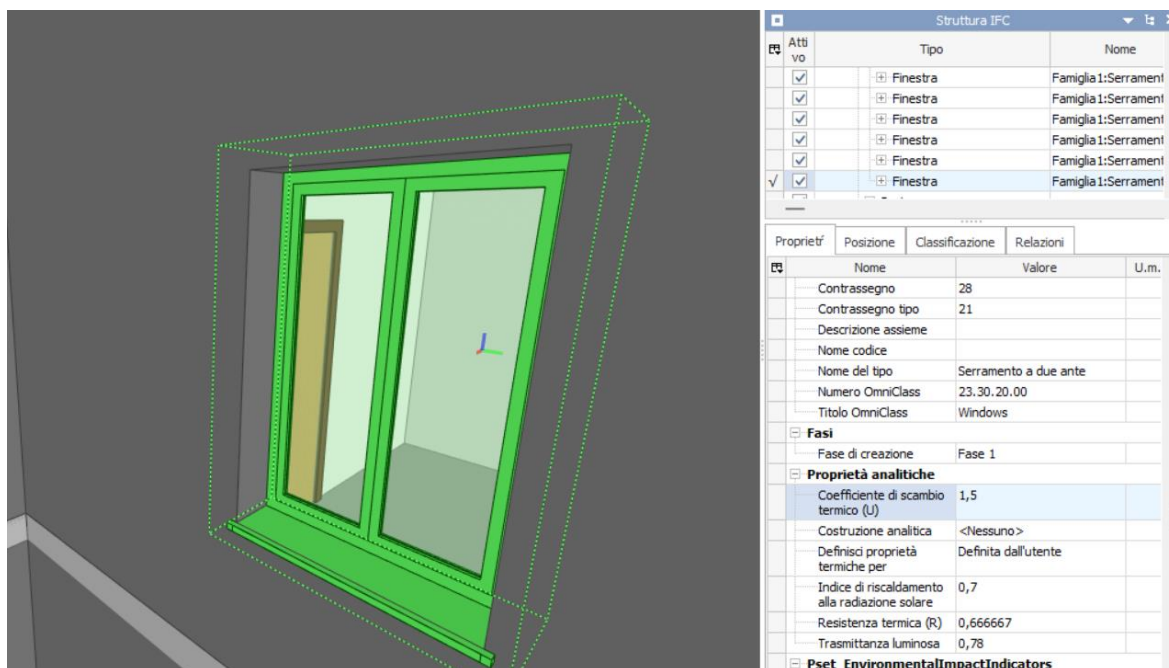


Figure 3-5 Window thermal transmittance properties in BIMviewer

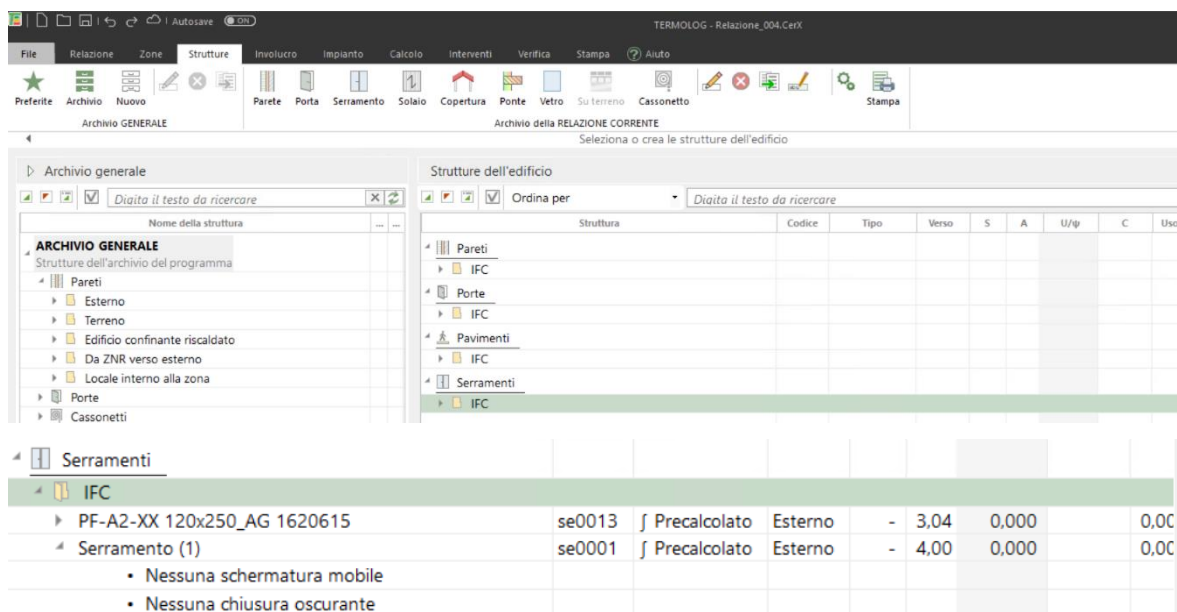


Figure 3-6 Window thermal transmittance properties in Termolog

Exporting a sample model from Termolog into IFC format is possible to see that the information regarding the transmittance are collected inside a set called "Pset_WindowCommon". This means that we need to export this parameter inside the correct set of parameters. As regards objects defined as IfcWindow, the IFC standard provides for a set of parameters called "Pset_WindowCommon" which contains a list of predefined parameters, in which we can find the Thermal Transmittance parameter. By adding the parameters to the schedules and then checking the "Export schedules as property groups" box, it was possible to transfer some information (such as the transmittance of the windows) that was previously not possible through the export of conventional properties (Revit and IFC properties).

Pset_WindowCommon		Pset_WindowCommon	
A		B	
ThermalTransmittance		Trasmissione luminosa	
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78
1.5000 W/(m²K)			0.78

Figure 3-7 Schedule for thermal transmittance properties in Revit

Proprietà	Posizione	Classificazione	Relazioni
Nome		Valore	U.m.
Fase di creazione		Fase 1	
Proprietà analitiche			
Pset_EnvironmentalImpactIndicators			
Reference		Serramento a due ante	
Pset_WindowCommon			
IsExternal		No	
Reference		Serramento a due ante	
ThermalTransmittance		1,5	
Quote			
Altezza		1 500	mm
Area		2,75483	m2
distanza vetro		15	mm
Larghezza		1 000	mm
Profondità imbotte		120	mm
Spessore avanzale		30	mm
Volume		0,04469	m3
Vincoli			
Altezza soglia		800	mm
Livello		Livello 2	

Figure 3-8 Window thermal transmittance properties exported as schedule in BIMviewer

As it is possible to see in the following images, the BIM viewer of Termolog is now capable of reading the information regarding the Thermal Transmittance. It is also possible to read the information in the “Structures of the Building” tab inside Termolog 13.

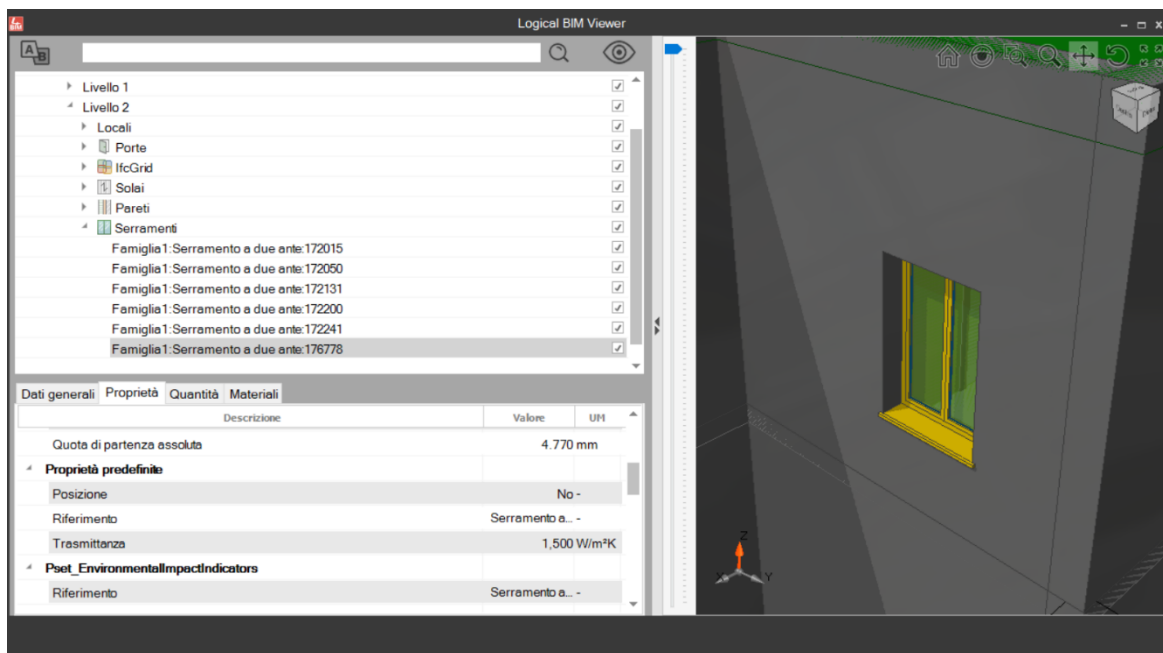


Figure 3-9 Window thermal transmittance exported as schedule in Termolog viewer

The screenshot shows the 'Strutture dell'edificio' (Building Structures) schedule. The table has the following columns: Struttura, Codice, Tipo, Verso, S, A, U/ψ, C, Uso, U, HT, Note. The 'Serramenti' (Windows) category is expanded, and one entry is highlighted in green:

Struttura	Codice	Tipo	Verso	S	A	U/ψ	C	Uso	U	HT	Note
Famiglia1 Serramento a due ante 174476	se0001	f Precalcolato	Esterno	-	1,50	1,500	13,50				

Figure 3-10 Window thermal transmittance exported as schedule in Termolog viewer

3.2.4. Environments

Before exporting, each internal environment of the building must have its own room assigned. The room will have the function of a thermal block inside Termolog.

The premises must touch the internal surfaces of the environment where they are located, i.e., the internal surfaces of the walls, the flooring, the intrados of the attics.

Within the BIM model it is necessary to define the spaces that must be in contact with the side walls, underlying floor and upper ceiling without penetrating into them or remaining distant from them. Spaces must be saved within the IFC file as "ifcSpace" objects. Assign inside Revit every environment with Space instead of Room.

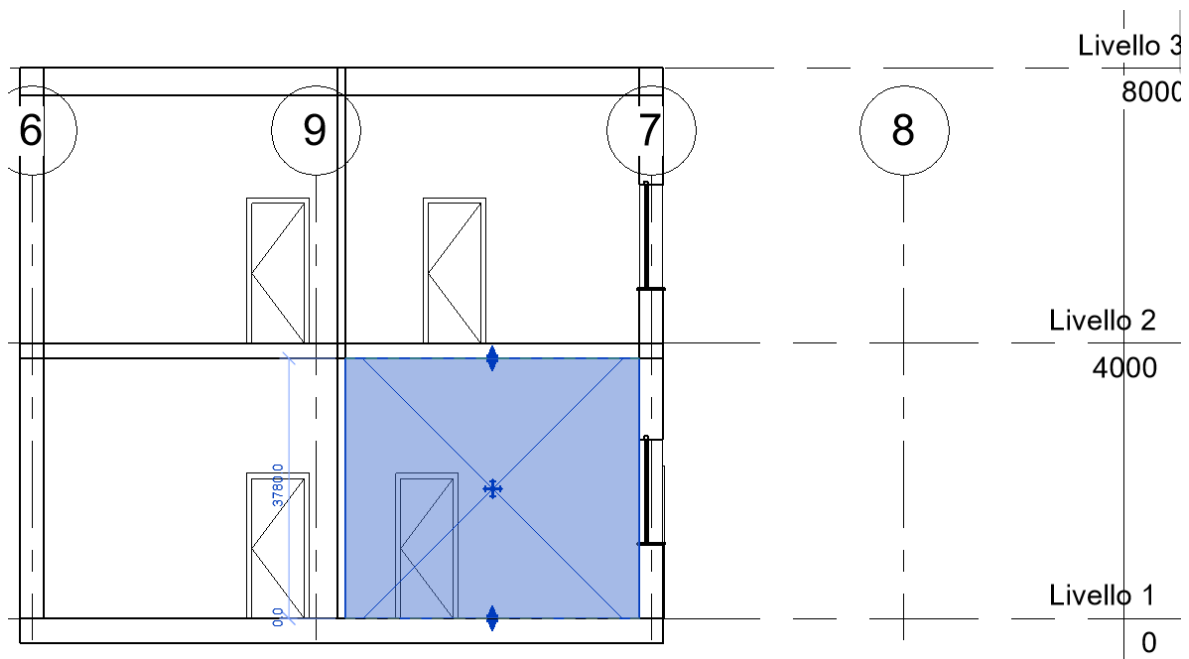


Figure 3-11 Environments modelling in Revit

To ensure that Termolog reads well the rooms that do not have a clear parallelepiped shape, go to the "Architecture" tab, open the drop-down menu of the "Room and area" group, open the "Calculation areas and volumes" settings and tick in the first Calculation form, "Areas and volumes".

3.2.5. Thermal Zones

Despite the organization of the rooms in different thermal zones within Revit, when importing the IFC file into Termolog, this is able to recognize only the rooms and group them within a single thermal zone.

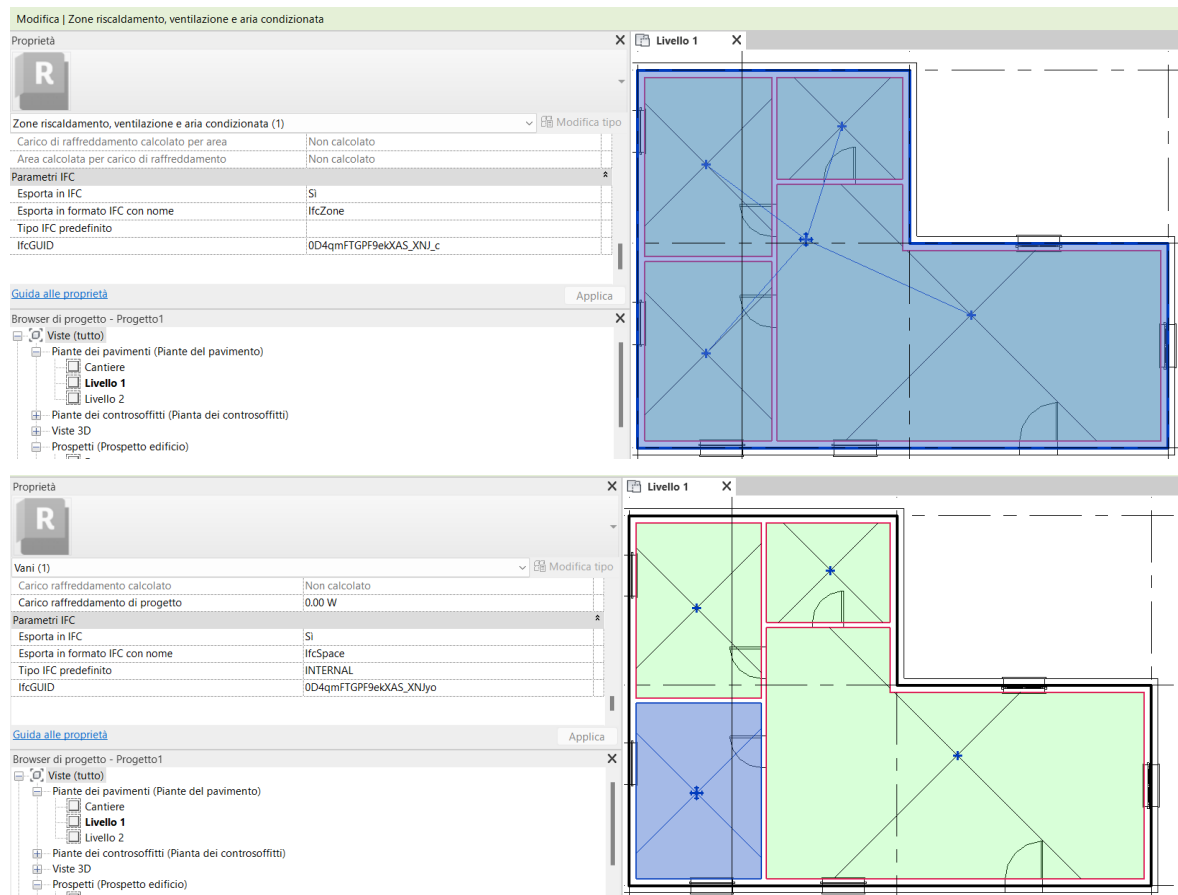


Figure 3-12 Thermal zones modelling in Revit

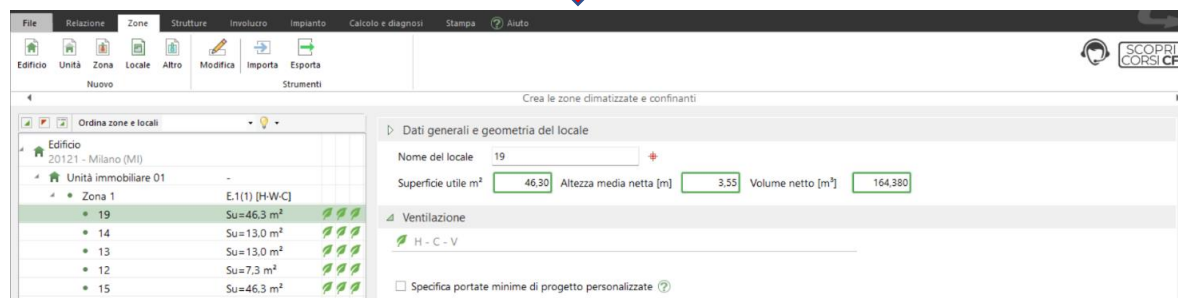


Figure 3-13 Thermal zones imported in Termolog

3.2.6. Door Thermal Transmittance

Before importing the IFC model, Termolog is able, through the internal BIM viewer, to open the file in order to observe and investigate all the imported IFC objects. By importing the Example Project, we observe within the viewer that the transmittance of the "door" objects is read correctly. As has been done for the windows Thermal Transmittance, also the door Thermal Transmittance was inserted in the correct property set.

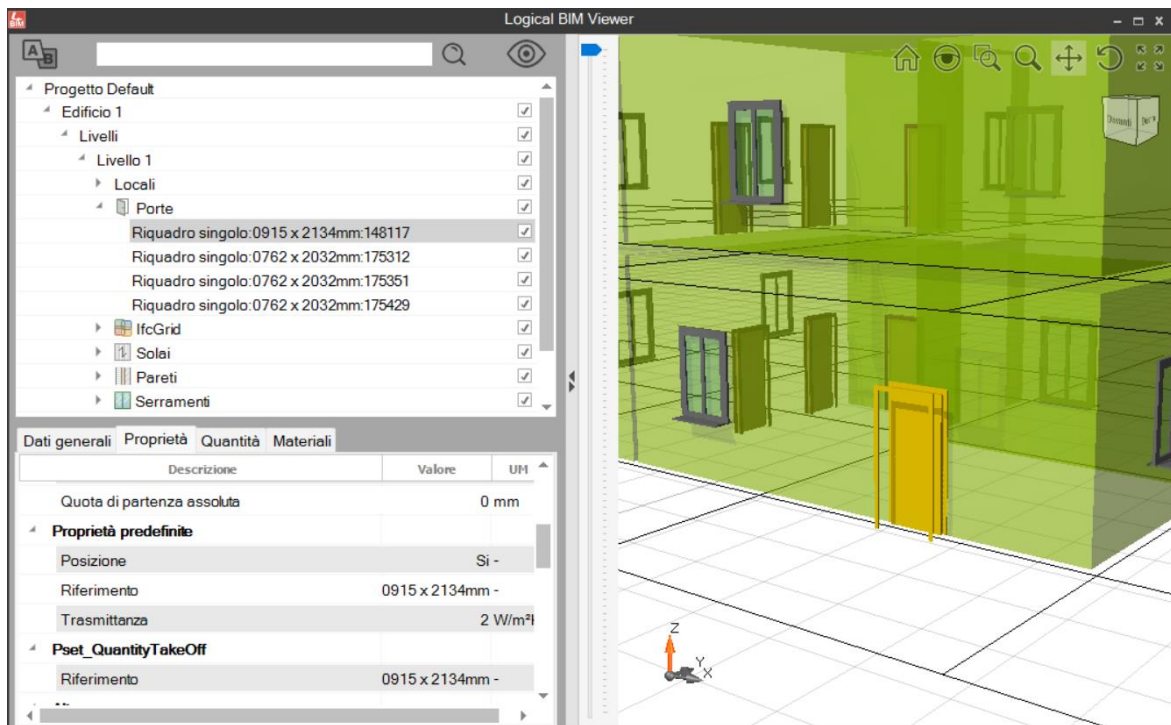


Figure 3-14 Door thermal transmittance exported as schedule in Termolog viewer

After closing the Termolog BIM Viewer and importing the file into the modelling space, the information regarding the door Thermal Transmittance is lost and the program automatically inserts a transmittance value equal to 1.

Struttura	Codice	Tipo	Verso	S	A	U/ψ	C
<ul style="list-style-type: none"> ▾ Pareti ▾ IFC <ul style="list-style-type: none"> ▸ Muro di base:Interno - 100 blocchi ▸ Muro di base:Muratura forata 300 	<ul style="list-style-type: none"> pa0009 pa0002 	<ul style="list-style-type: none"> ≡ Parete ≡ Parete 	<ul style="list-style-type: none"> Interno Esterno 	<ul style="list-style-type: none"> 12,4 34,0 	<ul style="list-style-type: none"> - - 	<ul style="list-style-type: none"> 2,538 1,987 	<ul style="list-style-type: none"> 68,052 71,717
<ul style="list-style-type: none"> ▾ Porte ▾ IFC <ul style="list-style-type: none"> Riquadro singolo 0762 x 2032mm 175351 Riquadro singolo 0915 x 2134mm 148117 	<ul style="list-style-type: none"> po0002 po0001 	<ul style="list-style-type: none"> ∩ Porta ∩ Porta 	<ul style="list-style-type: none"> Interno Esterno 	<ul style="list-style-type: none"> 5,0 5,0 	<ul style="list-style-type: none"> - - 	<ul style="list-style-type: none"> 1,000 1,000 	<ul style="list-style-type: none"> 10,000 10,000

Figure 3-15 Door thermal transmittance exported as schedule in Termolog

3.2.7. Project Location

The project location set within the Revit program does not appear to be imported within Termolog. By analysing the same file imported into Termolog through other BIM viewers, it is possible to observe how the geographical coordinates of the project location are correctly assigned to the model exported from Revit.

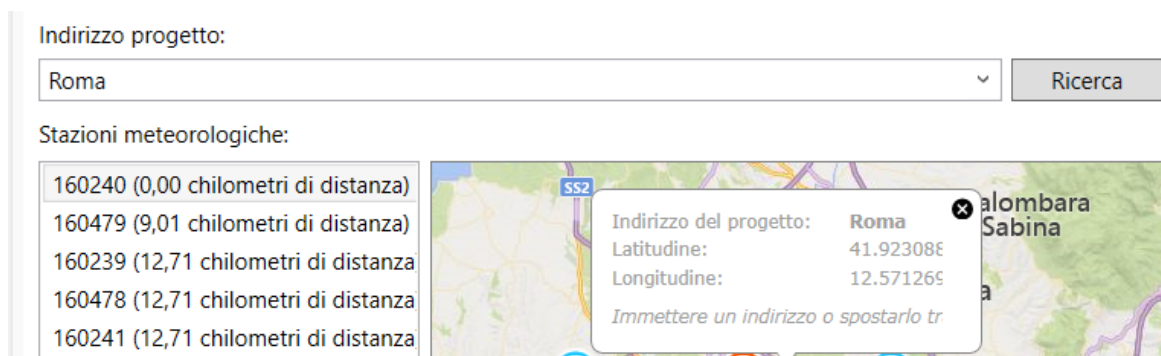


Figure 3-16 Project location in Revit

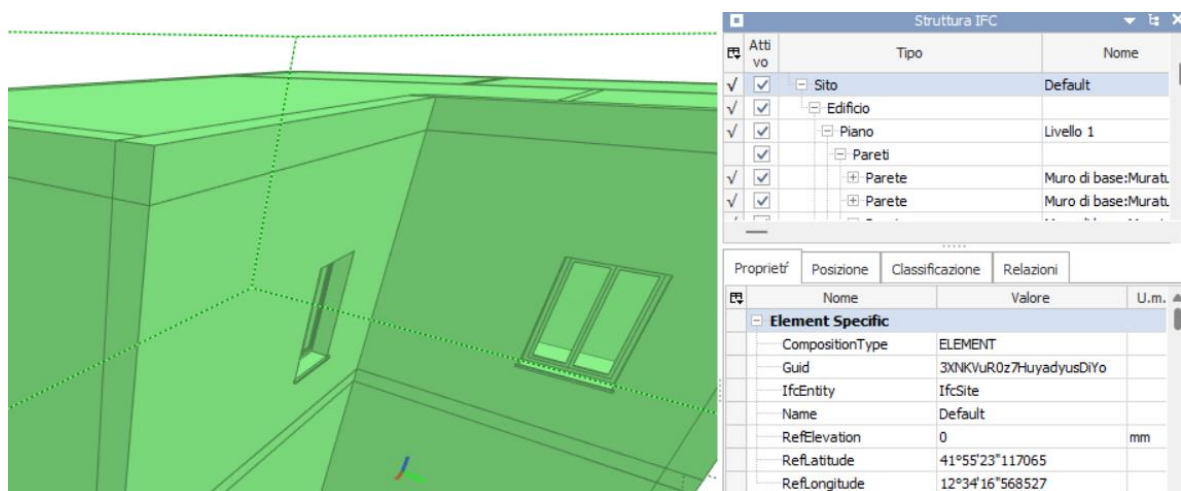


Figure 3-17 Project location in BIMviewer

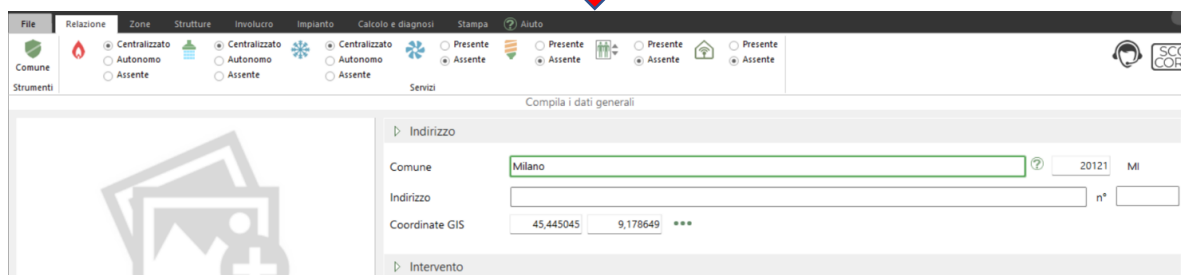
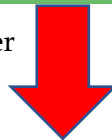


Figure 3-18 Project location in Termolog

3.2.8. Double Heights

We need to model the elements of the building by levels in such a way as to have an immediate correspondence in TERMOLOG. For example, we recommend modelling the perimeter walls by hooking them level by level without creating a single wall for the entire height of the building. If there are staggered levels, it is recommended to treat the portions of the building on different drawing levels. This because of the structure of the IFC format. As we described in the chapter “1.3.2 IFC” the top-down structure divides the model in storey before the classification of each object.

3.2.9. Elements that cross levels

Termolog does not read well those elements that cross the levels in Revit. For example, windows (especially in stairwells), doors that are at sidewalk level and cross any intermediate level, etc. For these reasons, as for the double high walls, it is essential to model in Revit the objects assigning them to a singular level. In those cases where the elements are forced to cross the levels, it is necessary to evaluate the creation of a model in which to simplify the elements of the building or the position of its elements, before exporting to IFC.

3.3. Interoperability assessment

We can consider the interoperability analysis completed for the import of IFC models from Revit to Termolog. Although it is carried out on a simplified model, the way in which the information is imported and exported is the same.

The table below summarizes all the practical aspects to consider when modelling for energy analysis export purposes. It should be noted that the following summary was drawn up between the version of Termolog 13 and that of Revit 2023.

Revit – Termolog interoperability via IFC	
Error	Solution
Roof: not imported or imported incorrectly	<ul style="list-style-type: none"> - Export the objects classified as ifcSlab and not ifcRoof. - Draw within Revit on the same level as the room below. - Triangulation drawing.
Window Dimensions: the size of the window takes into consideration also the height of the windowsill	<ul style="list-style-type: none"> - Draw the Architectural light of the window as the opening of the whole system (windowsill a roller shutters must be drawn outside of the created hole).
Window Thermal Transmittance: thermal transmittance not imported inside Termolog (but visible inside the BIMviewer)	<ul style="list-style-type: none"> - Check if the Thermal Transmittance is inside the IFC properties of the Window.

	<ul style="list-style-type: none"> - If Thermal Transmittance is still not present inside the imported file in Termolog try to export a BIM file from the energy software and check the correct property set where this information are collected. - Generate inside the BIM model the correct property set as a schedule, or a user defined property set.
<p>Door Thermal Transmittance: thermal transmittance not imported inside Termolog (but visible inside the BIMviewer)</p>	<ul style="list-style-type: none"> - Modify the model inside Termolog.
<p>Environments: not imported or imported incorrectly</p>	<ul style="list-style-type: none"> - Use Space instead of Room to assign the environments. - Spaces must be in contact with the side walls, underlying floor and upper ceiling without penetrating into them or remaining distant from them. - Assign "ifcSpace" to correctly export the BIM file.
<p>Thermal Zones: not imported</p>	<ul style="list-style-type: none"> - Group every environment in the corresponding thermal zone inside Termolog.

Project Location: not imported	- Modify the location inside Termolog.
Double Heights: not imported or imported incorrectly	- Treat the portions of the building on different drawing levels.
Elements that cross levels: not imported or imported incorrectly	<ul style="list-style-type: none"> - Model in Revit the objects assigning them to a singular level. - Evaluate the creation of a model in which to simplify the elements of the building or the position.

Table 3.2.9-1 Revit – Termolog interoperability via IFC

3.4. Application of the interoperability methodology

So now let's try to apply all the methodologies just described to evaluate the degree of interoperability on the same building initially tested in the methodological chapter and let's try to use the same method on bigger buildings.

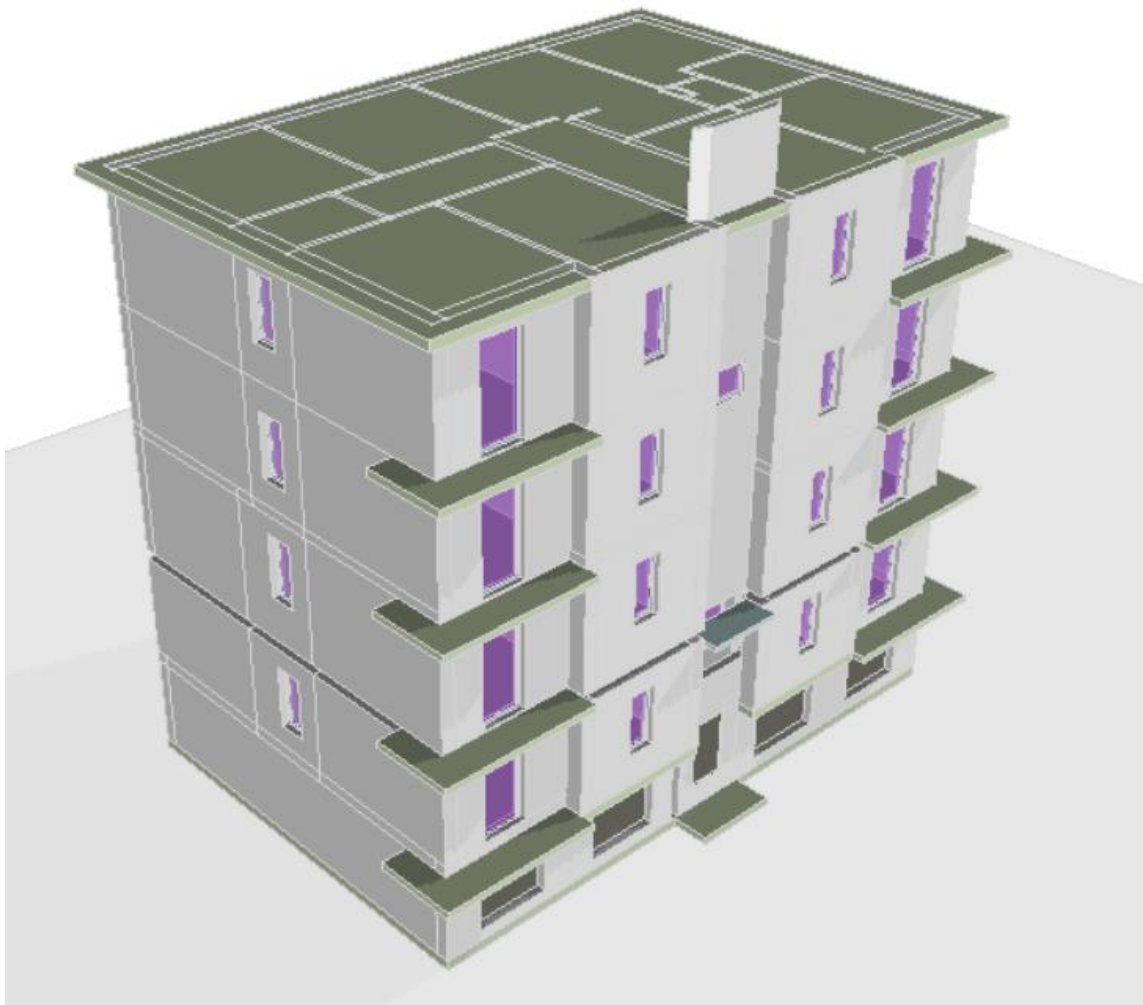


Figure 3-19 Residential building imported in Termolog via IFC after the application of the interoperability methodology

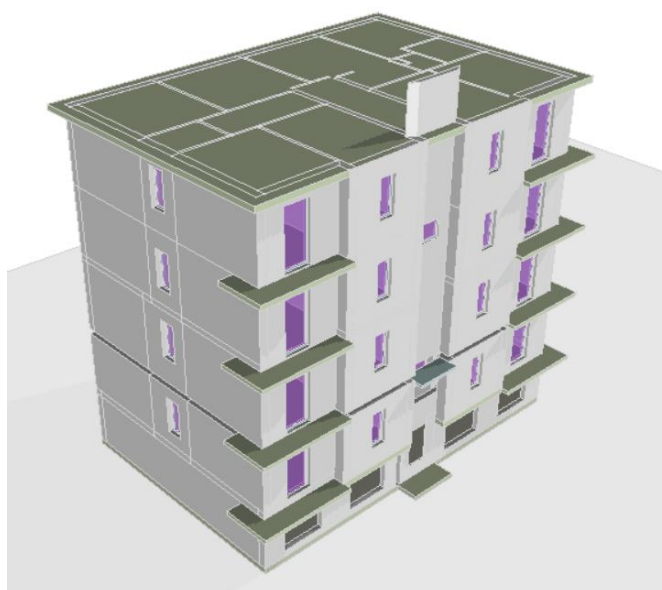
We can immediately see an improvement in the imported geometry. The walls and windows that previously made up the stairwell and which were in the middle between the floors have not been correctly imported, also after dividing them into different thermal zones for each

level. The roof (in this case only the attic as a surface bordering an unheated room) is imported correctly. We note a small difference regarding the final height of the stairwell wall. However, this does not affect the dispersing surfaces of the heated rooms. The transmittance of the windows is read correctly as the opening surfaces of the window. It is still impossible to associate the thermal zones with the rooms, the transmittance of the doors and the project location. A comparison of the model with and without the application of the interoperability methodology is shown below.

Before the application of the interoperability methodology



After the application of the interoperability methodology



4 Conclusions

The difficulty in BIM-BEM interoperability is one of the most common digital gaps in the world of design, where the entire evolution of the construction process is turning towards energy saving. BIM-BEM interoperability should save time and cost in the design process and BEM models should be accurate in order to guarantee the intentional energy savings. Nowadays, these two intentions are not yet guaranteed simultaneously. Importing from IFC and modelling via dwg reference requires almost the same effort.

The problem is related to the one-way interchange format exportation, in which the designer needs to simplify the model for exporting the IFC useful for energy analysis. After that, nothing can be changed inside the energy model and re-exported for further architectural modifications.

As developed within this paper, it is possible to make considerations (for each software) and develop an export methodology regarding IFC or gbXML formats within the chosen software, in order to set up the workflow during the design process, in such a way as to minimize the errors generated by the import/export of the files.

However, there remains a very important limitation concerning large-scale projects, where the software but also the computational technology of many computers is limited and very often with projects that contain a lot of information the IFC or gbXML files cannot be read by energy analysis software.

Despite the gbXML was created specifically for the transfer of architectural information for energy analysis, the export settings from Revit BIM software are very limited and do not allow you to export the model in an advanced state where there are architectural details that often cause errors during the energy software import process.

On the other hand, the IFC format, even if was not created for energy analysis purposes, is able to optimize the export process and limit the

generation of errors during import into energy analysis software. The IFC format therefore appears to have greater control over the export of data than the gbXML format.

Speaking therefore of IFC and gbXML formats it is possible to say that as regards the gbXML format there is a greater simplicity of the export settings at the expense of less control of the model during the export phase, while as regards the IFC format there is a complexity greater than the export process, while guaranteeing greater control of the exported information.

Regarding the interoperability between Revit and Termolog, the best results were obtained using the IFC format. However, this may not be valid if software other than these are taken into consideration. In any case, the methodology used in the second chapter can also be used as a guideline for comparison with other BIM modelling and energy analysis software.

5 Bibliography

- [1] S. Garagnani, «Building Information Modeling and real world knowledge: a methodological approach to accurate semantic documentation for the built environment,» in *Digital Heritage International Congress*, Online - Digital Heritage, 2013.
- [2] A. E. D. K. Smith, «Building information models BIM,» 15 October 2006. [Online]. Available: <http://www.wbdg.org/design/bim.php>. [Consultato il giorno 04 September 2022].
- [3] M. H. F. S. M. M. K. Letizia D'Angelo, «A novel BIM-based process workflow for building retrofit,» *Journal of Building Engineering*, vol. 50, 2022.
- [4] Biblus.Acca, «BIBLUS ACCA SOFTWARES,» ACCA SOFTWARES, 12 January 2022. [Online]. Available: <https://biblus.accasoftware.com/en/what-is-10d-bim/>. [Consultato il giorno 09 June 2022].
- [5] c. software, «cadlinesw,» 27 February 2017. [Online]. Available: <https://www.cadlinesw.com/cos-e-ifc-e-cosa-e-necessario-conoscere/>. [Consultato il giorno 05 July 2022].
- [6] BibLus-net, « BibLus-net,» 02 July 2015. [Online]. Available: <https://biblus.acca.it/uni-ts-11300-nuova-certificazione-energetica/>. [Consultato il giorno 08 11 2022].
- [7] A. S. A. D. Z. Pezeshki, «Application of BEM and using BIM database for BEM: A review,» *Journal of Building Engineering*, vol. 23, pp. 1-17, 2019.
- [8] A. A. Mahsa Farid Mohajer, «Integration of Building Energy Modeling (BEM) and Building Information Modeling (BIM): Workflows and Case Study,» *Building Technology Educator's Society*, vol. 27, 2019.
- [9] M. C. N. B. P. D. A. E. C. Elagiry, «IFC to Building Energy Performance Simulation: A Systematic Review of the Main Adopted Tools and Approaches,» in *In Proceedings of the BauSIM 2020-8th Conference of IBPSA*, Graz, Austria, 2020.

- [10 A. R., «ResearchGate,» 2019. [Online]. Available:
] https://www.researchgate.net/publication/337888446_A_review_on_the_challenges_of_BIM-based_BEM_automated_application_in_AEC_industry.
[Consultato il giorno 02 October 2022].
- [11 N. Moretti, X. Xie, J. Merino, J. Brazauskas e A. Parlikad, «An openBIM
] Approach to IoT Integration with Incomplete As-Built,» *Data. Appl. Sci.*, vol. 8287, p. 10, 2020.
- [12 A. Softwares, «Biblus.net,» ACCA, 17 February 2020. [Online]. Available:
] <https://bim.acca.it/ifc-2x3-coordination-view-2-0/>. [Consultato il giorno 07 July 2022].
- [13 P. P. A. Issa J. Ramaji, P. A. John I. Messner e P. and Ehsan Mostavi, «IFC-Based
] BIM-to-BEM Model Transformation,» *ASCE*, vol. 3, n. 34, pp. 1-13, 2020.
- [14 P. K. M. M. J. Klitgaard, «On the integration of digital design and,» *Digit. Archit. Constr*, 2006.
- [15 M. T. D.K. Smith, *Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*, USA: John Wiley & Sons, 2009.
- [16 M. Casini, «Sciencedirect,» 2019. [Online]. Available:
] <https://www.sciencedirect.com/book/9780128128176/handbook-of-energy-efficiency-in-buildings>. [Consultato il giorno 14 September 2022].
- [17 O. o. E. E. & R. ENERGY, «About Building Energy Modeling,» ENERGY GOV,
] [Online]. Available: <https://www.energy.gov/eere/buildings/about-building-energy-modeling>. [Consultato il giorno 06 December 2022].
- [18 A. O. M. D. G. Salvatore Magnano, «Dal Building Information Modeling al
] Building Energy Modeling: VPL per la gestione dell'interoperabilità mediante lo standard IFC,» Politecnico di Torino, Torino, 2020.
- [19 A. G. Mussi, «Infobuildenergia,» 24 January 2018. [Online]. Available:
] <https://www.infobuildenergia.it/approfondimenti/certificazione-energetica-regime-stazionario-e-regime-dinamico/#certificazione-energetica-differenza-tra-regime-stazionario-e-regime-dinamico>. [Consultato il giorno 09 November 2022].

- [20 mc4software, «<https://www.ingenio-web.it>,» Ingenio, 19 September 2019.] [Online]. Available: <https://www.ingenio-web.it/articoli/il-nuovo-quadro-normativo-europeo-per-il-calcolo-della-prestazione-energetica-degli-edifici/>. [Consultato il giorno 09 November 2022].
- [21 D. M. D. F. Aida Farzaneh, «Review of using Building Information Modeling] for building energy,» *Journal of Building Engineering*, vol. 23, pp. 127-135, 2019.
- [22 K. D. V. d. L. ,. A. S.-O. G. a. Gabriela Bastos Porsani, «Interoperability between] Building Information Modelling,» *Applied Science*, vol. 11, n. 2167, pp. 1-20, 2021.
- [23 A. Revit, «Manuale 2.0 dello standard IFC per Revit,» Autodesk, 2022.]
- [24 b. International, «buildingSMART International,» buildingSMART, 2022.] [Online]. Available: <https://technical.buildingsmart.org/resources/ifcimplementationguidance/ifc-guid/>. [Consultato il giorno 06 12 2022].
- [25 A. Help, «Document and present the design,» Autodesk, 16 August 2022.] [Online]. Available: <https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2022/ENU/Revit-DocumentPresent/files/GUID-586B9574-64DA-47BC-B8EC-DEF2D565928F-hm.html>. [Consultato il giorno 12 November 2022].
- [26 A. HELP, «Autodesk HELP,» Autodesk, 21 April 2017. [Online]. Available:] <https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2017/ENU/Revit-Analyze/files/GUID-36B2F66A-E423-4D9C-B266-3ABA57573F4A-hm.html>. [Consultato il giorno 03 January 2023].

6 List of Figures

Figure 1-1 The development of BIM	7
Figure 1-2 BIM Dimensions.....	10
Figure 1-3 gbXML bottom-up structure	15
Figure 1-4 IFC top-down structure	17
Figure 1-5 Energy Simulation Software	19
Figure 2-1 Interoperability methodology flowchart.....	27
Figure 2-2 Weather data input inside Revit.....	29
Figure 2-3 Building geometry input inside Revit	30
Figure 2-4 Thermo-physical characteristics of the materials input inside Revit.....	31
Figure 2-5 Thermal zones input inside Revit.....	32
Figure 2-6 HVAC input inside Revit.....	33
Figure 2-7 Revit model of residential building	63
Figure 2-8 Residential building imported in Termolog via IFC	64
Figure 2-9 Residential building imported in IES-VE via gbXML	65
Figure 3-1 Example model in Revit.....	67
Figure 3-2 Example model imported in Termolog via IFC	68
Figure 3-3 Roof modelling inside Revit.....	69
Figure 3-4 Window family modelling inside Revit	70
Figure 3-5 Window thermal transmittance properties in BIMviewer	71
Figure 3-6 Window thermal transmittance properties in Termolog.....	71
Figure 3-7 Schedule for thermal transmittance properties in Revit	72
Figure 3-8 Window thermal transmittance properties exported as schedule in BIMviewer	72
Figure 3-9 Window thermal transmittance exported as schedule in Termolog viewer	73
Figure 3-10 Window thermal transmittance exported as schedule in Termolog viewer	73

Figure 3-11 Environments modelling in Revit	74
Figure 3-12 Thermal zones modelling in Revit	75
Figure 3-13 Thermal zones imported in Termolog.....	75
Figure 3-14 Door thermal transmittance exported as schedule in Termolog viewer	76
Figure 3-15 Door thermal transmittance exported as schedule in Termolog	76
Figure 3-16 Project location in Revit	77
Figure 3-17 Project location in BIMviewer	77
Figure 3-18 Project location in Termolog	77
Figure 3-19 Residential building imported in Termolog via IFC after the application of the interoperability methodology	82

7 List of Table

Table 2.3.1-1 IFC export classes	35
Table 2.3.2-1 IFC Project Parameters & Property Sets.....	37
Table 2.3.3-1 IFC export setup tab - General.....	40
Table 2.3.3-2 IFC export setup tab - Additional content	41
Table 2.3.3-3 IFC export setup tab - Property sets	45
Table 2.3.3-4 IFC export setup tab - Level of Detail.....	46
Table 2.3.3-5 IFC export setup tab - Advanced	51
Table 2.3.3-6 IFC export setup tab - Geographic reference.....	52
Table 2.3.3-1 Energy Settings tab - gbXML	57
Table 2.3.3-2 Advanced Energy Settings tab - gbXML.....	62
Table 3.2.9-1 Revit – Termolog interoperability via IFC	81

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