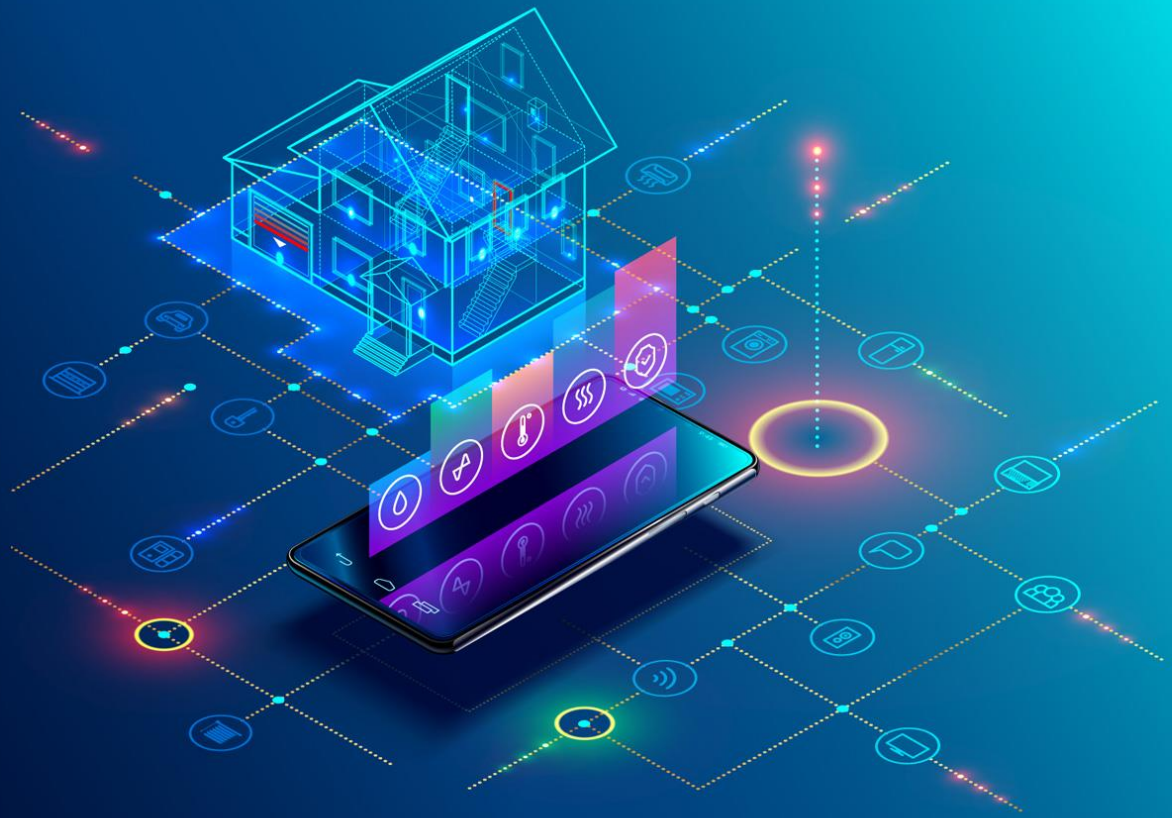


Analysis of BIM-to-BEM critical parameters and recommendations to solve the current bottlenecks



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BIM-SPEED

Harmonised Building Information Speedway for Energy-Efficient Renovation

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Analysis of BIM-to-BEM critical parameters and recommendations to solve the current bottlenecks

Issue Date	13 July 2021
Produced by	STRESS (RINA C)
Main author	Eva Raggi (RINA C)
Co-authors	Fabrizio Tavaroli (RINA C), Alberto Zinno (STRESS), Maria Regidor Sánchez (CARTIF), Antonio Gonzales Viegas (CYPE)
Version:	V 02
Reviewed by	Timo Hartmann (TUB), Maria Regidor Sánchez (CARTIF), Antonio Gonzales Viegas (CYPE), Jan-Derrick Braun (HTV)
Approved by	André van Delft, Timo Hartmann
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Addressed comments

Following table summarises the changes implemented within the deliverable in order to address the comments received from the monitor of the project. A general note is that D3.1 should be analysed also based on the project timeline, considering the issue date for task 3.1 activities at M12 in relation to other Deliverables mentioned in the comments (D3.2 and D2.2 due at M24 and D5.3 due at M36) which have been delivered after D3.1 completion.

#	Comment received	Reply and Review implemented
1	The issues identified in this deliverable should be addressed in D3.2, as such the relation between the 2 deliverables is unclear. D3.1 makes no reference to D3.2 and the other way around.	The relation between D3.1 and D3.2 has been clarified within paragraphs 1.1, 1.3 and 6. Additionally, paragraphs 2.2 and 2.3 of D3.2 (finalised later than D3.1) specified the relations between the 2 deliverables. From our side no further clarification is needed.
2	Following sentences such as "The BIM object is very simplified as the energy calculations do not required complex geometrical details of the frame." (page 30), one would expect a discussion of the details / information one has in a BIM model (understood here as an IFC file) and the level of detail required for energy calculations.	Additional information has been added at page 33.
3	In the whole deliverable the considered BIM model was developed with Autodesk Revit and other functionalities of Autodesk Revit have been used (such as "The energy model, as created through Revit "Energy optimization" panel from the architectural model,"). The related analysis is thus impacted by the export Revit does of IFC files: "Revit only exports the class IfcRelSpaceBoundary, which contains less information than the IfcRelSpaceBoundary2ndLevel,".	D3.1 starts from general considerations about the state-of-the art of the BIM-to-BEM process, from which it appears that Autodesk™ Revit software is the most common tool in the Architecture discipline (ref. at page 18) and, based on the current expertise of the consortium, 3 different BIM-to-BEM procedures have been analysed step-by-step. The purpose of task 3.1 is to identify main current and common bottlenecks and to provide a starting point for the development of procedures and tools (aim of task 3.2). For this reason, 3 procedures have been tested, starting from a common BIM test model developed with Autodesk Revit. The tool has been used just as an example for the BIM (which corresponds also to the most common BIM tool), as well as CYPETHERM, TRNSYS and Energy Plus have been used as BEM tools. Additionally, regarding the specific case of the "IfcRelSpaceBoundary2ndLevel" class (not exported by Revit), at page 43 it has been clarified that if the class is included within the IFC file, then the information of the relationship between objects and corresponding space boundaries is explicitly



		available, otherwise (as in the case of the IFC exported by Revit), it is possible to select the export of second level space boundaries (according to the procedure described at page 43) and retrieve some of the information. A development of a dedicate algorithm is then suggested for the next T3.2 activities.
4	<p>IFC is considered in this deliverable as something exported or generated from the BIM model. From a standards point of view, IFC is the BIM model:</p> <ul style="list-style-type: none"> • Page 31 "Extraction of information from the BIM model (IFC generation)" • Page 32 "Analysis of the IFC data model as extracted from BIM" 	A correction of step 1 and step 2 titles (including Figure 14) has been included according to the comment in order to avoid misunderstandings.
5	<p>Three approaches, each depending on some specific software (Revit - SketchUp, TRNSYS and CYPETHERM) are detailed according to the steps identified in Figure 14. It would've been useful to provide a table comparing the 3 approaches, and clearly listing the bottlenecks identified. The bottlenecks related to software should be clearly listed and separated from the others. If only software-related issues are identified (nothing regarding semantic interoperability for example), this should be clearly stated.</p>	<p>Appendix 1 "Current interoperability issues" provides a detailed comparison of the 3 approaches, listing the bottlenecks encountered in each category (e.g. weather data and location, geometry, building elements, thermal zones, HVAC and schedules) and providing a qualitative evaluation of the issue severity.</p> <p>Additionally, also the phase in which they were found during the BIM-to-BEM workflow has been identified to complete the analysis and classify the issue typology.</p> <p>Phase 1 and 2 refer to issues identified at tool level while phase 3 and 4 refer to issues more related to semantic interoperability.</p>
6	<p>As such, all recommendations are provided in section 5 and mainly concern Revit software family. While interoperability seems to be a focus of this deliverable, semantic interoperability is never addressed. Approaches such as BOT (Building Ontology Topology) have been proven useful in addressing energy calculations (especially regarding HVAC equipment) and also implemented Revit tools. There is no discussion regarding the potential benefits Semantic Web approaches could bring in this matter. D3.1 holds sentences such as "the information required can be bound to the BIM model in two ways: embedded [...] or linked [...]" (page 56) but approaches based on federation also</p>	<p>Within section 4, for each issue identified, possible solutions have been provided, divided into 6 thematic groups. A few practical examples have been suggested, at high level, also to solve semantic interoperability issues, in order to leave open a free development of tools and procedures and letting the details to be developed in task 3.2 (according to DoA, within task 3.2, h tools developers, based on their own expertise and already available tools have to develop and improve tools, additional functionalities and/or proper procedures to create a complete BEM starting from a BIM).</p> <p>Additionally, section 5 provides further recommendations to optimise the BIM-to-BEM process suggesting the completion of the following steps:</p> <ul style="list-style-type: none"> • step 1: populating IFC-based BIM with data according to appropriate BIM guidelines (the Revit environment is just one example); • step 2: exporting IFC-based BIM through a dedicated IFC exporter with automated rule-based data transformation;





	<p>seem pertaining here. Again, what is the link with the ontologies from D2.1, especially the BEM ontology? (added note by RINA: probably here intended as D2.2)</p>	<ul style="list-style-type: none"> • step 3: rigorous model checking; • step 4: BEM performance calculations and BIM enrichment based on the output. <p>Dedicated sub-paragraph on BOT (Building Ontology Topology) and Semantic Web approaches has been added within step 1 description at page 60 as well as the reference to BEM ontologies (D2.2, M1-M24 and therefore developing and ending 12 months after the D3.1) in order to clarify the relation input/output between the 2 tasks. Specifically, D3.1 analysis provided inputs for the development of the BEM ontology included in D2.2 (as described also in D2.2 section 1.1) and enabled the identification of some of the issues to be taken into account for the BEM Ontology development.</p>
<p>7</p>	<p>Finally, when it comes to BIM data quality check (section 5.3), two main things are missing:</p> <ul style="list-style-type: none"> • The standard approach which relies on the definition of MVDs for IFC compliance-checks • The semantic checker approach implemented in Kroqi that allows checking IFC files against an ensemble of requirements specified as rules. 	<p>Section 5 is aimed at providing additional recommendations to ensure consistency between BIM and BEM models. In particular, section 5.3 is dealing with quality checks. A standard approach based on the definition of MVDs and a semantic checker approach have been briefly introduced at page 62. For additional details on semantic checker approach implemented in KROQI please refer to task 5.3 activities (M13-M36) and to D5.3 “Rule-based model checking and validation of data interoperability” which is currently under development.</p>
<p>8</p>	<p>"This interoperability with the BIM SPEED Platform and the other tools will be further developed within Task 3.2" unfortunately D3.2 does not bring the necessary details and insights.</p>	<p>Interoperability between BIM SPEED Platform and the tools developed in task 3.2 is out of scope for this deliverable. Here it has been provided just as next step to be developed also due to the project timeline (D3.1 is due at M12 and D3.2 at M24). D3.2 and the related 9.2 section “Connection with BIM-SPEED Platform: recommended solutions” deals with the interoperability with the BIM SPEED Platform. Any specific comments should be provided directly to D3.2.</p>
<p>9</p>	<p>As a recommendation, the overall BEM procedure should be described using open BIM standards and approaches (definition of IDMs, specification of MVDs, etc.) and then the different software mentioned can be used to further illustrate how such standard procedure could be supported by this software and also highlight what is missing from existing software and could be added by the BIM-SPEED platform.</p>	<p>BEM procedure and requirements have been reported within section 3.1, where all the data needed to define a common data model and the thermal view of the building are listed. Generally, to complete a BEM and perform energy analysis a model including all the data mentioned is needed. Open BIM standards and approaches can support the BEM generation providing to BEM tools all the data needed.</p> <p>The software and the procedure analysed (which represented the practical starting point for the development of tools and procedures within BIM SPEED project) allowed, from a very practical point of view, to find bottlenecks and issues that need to be solved.</p>





Publishable executive summary

Enhancing the energy performance of buildings through deep renovation is strongly requested by the recent Directive (EU) 2018/844 and the new energy savings requirements and targets. Nowadays BIM (Building Information Model) tools are increasingly used in the process of design and construction works for building renovations and refurbishments. As most of the building data needed for the energy simulations are already included into BIM models, using BIMs as a data source for the automatic generation of BEMs (Building Energy Models) represents a unique opportunity to increase the effectiveness and the energy efficiency of renovations and move towards the BIM-SPEED goal of 30% time-reduction and 60% energy savings

Currently, BIM-to-BEM procedures involve time-consuming processes requiring additional input information and data corrections that should be entered manually. Besides, multiple limitations exist due to a lack of transparency of the data transferred. Solving the existing critical issues and generating automated or semi-automated BIM-to-BEM procedures represent a challenging goal to improve the building retrofit and renovation processes with respect to energy efficiency, saving time, lowering costs and reducing human errors. Moreover, a complete and reliable interoperability between BIM and BEM offers a better presentation of energy-related outputs and the capability of storing and organizing building data such as real-time information useful for calibrating energy models with up to date data.

This deliverable constitutes a first step to consolidate and speed up the process of converting BIM into BEM introducing a comprehensive evaluation of the actual bottlenecks and deficiencies of the existing BIM-to-BEM processes. The general overview of the current state-of-the-art and the more in-depth analysis of different procedures, starting from a common simplified BIM test model and proceeding step-by-step through three selected BIM-to-BEM workflows, lead towards the identification of the most relevant critical parameters and shortcomings. These critical issues require very time-consuming processes that usually discourage the designers from using the BIM-to-BEM approaches, especially for renovation projects and large buildings. To overcome the actual barriers, the present work investigates which strategies and key aspects can be optimized and standardized within the data exchange between BIM and BEM tools to accelerate the energy analysis and enhance the interoperability of the software avoiding the need of double modelling.

As results of the analyses carried out, the deliverable provides several recommendations and good practices to assist developers in enhancing the interoperability between BIM tools and energy simulation engines.





List of acronyms and abbreviations

API: Application Programming Interface
 BEM: Building Energy Model
 BIM: Building Information Model
 BEP: BIM Execution Plan
 EEB: Energy-efficient Building
 EED: Energy Efficiency Directive
 EPBD: Energy Performance Buildings Directive
 GbXML: Green building XML
 GIS: Geospatial Information System
 GUI: Graphical User Interface
 HVAC: Heating Ventilation Air Conditioning
 IDF: Input Definition Format
 IEQ: Indoor Environment Quality
 IFC: Industry Foundation Classes
 KPI: Key Performance Indicator
 MEP: Mechanical Electrical Plumbing
 MVD: Model View Definition
 nZEB: Nearly Zero-Energy Buildings
 RES: Renewable Energy Source
 TCP: Technology Commercialisation Platform
 TRL: Technology Readiness Level
 ULM: Unified Modeling Language
 WRT: With Regard ToXML: Extensible Markup Language

Definitions

BIM-to-BEM interoperability

BIM-to-BEM interoperability is the ability of BIM and BEM tools to communicate and exchange data correctly.

BIM Execution Plan (BEP)

A BIM Execution Plan (BEP) is a plan prepared by the design team and by the Contractor to illustrate how they intend to achieve and fulfil the objectives and requirements set by the client. There are two types of BEPs: pre-contract and post-contract. Both explain the details about the implementation of various aspects of the project information and the information exchange requirements detailed in a BIM protocol.



**.bui file**

Building Description file created by TRNSYS including all the information required to simulate the building.

Mapping

Process of matching an item from a group and associate it with another corresponding item of another group.

Model View Definition (MVD)

A Model View Definition (MVD) is a subset of the overall IFC (Industry Foundation Classes) schema able to describe the required data exchange for a specific BIM-based use case or workflow.

Open BIM

Open BIM is a universal approach for collaborative design, realization and operation of buildings based on open standards and workflows. Open BIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model.

Unified Modeling Language (ULM)

The Unified Modeling Language is a standardised modelling language enabling developers to specify, visualise, construct and document software systems. It is an important aspect involved in object-oriented software development.





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1. Introduction

1.1 Description of the deliverable content and purpose

The purpose of this deliverable is to carry out the initial analysis to speed up and consolidate the process for converting BIM to BEM in renovation projects, accelerating the energy analysis and enhancing the energy efficiency of the interventions. Currently, the BIM-to-BEM process is not automated and entirely linear. There is no direct connection from BIM to BEM tools without the need of manual post-processing data.

During the conversion from BIM to BEM, several deficiencies and errors are generated preventing the direct use of BIM as input for BEM. The process requires manual adjustments, simplifications and corrections that are extremely time-consuming especially for large and complex buildings. Because of these mismatches on the interoperability of data between BIM and BEM, the existing BIM-to-BEM procedures are not yet ready for wide spread market uptake to support renovation projects. The present deliverable intends to lay the foundation for a full development of the potential of using BIM as input for BEM in the housing renovation market. The following figure shows the workflow of Task 3.1 activities that have been structured through 4 main steps.

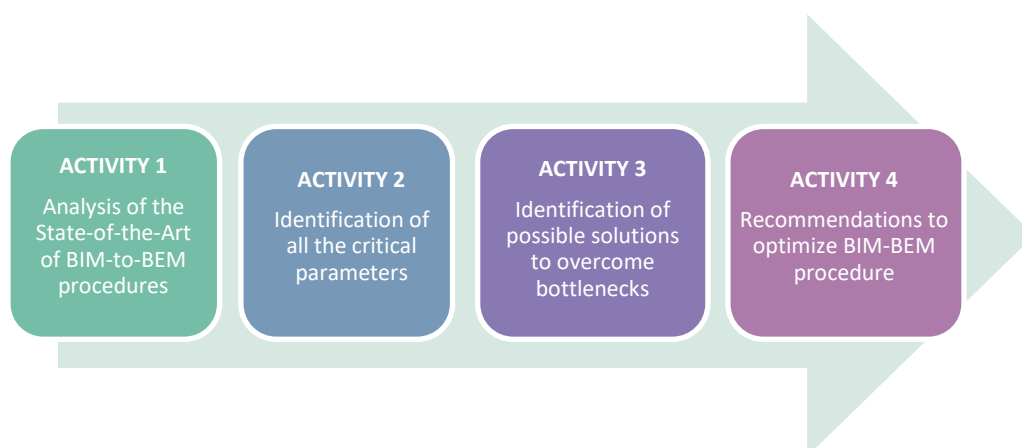


Figure 1: Task 3.1 workflow of the activities

Starting from a concise overview of appropriate papers, an analytical review of the current main BIM-to-BEM procedures in renovation projects and the analysis of relevant procedures, most of the weak points, critical parameters and bottlenecks have been investigated. To optimise BIM-to-BEM procedures and considering all the analyses performed on a common simplified BIM test model, an initial strategy to overcome the existing bottlenecks has been provided with advanced hypotheses, adequately verified, to automate the process as much as possible. In addition, some of the main challenges in the application of BIM for energy simulations such as interoperability issues, need of quality checks and easy solutions to solve existing errors are also analysed.

One of the final aims of the WP3 activities is a 40%-time reduction for the BIM-to-BEM conversion process compared to current practice. As results, this deliverable provides practical solutions and





recommendations for the following activities carried out within Task 3.2 and concerning the development of advanced procedures and tools for BIM-to-BEM efficient interoperability.

The recommendations provided can also be used as a starting point for the standardisation of the BIM-to-BEM process overcoming the lack of an official approach recognised by Energy Performance Buildings Directive (EPBD) or national standards and for the development of capabilities in a reverse direction: using BEM output for IFC model enrichment.

1.2 Contributions of partners

All the partners assigned to Task 3.1 have contributed to the development of this report. More specifically, partners' contribution to the deliverable can be divided as follows:

Table 1: Contribution of partners

#	Partner	Contribution
1	STRESS	Leader of the deliverable, coordination of the overall task activity, general state-of-the-art overview, analysis of “.ifc-SketchUp (with Euclid plug-in)-EPlus” procedure, comparison between different approaches and development of the final recommendations.
2	CARTIF	Analysis of “.ifc-TRNSYS” procedure and contribution in the development of the final recommendations.
3	CYPE	Analysis of the current “.ifc-CYPETHERM Suite” procedure and contribution in the development of the final recommendations.
4	UNIVPM	General contribution for “.ifc-CYPETHERM Suite” from the user’s point of view.
5	MTB	General contribution in the definition of the data and requirements needed for the decision-making tool.

1.3 Target group and relations to other activities

The main target group of this deliverable are tool developers focused on the automation and standardisation of the BIM-to-BEM process and by designers and energy modelers who will directly use a BIM-to-BEM approach on building renovation projects.

Task 3.1 is directly related to Task 3.2 and linked to other activities carried out within the Energy Cluster. Together with Task 3.2, it receives inputs from WP2 (BIM modelling information) and provides outputs useful for WP4 and WP8 activities. Besides, it provides some starting points for WP1 in the definition of which information must be collected about existing buildings to enable the creation of BEM models. This document provides direct inputs for tool developers developing advanced procedures and tools for creating BEMs (activities developed within Task 3.2 and including both a “simple box” tool building professional for non-energy experts and a “full BIM-to-BEM” approach for energy experts) and related analytical models due in M24. Following the scheme of the interconnections of the whole Energy Cluster in which Task 3.1 represent the first step.



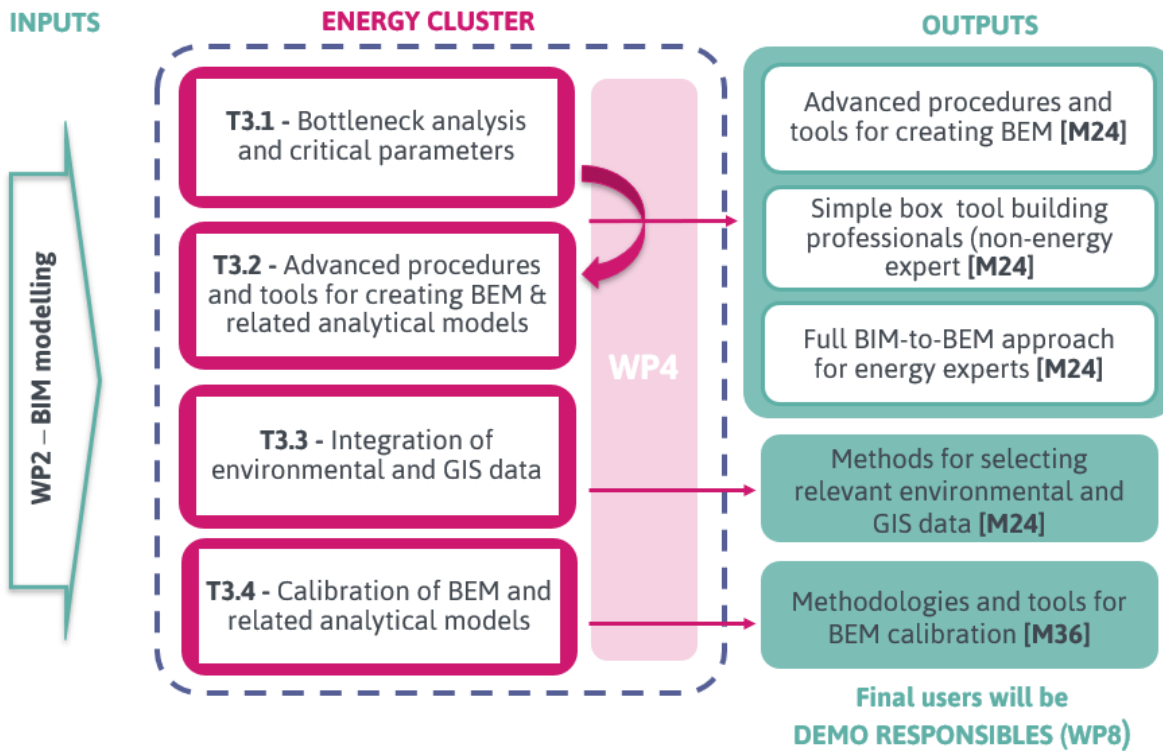


Figure 2: Scheme of Energy Cluster relations to other activities



2. Analysis of the current State-of-the Art for the BIM-to-BEM

The creation of a detailed BEM is a very lengthy, laborious and resource consuming process. It must start from an architectural model (basically concerning geometry) and must involve an energy expert to enrich the model with all the energy related information such as:

- thermo-physical characteristics of the envelope (materials properties);
- specification of the energy performance of windows;
- space use and features to identify homogeneous thermal zones;
- thermal loads due to the specific use of the different thermal zones;
- ventilation rates of the thermal zones (per occupant or space size);
- set point temperatures of each thermal zone;
- HVAC systems for the building and for each thermal zone (sub-systems).

Since a large part of these information can be implemented in BIM (enriching the BIM model with energy related data) in different level of details and at different design stages, the possibility to automate the BIM-to-BEM process has long been under evaluation.

Up to now, energy modelling software is unable to correctly read all the information coming from a BIM-based model and reliably generating high quality BEMs from BIMs remains difficult. Users must correct errors and wrongly-translated information manually, simplifying models and re-modelling building elements directly in BEM tools. Consequently, energy performance simulation and analysis are usually performed in a traditional way without a direct connection with BIM.

This section provides a description and a review of the current State-of-the-Art of the interoperability between BIM and BEM, focusing on renovation projects. To date, based on a thorough literature review, there is not an official approach with a complete and reliable interoperability between the two models. After a general overview of the available software and procedures supporting BIM-to-BEM processes, based both on previous research and scientific publications and on the experiences of the partners involved in the present task, three main procedures that have been developed by different BIM-Speed partners are introduced and deeply analysed in the following chapters.

2.1 General overview of the current BIM-to-BEM workflow

The whole BIM-to-BEM process involves different elements and file exchange formats. A general overview of the main components involved into the process is schematised within the following Figure 3.



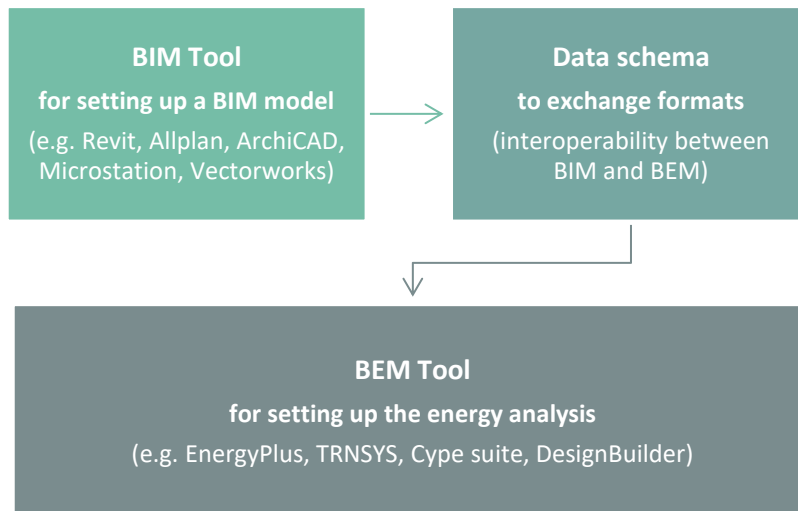


Figure 3: General overview of the whole BIM-to-BEM process

BIM tools

There are several tools able to generate Building Information Modeling (BIM), 3D object-oriented digital models of buildings, and built collaborative environment for the data exchange and the data management during the lifecycle of a building. The main BIM tools used to generate BIM include: Revit (by Autodesk), Allplan and Vectorworks (by Nemetschek), ArchiCAD (by Graphisoft), Microstation (by Bentley Systems) and Tekla (by Trimble). As confirmed by an analysis of three editions of the BIM Valladolid contest (an annual competition dedicated to the different uses of BIM in building life cycle, from early design to operative maintenance) shown in the Figure 4 (the graphs represent respectively: (A) results of the 2014 edition, (B) results of the 2015 edition and (C) results of the 2016 edition of the Valladolid contest), Autodesk™ Revit software is the most common tool in the Architecture discipline on the market, although its use in the contest has declined from 52,6% in 2014 to 42,9% in 2016.

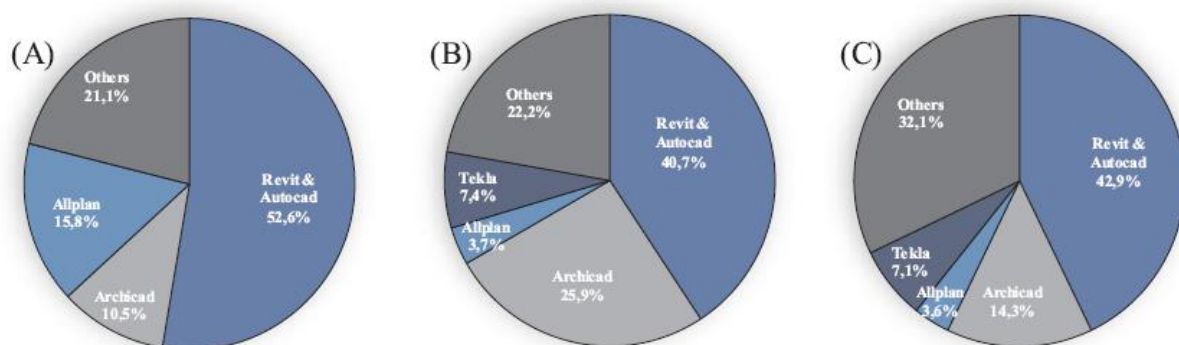


Figure 4: Percentage of software use in Architecture discipline. (A) 2014 Contest edition, (B) 2015 Contest edition and (C) 2016 Contest edition. [Source: Bellido-Montesinos, Lozano-Galant, Castilla, Lozano-Galant. Experiences learned from an international BIM contest: software use and information workflow analysis. In *Journal of Building Engineering* 21 (2019): 149–157]



Data schema to exchange format

To exchange BIM models with other tools for further analysis, it is required to export the model to a data schema (digital data structures) that is commonly accepted by other tools. There are basically 2 alternatives to exchange data between BIM and BEM programs:

- the gbXML (Green Building Open XML) schema;
- the IFC (Industry Foundation Classes) schema.

The IFC format provides an open standard for description and exchange of information among different applications and has a wider scope in comparison to gbXML which focuses mainly on energy simulation. IFC provides a common language which may be used by all engineering disciplines and offers a set of entities suitable for storing information. The following table, derived from the literature review, provides the main features of both formats.

Table 2: Comparison between gbXML and IFC format based on literature review [Source: Kamel, E. Memari, A. M., *Review of BIM's application in energy simulation: Tools, issues, and solutions, Automation in Construction*. 97 (2019) 164–180]

Characteristics	gbXML	IFC
Presentation of building's geometry	Only rectangular geometry	Any geometry
Data structure	XML (eXtensible Markup Language)	IFC, PKZIP and XML
Data structure approach	Top-down approach with relatively more complex representation	Bottom-up approach with relatively more straight forward representation
Domain of application	Mostly energy simulation domain	Different domains such as building construction to building operation
Capability of defining thermal zones	Yes	Yes
Location	Yes	Yes
Standard for minimum content for a certain type of model and using subjects	No	Yes – there is MVD standard for IFC and IDM capabilities
Material thickness	Yes	Yes
Limited data related to HVAC system	Yes	Yes

Furthermore, one of the features of IFC is the capability of defining Model View Definitions (MVD), subsets of the overall IFC schema, targeting specific data exchange modes for specific uses or workflows. To extract information from a BIM tool also for energy analysis purpose, there are two main model views definitions (MVDs) for IFC models:

- IFC2x3 Coordination View 2.0 is the default certified version for exporting, generally supported by other systems and based on the Model View Definition (MVD) called "Coordination View 2.0". The "Coordination View 2.0" is normally used for the coordination between the architectural, structural engineering and building services (MEP) task during the design phase. It contains definitions of spatial structure, building elements, structural modelling elements, and building service elements that are needed for coordinating design information among the different disciplines;







- IFC4 Design Transfer View: the newest version of IFC defined by buildingSMART, based on the Model View Definition (MVD) called “Design Transfer View” finalised to exchanging IFC models with other applications. IFC4 schema purpose is to extend and overcome certain limitation of IFC 2x3, however the Design Transfer View is still a beta version and is not yet widely supported.

BEM tools

There are several tools available on the market that are commonly used to assess the energy performance and the thermal comfort of a building. BEM tools, as shown in the following Table 3 can be divided into two main groups:

- Independent energy simulation engines with graphical interface;
- Energy simulation engines without a graphical interface.

Table 3: Overview of GUIs and energy simulation engines [Source: Kamel, E. Memari, A. M., Review of BIM's application in energy simulation: Tools, issues, and solutions, Automation in Construction. 97 (2019) 164–180]

Energy simulation GUI only	Energy simulation engine	Independent energy simulation engine with graphical interface
OpenStudio DesignBuilder Hevacomp Simergy BEopt	 EnergyPlus	Ecotect TRNSYS IDA ICE ApacheSim (used in IES VE) EDSL Tas
GBS eQuest RIUSKA	 DOE2	Modelica language (can be used with graphical interfaces such as Dymola)

Usually, energy simulation engines have their own input formats with highly specialised syntax and semantics, this makes the interaction with other software potentially more difficult and error-prone. Therefore, Energy simulation engines without a graphical interface, such as EnergyPlus and DOE2, can be linked to Graphical User Interfaces (GUIs) to facilitate the energy modeling creation process allowing the user to input data and develop the geometric model in a more “user-friendly” way. The analysis of three editions of the BIM Valladolid contest shown in Figure 5 (the graphs represent respectively: (A) results of the 2014 edition, (B) results of the 2015 edition and (C) results of the 2016 edition of the Valladolid contest) indicates that DesignBuilder (working with EnergyPlus as energy simulation engine) is the most popular specialized tool used in association to the main BIM architectural software.



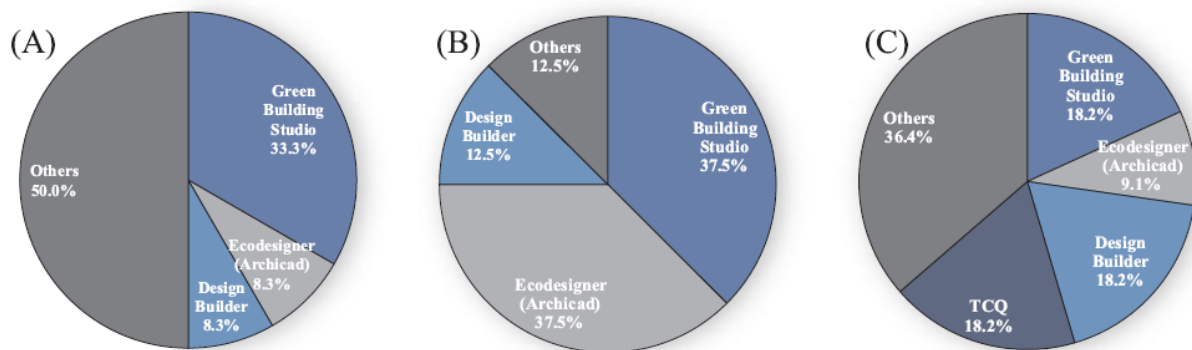


Figure 5: Percentage of software use in energy efficiency discipline. (A) 2014 Contest edition, (B) 2015 Contest edition and (C) 2016 Contest edition. [Source: Bellido-Montesinos, Lozano-Galant, Castilla, Lozano-Galant. *Experiences learned from an international BIM contest: software use and information workflow analysis. In Journal of Building Engineering 21 (2019): 149–157*]

2.1.1 BIM-to-BEM automated interoperability

There are several studies that investigated the interoperability issues targeting BIM-to-BEM processes. Several research studies contribute to the knowledge in BIM to BEM interoperability by identifying common problems, either in geometric aspects or on the semantic level, and by developing different tools to improve the (semi)automated interoperability process. Among these studies, the most important are:

- Paiva L. et al. in “Interoperability: A Data Conversion Framework to Support Energy Simulation” proposes an interoperability solution aiming to go from (building) construction models to energy simulation models based on the concept of Plug’n’Interoperate (PnI). The PnI provides a dynamic-interoperability to support data conversion from GbXML to IDF (EnergyPlus Input Data File). The developed architecture for the Plug’n’Interoperate (PnI) platform has been tested and validated in a case study building.
- Kim I. et al. in “Development of an IFC-based IDF converter for Supporting Energy Performance Assessment in the Early Design Phase” developed an Industry Foundation Classes (IFC)-based Input Data File (IDF) converter to use as a middleware to minimize the loss of information and generate additional information during the performance analysis process. The IDF converter was validated in the context of an energy performance assessment of a five-floor building designed by Revit Architecture.
- Kim J.B. et al. in “Developing a physical BIM library for building thermal energy simulation” developed a Modelica library for Building Information Modeling (BIM)-based building energy simulation. By using the ModelicaBIM library, a semi-automatic translation from the building models in BIM to building energy modeling (BEM) using a BIM’s authoring tool’s Application Programming Interface (API) was addressed.
- Ramaji I.J. et al. in “Leveraging building information models in IFC to perform energy analysis in OpenStudio” developed a workflow for generation of energy simulation models in OpenStudio® Model (OSM) format directly from a building information model in IFC format. An add-on was developed in OpenStudio® to automate the transformation process. The add-on is linked to a BIMserver, which is an open source server-based platform for the development of tools leveraging IFC files. To test the model transformation



workflow and the developed tool, a simple case study model was created in Autodesk Revit, while the Sketchup Plugin was used for visualization of the OpenStudio® model.

- Garcia E.G. et al. in “Interoperability from building design to building energy modeling” developed a corrective tool for modifying the gbXML file and converting it to DOE-INP file for use in eQuest. The solutions proposed the design of a novel Extensible Style Sheet Language Transformation (XSLT), implemented with Microsoft Visual C# Studio 2013, which includes a series of instructions to facilitate the information exchange between building design and energy modeling fields. The effectiveness of the solution has been tested in three real case studies.

All the previous experiences demonstrate that the flow of information from BIM to BEM is not yet completely automated and there is not a standardised process. Therefore, the current interoperability between BIM-to-BEM is only possible through different manual steps. The following Figure 6 shows a general overview of the BIM-to-BEM workflow, starting from the definition of the BIM model (steps 1 to 3) with the mapping of building information into a BIM file under certain file standards (e.g. gbXML or IFC).

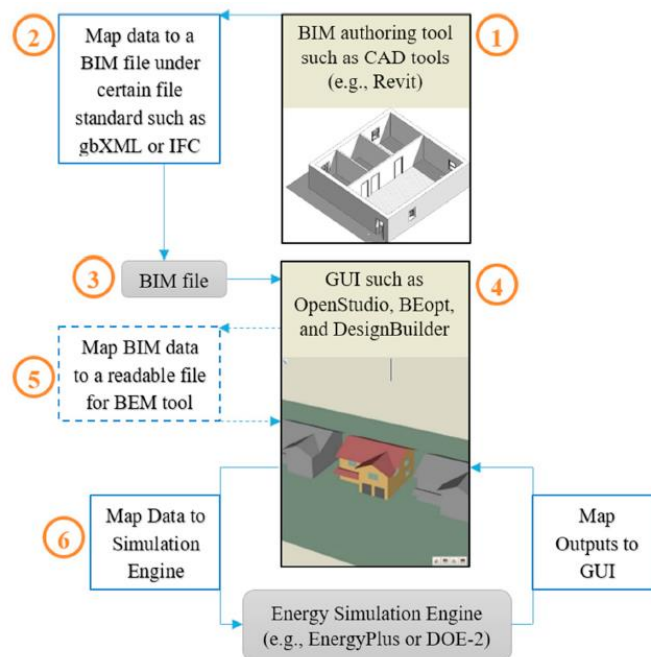


Figure 6: BIM-to-BEM general workflow [Source: Kamel, E. Memari, A. M., *Review of BIM's application in energy simulation: Tools, issues, and solutions, Automation in Construction*. 97 (2019) 164–180]

Since, currently, none of the major energy simulation engines such as EnergyPlus and DOE2 is capable of directly importing BIM files (with gbXML and IFC standards), the use of intermediate software that offers Graphical User Interfaces (GUIs) to control and enrich BIM with the capability to import BIM files is mandatory (step 4). Through GUIs, such as SketchUp, OpenStudio, DesignBuilder and IFC Builder it is possible to map the required information from the BIM file to a readable file for BEM tool (step 5). The process of mapping data from the GUI to a readable file for simulation engine (such as EnergyPlus or DOE-2) and map the outputs of the simulation into the





GUI represents the last step (step 6) of the BIM-to-BEM process. In the following sections, several software applications BIM-Speed partners use for the BIM-to-BEM process are described and evaluated.

2.2 Description of “Revit – SketchUp (with Euclid plug-in) – EnergyPlus” BIM-to-BEM procedure

This procedure is based on the use of Revit as the authoritative repository of data about building, Green Building Studio as the converting tool and on the use of EnergyPlus as the energy simulation engine. The procedure, developed within the P2ENDURE EU-funded research Project (H2020) for a specific demo case, is characterised by a partially-automated input data process from BIM to BEM through the SketchUp interface (with Euclid plug-in, formerly OpenStudio Legacy). The used software and some general features are reported in the following Table 4.

Table 4: Software used within the “.IFC-SketchUp-EnergyPlus” procedure

Software	Description	Open source/fee
Revit® 2018	Popular and multidisciplinary BIM software developed by Autodesk® that produces consistent, coordinated and complete model-based building design and documentation, providing collaboration between different aspects of the design.	Free educational use for 3 years for students, after registration. Otherwise Revit is a proprietary tool for which a license needs to be acquired
Autodesk® Green Building Studio	Autodesk® Green Building Studio is a flexible cloud-based service that allows to run energy building performance simulations. It can be used also as a translator to get an .IDF file.	Free platform on https://gbs.autodesk.com/gbs
SketchUp Make 2017	Architectural software here used as an auxiliary capability to check geometric data for consistency and correctness of the .IDF	Downloadable for free from https://www.sketchup.com
Open Studio v2.8.0	Cross platform collection of software to support building energy modelling using EnergyPlus. Open Studio is needed to install the Euclid plug-in.	Downloadable for free from https://www.openstudio.net/
Euclid 0.9.3	Euclid (formerly OpenStudio Legacy) is a free and open-source plug-in for SketchUp that makes it easy to create and modify the geometry inputs for building energy models.	Free and open source tool downloadable from https://bigladdersoftware.com/projects/Euclid/
EnergyPlus 8.7.0	EnergyPlus™ is a whole building energy simulation program used to model energy consumption in buildings. Input file for Energy Plus is the .IDF (Input Definition Format) file, a text format.	Free and open source tool downloadable from https://energyplus.net/

In this procedure the BIM is developed with Autodesk Revit™ and completed with all the geometrical features and most of the materials thermo-physic characteristics. Before starting the export process of the BIM model to an IDF file, the model must be simplified eliminating unnecessary data and an “Energy Model” has to be created



within the “Energy Optimisation” panel of Revit. The so-created BIM file is then uploaded to the Green Building Studio cloud-service that converts the BIM file into the IDF file format of the EnergyPlus simulation engine. Because of shortcomings in the above conversion process, the IDF file has to be manually controlled and amended. To this end, this procedure suggested to upload the resulting IDF file to SketchUp with the help of the Euclid plug-in (formerly Legacy OpenStudio). Then SketchUp together with the Euclid plug-in can be used as auxiliary tools to check the consistency and the correctness of the data exported, in particular, with respect to the geometry of the different building elements. Using the provided GUI it is possible to manually inspect the IDF model for errors and to provide manual adjustments and corrections. As a final step, the IDF exported from SketchUp is uploaded into the energy simulation engine EnergyPlus and, through the IDF Editor, the BEM model is manually enriched with all the missing data concerning the non-geometric design properties (HVAC specifications, operating and usage schedules, etc.). Figure 7 illustrates the conceptual workflow of the process.

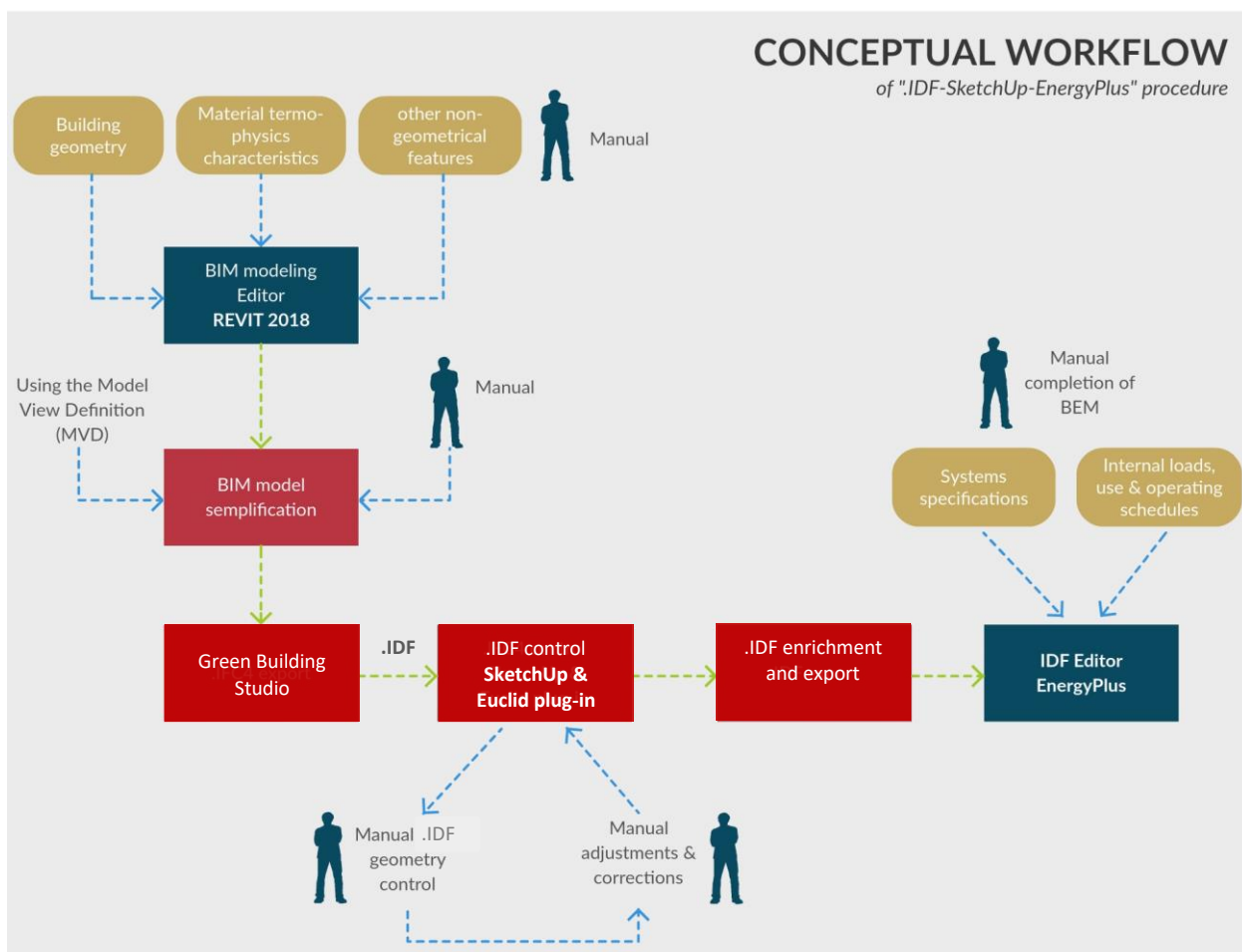


Figure 7: “.IDF-SketchUp-EnergyPlus” conceptual workflow of the procedure

The strength of this procedure is that it uses free and open source software (except for Autodesk Revit™ for generating the initial BIM). SketchUp (with the Euclid plug-in) is a program which is experienced as very convenient by most designer providing a GUI for an IDF geometry control tool.



The process is not automated and requires significant manual work: many geometrical errors have to be checked and manually adjusted within SketchUp before exporting a correct .IDF file suitable for EnergyPlus. All the HVAC specifications and the building use and operating schedules must be added manually within the EnergyPlus IDF Editor.

2.3 Description of “.IFC – TRNSYS” BIM-to-BEM procedure

The “.IFC-TRNSYS” BIM-to-BEM procedure uses a tool developed using the C# programming language and the Visual Studio platform. The tool used the open-source xBIM Toolkit to develop tailored algorithms that allow to automatically extract information from an .IFC file and generate the input file needed for including building information in TRNSYS simulations (.bui format). The file generated contains the information related to the constructions, materials and thermal zones composition of the building, and optionally other information such as the heating and cooling systems (limited to the data that can be included within the starting BIM tool). The procedure is currently under development and allows an automatic extraction of the main mandatory information. The following table shows the principal features of each software used in this process.

Table 5: Software used within the “.IFC-TRNSYS” procedure

Software	Description	Open source/fee
Revit® 2018	Popular and multidisciplinary BIM software developed by Autodesk™ that produces consistent, coordinated and complete model-based building design and documentation, providing collaboration between different aspects of the design.	Free educational License for 3 years for students, after registration. Then the license is subject to payment.
TRNSYS	TRNSYS is an extremely flexible graphically based software environment used to simulate the behaviour of transient systems. Particularly, thanks to its high flexibility to extend modelling capabilities and configure innumerable system combinations, it is nowadays one of the most widely-used applications within the energy and construction research community. However, this versatility is, at the same time, linked to a higher level of complexity and time consumption when it comes to specify the input data for the simulation. This might be one of the reasons why, although widely used in the research field, it is not so extended in commercial applications within the Architectural, Engineering & Construction (AEC) industry.	Commercial License.
xBIM Toolkit	xBIM Toolkit (eXtensible Building Information Modelling) is a .NET open-source software development toolkit that supports the BuildingSmart Data Model (aka the Industry Foundation Classes IFC).	The XBIM library is made available under the CDDL Open Source licence





	xBIM allows .NET developers to read, create and view Building Information (BIM) Models in the IFC format. There is full support for geometric, topological operations and visualisation. In addition, xBIM supports bi-directional translation between IFC and COBie formats. Core libraries for data manipulation are all written in C#, core of geometry engine is written in C++.	
Visual Studio 2019	Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. Its built-in languages include C, C++, C++/CLI, Visual Basic .NET, C#, F#, JavaScript, TypeScript, XML, XSLT, HTML and CSS. Support to other languages is available via plug-ins.	Free, fully-featured IDE for students, open-source and individual developers. License subject to payment for professionals and enterprises.

For this procedure, it is important to consider that not all BIM models contain the same information and not all the information required by TRNSYS are included within the IFC file generated from a BIM model. It depends on the software used and how it exports the IFC file (here Autodesk Revit). Some information, relevant for the BEM generation, is explicitly accessible in the IFC, such as the names and properties of the materials and other data related to the constructions, while some other information, not directly available within the IFC is required to be calculated or manually entered (i.e. orientation of the walls, some material thermal properties, etc.). When the information needed by TRNSYS is not available or exportable directly from an IFC file, such as materials thermal properties in some cases, it is necessary to use support tools to manually input calculated or default values to complete BEM models that provide accurate simulation results.

The developed C# tool consists of the following modules:

- program initialization - calling of the main functions;
- specific algorithm for the extraction of the information related to the construction elements and its storage in an intermediate database;
- specific algorithm for the extraction of the information related to space boundaries and its relationships with other objects; this information is also stored in an intermediate database;
- specific algorithm for the generation of the TRNSYS building input file (.bui) using the information in the database;
- specific algorithm for the generation of the TRNSYS configuration input file (.dck).

To write a suitable TRNSYS .bui input file, ready for use in TRNSYS that contains all the relevant information for the energy calculation, the developed BIM-to-BEM specific tool first generates an intermediate structure, where all the information related to the building is stored according to the structure required by TRNSYS and then automatically writes the .bui file. While preparing this report, some adjustments have been made to the tool to deal with the particularities of the BIM test model and make the tool more suitable for any kind of BIM models regardless the software used and user modelling procedure. Figure 8 illustrates the conceptual workflow of the process.



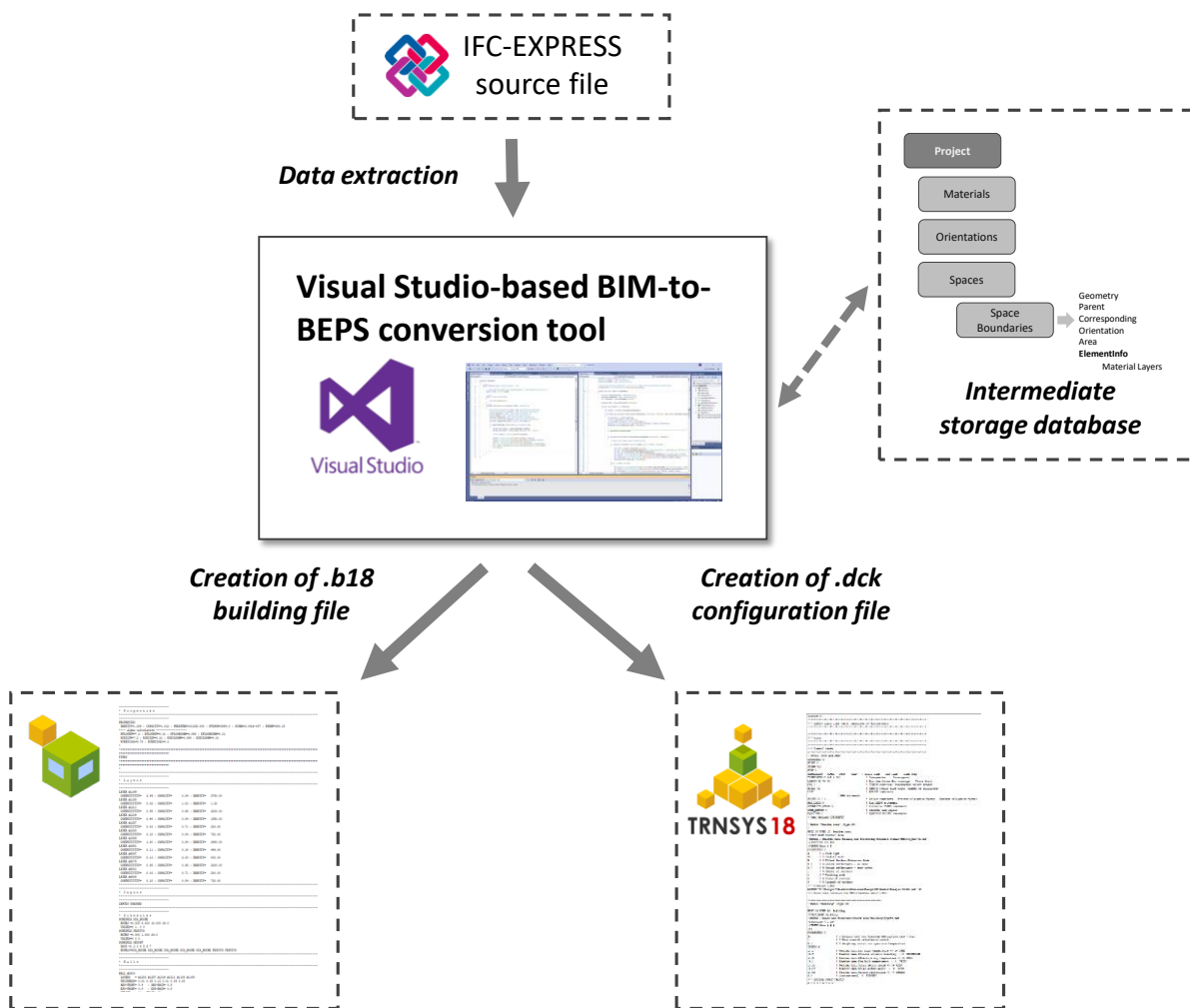


Figure 8: "IFC-TRNSYS" conceptual workflow of the procedure

The strength of the tool is that it allows to generate the .bui input file with the information related to material, walls and thermal zones without any manual work, as long as the IFC file contains the basic information needed. Saying this the tool is still under development and not yet ready for commercial use.

2.4 Description of actual ".IFC - CYPETHERM Suite" BIM-to-BEM procedure

This approach makes use of the CYPETHERM program, which works with an open BIM model (IFC file) to develop the necessary calculations and analyses to construct an energy model. Every application of the CYPETHERM Suite adds a new traceable layer of information which allows the transparency of the process and the collaboration of different professionals in every step. The introduction of data to the processed IFC is partially-automated while the accuracy and coherence of the information is carefully controlled. The used software and some general features are reported in the following Table 6.



Table 6: Software used within the actual “.IFC-CYPETHERM Suite” procedure

Software	Description	Open source/fee
Revit® 2018	Popular and multidisciplinary BIM software developed by Autodesk™ that produces consistent, coordinated and complete model-based building design and documentation, providing collaboration between different aspects of the design.	Open source for 3 years for students, after registration. Then the license is subject to payment.
Complementary Open BIM for Revit tool by CYPE	Plug-in for Revit which allows exporting the BIM model using the IFC Standard. One copy is saved in a specific folder in the pc, while a file is associated to a project in the BIMserver.center (cloud store for storage and collaboration). This plug-in is used with Revit® 2018.	Free tool
AllPlan	BIM software developed by Nemetschek that provide support for the entire BIM process with efficient and straightforward workflows. Different solutions are available for Architecture, Engineering, Bridge and BIMplus.	A 30 days trial version can be freely downloaded from the official website. Then the license is subject to payment.
ArchiCAD	Architectural BIM CAD software developed by Graphisoft. Offers computer aided solutions for handling all common aspects of aesthetics and engineering during the whole design process of the built environment (buildings, interiors, urban areas, etc.)	A 30 days trial version can be freely downloaded from the official website. Then the license is subject to payment.
IFC Builder	Application used to modify existing project (imported using the IFC standard). It allows the definition and check of the geometry, locals and thermal zones.	Free application
CYPETHERM LOADS	Tool used for the calculation of building thermal loads, according to the Radiant Time Series Method proposed by ASHRAE.	Free tool
CYPETHERM HVAC	Tool used to create and size HVAC systems.	A 30 days trial version can be freely downloaded in the BIMserver.center store
CYPETHERM EPlus	Tool used for building modelling and energy simulation using the EnergyPlus engine.	A 30 days trial version can be freely downloaded in the BIMserver.center store

Once the IFC geometry has been generated, it is uploaded to BIMserver.center. There, it is possible to include new professionals in the project, who can be assigned to specific permissions and tasks, and thus documenting the advances and modifications of every included participant. First the thermal loads will be calculated (CYPETHERM LOADS) from the IFC geometry, which will lead to the calculation of the equipment (CYPETHERM HVAC) and the energy efficiency (CYPETHERM EPlus). EnergyPlus™ will be the calculation engine. Figure 9 illustrates the conceptual workflow of the process.



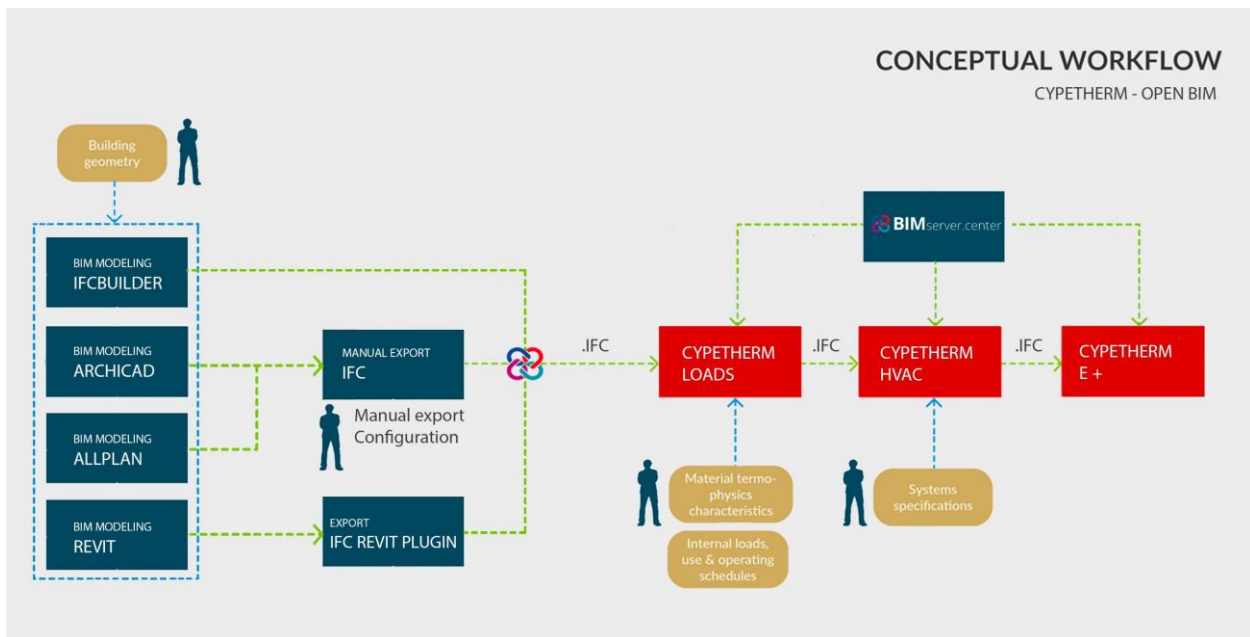


Figure 9: “IFC-CYPETHERM Suite” conceptual workflow of the procedure

The strength of this workflow is that it works with open formats, which means that it can be followed by any user of any BIM tool capable of exporting data to .IFC (which is an international standard and basic feature of any BIM program). Additionally, the programs has user-friendly interfaces which guide even the non-specialized users step-by-step through the calculation process, warning them in case of the occurrences of incoherences and contradictions of the applied regulations. The similarity of the environments of all the software makes the learning curve more intuitive and working in BIMserver.center allows the real time collaboration of different users in the same project through a consolidation of the different layers of information in IFC, integrating them in the BIM project on the cloud.

The main obstacle is that some IFC models are harder to process due to how they were modelled and exported to IFC, which sometimes leads to the need of corrections in the architecture model, with the subsequent loss of time.



3. Identification of the critical parameters and bottlenecks

As confirmed by the analysis of the state-of-the-art, different procedures supporting BIM-to-BEM process have been developed by BIM-Speed partners but currently, there are still gaps and disconnections and there is not an official approach. The chapter analyses the weak points of the existing procedures identifying additional critical parameters and bottlenecks that can be used as a starting point for the automation and standardisation of the process.

To this end, the following paragraphs provide a detailed analyses of the three BIM-to-BEM processes and related interoperability of data with a focus on inconsistent data, regarding building geometry, thermo-physics characteristics, system data, internal loads and operating schedules. All the procedures have been investigated starting from a common simplified test building model (BIM test model) and carried out through a common scheme to standardise the analysis and be able to compare the results.

3.1 Common scheme for the analysis of the current BIM-to-BEM procedures

BIM provides a parametric three-dimensional model that includes a large amount of geometric and parameter-based information of all the elements and objects. BEM does not require the same level of detail. The geometrical and thermal view of a building is much simpler than a complete architectural BIM model. Construction elements such as exterior walls, slabs or windows are simply considered as heat transfer surfaces between thermal zones with all their thermal properties.

Due to the different nature and data structures of BIM models and energy simulation engines, it is essential to map which building information is needed for BEM and available from BIM and how it must be defined within the BEM to prevent loss of data and to identify which data can be properly exchanged.

Data with influence on the real behavior of a building and required to perform building energy simulations can be divided into three main groups: data needed to define the thermal view of the building, system data and data related to internal loads, building use and operating schedules.

The thermal view of the building includes:

- building geometry and orientation, including any external shading (dimension and distance);
- weather data;
- thermal characterisation of the building envelope (opaque and transparent components) and in general of all the building elements that bound thermal zones (walls, slabs, ceilings, doors) including their detailed stratigraphy (material layers and thickness);
- thermal-physical properties of the materials of the building envelope such as density, heat capacity, thermal conductivity, some radiation and heat transfer parameters with reflective and conductive properties in case of windows.

The information on the HVAC includes:

- HVAC specifications (equipment, system, plant);
- information on energy system and control strategies.

Internal loads, building use and operating schedule include:



- space use and relevant properties to identify homogeneous thermal zones (including ventilation rates);
- thermal loads due to lighting, equipment and people;
- internal conditions as the set point temperatures of the thermal zones;
- operating and usage schedule.

To analyse the existing relevant BIM-to-BEM procedures, a common simplified test building model was developed using the BIM authoring tool Autodesk Revit (as example), containing all the relevant data for the thermal view characterisation, the internal loads and the building use. HVAC specifications and operating schedules of the systems are not implemented since they can not directly be inserted into Revit. The BIM test model consists of a two-story model with rectangular ground plan and a flat roof as shown in Figure 10 and is characterized by 3 different thermal zones (2 heated and 1 not-heated) as shown in Figure 11.

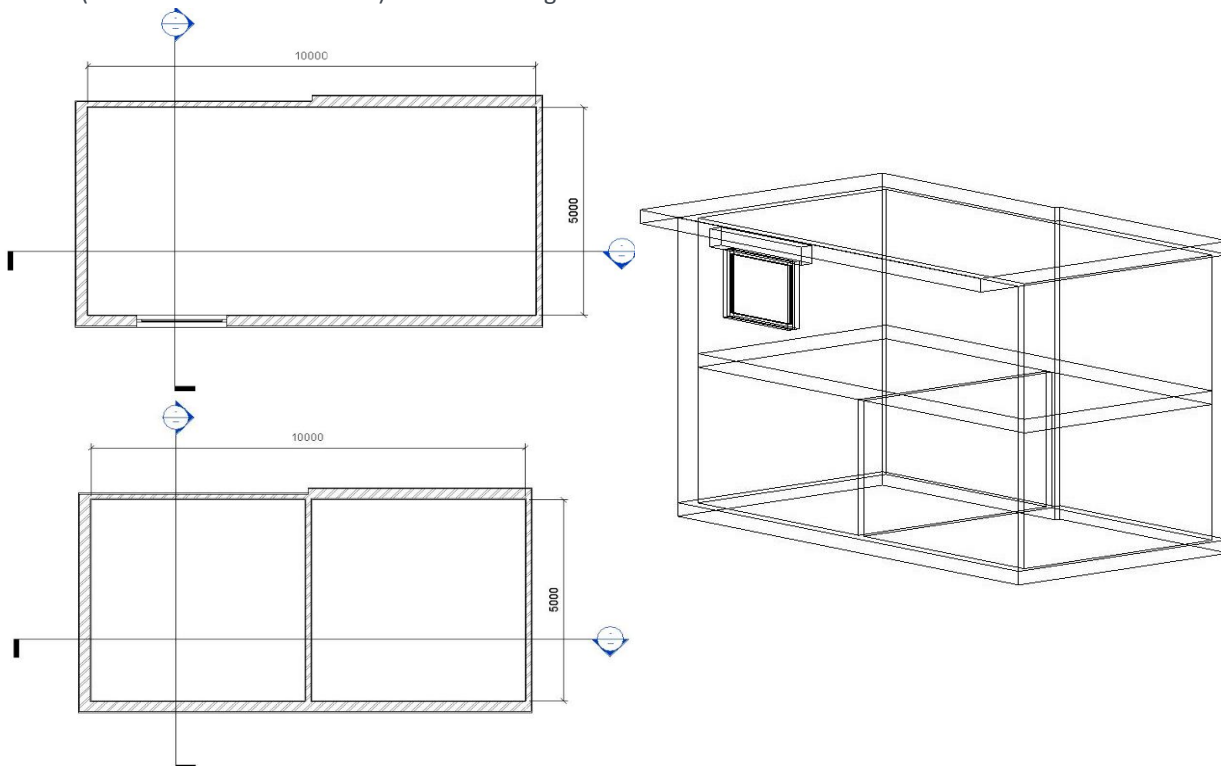


Figure 10: BIM test model: floor-plans and isometric views

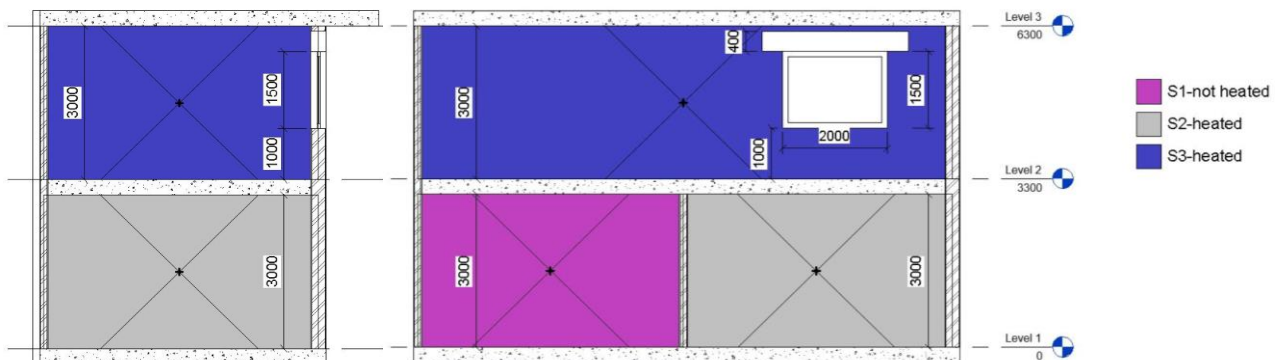


Figure 11: BIM test model: thermal zones



Table 7 summarises the geometrical information of the BIM test model.

Table 7: BIM test model: geometrical information

	u.m.	Space 1- not heated	Space 2- heated	Space 3- heated	TOTAL heated
Net surface area	m2	24,60	24,60	50,00	74,60
Gross surface area	m2	28,35	29,27	57,62	86,89
Height net	m	3,00	3,00	3,00	6,00
Height gross	m	3,30	3,45	3,45	6,75
Net volume	m3	73,80	73,80	150,00	223,80
Gross volume	m3	93,54	100,97	198,80	299,77

The BIM test model is composed by two types of external walls and an internal wall characterized by different thickness, a ground floor, an internal slab and a flat roof with the same stratigraphy and one window with a roller shutter box. The materials with relevant thermal properties included into the BIM test model are summarised in the following Table 8.

Table 8: BIM test model: materials thermal properties

	u.m.	Plaster	Brick	Concrete	Wooden frame*	Roller shutter box*
Thickness	mm	20	250	300	60	290
Thermal conductivity	(W/mK)	0,72	0,54	1,046	0,21	1,74
Specific heat capacity	J/(g °C)	0,84	0,84	0,657	0,19	0,1
Density	(kg/m ³)	1860	1550	2300	496	21,72
Emissivity	(-)	0,9	0,95	0,95	0,85	0,85
Permeability	ng/Pasm ²	216,6	182,4	182,4	0	0

* these are equivalent materials to get $U_{frame}=2,2 \text{ kWh/m}^2\text{K}$ and $U_{box}=6 \text{ Wh/m}^2\text{K}$ (net of surface resistances)

Table 9 summarises the stratigraphies of the building opaque elements.

Table 9: BIM test model: stratigraphies

Building components	Layer	Thickness [m]	Total Thickness [m]	Thermal Transmittance (W/m ² K)
External Wall_EW01	Plaster	0.02	0.29	1.45
	Brick	0.25		
	Plaster	0.02		
External Wall_EW02	Plaster	0.02	0.16	2.23
	Brick	0.12		
	Plaster	0.02		
Internal Wall_IW01	Plaster	0.02	0.16	1.86
	Brick	0.12		
	Plaster	0.02		
Ground floor_GF01	Concrete slab		0.30	2.01
Roof_RF01	Concrete slab		0.30	2.34
Internal Floor_IF01	Concrete slab		0.30	1.60
Roller shutter box	Wood panel		0.29	2.97



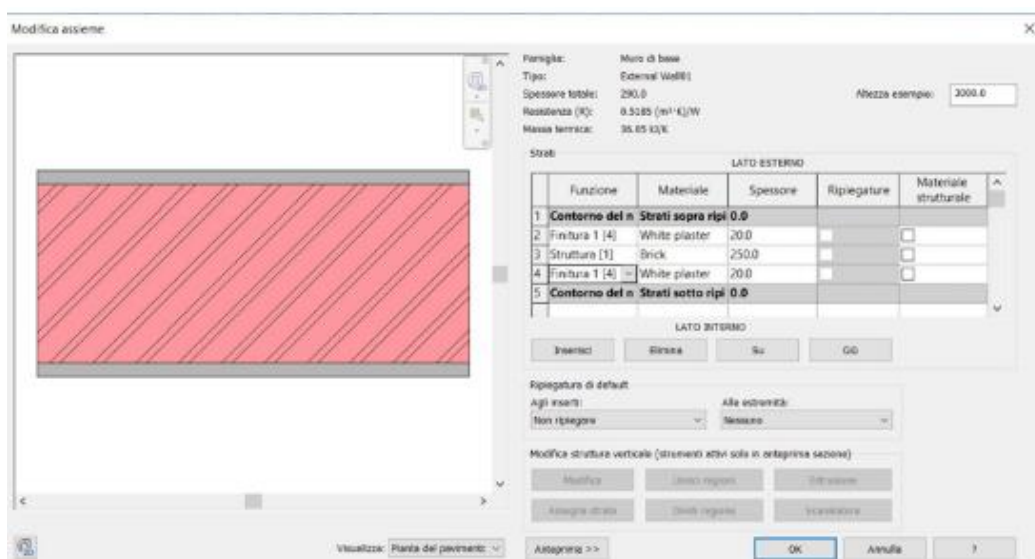
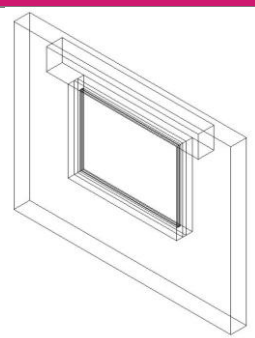


Figure 12: BIM test model: example of stratigraphy

The window properties are described in the following Table 10. The BIM object is very simplified under the geometrical point of view, as the energy calculations do not require complex geometrical details of the frame which can be relevant for architectural or other purposes. Specifically, geometrical details of the frame as hollow chambers geometry, differences between fixed and mobile frame, locking systems as well as windows handles and hinges are not needed for energy analysis (as included indirectly within thermal properties data) and not modeled, under the geometrical point of view, in the simplified test case. Table 10 summarises the data needed for the energy simulation and included in the BIM object, basically what is relevant is the area occupied by the frame, by the glazing part and the relevant thermal and visual properties.

Table 10: BIM test model: window object

Window properties		W01	Window BIM object
External dimensions	m	2 x 1,5	
Analytical construction (glass)		double glass SC =0,2	
Frame material		wooden frame	
Glazing area	m2	2,34	
Frame area	m2	0,66	
Glazing Thermal transmittance	W/m2K	3,129	
Glazing Thermal resistance	m2K/W	0,3196	
Glazing Light transmittance	-	0,18	
Frame Thermal transmittance	W/m2K	2,2	

In addition to the features used to characterise the thermal view of the model, each designed space has been enriched with a series of information and attributes about occupants, equipment and lighting for the definition of the internal energy gains. Figure 13 shows the information implemented into the BIM test model to be verified the BIM-to-BEM process interface. Default typical operation schedules and heating setpoint of 20 °C were considered.



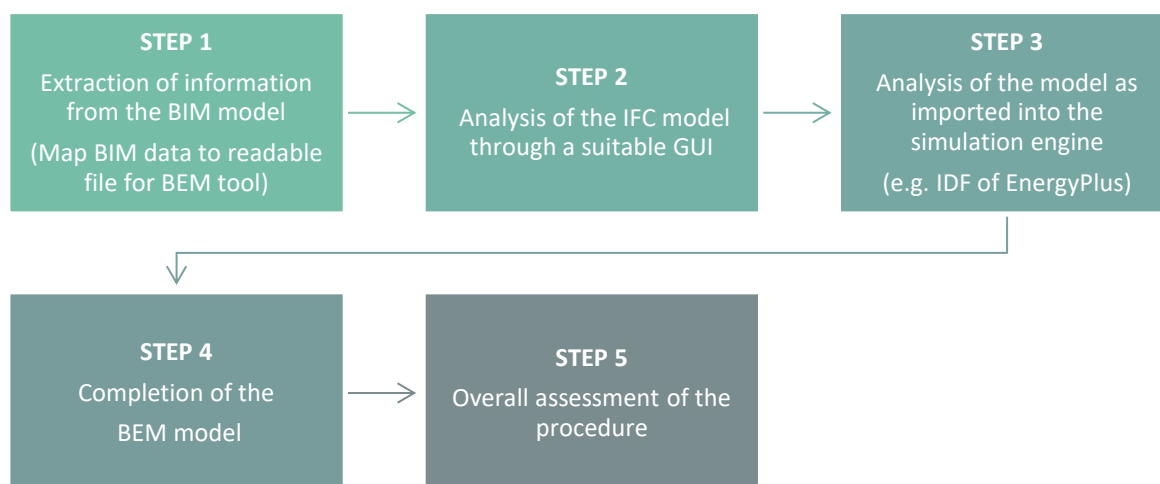


Parameter	Value	Parameter	Value
Energy Analysis		Energy Analysis	
Area per Person	1,429 m ²	Area per Person	10,000 m ²
Sensible Heat Gain per person	80,59 W	Sensible Heat Gain per person	73,27 W
Latent Heat Gain per person	80,59 W	Latent Heat Gain per person	58,61 W
Lighting Load Density	9,69 W/m ²	Lighting Load Density	6,03 W/m ²
Power Load Density	5,81 W/m ²	Power Load Density	2,15 W/m ²
Plenum Lighting Contribution	20,0000%	Plenum Lighting Contribution	20,0000%
Occupancy Schedule	Occupancy residential	Occupancy Schedule	Disattivato - 24 ore
Lighting Schedule	Lighting residential	Lighting Schedule	Attivo - dalle 8:00 alle 18:00 (50%)
Power Schedule	Power residential	Power Schedule	Disattivato - 24 ore
Outdoor Air per Person	3,54 L/s	Outdoor Air per Person	0,00 L/s
Outdoor Air per Area	0,91 L/(s·m ²)	Outdoor Air per Area	0,00 L/(s·m ²)
Air Changes per Hour	0,000000	Air Changes per Hour	0,000000
Outdoor Air Method	by People and by Area	Outdoor Air Method	by People and by Area

Figure 13: BIM test model: internal conditions for heated spaces (left table) and not-heated spece (right table)

The analysis of the selected BIM-to-BEM procedures, starting from the BIM test model described above, has been structured over five main steps decomposing the BIM-to-BEM process into a series of key activities, to conduct tests, investigate the capabilities and limitations of the three processes, assuring that conversions work. For each step the data properly exchanged and those missed or mismatched have been accurately investigated, categorized and reported to find solutions and develop proper corrective actions and tools to rectify them.

Figure 14: Structure for the common analysis of BIM-to-BEM current procedures



Step 1: Extraction of information from the BIM model

BIM includes a great deal of geometric and parameter-based information, many of which are irrelevant for energy simulations, or are not required at the same level of detail. The extraction of the relevant data, intended as the mapping of relevant BIM data to a readable file for BEM tool, or the simplification of the BIM original models is therefore an important step in the realization of suitable BEM models.

For the aspects of creating and checking BIM models it is important to ensure that all or most of the relevant data are properly included in the models please refer to the dedicated sections (paragraphs 5.1 “BIM tools/Revit modelling guideline to set up BIM models”, 5.2 “IFC exporter and automated rule-based data





transformation” and 5.3 “BIM Data quality check - Rigorous model check”) that are provided later in the document. The BIM test model, as previously described, includes minimal information which are all required to be included within the BEM. This step is therefore limited to the analysis of the different ways to export the model into the IFC standard required by the procedure analysed.

Step 2: Analysis of the IFC model through a suitable GUI

The IFC data model file has been analysed through:

- the Graphical User Interface (GUI) of EnergyPlus for the two procedures using this simulation engine;
- an independent energy simulation engine including a graphical interface for the procedure using TRNSYS;

The detailed check of the input file has been performed investigating the model for possible errors, focusing on:

- the geometry and dimensions of the elements and thermal zones;
- the thermal zone boundaries (the surfaces between a thermal zone and the building component marking the boundary of) and the definition of the function of the elements (e.g. external, adiabatic, interzone, in contact with ground, etc.);
- the elements (as materials, building structures, spaces, etc..) names and codes. All the elements should keep the original name or code as specified into the BIM model;
- the correct assignment of constructions and materials;
- the relationship between objects (e.g. the window and the wall it belongs to);
- the correct definition of all the other verifiable parameters, as extracted from BIM and included within the IFC.

Step 3: Analysis of the model as imported into the simulation engine

Once the file extracted from BIM was checked and adjusted where needed, a further analysis of the data imported into the energy simulation engine was done to find possible errors in those sections not previously investigated (e.g. the thermal properties, internal conditions related occupancy, lighting and equipment, etc..). Generally, within this step, the whole data integrity of the BEM was investigated. In particular, we checked that the properties of the elements and the information implemented within the BIM file and relevant for the energy simulation matched those included in the corresponding library and section of the energy simulation engine. In general, it is important to keep the original and initial information intact while transferring data between BIM and BEM software.

Step 4: Completion of the BEM model

To complete the BEM model, any totally or partially missed data has been introduced directly within the simulation engine. This step refers to HVAC data including system properties and operational schedules.

Step 5: Overall assessment of the procedure



This final step closes the analysis with an overall assessment of the procedure considering the whole process from BIM to BEM, emphasizing the weak points and the most critical issues and paying attention to the interoperability between software.

3.2 Detailed analysis of “Revit – SketchUp (with Euclid plug-in) – EnergyPlus” BIM-to-BEM procedure

The procedure analysed investigates the interoperability between BIM and BEM via Green Building Studio using EnergyPlus as final energy simulation engine. The workflow includes the use of SketchUp with the Euclid plug-in (formerly Open Studio Legacy) as a graphical interface to investigate the completeness of the IDF as exported from Green Building Studio, coupled with Insight 360. The analysis is based on the BIM test model as previous described and followed the steps indicated within the common procedure.

Step1: Extraction of information from the BIM model

The BIM test model was developed with Autodesk Revit™ 2018 and since all the data included are required to be exported, no simplification of the BIM model is needed and here analysed.

To extract information from Revit following the procedure, first an “Energy model” was created from the “Energy Optimisation” panel of Revit, then the model was uploaded into Green Building Studio to export an IDF file through Autodesk Insight 360 as shown in the following Figure 15. The energy model generated from Revit shows clearly the presence of geometric inaccuracies evaluated in detail in the following analysis.

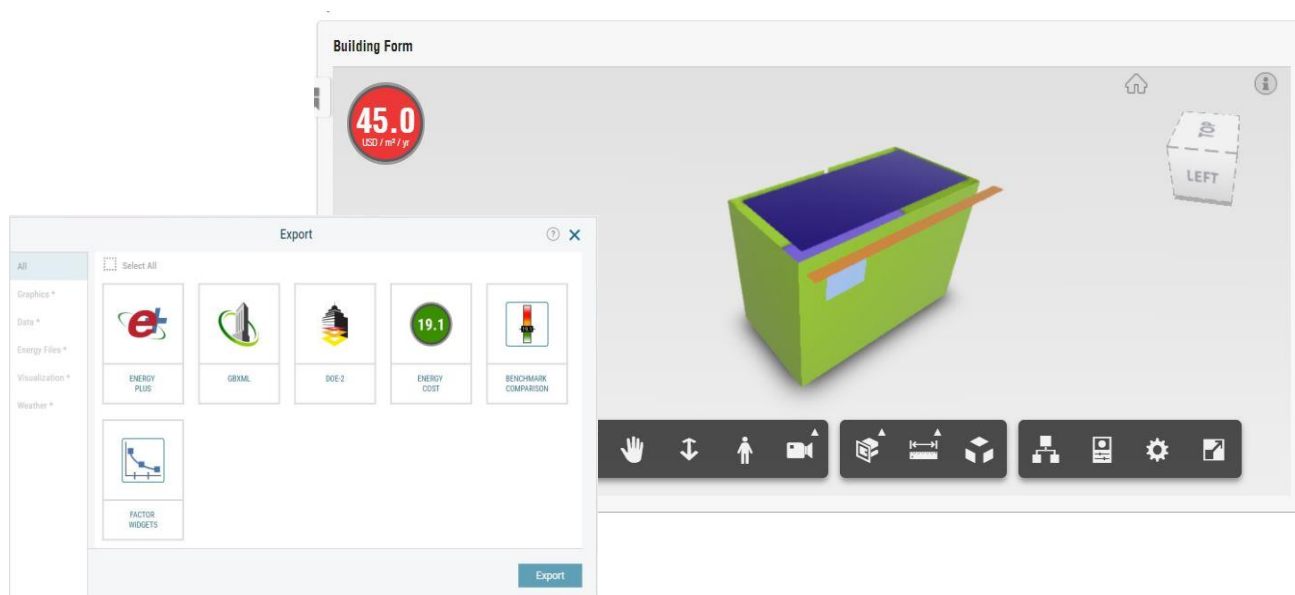


Figure 15: Extraction of an IDF file from a BIM model through Green Building Studio and Insight 360

Step 2: Analysis of the IFC model through a suitable GUI

The IDF file as generated from previous step was analysed using the GUI of SketchUp (combined with Euclid plug-in). In SketchUp only the data concerning geometry, thermal zones (just the spatial definition, not also the internal conditions) and construction elements names and types as walls, floors, roofs and



windows can be inspected. No information about materials thermal properties, internal loads and other information included within the original BIM test model can be analysed within this step.

Examining the energy model, the geometry transfer appears inaccurate: jagged edges and small gaps between surfaces are present. This is due primarily to the inefficiency of the energy model creation process within Revit and can be minimized setting a smaller resolution value for the “Analytical Surface Resolution”.

Following Figure 16 shows the IDF model as imported and optimised into SketchUp with the Euclid plug-in.

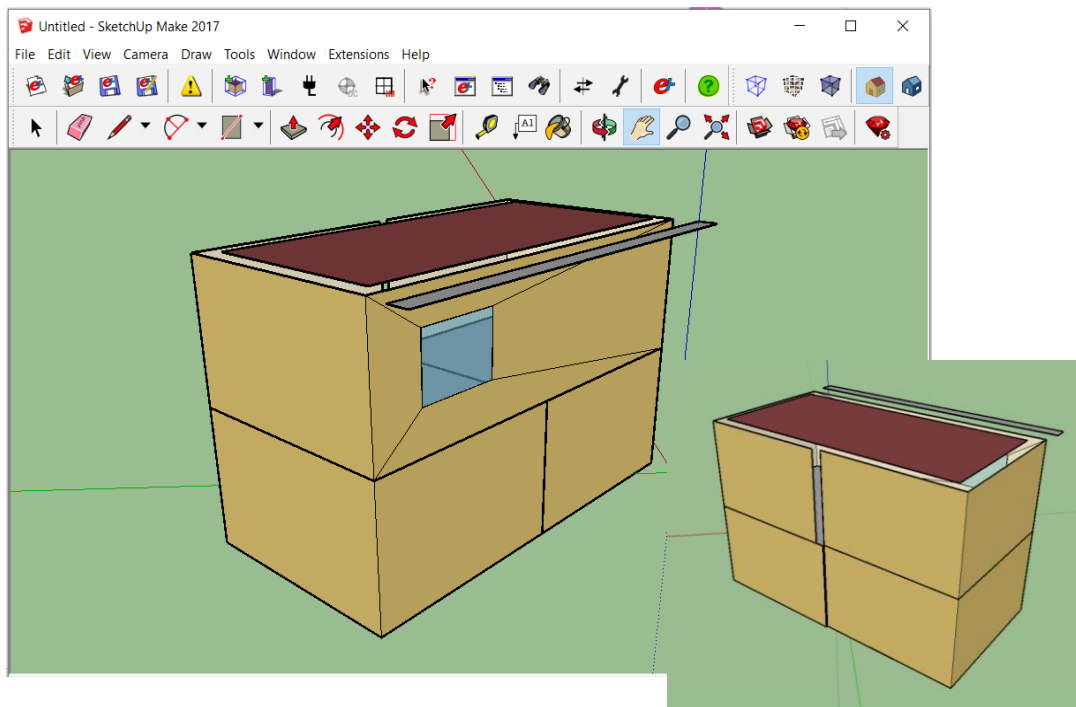


Figure 16: Analysis of the IDF file as imported into SketchUp and Euclid plug-in

The following critical geometric issues have been identified through a manual and visual inspection:

- some surfaces junctions are not correctly closed, especially in correspondence of walls with different thickness and in the walls-roof junctions;
- the external wall elements are automatically divided into small sub-surfaces where an element as a window is present on the wall surface;
- the shutter box has not been included in the model and the window’s frame geometry is not correctly transferred.

At this step of the procedure, the test model, as exported into the IDF format, requires some manual adjustments to correct all the previous geometric issues, make the geometry coherent with the original BIM test case and restore the test model for a correct BEM final simulation.



The thermal zones, with the original names, the surfaces boundary conditions and the definition of the elements (e.g. wall, floor, roof), are correctly transferred and recognised, but, in addition to the previous geometric errors, some other discrepancies about the correct definition of the volumes and surfaces are present. The energy model, as created through Revit “Energy optimization” panel from the architectural model, is characterized by surfaces without thickness: for each 3D wall element an equivalent surface positioned along the centre line of the wall is automatically generated, hence the discrepancy with the gross and net floor areas and volumes. The following Figure 17 schematises the position of the boundary surfaces automatically generated. Usually model volumes and areas are over dimensioned with respect to real net volumes and under dimensioned with reference to gross volumes and areas.

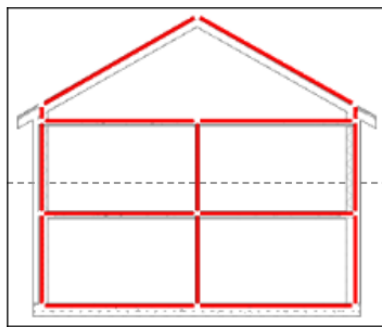


Figure 17: Rules implemented by Revit for the automatic generation of boundary surfaces

Checking the object information of each building element (e.g. walls, floors, windows), it appears that there is a loss of element and construction type original names. All the building elements and the construction types have been re-named with a new numerical code without any references to the original names. To allow a clear identification of the building elements, across the different software included in this procedure, it is essential that all elements keep the original names and codes as specified into the original BIM model. Therefore, some manual adjustments must be done re-naming correctly all the objects and building elements before moving to the next step and importing the model into EnergyPlus for the final BEM generation and simulation.

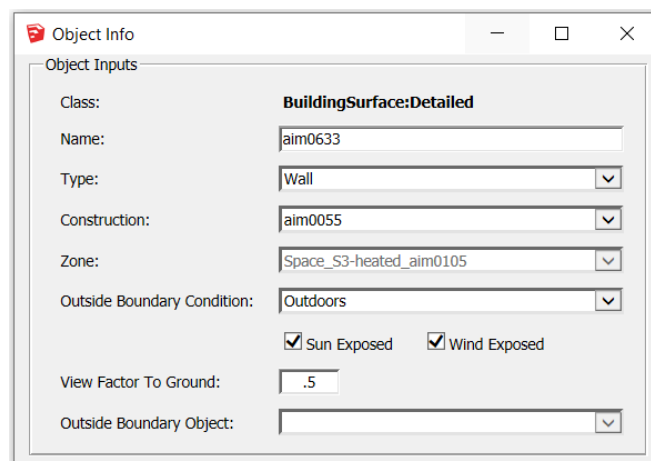


Figure 18: Loss of object’s original names



Step 3: Analysis of the model as imported into the simulation engine (EnergyPlus)

Once all previous manual adjustments have been made upon the IDF file, the test model can be imported into EnergyPlus and thoroughly analysed with the IDF Editor to find possible errors for all those items not previously investigated.

The IDF file, as opened with EnergyPlus, includes data concerning geometry, constructions and materials attributes and the correct identification of thermal zones. Nevertheless, the model shows a series of problems, listed below, that need further correction, removal and addition of some data.

- Presence of “additional objects”: analyzing the IDF file of the test model it appears that some additional default data has been automatically created. All these data, not coming from the original BIM test model and concerning, as an indication, convection algorithms for the surface heat transfer, parameters for the creation of 24-hour weather profile used for sizing, zone infiltration design rate, HVAC template and some output settings must be removed manually. In general, to avoid errors, it is advisable to remove all items excluded from the class list shown in the following Figure 19.

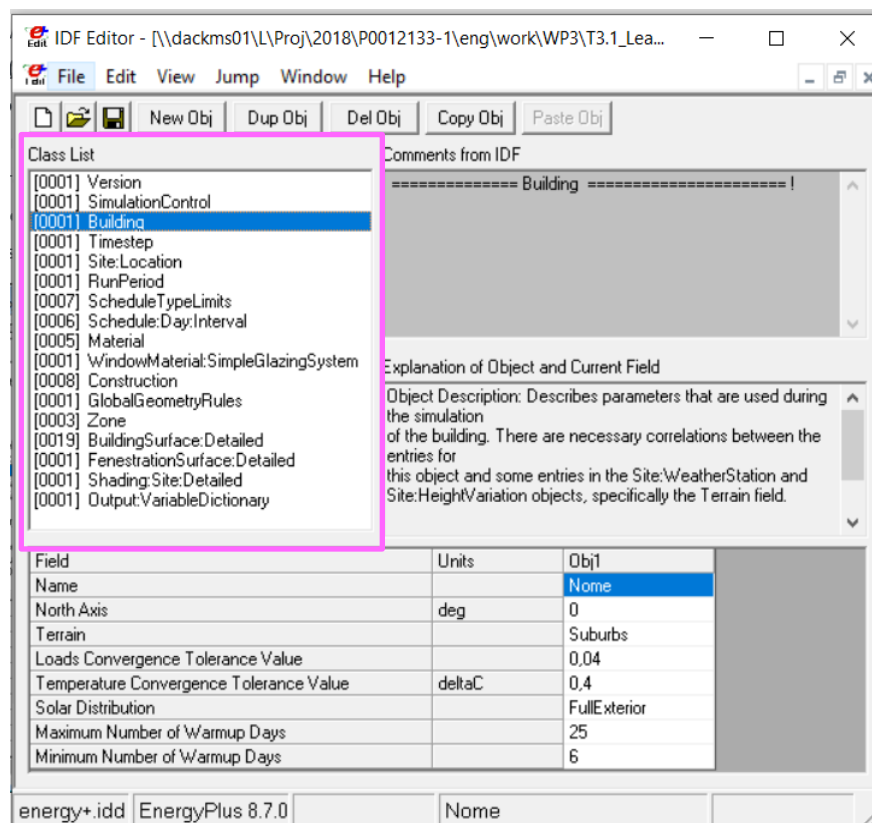
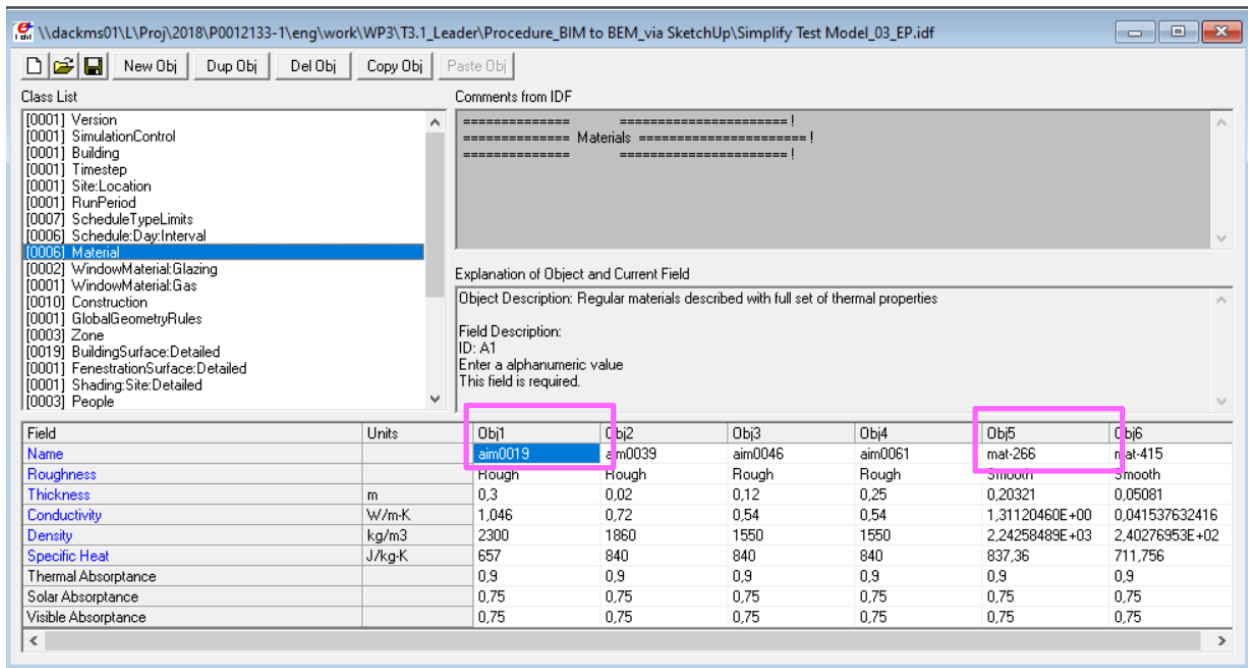


Figure 19: Recommended Class list

- Loss of all the original objects names: generally, within the IDF file all the original object names coming from the BIM test model (those not jet modified within SketchUp and Euclid plug-in) are not correctly transferred and all the elements have been re-named with new codes.



- **Materials (opaque):** material data of walls and slabs, with all thermal properties (thickness, conductivity, density and specific heat) have been correctly transferred from the original BIM test model. Only the original identification names were lost and must be manually re-entered and re-linked, where needed, to other elements (e.g. for the definition of the construction elements stratigraphy). Materials referring to the shutter box and the window frame are missing while additional materials, typically defined with “mat-num. code”, represent an important error and must be eliminated. The following Figure 20 shows the field related to the material properties as imported into EnergyPlus.



Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		aim0019	aim0039	aim0046	aim0061	mat-266	mat-415
Roughness		Rough	Rough	Rough	Rough	Smooth	Smooth
Thickness	m	0,3	0,02	0,12	0,25	0,20321	0,05081
Conductivity	W/m-K	1,046	0,72	0,54	0,54	1,31120460E+00	0,041537632416
Density	kg/m3	2300	1960	1550	1550	2,24258489E+03	2,40276953E+02
Specific Heat	J/kg-K	657	840	840	840	837,36	711,756
Thermal Absorptance		0,9	0,9	0,9	0,9	0,9	0,9
Solar Absorptance		0,75	0,75	0,75	0,75	0,75	0,75
Visible Absorptance		0,75	0,75	0,75	0,75	0,75	0,75

Figure 20: Material field properties as imported into EnergyPlus

- **Material (glazing):** the IDF file of the test model does not contain the right assignment regarding the thermal properties of glazing. Two objects were created automatically, but they do not refer to the data included within the original BIM test model. To define the correct energy performance of the windows, it is therefore required to set up all the relevant parameters manually within the IDF Editor.
- **Constructions:** construction elements’ names, as corrected within SketchUp (combined with Euclid plug-in), have been coherently imported within the “building surface” field. Stratigraphies should be manually corrected, re-associating the re-arranged material and constructions names as defined within previous steps.
- **Windows:** the IDF file of the test model includes only the external dimensions of the window and the relationship between objects (e.g. the window and the wall it belongs to). Data about the shutter box and the frame are missing and must be added manually with the IDF Editor.
- **Schedule:** analyzing the IDF file of the test model some schedules have been generated within the proper fields. Data about lighting, equipment and occupancy schedule, as defined within the BIM test model are reported within the “Schedule:Day Interval” field, but a careful evaluation and some manual





corrections are required. As for what happened for the other objects, the schedules identification names are lost and must be manually re-entered and re-linked (where needed). Moreover, beside the correct schedules additional schedules have been automatically generated and have to be removed.

- **Internal loads:** all the data included within the IDF file of the BIM test model about internal loads due to lighting, equipment and occupancy are not correct. All the fields must be discarded and manually entered directly with the IDF Editor.

Step 4: Completion of the BEM model

To obtain a full BEM model with this procedure, an enrichment of the IDF file that includes the manual entry of all those parameters not included into the BIM test model and not already added or corrected in the previous steps is needed. Particularly, all the information about HVAC must be added with the complete definition of the generators, the distribution and emission systems, the control types and the operating schedules.

Other missing data generally refers to airflow data, parameters for the correct definition of the internal loads, more accurate data about user behavior and external weather conditions. The weather conditions can be simply uploaded on the EP-Launch using one of the weather files downloading directly from the EnergyPlus website.

Step 5: Overall assessment of the procedure

The “Revit – SketchUp (with Euclid plug-in) – EnergyPlus” BIM-to-BEM procedure showed important critical issues regarding the interoperability between the software. Several data were lost during the translation of the model from IFC to IDF format. A lot of manual adjustments and correction had been required. Generally, this procedure enables the translation of building geometry and material properties but all other relevant information for a correct BEM simulation are not transferred. *BIM and BEM models are not automatically synchronized, and it is not possible to coordinate automatically further developments and adjustments, due for instance to design evolvments, of one of the models with the other one and the process must start from scratch again with the BIM to BEM conversion.*

All the critical issues analysed are inevitably more complex for large and articulated buildings and will require a big deal of manual data input.

3.3 Detailed analysis of “.ifc - TRNSYS” BIM-to-BEM procedure

This section investigates the interoperability between BIM and BEM procedure using TRNSYS as energy simulation software. It follows the steps indicated in the common procedure and presents the analysis of the information contained in the IFC file and the progress and difficulties encountered to automatically generate energy performance simulation TRNSYS files.

Step 1: Extraction of information from the BIM model

Firstly, the BIM test model, developed with Autodesk Revit™ 2018, was checked to verify the compliance with TRNSYS. The materials of the window were manually changed to include the name of a selected TRNSYS window ID for the glazing window element, this window ID has been used to match with the TRNSYS library. Moreover, the energy setting has been modified to change the export category to spaces instead of rooms. Before exporting the BIM test model to IFC, an “Energy Analytical Model”, shown in the following Figure 21 must be created, through the Revit tool, to obtain all the spaces boundaries. The energy model thus generated shows the



presence of the same geometric inaccuracies as already tested within the procedure based on SketchUp and Energy Plus. The model is characterized by surfaces without thickness: for each 3D wall element an equivalent surface positioned along the center line of the wall is automatically generated, hence the discrepancy with the gross and net floor areas and volumes. Usually model volumes and areas are over dimensioned with respect to real net volumes and areas and under dimensioned with reference to gross volumes and areas.

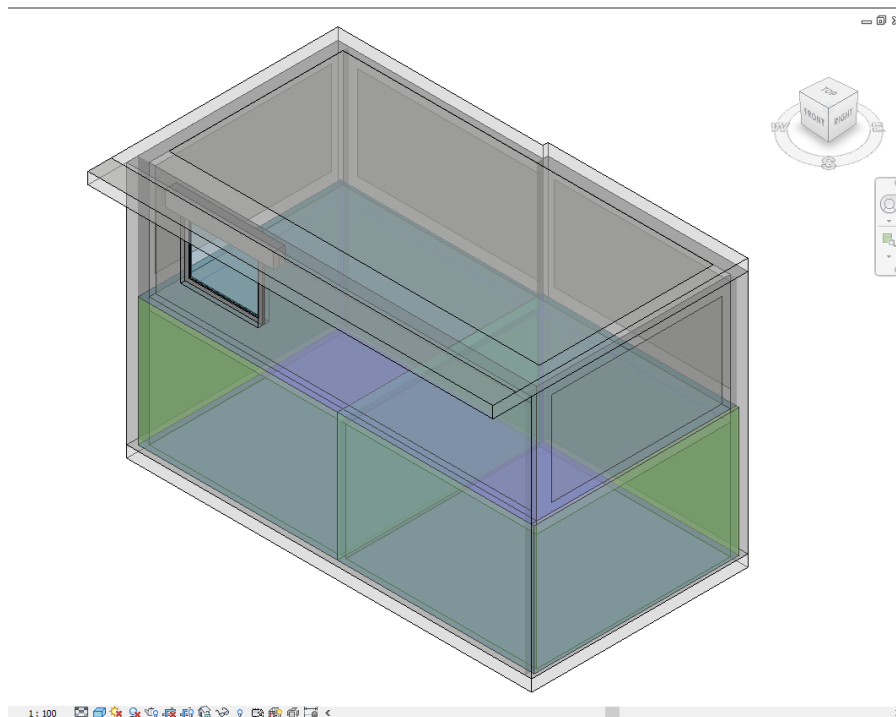


Figure 21: Revit™ - Energy Analytic Model of the BIM test model.

Within the dedicated menu for the IFC export, the IFC4 Design Transfer View was selected and edited including the 2nd level space boundaries to obtain the class `IfcRelSpaceBoundary`. Moreover, also the property sets options “Export Revit property sets”, “Export IFC common property sets” and “IFC Site” have been chosen (the location of the building can be included directly within Revit™).

Step 2: Analysis of the IFC model through a suitable GUI

Examining the IFC data model as extracted from the BIM tool, the following observations were made:

- the geometry and dimensions of all the building elements, and thermal zones are contained in the IFC file, but, as previously described, there are some discrepancies on the correct definition of volumes and areas. The developed IFC – TRNSYS algorithm can manage the geometrical information and through several programmed matrix operations, the location and geometry can be extracted. This information is necessary for the calculation of the building element orientation;
- the geometric definition of the space boundaries is contained in the IFC, but other information might be missing depending on the exporter tool. Revit only exports the class `IfcRelSpaceBoundary`, which contains less information than the `IfcRelSpaceBoundary2ndLevel`, therefore some information related to the



corresponding boundaries (which makes the connection between thermal zones) or parent boundaries (which defines for example the wall a window is included in) must be calculated and manually added. The features of the space boundary identified within the IFC standard are summarised within the following Table 11:

Table 11: Types of space boundary considered in the IFC standard

[Source: https://standards.buildingsmart.org/IFC/RELEASE/IFC4_1/FINAL/HTML/schema/ifcproductextension/lexical/ifcinternalorexternalenum.htm]

Constant	Description
Internal	The space boundary faces a physical or virtual element where there is an internal space on the other side
External	The space boundary faces a physical or virtual element where there is an external space on the other side
External_Earth	The space boundary faces a physical or virtual element where there is earth (or terrain) on the other side
External_Water	The space boundary faces a physical or virtual element where there is water (water component of terrain) on the other side
External_Fire	The space boundary faces a physical or virtual element where there is another building on the other side
Not defined	No information available

Nevertheless, when exporting the BIM test case, the unique parameters available are “Internal” or “External”, which makes it necessary to seek other ways to obtain the real condition. For instance, if the related element is a slab, the Object Type could be: “Ground Floor”, “Intermediate Floor” or “Roof”. To supplement the information supplied so far, in case of the ground floor, it is acceptable to assume, for example, a boundary condition for the surface that considers ground temperature;

- the IFC file contains all the information related to name and codes, if it has been introduced when creating the BIM model, without any loss;
- the materials thermal properties needed for the building energy simulation are not correctly transferred from the original BIM test model to the analysed IFC. The treatment of these data varies depending on the IFC class that defines the relation between the building element and the set of materials layers of which it is composed. In this case study (BIM test model generated by Revit), density, thermal conductivity and heat capacity must be added to the IFC file manually or through other supporting tools;
- the relationship between objects are generally included with the `IfcRelSpaceBoundary2ndLevel` class. If this class exists in the IFC file, the information of the relationship between objects and corresponding space boundaries is explicitly available. Nonetheless, within this procedure (starting from Revit as an example) and using the `IfcRelSpaceBoundary` class, it is possible to select the export of second level space boundaries, but still some needed information are lost. Making use of the geometric features and location, it is possible to obtain the lost information, but accurate algorithms must be developed;
- the schedules for the occupancy, lighting and equipment customization are not correctly transferred by the Revit exporter, therefore some manual corrections must be done either by including the information in the IFC file or adding it in the TRNSYS environment. In the first case, the developed BIM-to-BEM tool can extract the information from the IFC file and convert it to the TRNSYS requirements in the input file;



- The weather file must be manually added based on the location included in the BIM model.

Step 3: Analysis of the model as imported into the simulation engine

As previously mentioned, the IFC to TRNSYS algorithm must deal with missing data in the IFC model, either because they are not considered within the IFC standard or because the exporter tool does not provide them in a correct way. The building information must be included in the TRNSYS configuration file (.dck) through the Type56, the TRNSYS Multizone Building Model component, which allows to set some parameters of the building file (.bui). Similar to the idf files of Energy Plus, the TRNSYS building file has its specific order and way for the configuration of the information, and it must be strictly followed. The process and the main bottlenecks are explained below based on the simple BIM test model presented in section 3.1.

- Generic properties: the .bui file needs to specify some generic properties and internal parameters that can be assumed by default or entered manually, particularly when they are not contained in the IFC file.
- Inputs: this section defines the parameters that are internally used in TRNSYS for some calculations. This is the case, for instance, of the ground temperature that must be included in the model (assumed by default or entered manually).
- Materials (opaque) properties: materials thermal properties (conductivity, density and specific heat) have not been correctly transferred and must be manually added to the IFC and the intermediate database. Once the database has been filled with all the required data, the .bui file can be created. Some units used in TRNSYS do not belong to the International System of Units, thus the numbers presented here differ from the model specifications exposed before.

```
LAYER #1655
CONDUCTIVITY= 0.66 : CAPACITY= 0.84 : DENSITY= 1860 : PERT= 0 : PENRT= 0
LAYER #1681
CONDUCTIVITY= 0.49 : CAPACITY= 0.84 : DENSITY= 1550 : PERT= 0 : PENRT= 0
LAYER #2357
CONDUCTIVITY= 0.95 : CAPACITY= 0.66 : DENSITY= 2300 : PERT= 0 : PENRT= 0
LAYER #3025
CONDUCTIVITY= 1 : CAPACITY= 0.84 : DENSITY= 2480 : PERT= 0 : PENRT= 0
LAYER #3046
CONDUCTIVITY= 0.11 : CAPACITY= 0.19 : DENSITY= 496 : PERT= 0 : PENRT= 0
*-----*
```

Figure 22: Material properties definition for TRNSYS simulation (.bui file).

- Schedules: customised schedules are not transferred directly from BIM models. Schedules must be added manually within the IFC file (then the BIM-to-BEM developed tool is able to generate the needed schedules with the TRNSYS input file format) or directly in TRNSYS environment. If the thermal zone is “occupied”, the schedules for the occupancy are defined as follows.

```
*-----*
* S c h e d u l e s
*-----*

SCHEDULE OCCUPANCY680
HOURS = 0.000 1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000 11.000 12.000
VALUES = 0.9 0.9 0.9 0.9 0.9 0.9 0.7 0.4 0.4 0.2 0.2 0.2 0.2 0.
SCHEDULE OCCUPANCY1094
HOURS = 0.000 1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000 11.000 12.000
VALUES = 0.9 0.9 0.9 0.9 0.9 0.9 0.7 0.4 0.4 0.2 0.2 0.2 0.2 0.
```

Figure 23: Definition of the schedules in TRNSYS.



- Constructions: this category defines every element that constitutes the building, except windows. The information needed, as shown in the following Figure 24, is the reference of the element (the construction elements' names, as defined within the BIM test model are substituted by a reference code), its material layers with thickness, and some other parameters related to heat transfer coefficients, solar radiation absorptance and emissivity of the material, which can be specified by default or manually customized. There is not an evident relationship between the original BIM elements' name and the reference codes used (chosen as the IFC references).

```

CONSTRUCTION #432
LAYERS = #1655 #1681 #1655
THICKNESS = 0.02 0.25 0.02
ABS-FRONT= 0.4    : ABS-BACK= 0.5
EPS-FRONT = 0.9    : EPS-BACK = 0.9
HFRONT = 11 : HBACK = 64

CONSTRUCTION #4116
LAYERS = #2357
THICKNESS = 0.3
ABS-FRONT= 0.4    : ABS-BACK= 0.5
EPS-FRONT = 0.9    : EPS-BACK = 0.9
HFRONT = 11 : HBACK = 64

```

Figure 24: Example of wall definition in the .bui file.

- Windows: all of the window relevant data must be added manually setting a suitable TRNSYS ID code, the material layers and all the relevant information in the .bui file. TRNSYS has its specific definition for windows so that the data can not be imported just as they appear in the IFC. TRNSYS relies on an specific library with multiple windows types: from one single panel to several, different separations, frames material, absorption and shading parameters, etc.
- Internal loads: to define internal gains, some additional data must be defined and manually added.
- Thermal zone: thermal zone boundaries are correctly transferred, areas and the orientation can be extracted from the IFC file through several calculations. The zone definition contains every boundary surface with references to the building element, total area and position. If the surface is "external", the orientation is needed, if the surface is "internal", the adjacent space and surface is needed, while for "boundary" surfaces the boundary condition is needed. Other parameters related to the solar radiation are required and as they do not appear in the IFC, they can be specified using TRNSYS values by default or manually customised. Figure 25 shows an example of the thermal zone definition in the .bui file.





```

-----
* Zone #1108 / Airnode #1108
-----
ZONE #1108
RADIATION MODE
  BEAM=STANDARD : DIFFUSE=STANDARD : LONGWAVE=STANDARD : GEOMODE=3D_DATA : FSOLAIR=0
DAYLIGHTMODE
  DLSHADE =-1
AIRNODE #1108
WALL =#1464 : SURF= 14 : AREA= 0.2144999999999992 : EXTERNAL : ORI=E_225_90 : FSKY=0.5
FLOOR =#4155 : SURF= 15 : AREA= 26.8732 : ADJACENT=#184 : ADJ_SURF= 7 : BACK
FLOOR =#4165 : SURF= 16 : AREA= 26.882624999999999 : ADJACENT=#680 : ADJ_SURF= 13 : BACK
WALL =#4168 : SURF= 17 : AREA= 16.764 : EXTERNAL : ORI=E_225_90 : FSKY=0.5
WALL =#4169 : SURF= 18 : AREA= 17.457 : EXTERNAL : ORI=S_315_90 : FSKY=0.5
WALL =#4170 : SURF= 19 : AREA= 33.7425 : EXTERNAL : ORI=W_45_90 : FSKY=0.5
WINDOW = #4171 : SURF= 20 : AREA = 3 : EXTERNAL: ORI = W_45_90 : FSKY = 0.5 : GEOSURF = 0
WALL =#4173 : SURF= 21 : AREA= 17.2425 : EXTERNAL : ORI=N_135_90 : FSKY=0.5
ROOF =#4174 : SURF= 22 : AREA= 53.755825 : EXTERNAL : ORI=H_0_0 : FSKY=0.5
WALL =#4176 : SURF= 23 : AREA= 16.9785 : EXTERNAL : ORI=E_225_90 : FSKY=0.5
REGIME
HEATING = HEATING1108
COOLING = COOLING1108
CAPACITANCE = 180 : VOLUME = 150 : REFAREA = 53.755824999999999 : TINITIAL= 20 : PHINITIAL= 50
    
```

Figure 25: Example of thermal zone definition in the .bui file.

Figure 26 shows the .bui file generated by the BIM-to-BEM tool in TRNBuild, the TRNSYS module devoted to building a BEM.

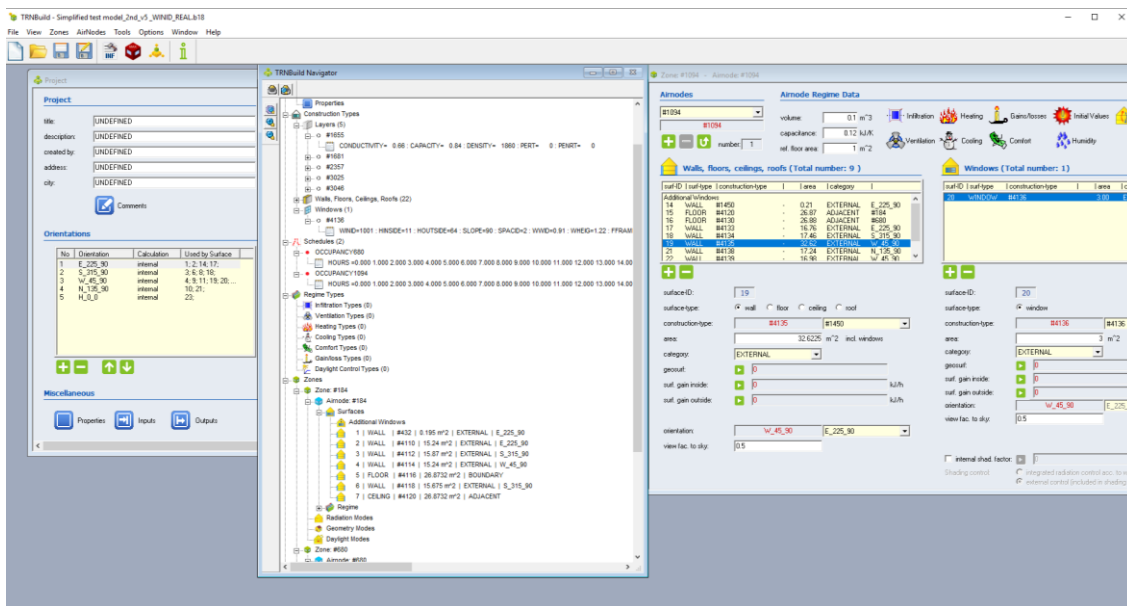


Figure 26: Building model opened in TRNBuild after the BIM-to-BEM process.

Step 4: Completion of the BEM model

As for the previous procedure, also for this workflow, to obtain a full BEM model, it is necessary to include weather data into the model and manually insert all the parameters related to HVAC systems. TRNSYS works with different weather databases such as the EnergyPlus format or Meteororm, which are available for a wide number of locations. However, it could happen that the location at issue does not have any associated weather file, so the best





way to proceed is to manually select the file that better meets the model climate conditions. Other adjustments like the simulation time steps must be defined by the user.

Step 5: Overall assessment of the procedure

As previously mentioned, this BIM-to-BEM procedure is still under development and many improvements must be done before considering this process automatic. Some data are not exportable from a BIM tool, others are not considered within the IFC standard and therefore, for those data there is the need of manual input. Since TRNSYS owns specific libraries and no information from the IFC can be implemented, in certain cases, as for instance when defining the windows, some modeling guidelines must be followed. Additionally, since TRNSYS is a very specialized and complex software, to define a complete BEM, the information required is often much wider than the one provided in BIM models, especially regarding HVAC systems. In general, the procedure can deal with many types of buildings regardless their geometry and size in a reliable way with the need of a certain amount of manual intervention.

3.4 Detailed analysis of actual “.IFC – CYPETHERM Suite” BIM-to-BEM procedure

The procedure analysed investigates the interoperability between BIM and BEM using the CYPETHERM Suite (IFC builder, CYPETHERM Loads, CYPETHERM HVAC and CYPETHERM EPlus).

The workflow allows the works with open formats starting from any BIM tool (Revit, IFCBuilder, ArchiCAD, AllPlan, Aecosim, etc.) through open IFC formats. The analysis is based on the BIM test model as previous described and follows the steps indicated within the common procedure. The final energy engine included within CYPETHERM EPlus is EnergyPlus.

Step 1: Extraction of information from the BIM model

Generally, there are currently three possible ways depending on the initial BIM software used. The shortest and most accurate way is working directly with IFC Builder, which natively produces a BIM model in IFC format with no loss of information. This allows a one-click issue-free communication with the CYPETHERM Suite, since they work in open BIM formats such as IFC. This process is completely automatic, but not all the relevant data for the thermal view of the building can be introduced at this step with the IFC builder (as materials properties, stratigraphies, thermal zones, etc.) must be included within the model during the following phases using the other complementary CYPETHERM tools.

Alternatively, the second way to extract information from a BIM model, generated in this case with Autodesk Revit™, uses the plug-in “Complementary Open BIM for Revit” provided by CYPE, which configures the export settings for an optimal generation of IFC entities. This is a hybrid solution that is automatic depending on the geometry of the model to export. Buildings with common shapes allow a direct export while more singular geometries usually encounter issues which can lead to the need of some manual adjustments and simplifications of the BIM model.

The last way to extract information from a BIM model, generated by other BIM applications such as Archicad, Allplan or Aecosim, consists in a non-automated exportation of the project to IFC, having to configure the export process manually, which can lead to communication problems, especially for more complex models.



Step 2: Analysis of the IFC model (from any BIM tool) through a suitable GUI

The transportation of data between software of different developers has some limitations due to the different internal logics and ways of implementing geometry and data; nevertheless, the CYPETHERM Suite has been designed to accept a wide range of IFC coming from different sources.

Analysing for example the IFC of the BIM test model, as imported into the IFC Builder, it appears that the whole geometry of the BIM test model is correctly imported, especially regarding the Spaces Boundaries (walls, slabs and roof limiting the internal spaces). Areas and volumes are correctly transferred while just a minor adjustment concerning the ground floor exposition is needed. Horizontal and vertical elements as well as openings are identified as defined in the previous BIM tool with the correct name and thickness. Following Figure 27 shows the IFC model as imported into IFC Builder.

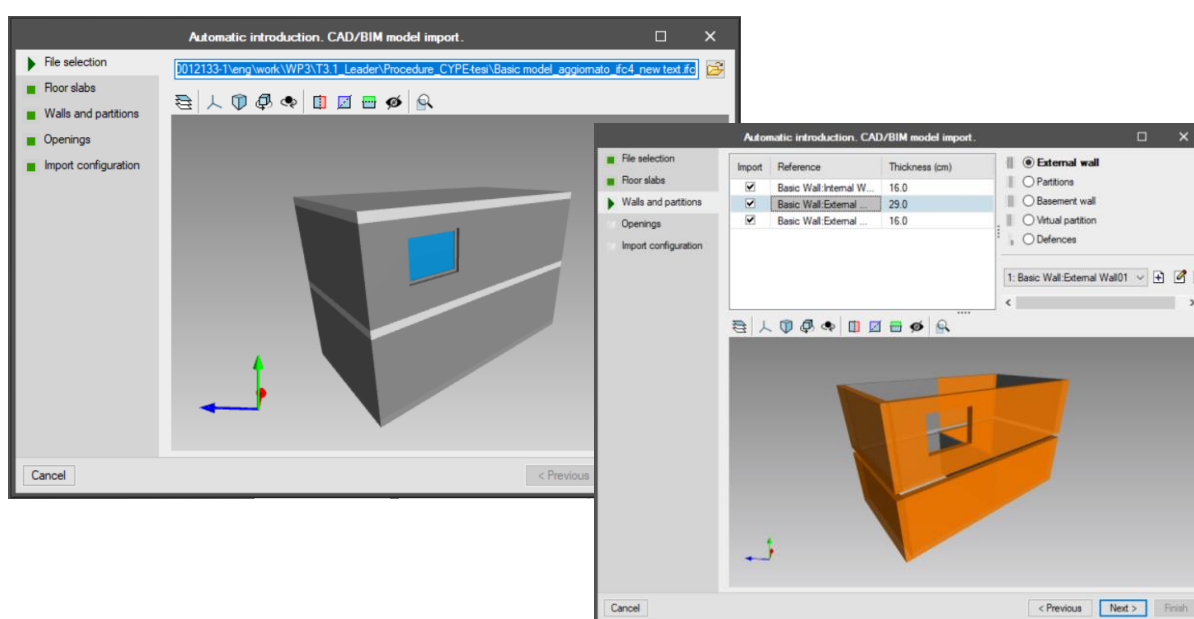


Figure 27: Analysis of the IFC file as imported into IFC Builder

In addition to the geometry, for later analysis and calculations in the CYPETHERM Suite, the test model must include the defined spaces, which are specific entities (IFCspace) exportable by any BIM software, with the correspondent Space Boundaries. The automation of the introduction of such spaces depends on the source software: Revit, for example, allows the automatic introduction of “Rooms” instances per level, whereas other BIM software do not include such a feature. Despite that, the automatic use of those spaces modeled for other BIM purposes (i.e. to develop a surface plan, a mandatory document in any project worldwide) is not always appropriate for performing thermal calculations without manual adjustments. In the case of the BIM test model, the IFC Builder requires the manual introduction of locals and thermal zones. The general rule is that smaller and simpler IFC models can be exported issue-free to a file with enough data that can be read by CYPETHERM Suite, whereas singular shapes usually have to face manual modifications and even simplifications.

The following elements are not transferred from the BIM test model and must be manually re-inserted within the other tools of the CYPETHERM Suite:



- materials thermal properties and stratigraphies;
- internal conditions related to occupancy, lighting and equipment;
- HVAC data and operation schedules.

Step 3: Analysis of the model as imported into the simulation engine

To import the IFC model into CYPETHERM, the project must be uploaded to the Common Data Environment BIMserver.center, CYPE's free open platform that manages the communication between software and keeps track of the model updates as they are developed by one or more participants of the project.

Once in BIMserver, CYPETHERM (with the login information of the correspondent user) will be able to access the information of the model and work with it from any device with internet connection – including smartphones. All the changes applied to the local model will be updated in BIMserver, using a notification system to keep all the participants updated in real time.

Once all previous minor adjustments have been made, the test model can be imported into the CYPETHERM LOADS (the first tool of the suite) to manually input all the materials properties, create stratigraphies and assign stratigraphies to each the building element as shown in the following Figure 28. This manual step is necessary as, to date, the detailed CYPETHERM database is not able to match with all the databases of all the BIM software.

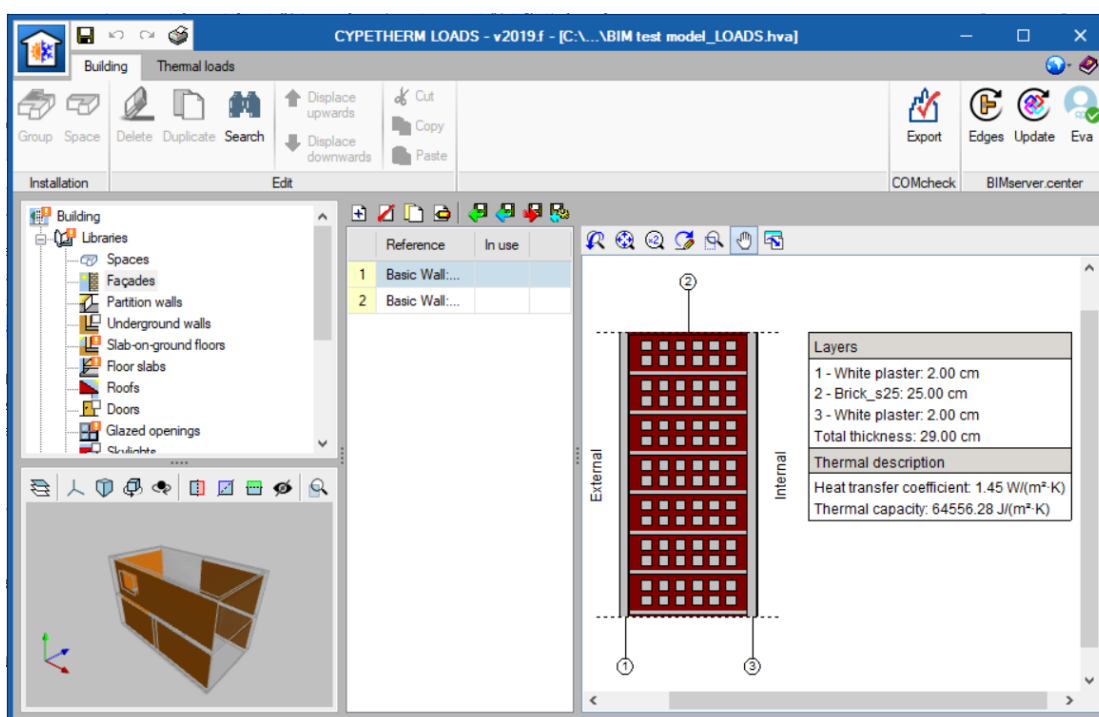


Figure 28: Stratigraphies definition within CYPETHERM LOADS

Moreover, for each local, it is possible to define the thermal loads according to custom profiles, as well as the climate conditions and orientation of the project. The IFC model does not include any data concerning HVAC system. CYPETHERM LOADS enables also to calculate the thermal loads of the project according to the introduced data and the selected calculation criteria.





Step 4: Completion of the BEM model

The IFC file of the test model, as enriched from the previous steps, is then transferred via BIMserver to CYPETHERM HVAC, which can create and size heating, cooling and ventilation systems according to the previously calculated thermal parameters (demand and building properties). All the information about materials, stratigraphies and spaces, previously introduced with CYPETHERM LOADS, must be re-uploaded from the CYPETHERM library folder (where, during previous steps, this information must be saved). All the information about HVAC systems must be added manually as well as the operating schedules. Once the HVAC system is complete, the IFC model is transferred to CYPETHERM EPlus to determine the energy performance of the test model and complete the BEM model.

Step 5: Overall assessment of the procedure

The core concept of the “.IFC-CYPETHERM Suite” BIM-to-BEM procedure is to work with open formats. The use of IFC format for the whole process is aimed at implementing a more universal approach able to adapt to any kind of BIM user and any kind of software.

The analyzed workflow leads a big deal of benefits, such as the capability to use any BIM software able to export IFC models and the chance to initiate the project tracing all the advances and modifications of the project in real time, documenting the actions and attributing the relative responsibilities. Nevertheless, the procedure showed a few critical issues: the whole process depends on the integrity of the first IFC file, which can be difficult to read if the user has not applied suitable export settings for their project. This interoperability problem has been partially solved through the specific plug-in developed for Revit that could be implemented in the future also for other BIM solutions. Moreover, a lot of information included within the BIM model (as material properties, stratigraphies, thermal zones, etc.) are lost, or not included in case of the IFC Builder. All those data must be manually entered step by step using the different tools of the CYPETHERM Suite and need to be re-uploaded manually from the libraries moving from tool to tool.

Generally, this procedure enables an accurate transfer of the building geometry and allows a semi-automatic synchronization between the models, requiring just a few manual adjustments.

3.5 Comparison of different BIM-to-BEM workflow

To speed up the BIM-to-BEM process, a comparison of the selected procedures above described has been conducted. All the procedures successfully completed the creation of BEM, however, none of them is fully automated and all require a certain amount of users’ experience. The main problem for the BIM-to-BEM process is the interoperability between software and their automated integration. Loosing data through information exchange between tools represents one of the most common problems.

The interoperability issues analysed are not limited to the ability of BEM tools to read the input information but can be identified at different phases:

- phase 1: BIM authoring tools are not able to include all the required information or to easily define attribute for a specific data;
- phase 2: BIM authoring tools do not transfer all the information into the required schema (IFC or gbXML) correctly;





- phase 3: the mapping process to identify all the relevant information to define the thermal view of the building does not work properly and the information can not be transferred properly into the BEM tool's format;
- phase 4: BEM tools are not able to read all the information coming from BIM.

The findings of the previous analyses have been summarised in Table A.1, included within Appendix 1, to provide a general overview of the current BIM-to-BEM interoperability issues, complete with the identification of the phases in which they were found.

Currently all the procedures are highly time-consuming and error-prone and manually re-entering of data is a common practice. Although a lot of information needed for the completion of BEM models can be acquired automatically from the BIM models, some other information is lost in between tools passages and some objects are missing, not readable by the energy simulation engines or in wrong "position". Issues regarding the correct definition, under the thermal point of view, of the windows are commonly observed among all the procedures as well as the lack of HVAC systems data transfer. All the missing data must be added manually.

One of the most critical steps within the interoperability process concerns the proper initial conversion of the BIM model into the IFC schema. The BIM-to-BEM procedure via SketchUp does not include a customizable settings of this step while the BIM-to-BEM procedures based on the CYPETHERM Suite and TRNSYS allows the user to configure the export process manually (in case of the CYPETHERM SUITE, a dedicated plug-in has been developed for Revit).

Generally, all the procedures involve just a one-directional flow of information, from BIM to BEM, without the possibility to implement the data exchange bidirectionally.

The comparison between the different procedures analysed indicates that the BIM-to-BEM procedure based on the CYPETHERM Suite enables the users to elaborate a BEM starting from any BIM tool able to export an IFC file, using an Open BIM approach with a higher expansion capability than the other procedures. Indeed, the Open BIM approach supports a transparent, open workflow, allowing project members to participate regardless of the software tools they use. Moreover, Open BIM provides enduring project data for use throughout the asset life-cycle, avoiding multiple input of the same data and consequential errors.

The main bottleneck of this method, to date, is that not all the common BIM software feature user-friendly IFC export configurations, meaning that a careful manual setting for the .IFC file generation is needed with some inevitable loss of time. Additionally, some limitations exist with regards to the generation of IFCSpaces (the thermal spaces to be calculated within a BEM) inherited from the BIM tools. Dedicated sections on the identification of possible solutions and a collection of recommendations to optimize the general BIM-to-BEM procedure have been provided below.



4. Identification of possible solutions

This section identifies all the main potential solutions to overcome the shortcomings and to further automate and optimize the BIM-to-BEM process, starting from the critical analyses of the three selected BIM-to-BEM procedures used at BIM-Speed partners today that are detailed above.

The purpose is to achieve greater automation in the actual interoperability workflows from BIM-to-BEM with the reduction of the existing gaps between the two models and the need of manual correcting actions.

For each critical issue find out during the previous activities, possible practical solutions will be investigated and clearly reported.

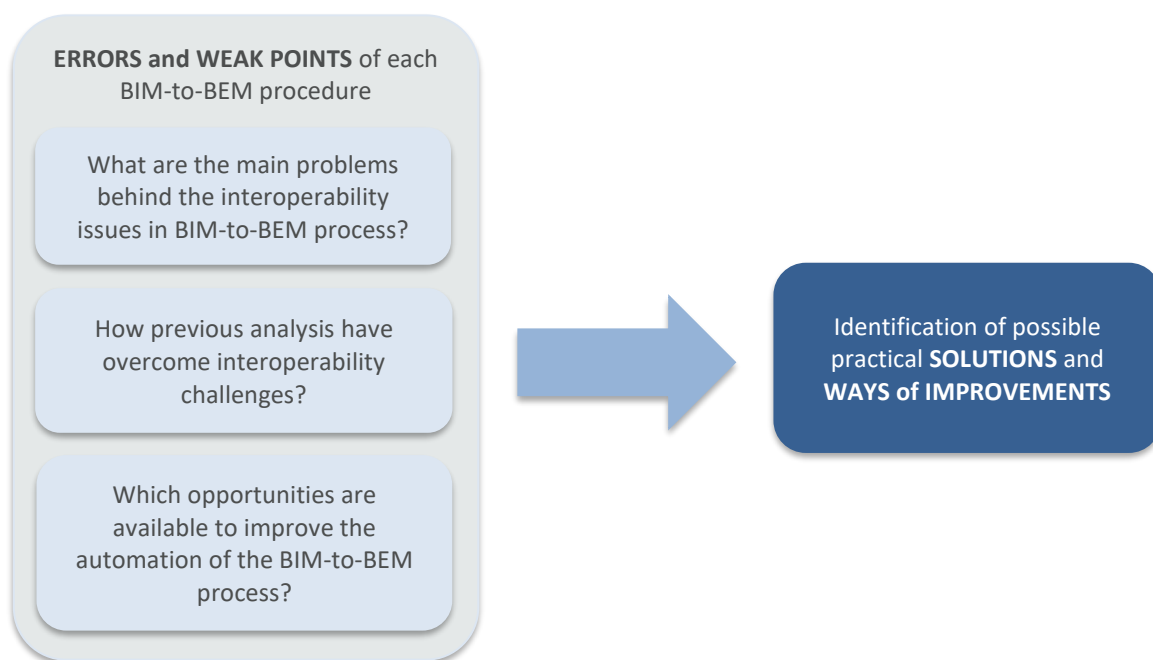


Figure 29: Conceptual workflow to investigate for solutions

The major issues and challenges observed have been reported and divided within six thematic groups:

- weather data and location;
- building geometry;
- building elements;
- thermal zones (including internal loads, space uses);
- HVAC systems, plant and equipment;
- Schedules.

Most of the solutions investigated to overcome the current critical issues for the BIM-to-BEM procedure can be summarised with a development of a set of tools, middleware and procedures able to act as intermediaries between structures and programs, allowing BIM and BEM tools to communicate despite the diversity of protocols.





4.1 Weather data and location

BIM models do not contain surrounding physical features as well as weather and environmental data of the context in which the building is located. All the procedures analysed overcome this issue linking proper weather files (obtained from common databases) directly within the BEM tools and adjusting manually any external shading. Only the name of the location, used for the general description of the model, can currently be transferred. All these aspects will be investigated within Task 1.4 “Environmental, climate and surrounding data”. The purpose is to automatically select via web services, using GIS data and building coordinates, the suitable weather data, and the build and natural environment of the building generating proper solar masks.

Moreover, Task 3.3 “Integration of environmental and GIS data to BEM” is focused on the development of methods for enriching BEM using GIS data integrating automatically weather files into the models.

Therefore, for what concern weather data and location interoperability issues, refers to the mentioned tasks that will be developed later in the project.

4.2 Building geometry

Although most of the geometrical data are easily transferred from BIM to BEM, there are a few mismatches to be corrected. Usually, BIM tools offer two or more ways to model elements and building geometry. This can lead to IFC models whose geometry has been generated very differently, thus making it difficult to read the whole geometry and the building element shapes properly.

Generally, the geometric inaccuracies which can affect the BIM-to-BEM process can mainly be grouped into 3 categories: clashes, surface errors and space incorrect definitions.

- Clashes occur when components making up a built asset are not spatially coordinated and conflict (e.g. there are not proper intersections between the solid geometric representation of architectural building components as walls, slabs and spaces). Clashes can affect BEM by altering the space boundary surface typology;
- Surface errors include the generation of extra surfaces and redundant data as in the case of the sub-surfaces generated for walls holding elements as windows within the BIM-to-BEM procedure via SketchUp;
- Space incorrect definitions occurs when the 3D architectural building components are simplified with 2D surfaces positioned along the center line of the components, both for external and internal components, generating in this way a discrepancy between the gross and net floor area and volume.

All these errors lead to inconsistency in areas and volumes calculations and are more relevant, numerous and their adjustment requires more time, the more complex the building is. To solve the listed issues related geometry, a practical solution, applied by all the procedure analysed, is the manual correction of the punctual errors with the re-insertion of the elements with a GUI or directly with BEM tools. To solve the discrepancies about the net volumes and floor areas, an option can be to take this information directly from the IfcSpace properties calculated in Revit.

An improvement opportunity to optimize the interoperability and overcome the geometrical errors is given by the publication of a comprehensible multi language user guide that allows user to know the requirements of the exported IFC and integrate these requirements as “integrated criteria” in their process of development.

Additionally, the definition of requirements towards the BIM models in the Employer Information





Requirements (EIR) and in the BIM Execution Plan (BEP) clarifying how models must be created would reduce, and ultimately eliminate the manual “adaptation” of the BIM model for the BEM execution.

For this purpose, the user needs to be familiar with the BIM structure which is more complicated when the model include multiple floors, openings and other building components. The understanding of the requirements of the IFC models (and their inherent IFCspaces and relevant boundaries) is, indeed, crucial to guarantee an operative workflow that goes from BIM to BEM using for instance the open BIM technology, as in the case of the CYPETEHRM Suite procedure. Furthermore, this requires framing the execution of the BEM model as an additional “BIM use” to be considered in the BIM Execution Plan (BEP) from the start of the project.

Another possible solution to address the challenges related to geometrical issues is given by the development of a correction tool, or by the implementation of existing algorithm into the BIM-SPEED BIM-to-BEM process (as the Common Boundary Intersection Projection CBIP algorithm), to automatically resolve the issue related to the building envelope automatically closing edges, removing redundant data and positioning the external surfaces on the internal or external line of the architectural components.

4.3 Building elements

Following, the most critical issues regarding building components are characterized and practical solutions are shown. Generally, the transfer issues which can affect the BIM-to-BEM process, can be grouped into 4 main categories: identification names of the building elements, materials thermal properties, stratigraphies of the opaque elements and windows.

A common issue that complicates the BIM-to-BEM process and the further energy evaluations, is represented by the loss of building elements original names with the assignment of new codes that makes the recognition of elements more difficult (apparently, this is not an issue for the TRNSYS procedure as the procedure extracts the information from the IFC directly). To address this issue, within the three procedures, the user must change the names of the building elements manually. Obviously, this manual solution is impracticable for large models with a great deal of different elements. A development of a specific tool or functionality keeping or linking the original elements names of the BIM models is therefore needed to assure the BEM models elements can be easily checked and inspected.

Regarding materials thermal properties, in some cases they are correctly transferred, in others manual corrections are applied to finalise the BEM model. Since in general, a material is first characterized by its name that corresponds to a key in a material database including also the material thermal properties, the development of a complementary tool or functionality matching the BIM databases (when available) with the libraries used within the BEM tools would allow to automatically enrich and populate the IFC, or other schema to exchange data, with all the proper thermo-physical information, avoiding the loss of some data and the creation of others not consistent with the original BIM model. The tool can also help with the automatic creation of the building stratigraphies linking every construction layer with the corresponding materials of the BEM library. Another possible improvement of the general BIM-to-BEM process, although not providing a global and holistic standardised solution, could be the development of an add-on through the Application Programming Interface (API) of Revit, which is full accessible.





Windows represent a common weak point within the actual BIM-to-BEM interoperability procedures. Generally, BIM models do not contain detailed and precise information about the thermal properties and shading devices of windows. Windows geometry is transferred in a simplified way by all three procedures, but the thermal properties must be redefined within the BEM tool. Such errors could be simply resolved manually, however, to improve the input of the windows construction data the windows databases of BIM and BEM should share the same information.

4.4 Thermal zones

The definition of thermal zones, composed by a space or a group of homogenous spaces, is usually a crucial task that requires a lot of knowledge of building physics. The creation of thermal zones allows to define spatial requirements zoning the internal spaces of a building into different categories. In some cases, the thermal zones spatial definition, when already included within BIM models, is correctly transferred, but many of the parameters required to characterise zones within a BEM, such as internal set point conditions, related internal temperature and humidity, space uses, required ventilation rates or the internal loads due to people, lighting and equipment have to be implemented and customised directly with the BEM tools or manually included in the IFC file. Within the open BIM workflow, for example, the thermal zones must be identified inside the CYPETHERM suite through a quick manual intervention of the user. Defining them in the BIM tools can be problematic because till now there is no clear data structure or standard that guarantees that all the files from different tools will be able to be read the information uniformly for later calculation and analysis.

Nevertheless, after identifying the thermal zones with the CYPETHERM suite, the later export of the calculation results would allow the consolidation of the data of thermal zones in the source BIM tool (importing or referencing such IFC) or in Common Data Environments or online platforms such as BIMserver.center and BIM SPEED Platform. To address the challenges related to thermal zoning, different criteria about data persistence in open and accessible formats could be considered to provide users with feasible guideline to manage information openly. An opportunity to improve the automated definition of the thermal zones consists in the development of a tool looking for similarity in adjacent spaces and including rules able to identify spaces with similar uses, space-conditioning requirements, HVAC systems and heating and cooling setpoints exists. A good rule for zoning a building is that perimeter spaces should be zoned separately to core spaces. This is because the effect of façades and so the external conditions, might affect differently the perimeter areas than the internal areas. Moreover, for perimeter spaces, spaces with different orientations and substantially different façade types (e.g. an opaque wall and a glazing wall) should be zoned separately as subjected to solar gain differently and/or at different times.

4.5 HVAC systems, plants and equipment

Within the current BIM-to-BEM processes there is a lack of data exchange regarding HVAC systems, plant and equipment information. All the systems specifications as well as the control strategies must be set up directly within the BEM tools, manually or uploading default values, before running the simulations. To date, BIM models do not include all the HVAC specifications required for the energy assessment.

Possible solutions to solve the issues concerning the lack of HVAC systems data within the BIM-to-BEM interoperability models consists in the use of IfcPropertySet to provide the missing information and/or



focusing in the development of a middleware, a set of software that act as intermediaries between structures and programs, allowing them to communicate despite the diversity of protocols. HVAC data could be set up with the BEM tools and made available in a Common Data Environment or online platforms such as the BIM SPEED Platform.

4.6 Schedules

Setting up detailed schedules for the occupancy, lighting and equipment uses and the operational functioning of the HVAC system allows to improve the accuracy of building energy simulation. Indeed, these data play a significant role in the amount of energy used in building. Default input might generate large discrepancy between the real behaviour of a building and the data predicted by energy simulation. Some BIM tools, as Revit, offers the opportunities to define customised schedules, in a simplified way, applying a customised day for the whole year but does not allow to differentiate weekdays from weekends, as shown in the following Figure 30.

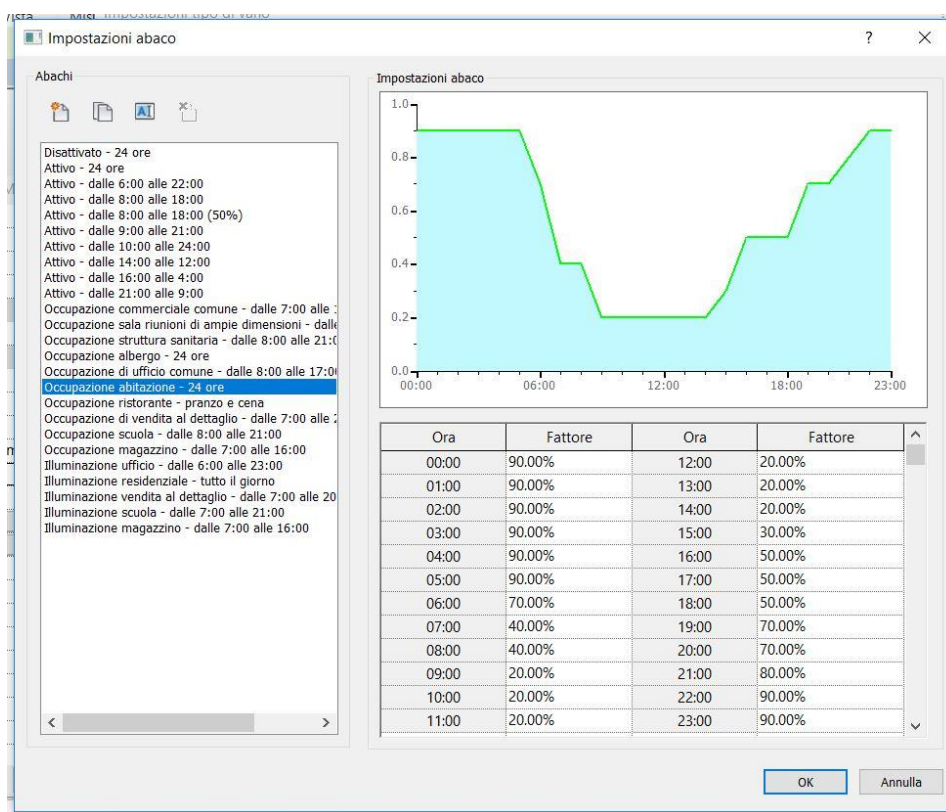


Figure 30: Example of occupancy schedule set up with Revit

In some cases, the schedules, when already included within BIM models or in the IFC file, are correctly transferred, although simplified. Within the open BIM workflow, the schedules, as the thermal zones, have to be firstly set up manually inside the CYPETHERM suite and then can be available in the source BIM tool or in Common Data Environments or online platforms such as BIMserver.center or the BIM-Speed platform. A way of improvement could be the development of an algorithm capable of extracting the required information already included within BIM models as a starting point.





5. Recommendations to optimise BIM-to-BEM procedures

This section provides additional recommendations and good practices to assist both developers and users in the enhancement of the interoperability between BIM and energy simulation engines, overcoming bottlenecks and to speed up the whole BIM-to-BEM process. The recommendations provided can be used as a starting point for the standardisation of the BIM-to-BEM process trying to get over the lack of an official approach.

To get reliable energy simulations for building renovation projects, an essential pre-requisite is an exhaustive and suitable data collection on site to enrich the already available information with real data. This activity will be detailed within WP1 and WP2 of the BIM-Speed project, while deliverable D3.1 focuses mainly on the BIM-to-BEM workflow and interoperability.

To ensure consistency between the BIM and BEM models four essential steps have been identified:

- step 1: populating IFC-based BIM with data according to appropriate BIM guidelines (the Revit environment is just one example). The development of a suitable BEM Ontology for renovation projects is part of this step and details will be provided with D2.2;
- step 2: exporting IFC-based BIM through a dedicated IFC exporter with automated rule-based data transformation;
- step 3: rigorous model checking;
- step 4: BEM performance calculations and BIM enrichment based on the output.

The process starts with the creation and population of the BIM, this is followed by rule-based data transformation to meet data formatting needs of the simulation engine and by continuous model and data checks with detection and correction of faulty information. Once all missing data are added, the execution of simulations and the analysis of results can be performed. The last step will focus the attention on the importance of making available all the data added and/or changed within BEM tools for BIM models and the potential integration with the BIM SPEED Platform.

5.1 BIM tools/Revit modelling guideline to set up BIM models

BIM provides a structured methodology to store, manage and use all relevant building information. Multilingual comprehensive guidelines, informing about the IFC and the open BIM requirements, guiding the users towards suitable BIM creation according to specific BEM requirements, allow both designers and users to produce BIM models in a consistent and standardised manner avoiding manual and ad-hoc adaptation of the models in order to obtain suitable and complete BEM models. To be effective, the guidelines should also be integrated, as an additional BIM use to be considered, into the BEP.

Specific BEM tools requirements currently drive the creation of BIM models for energy analysis. Generally, existing guidelines provide instructions to ensure the creation of the most proper IFC files. Some of the requirements are, as a first example:

- proper orientation of the building with respect to the real North;
- proper classification of the building element functions (internal, external, in contact with ground);
- proper union of the building elements;



- all internal locals of the building must belong to a given space. Not empty areas should be left unmapped;
- no internal locals of the building can belong simultaneously to 2 spaces (spaces should not overlap);
- external shadowing buildings are modelled as mass blocks (exported as IfcBuildingElementProxy);
- for locals with different internal heights, auxiliary floor surfaces should be used;
- dealing with residential building, each individual dwelling should be considered as a single zone with no further partitions.

In order to apply repetitive procedures and corrective actions, suitable scripts in Dynamo, an open source Revit plug-in, could be developed, for instance, when there is the need to join some geometrical elements (using the main command: join.geometry). Additionally, the Revit Application Programming Interface (API) could be used for more complex and replicable changes.

The following instructions have been taken from previous studies carried out within the P2ENDURE EU-funded research Project (H2020) developed by the Technische Universität Berlin (TUB). The following Figure 31 provide a high-level diagram showing all the necessary input data required to set up a complete BEM, including geometry, material properties, building systems, site conditions and building operation information.

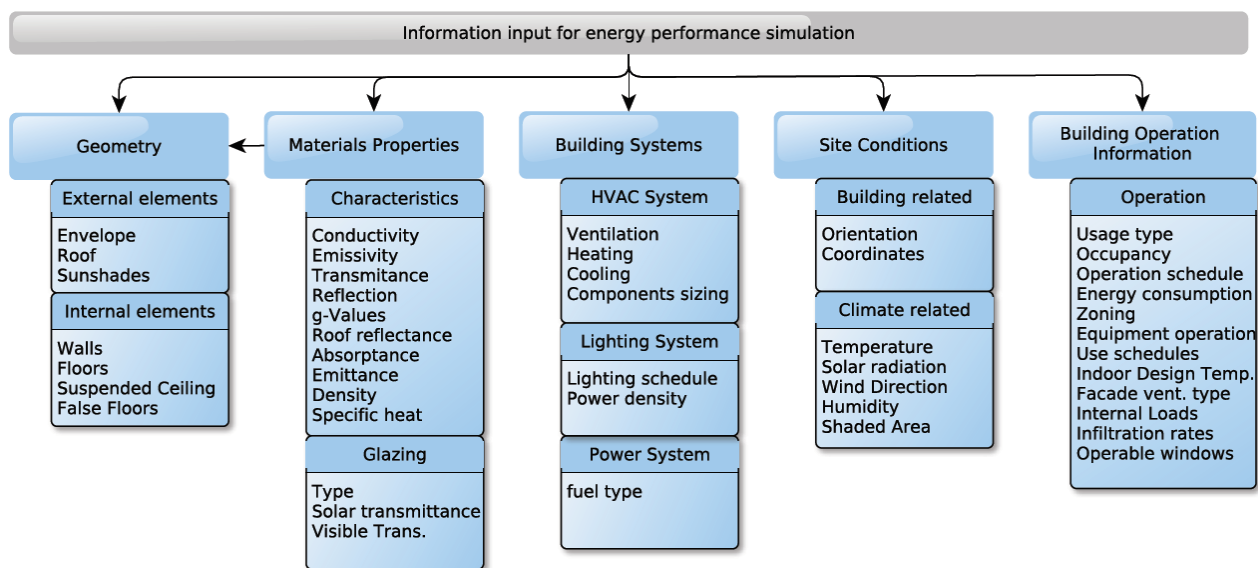


Figure 31: Information required for energy analysis simulations

[Source: L. Ungureanu, T. Hartmann. *Information Modeling Requirements for Building Energy Analysis*. 2016]

To ensure full interoperability, all the building objects must be defined in the same way by all the tools involved within the BIM-to-BEM process. Otherwise the interoperability is interrupted, and loss of data occurs.

For energy purposes, BIM models contain architectural design data (building geometry, materials), a few HVAC design data and other data (occupancy and operating schedules). Those models do not have to be populated with structural design data.





The following Figure 32 shows the UML class diagram (Revit environment), for the Building Elements Information block (dealing with building geometry), presenting the structure of the information required with specific attributes and interconnections of classes and objects.

Basically, the information required can be bound to the BIM model in two ways:

- embedded, in case of building specific information;
- linked, in case of shared information, associating two data sets.

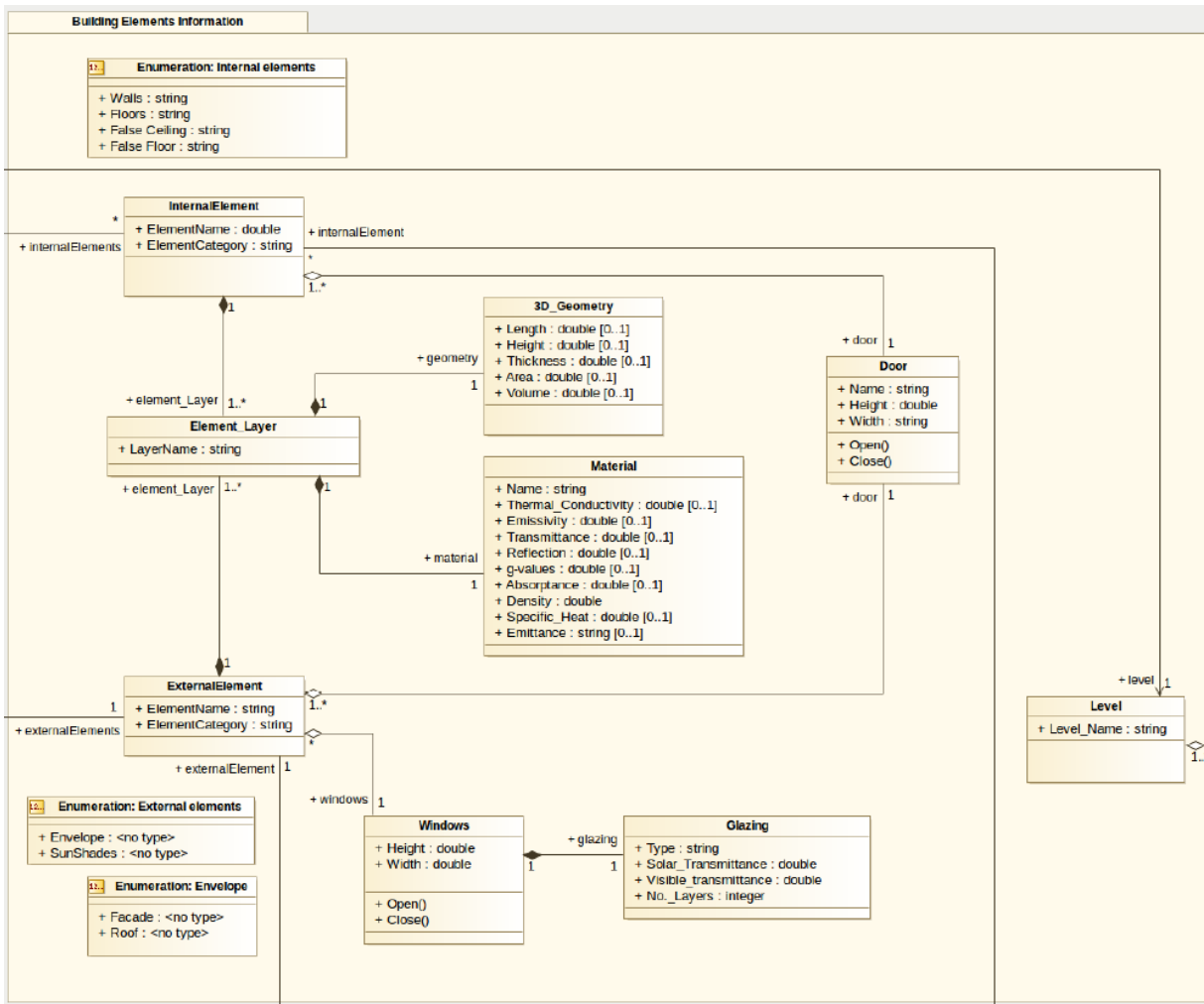


Figure 32: UML class diagram – Building Elements Information block (Revit)

[Source: L. Ungureanu, T. Hartmann. Information Modeling Requirements for Building Energy Analysis. 2016]

A deep analysis of this kind of information and the whole structure of the data required is of primary importance to develop advanced procedures, guidelines and tools for the BEM generation. Further analysis should be therefore carried out and applied within the next step of the BIM SPEED developments.





5.1.1 Building Ontology Topology (BOT) and semantic web approaches

To create a BEM model of an existing building and its renovation project, a great deal of data coming from different sources (e.g. surveys, available as-built drawings, HVAC schematics, reports, occupational patterns, site conditions analysis, etc.) are required. Building Topology Ontology (BOT) and semantic web approaches can be used to link heterogeneous data sources and transform the data into semantically suitable information automating the creation of BEM models. In particular, the development of a specific BEM Ontology, linked to the IFC schema, can support the interoperability between BIM and BEM, assisting data tracking and integration and reducing both manual errors and manual activities needed to develop a complete BEM with all the information required to perform energy analysis.

A suitable BEM Ontology development can support at first the enrichment of IFC-based BIM data assisting the definition of specific BIM objects with a minimal set of information required to develop complete BEMs. As second step, the BEM Ontology may also be used to facilitate the retrieval of missing or lost information across the BIM-to-BEM process reducing manual interventions.

Details on BEM Ontology development are available within D2.2 BIM Family Ontology, while the development of a suitable BIM object library for the renovation will be carried out within task 2.3 activities.

5.2 IFC exporter and automated rule-based data transformation

Key feature for an automatic or semi-automatic BIM-to-BEM process is the automatic transformation and formatting of data from their original source (BIM) to valid inputs and formats for BEM, to characterise the thermal view of the building without any loss. This process represents one of the most error prone steps within the BIM-to-BEM interoperability and should be automated and standardised as much as possible.

Many commercial BIM authoring tools have their own integrated IFC exporters (e.g. the “Model View Definition” MVD for Revit) with data transformation rules that extract the data needed for the creation of BEM from the BIM. Transformation rules are generally complex to be developed and time consuming as they include data reduction and simplification as well as data translation and interpretation. Depending on the software, they can feature a different level of adaptability and definition of the IFC elements to be exported setting different levels of details. Nevertheless, although the basic mapping process of native elements into IFC elements is a minimum in all the software, the export is often not perfect.

Some of the data, numerical values, are usable as extracted while other data must be transformed to create required inputs according to the syntax of the energy simulation engine. Therefore, a dedicated IFC exporter must be developed to support the correct export of data (geometry, material thermal properties, internal gains, schedules, etc.), automatically performing all the required data transformations.

In the framework of the CYPETHERM procedure, a software able to take any IFC coming from any software and make it readable for the CYPETHERM Suite is currently under development. The software will serve as a “bridge” to make the information (f. e. Thermal bridges) explicitly readable.

Transformation rules are represented by one or more algorithms which perform simplifications, translations or transformations wrapping numerical data and writing new inputs using a suitable format.





Useful rules could include:

- skipping of redundant objects to energy simulations, as internal walls with no significant thermal capacity and entirely contained within a thermal zone. The geometry simplification will also reduce the complexity of the models and facilitate communication between software;
- linking of material and construction objects, including original names and thermal properties, to BEM tool libraries;
- simplification of the window geometry, often to detailed, with the adjustment of window area to effective glass and frame areas and the link with the proper thermal properties;
- identification of the major thermal bridges;
- transformation of walls and slabs protruding outside of the interior building volume into building shades objects.

The above-mentioned guideline to set up BIM models could include also a mapping guideline for native elements, clarifying which IFC entities are relevant for the BEM and allowing the users to manually configure their BIM tools to successfully export the model. Alternatively, as BIM tools support .txt files, chargeable mapping templates (created as .txt files) could be published in order to automate and standardise this process.

5.3 BIM Data quality check – Rigorous model check

Within the Open BIM workflow, the quality of the data is automatically checked when the model is imported into the specific BEM tool. Currently, this checking is based on the presence of space boundaries information attached to the IFCspaces. To ensure the good execution of the IFC model for later BEM creation, the IFC export settings should be checked following specific export guides and documentations published by tool developers about their software (e.g. CYPETHERM suite BIM user guide).

The development of BIM modelling guidelines and transformation rules to export IFC into BEM models will increase the efficiency and effectiveness of the BIM-to-BEM interoperability, nevertheless, multiple inaccuracies and missing data might be present and limit the communication between BIM and BEM models. A model checking procedure is therefore needed to verify the consistency of the models as proposed in “A tool for IFC building energy performance simulation suitability checking” (Lilis, Giannakis, Katsigarakis and Rovas – See Ch. 7 References). The data quality checks should be repeatedly performed throughout the process and should include four different levels of controls as shown in the following Figure 33 and characterised by:

- a first pre-checking step following BIM modelling guidelines and transformation data rules. A quick initial check can be done visually.
- a data consistency check focusing on the compatibility of the data with the adopted schema (e.g. IFC schema). The data are analysed under the syntactic point of view;
- a step focusing on the data correctness to detect any errors that might occur in the definition of the building geometry and thermal zones;



- a last step to check data completeness in order to verify the existence of required data and the integrity of the whole BIM file (checking building elements data, HVAC data, schedules, etc).

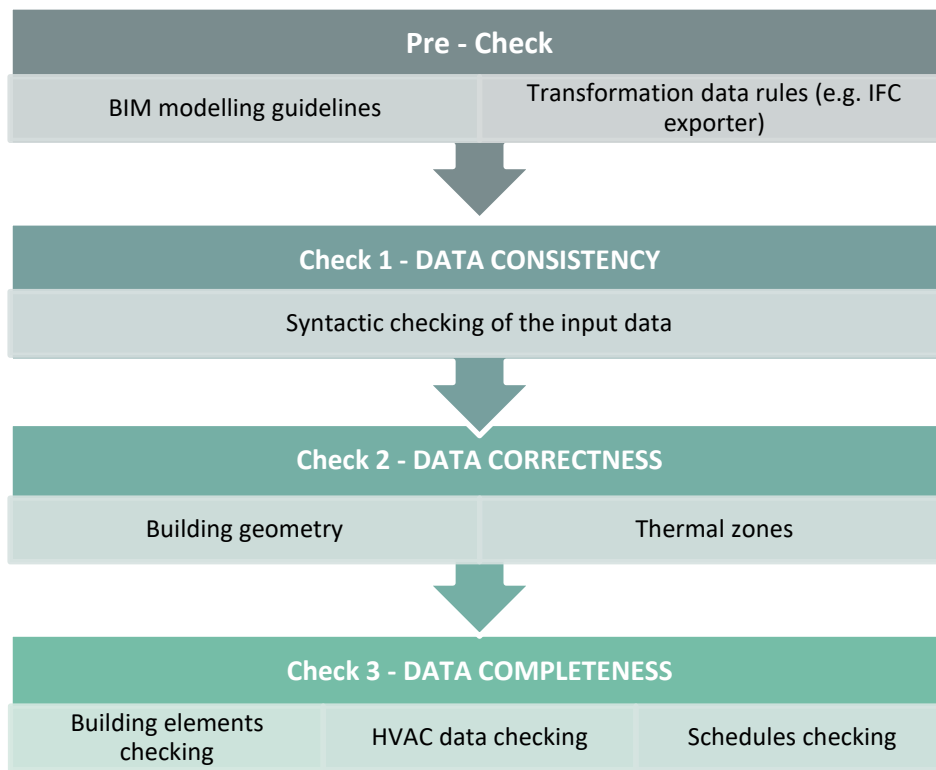


Figure 33: Proposed data quality check procedure

[Source: Lilis, G.N.; Giannakis, G.; Katsigarakis, K.; Rovas, D.V., V.2018. A tool for IFC building energy performance simulation suitability checking, In Taylor & Francis Group (ed.), ECPPM 2018, Proc. 12th conf., eWork and eBusiness in Architecture Engineering and Construction, London, UK: 57-64]

The proposed checking procedure should be performed automatically by a dedicated tool including specific rules and requirements. The user should have the possibility to properly manage the checking rules personalising and fitting some parameters to the specific building. The procedure should also be able to report in detail any found errors.

In general, two approaches for the BIM quality check can be implemented:

- a standard approach which relies on the definition of MVDs for IFC-compliance checks. MVDs allow to define model subsets and validation rule-sets. They are mostly used to check the storing requirements and detect non-conformities with associated 3D visualization. The output of the validation process is often a viewer displaying the geometric representation of non-compliant IFC instances. This traditional approach is not very flexible and dynamic and has limited scopes for the verification of IFC models (e.g. restricted scope of applying conditions and constraints on several branches of an IFC model, poor geometric analysis, lack of mathematical calculations, etc) (M. Fahad, B. Fies, N. Bus – Semantic BIM Reasoner for the verification of IFC Models, 2018)
- a semantic checker approach to check IFC files against an ensemble of requirements specified as rules, with dedicated rule languages (e.g. SWRL, Jess or N3Logic). The approach has been implemented in KROQI and details can be found within D5.3 “Rule-based model checking and validation of data





interoperability". A semantically validated IFC should not only comply with all the syntactic constraints defined in the IFC schema, but also has to fulfil additional rules about the proper usage of model elements.

5.4 Integration of BEM additional data and outputs within BIM

Once the quality check has been performed, additional data (e.g. regarding some HVAC data and simulation run control data) must be manually added, with a text editor or a given simulation tool utility, to the models before the energy simulation can run.

As the energy simulation results can have a significant impact on the design decisions and may support design in choosing between different design alternatives, it is extremely important to automatically integrate the original BIM with all the additional data and outputs of the simulations to inform automatically all the users involved in the renovation process and allow all the performance verifications against targets and standard requirements.

Therefore, associated IFC interfaces of the energy simulation engines able to read the simulation inputs and outputs should be available, ready to transmit the appropriate information to the BIM SPEED Platform, in the suitable format and enriching the original BIM models. This interoperability with the BIM SPEED Platform and the other tools will be further developed within Task 3.2 and the activities of Work Package 5.





6. Conclusions and future works

The challenge is to solve the current barriers for an accurate and time-efficient BIM-to-BEM workflow. Currently, there are a few barriers for wider utilization of BIM in energy analysis, the most critical are due to the difficulties in the interoperability of data, absence of standardized methods and guidelines and lack of direct connections between tools. The ambition is also to provide potential benefits for the achievement of the following topics:

- standardization of the BIM-to-BEM process;
- time reduction for the actual BIM-to-BEM process by 40% comparing to current practice;
- integration with the BIM-Speed Platform.

The present work represents the first step for the development of advanced procedures and tools, in the framework of renovation projects, able to create BEM models directly from the available BIM, acquiring the geometry and all the thermo-physical properties, enriching and providing the models with more accurate inputs and trying to decrease the manual input from the user.

This deliverable introduced deep analyses of the current BIM-to-BEM workflows, both through a wider literature review and investigating three main BIM-to-BEM workflows using a common BIM test model, highlighting all the critical issues that occurred and showing all the inconsistency between both data models. Such errors can currently be solved manually, however the user needs to be familiar with the BIM file structure which is more complicated when the model include multiple floors, openings, and other building envelope components. All the initial analyses made it possible to proceed towards a detailed comparison of the procedures to deeply understand how to address the interoperability between the data included into BIM models and the input data requirement for the energy simulation.

The comparison showed that currently all the procedures are time-consuming, error-prone and involve just a one-directional flow of information, from BIM to BEM, without the possibility to implement the data exchange bidirectionally. Manually re-entering of data is a common practice. The analysis of the BIM-to-BEM procedure based on the CYPETHERM Suite showed the potential benefits of utilising an Open BIM approach with a high expansion capability and integration potential of the CYPETHERM Suite. Indeed, the Open BIM approach supports a transparent and open workflow, allowing users to participate regardless of the software tools they use. Additionally, with the CYPETHERM Suite, the whole geometry transfer appears more accurate than the other procedures.

Within section 4 the most critical issues to the automation of the BIM-to-BEM process have been clarified and divided into six thematic groups, with the identification of a few possible practical solutions to overcome and solve specific issues.

Generally, for the optimization of the information exchange, the previous analysis revealed that there is a need for developing detailed guidelines, corrective tools and middleware working between BIM and BEM, in order to eliminate all the interoperability errors and automate the process.

The recommendations included within section 5 have been developed on the basis of wider considerations for the optimization and standardisation of the whole BIM-to-BEM process and the achievement of 40%-time reduction compared to current practices. Surely, the automation in the generation of BEM input files





directly from BIM data and the use of intelligent data libraries will help solve the current time-consuming BIM-to-BEM process and will develop a great potential for increasing the application of advanced energy modeling.

In the framework of the evaluation of planning alternatives and the decision-making tool development carried out within Task 4.5, an optimised BIM-to-BEM process represents an essential early step to compare the expected outcome of different renovation scenarios. Each scenario outcome comes, indeed, from holistic building simulations (including energy performance simulations) and is rated by a number of KPIs.

The results of this deliverable will be used as a basis for the development of procedures and tools in the framework of Task 3.2 activities and will fit in a wider context in order to meet Work Package 3 objectives and support other further BIM SPEED activities.





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APPENDIX 1 – Current interoperability issues

The identified issues have been then categorised (using different colours) based on three qualitative levels of severity:

- Issues that require a considerable users' manual intervention (time and expertise)
- issues that require just a few adjustments (solvable relatively in short time)
- issues that require fast users' manual intervention

- phase 1: BIM tool is not able to include all the required information or to easily define attribute for a specific data;
- phase 2: BIM tool do not transfer correctly all the information into the required schema (IFC or gbXML);
- phase 3: the mapping process to identify all the relevant information do not work properly and the information cannot be transferred properly into the BEM tool's format;
- phase 4: BEM tool is not able to read all the information coming from BIM;

Table A.1: Results of the comparison between the analysed procedures

INTEROPERABILITY ASPECTS INVESTIGATED		PROCEDURE INVESTIGATED with the BIM test model					
		Revit + SketchUp (Ecluid plug-in) + EnergyPlus	Identified phase for the interoperability issues *	Revit - TRNSYS	Identified phase for the interoperability issues *	Any BIM tool – CYPETHERM Suite	Identified phase for the interoperability issues *
1. Weather data & location	1.1 - Weather file	Weather files added manually with EnergyPlus.	phase 1	Weather files must be added manually. They can have different formats. The most used in TRNSYS is meteonorm.	phase 1	Weather can be added manually or fill the data according to recorded data from ASHRAE database.	phase 1
	1.2 - Location	Correctly transferred	-	Correctly transferred	-	To be specified in CYPETHERM LOADS.	phase 4
	1.3 - Building orientation	Correctly transferred	-	Correctly transferred	-	Correctly transferred	-
2. Whole Geometry	2.1 - 3D building model	The geometry is inaccurate: 1. not all edges are correctly closed 2. sub-surfaces are generated for walls holding elements as windows Manual corrections using GUI are required Manual correction of the identified issues are not feasible for large models.	phase 2/3	The geometry is correctly transferred.	-	The geometry is considerably accurate, especially regarding the IFCSpaces and the Spaces boundaries; nevertheless, there are some limitations in the creation of spaces with a more complex shape.	phase 1
	2.2 - Areas and volumes	Inconsistency for net/gross area and volume calculation. Boundaries of the BEM model are positioned in the centreline of the walls and in the upper face of slabs Manual corrections using GUI are required or a certain range of error must be recognised.	phase 2	Inconsistency for net/gross area and volume calculation. Boundaries of the BEM model are positioned in the centreline of the walls and in the upper face of slabs. Currently, manual corrections are required, or a certain range of error must be recognised. A way to extract net volume and floor area from the property sets previously calculated in Revit could be developed.	phase 2	Correctly transferred	-
3. Buildings elements	3.1 - Materials	1. Partial transfer: materials thermal properties are correct, but the original names of the BIM test model are lost 2. Some additional materials are created and must be deleted Manual corrections using EPlus are required	phase 2/3	In some cases (NOT from Revit) thermal properties of materials are correctly transferred as long as the IFC contains them. When not transferred, complementary tools must be used, or direct manual corrections of the IFC are required.	phase 2	The type of the elements is transferred, but not the materials, because the calculation database of CYPETHERM cannot match all the databases from every BIM tool that can be used to create the initial IFC.	phase 2/3





INTEROPERABILITY ASPECTS INVESTIGATED		PROCEDURE INVESTIGATED with the BIM test model					
		Revit + SketchUp (Ecluid plug-in) + EnergyPlus	Identified phase for the interoperability issues *	Revit - TRNSYS	Identified phase for the interoperability issues *	Any BIM tool – CYPETHERM Suite	Identified phase for the interoperability issues *
3. Buildings elements	3.2 - Constructions (opaque stratigraphies)	Partial transfer: the original names of the BIM test model are lost. Materials names (as manually corrected) must be re-associate to each stratigraphy Manual corrections using GUI and EPlus are required	phase 2/3	The material layers of each building element and their thermal properties are correctly transferred.	-	The stratigraphies have to be redefined again per type of element using the CYPETHERM database.	phase 2/3/4
	3.3 - Windows	Partial transfer: external dimensions are correct. Glazing materials and frames geometry and properties must be added. Any further components (e.g. framework, doorstep) is present except for glaze. Manual corrections using EPlus are required	phase 2/3/4	Information about windows is not transferred. TRNSYS has its own predefined windows types within a wide library. The window name of the IFC must be the code corresponding to a certain window type of TRNSYS. Otherwise, the BEM will not include window related information.	phase 2/3	Dimensions are correctly transferred, though their materials have to be redefined by type of element.	phase 2
	3.4 - Shutter box	Shutter box is missing. Manual correction using GUI and EPlus is required	phase 2/3	Shutter box is missing. Manual corrections are needed	phase 2/3	Shutter box not transferred to CYPETHERM, though it can be quickly defined in the window properties.	phase 2/3/4
	3.5 - External shading	Shading elements are missing. Manual correction using GUI and EPlus is required	phase 2/3	Shading elements are missing. Manual correction is needed. (under development)	phase 2/3	Shading elements correctly imported.	-
4. Thermal zones	4.1 - Thermal zones boundaries and location	Correctly transferred	-	Correctly transferred	-	Thermal zones have to be redefined in CYPETHERM, though it is a quick action.	phase 2/3/4
	4.2 - Set point conditions (temperature, humidity)	Set point conditions added manually with EnergyPlus	phase 2/3/4	Correctly transferred	-	These conditions are defined in CYPETHERM automatically according to the comfort standard chosen for the project.	phase 2/3/4
	4.3 - Spaces use	No data transfer Manual correction using EPlus is required	phase 2/3/4	Correctly transferred	-	Not transferred, have to be redefined in CYPETHERM.	phase 3/4





INTEROPERABILITY ASPECTS INVESTIGATED		PROCEDURE INVESTIGATED with the BIM test model					
		Revit + SketchUp (Ecluid plug-in) + EnergyPlus	Identified phase for the interoperability issues *	Revit - TRNSYS	Identified phase for the interoperability issues *	Any BIM tool – CYPETHERM Suite	Identified phase for the interoperability issues *
4. Thermal zones	4.4 - Internal loads (people, lighting, equipment)	Data included into the IDF file not correct. Manual correction using EPlus is required	phase 2/3/4	A few properties to characterise thermal gain are not transferred and have to be redefined in TRNSYS.	phase 3/4	Not transferred, have to be redefined in CYPETHERM.	phase 3/4
	4.5 - Ventilation rates	No data transfer Manual correction using EPlus is required	phase 1/2/3/4	Not transferred, have to be redefined in TRNSYS.	phase 3/4	Not transferred, have to be redefined in CYPETHERM.	phase 3/4
5. HVAC	5.1 - HVAC specifications	HVAC specifications have to be added with EnergyPlus	phase 1	HVAC specifications have to be added with TRNSYS	phase 1	Not transferred, have to be redefined in CYPETHERM.	phase 1
	5.2 - HVAC controls strategies	HVAC control strategies have to be modelled with EnergyPlus	phase 1	HVAC control strategies have to be modelled with TRNSYS	phase 1	Not transferred, have to be redefined in CYPETHERM.	phase 1
6. Schedules	6.1 - Occupancy	Partial transfer: within Revit it is possible just to set simplified schedules however the values are transferred while the original names of the BIM test model are lost. Additional schedules have been automatically generated and must be deleted. Careful checks and manual corrections using EPlus are required	phase 1/2/3	In some cases (Revit exporter) the information about schedules is not transferred and some manually work must be done either modifying the IFC or using the BEM tool. When the information is available in the IFC, data are correctly transferred	phase 2	Not transferred, have to be redefined in CYPETHERM.	phase 3/4
	6.2 - Lighting		phase 1/2/3		phase 2		phase 3/4
	6.3 - Equipment		phase 1/2/3		phase 2		phase 3/4
	6.4 - HVAC operating	HVAC operating schedule have to be modelled with EnergyPlus	phase 1	HVAC operating schedule have to be defined with TRNSYS	phase 1	Not transferred, have to be redefined in CYPETHERM.	phase 3/4

