BIM SPEED

# A set of support tools and standardised procedures for BEM creation

## Deliverable Other D3.2

Deliverable Other: Final version, issue date on 05.01.2022

BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union’s Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

# A set of support tools and standardised procedures for BEM creation

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# Publishable executive summary

The aim of BIM-SPEED is to overcome the barriers of building renovation through more efficient information management, with great potential for replication on a European scale. One of the barriers to be overcome is the inefficiency of the current instrumental processes. During the development of the BIM-SPEED project, the inexistence of a clear and fluid workflow to generate a BEM energy model from a BIM model has been detected. This is largely due to the difficulties in transforming architectural BIM models composed by walls, slabs, windows, etc. in energy models (BEM) suitable for energy simulation engines composed by surfaces, edges, adjoining, etc..

This deliverable focuses on the implementation of a suite of tools to work with BIM-SPEED solutions and analyze their behaviour according to the project edge conditions, facilitating the automation of the process. The objective of this task is to generate a set of support tools and standardized procedures capable of bridging the gap between the BIM and BEM models, also the tools have to be capable of manually generating BEM models (without any previous BIM) in order to carry out thermal simulations and verify the viability of the building envelope and its systems, especially in renovation projects. The following aspects will be taken into account:

- The priority use of open formats to support the project information.
- Compatibility of the tools developed with the rest of the BIM project development tools on the market to achieve the greatest possible replicability, regardless of the modelling software chosen by the architectural or engineering studio.
- Optimization of the proposed energy solutions.
- Cost - effective solutions.
- Linking calculation tools with data collection solutions by plug and play.

The toolbox developed in this deliverable responds to the main problems detected in the process of converting BIM models into BEM models and is capable of generating simplified BEM models without any previous BIM model. The BIM-Speed set of tools are capable of reading most widespread standard exchange format in the building construction sector, that is the IFC; even though all major BIM tools are capable of reading and writing information to this format, at the moment there is no fluid interoperability between BIM tools and Energy Simulation tools some features necessary for the realisation of BEM models are not exported explicitly, such as thermal bridges.

Specifically, receiving application is in charge of interpreting and computing the information of the IFC to generate this information, which is not trivial due to the heterogeneity of the IFC files. Another problem is that although the IFC is a standard format, there is no agreement on what information it should contain in the development of a BIM project, so the reality is that each model has geometric entities associated with more or less arbitrary information.

There are some ideas about the degree of definition of BIM models such as LOD and LOI, but there is no guarantee that all IFC models generated by all applications and by users following different company policies and BEPs capable of exporting to this format will have a consistent data structure that a potential parser / importer can expect to find. This means that even if the IFC contained all the information required to make a reliable and accurate energy calculation, it would not be possible to create a system that automatically captured user-defined data in all cases.

Therefore, the reality is that when developing BIM software, there is a trade-off between the degree of process automation and the holistic dimension of the solution. It is not possible to achieve an automatic BIM-to-BEM import, capable of parsing all the possible data structures and organizing them into standardized and agreed thermal layers, as these structures may be arbitrary and there may be user-defined data entries in which the software will not know what to do.

Again, although the IFC supports more or less standardised entities to define these data (e.g. IfcMaterialLayerSet for the layers), there is no guarantee that information not contained in the standard will be defined always in the same way.

The opposite case could work correctly independently of the IFC: the user would define every time all the information in the BIM to BEM translation. This way, the organization of the information in the BIM file would not matter, since everything would be redefined later within the BEM software (the receiving application). However, this is not feasible either, because it would duplicate the work in each project (each element would have to be defined in the BIM model and in the BEM model), reducing the fluidity of the workflow and increasing the possibilities of human error and the appearance of BIM - BEM inconsistencies.

The tools implemented during the project and described in this report have been designed with a criterion of balance between replicability in all cases, independently of the BIM software and the chosen modelling criteria, and the automaticity of the process.

# List of acronyms and abbreviations

BEM: Building Energy Model

BEP: BIM Execution Plan

BIM: Building Information Model

HVAC: Heating Ventilation Air Conditioning

IFC: Industry Foundation Classes

KPI: Key Performance Indicator

LOD: Level of Detail

LOI: Level of Information

MEP: Mechanical Electrical Plumbing

Open BIM: BIM Technology using Open formats (IFC)

# Definitions

**BIM-to-BEM interoperability**

BIM-to-BEM interoperability is the ability of BIM and BEM tools to communicate and exchange data that are readable for both correctly.

**BIM Execution Plan (BEP)**

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 BEP: 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.

**Mapping**

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

**Open BIM**

Open BIM is a universal approach for the 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. Open BIM is based on the use of open formats (IFC, DXF, BCF, JSON, etc). This means that the development of a BIM project does not depend on the use of a specific manufacturer's software, since open formats can be read by any brand (unlike proprietary formats, such as .rvt).

# Contents

# List of Figures & Tables

# 1. Introduction

## 1.1 Description of the deliverable content and purpose

The following sub-sections introduce the essential content of this work package, its relationship with other work packages and the contribution of all collaborators. This deliverable contains the description of the procedures and development that have been carried out to achieve the objectives described in the task; understanding BIM to BEM procedures; configuring a “simple box” tool for non-energy experts; developing a “full BIM to BEM” approach for energy experts, including an automatic conversion; providing a tools that supports BEM analysis starting from 2D plans; connecting BEm tools with the BIM-SPEED platform. These procedures will be developed in the following points according to the structure described below.

This document, which describes in detail the process followed for the solution of these problems, follows the following structure:

**Section 1: Introduction of the problem**

- **Point 1:** The present introduction, which describes the content of this document, participants and contributions.
- **Point 2:** The requirements and incidences detected in previous deliverables that prevent the smooth workflow to convert BIM models to BEM models.

**Section 2: Developed solutions: BIM-BEM workflow**

- **Point 3:** An overview of the developed solutions, their purpose and their features.
- **Points 4, 5, 6 and 7:** Detailed description of the tools.
- **Point 8:** Advanced BIM-BEM workflow using the tools.
- **Point 9:** Integration of the workflow with existing tools, platforms and calibration procedures.

**Section 3: Conclusion**

- **Point 10:** Conclusion and further development.
- **Point 11:** External references.

This structure is a reflection of the workflow followed throughout the development of the tasks of this deliverable. From the beginning of the development process, a continuous integration process has been carried out with the rest of the members of the consortium; the use cases in the application layer and the implemented domain models revolve around the concepts of the previous analysis and guarantee that the solutions achieved are capable of solving these requirements according to the criteria established in the project. The solution consists of four desktop tools that respond directly to these requirements:

**Open BIM Construction Systems**

The lack of standardization in the definition of construction elements makes it difficult to define construction systems in BEM energy calculation software. This application allows the definition of construction materials with their thermal characterization, which allows the creation of a dynamic mapping capable of storing the construction systems created and their data in user libraries, so that these elements are automatically assigned in subsequent works, regardless of the subsequent analysis tool chosen.

It creates an IFC type agnostic mapping that decouples the generation of the BEM model from the BIM tool used and allows reusing the definition of elements in multiple projects, automating the process of defining construction systems after defining them the first time within the application.

**Open BIM Analytical Model**

The lack of detail and standardization in the geometric definition of generated models makes it impossible to calculate accurately and reliably using strictly the entities generated in BIM projects without later geometric computation.

This application performs this geometric computation, allowing the creation of BEM models with high precision geometric definition for subsequent energy calculations and analysis that are compatible with open formats such as IFC (2x3 and 4). This geometric calculation procedure can be automatic (by pressing a button) or customized, allowing the user to define in detail the elements read from the IFC and their interpretation to transform them into elements of the BEM model.

**BIMtoBEPS tool based on TRNSYS**

This tool aims at covering the full BIM to BEM process, namely, the generation of BEM through dedicated algorithms handling with the information contained in the IFC. The main purpose is to facilitate energy demand calculation of buildings directly from the IFC, with scant user interaction, by using building element layers, attributes and geometry, and spatial zones information.

**Simple BEM generator**

The Simple BEM generator is a tool to create a computable BEM without the input of an existing BIM. It can especially be useful to conduct initial fast simulations and optimization procedures to create an overview for such projects, where a BIM does not exist yet. As creating a detailed BIM is often a lengthy process, these initial results can help decide whether a specific project is worth the effort or whether another project might have a greater potential for improvement.

The toolbox fulfils the following objectives:

**1. Overcoming the detected bottlenecks of the BIM-to-BEM process**

The main difficulties of the current workflow to generate BEM models from BIM models have been widely described in Deliverable 3.1. This analysis (synthesized in Point 2) has served as a basis for developing the most important functionalities of both tools. These functionalities are further described in Points 3 to 8. The use cases or application services of the tools come directly from the requirements of this analysis, and the domain models orbit around the concepts derived from it. The infrastructure (I/O) layer of the applications is based on communication with open formats (Open BIM) and is detailed in the second section of this document.

**2. Reducing the time for the BIM-to-BEM process by 40%**

The problems in the current workflow force the professionals of the construction sector to duplicate the models: on the one hand they make a BIM model that has multiple BIM uses (depending on the project), and on the other hand they make a BEM model to carry out the necessary energy analyses. Some of the developed tools are able to synchronize the information of the BIM model in real time, establishing a direct information bridge between the BIM model and the BEM model. The purpose of BIM-SPEED is to reduce time for the BIM-to-BEM process by 40%. This time reduction will be demonstrated through the direct application of the new tools on the demonstration cases and it will be reported within deliverable 4.2.

**3. Developing a set of BEM creation tools for both a “simple box” approach and a full BIM–BEM approach**

Just as there are BIM uses that determine the ultimate purpose of a BIM model as the case may be, BEM models have multiple applications and multiple professionals need to integrate them into their professional work.

The proposed tools present two workflows: a simple or "one click" workflow, where the BEM model is automatically generated, and a more precise workflow, where the professional can define in detail the characteristics of all the layers of the building materials of the project and the geometric definition of all the edges of the rooms. Both workflows are further explained in the following points.

**4. Increasing the level of accuracy of energy models to achieve the optimal design of renovation projects**

Even when an accurate energy modelling of the building is carried out, a high discrepancy between predicted energy consumption and actual energy consumption can be found in the practice, especially in the case of existing buildings (up to 250%). This discrepancy is generally attributable to the uncertainties in physical models and BEM assumptions (Baglivo C, Congedo PM, Fazio A (2014) Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate. Building and Environment 82:467–480. doi: 10.1016/j.buildenv.2014.09.019) and can be overcome using proper calibration procedures.

## 1.2 Contributions of partners

Table 1: Contribution of partners

| # | Partner | Contribution |
|---|---|---|
| 1 | **CYPE** | Development of two tools:<br>• Open BIM Analytical Model<br>• Open BIM Construction Systems<br><br>The development includes the following activities:<br>• Implementation of the tool as multilingual desktop application.<br>• Integration with IFC format (import + export).<br>• Development of multilingual documentation. |
| 2 | **CARTIF** | Development of the BIMtoBEPS based on TRNSYS tool. |
| 3 | **UNIVPM** | Harmonization between BIM-to-BEM approach and calibration procedure |
| 4 | **STRESS** | Connection with previous WP, document structure. |
| 5 | **MTB** | Development of tool: Simple BEM Generator |

## 1.3 Target group and relations to other activities

The target group of this deliverable consists of professionals in the field of Architecture, Engineering, Construction and Operations who need to perform energy analysis within the framework of developing a BIM project (both new plant projects and renovation projects). This group includes profiles with high knowledge of energy analysis and calculation as well as others with superficial notions.

**Task 3.1. BIM-to-BEM bottleneck analysis and critical parameters**

A clear workflow for the use of BIM technology in renovation projects was detailed, software tools used in the workflow where described and the needs for the implementation highlighted, which was taken into account throughout the software development phase. The output of this task serves as input for the initial implementation and further development of the tools of this task. The main problems detected have been solved as integral functionalities of these, ensuring the smooth workflow BIM - BEM.

**Task 3.4. Calibration of BEM and related analytical models**

The different levels of accuracy of the BEM models obtained with the “simple box” and full BIM-BEM approaches were determined based on prior state-of-the-art on BEM calibration, to allow a successful application of the BEM calibration procedure. Thus, the defined BEM accuracy levels will be reflected in the calibration procedure to be delivered in D3.4, which will be extensively described in D3.4. The BIM-to-BEM tools developed in this project allows changes in the BIM model to be dynamically updated in the BEM model, allowing the calibration of all project models in a holistic way.

**Task 4.5. Holistic performance assessment**

A holistic performance assessment based on a detailed BEM will be enabled by results for Task 4.5. The Simple BEM generator from this work package will in addition allow a simplified performance assessment. This poses a preceding step to judge, whether the extensive elaboration of an accurate BEM model will be worth the effort.

**Task 5.2. Interoperability between multidisciplinary BIM tools and services**

The tools implement an exporter to an IFC with standard structure that will facilitate later reading by external services. The output of these tools is designed to be easily processed as input by the processes of task 5.2, facilitating its integration with other tools of other developers (such as Revit) and with platforms (such as the BIM-SPEED platform and BIMserver.center).

**Task 5.3. Rule-based model checking and validation of data interoperability**

The data structures of the implemented tools’ output have been profusely documented and structured, facilitating the later communication, analysis and checking by the BIM-SPEED platform. For example, the applications developed will need IfcSpace BIM entities to be able to process the spaces and generate their BEM model. This means that as a direct consequence of the output of this task, the services of checking and verifying BEM models directly from the BIM-SPEED platform.

**Task 7.1 Multi-criteria decision-making of renovation strategies**

The Simple BEM generator of this task allows creating simplified models to conduct an initial optimization procedure. Besides a simplified but easy to achieve performance overview, this is one way to create design alternatives that are to be considered for a detailed holistic performance assessment.

**Task 8.3 EU competition for BIM-based renovation plans**

The output of this deliverable, that is, the tools implemented can be taken into consideration in the organization and dissemination of the contest.

# 2. BEM tools requirements: BIM and other data input

## 2.1 Overview of the general BEM requirements

A Building Energy Model (BEM) is needed to perform, using computer-based simulation software, a detailed analysis of a building's energy use. It takes as input a description of a building including geometry, construction materials and lighting, HVAC, domestic hot water and renewable generation system configurations, component efficiencies and control strategies.

A complete BEM also needs descriptions of local weather conditions including building orientation and external shadings and the building's use and operations including schedules for occupancy, lighting, plug-loads and thermostat settings. BEM simulation software combines these inputs using building-physics equations to provide an approximate representation of the building needed to calculate thermal loads, the system response to those loads and the resulting energy use and consumption on a yearly, monthly, hourly or shorter basis.

Currently, an energy modeller builds a BEM manually, using one of the many tools available on the market and starting from scratch with a new empty model, building first the geometry and then enriching the model with all the energy related information. To be effective, a BEM must represent accurately the thermal view of the building, which include the definition of the building geometry, the thermal characterisation of the building envelope with the definition of the stratigraphies of all the building components (walls, slabs, windows, doors, etc.), the thermal-physical properties of the materials, the HVAC specifications including the control strategies and the operating schedule as well as the characterisation of the internal loads.

The possibility to automatically incorporate available BIM data within the development of BEM for the evaluation of the energy efficiency aspects of the retrofitting projects in order to support the design of high-performance buildings is becoming increasingly important. Exploiting and automating the BIM-to-BEM process can save time needed for the BEM creation and increase the accuracy of the energy-related simulations.

## 2.2 Current BIM-to-BEM bottlenecks and major critical issues

Deliverable 3.1 deeply analysed the current status of the BIM-to-BEM processes and identified the current bottlenecks and the major critical issues. Lack of a complete interoperability between tools is certainly one of the main weak points of the process and involves data loss and the need of manual adjustments and corrections. Interoperability issues are due to the different nature and data structure of the two models that to date it does not allow an automated integration between BIM and BEM tools. As reported in chapter 3.5 of Deliverable 3.1 one of the most critical issue within the interoperability process concerns the proper initial conversion of the BIM model into the IFC schema. 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. Table A.1 included in Appendix 1 of Deliverable 3.1 details all the BIM-to-BEM interoperability issues experienced with the BIM-to-BEM procedures analysed in BIM-SPEED project. The findings have been categorised within different thematic groups, identifying the phase in which the issues occur and providing different qualitative levels of severity. The purpose is to get an easier comparison between the procedures and to facilitate the identification of the opportunities to improve the automation of the BIM-to-BEM process.

## 2.3 Area of improvements and recommendations to optimize BIM-to-BEM procedures

The results of all the previous activities of Task 3.1 have been arranged in order to define a few areas of improvement and identify the starting points for the development of the tools and the advanced procedures carried out within task 3.2. Most of the solutions to overcome the current critical issues concern the development of a set of tools able to act as intermediaries between software, allowing BIM and BEM tools to communicate despite the diversity of protocols. In general, the use of open BIM technology and the IFC standard for the whole BIM-to-BEM process can help to implement a more universal approach and an operative workflow including the possibility to exchange information with other applications and tools. The first important aspect to be solved concerns the initial conversion of the BIM model to the IFC schema for which the development of a dedicated "IFC exporter" with automated rule-based data transformation is suggested in order to meet the specific data formatting needs of the energy simulation engine used and to characterize the thermal view of the building avoiding data loss. A few IFC exporters, as the "Model View Definition" for Revit, already exist but, in the framework of a BEM creation, the export of IFC elements is often not completely working and relevant data are in some cases lost. As mentioned in chapter 5.2 of Deliverable 3.1, useful rules to be included within the transformation algorithms concern a geometrical simplification of some elements (skipping all the redundant objects), a connection between objects properties and BEM libraries (e.g. materials properties) and the automatic identification of thermal bridges and shading objects. A simplified solution could be represented by the creation of proper mapping and conversion templates (.txt files) in order to reduce some of the abovementioned issues and provide a guide for the user to manually change the already existing IFC exporter implemented in BIM tools.

A second important aspect to fix regards the geometric inaccuracies which can affect the BIM-to-BEM process as clashes, surface errors and spaces incorrect definition. To overcome all these geometrical errors two main possibilities have been identified:

- The development of a comprehensible multi language user guide that allows user to know the requirements of the exported IFC clarifying how BIM must be created for the BEM execution;

- The development of correction tools and/or the implementation of existing algorithms 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.

Another relevant issue to overcome concerns the loss of information of the building elements, in particular the loss of the elements' original names or codes, which complicates the inspections between the models. To solve this aspect a specific tool or functionality keeping or linking the original elements GUIDs between BIM and BEM in order to allow an easy check between elements and models should be implemented.

In general, an element (material or building component) is first characterized by its name that corresponds to an GUID in a database which includes additional properties and data, 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 models. Concerning the thermal zones definitions, usually they can be easily and quickly implemented manually by the user with a good reliability based on the experience of the modeller. Anyway, a complementary tool or functionality could be developed in order to improve their automatic creation, looking for similarities in adjacent spaces (similar uses, space-conditioning requirements, HVAC systems, etc.).

Currently the best option, in terms of time-savings and reliability, to build a complete BEM is to input both HVAC systems specifications, the related control strategies and the occupancy, lighting and equipment schedules directly within the BEM tool, manually or uploading default values. In line with the BIM SPEED purpose, those data could be set up with the BEM tools and made available in the BIM-SPEED Platform. To speed up the process, a user-friendly interface is needed, in particular for the "simple box" approach, to allow also non-professionals to create a simplified BEM model guiding them in an intuitive way (e.g. with the use of a wizard or a setup assistant) through a series of predefined steps. To conclude the overview of the opportunities identified to address the development of tools and procedure also the aspect of real time collaboration between tools is relevant. Actually, the BIM-to-BEM procedures involve just a one-directional flow of information, from BIM to BEM, without the possibility to implement the data exchange in a bidirectional way, therefore it is important to start taking first steps also in this direction. In the following chapters all the tools developed in order to optimise the BIM-to-BEM procedures will be described.

# 3. Toolbox for BEM modelling and analysis – Methodological concept behind the development

The toolbox developed in this deliverable responds to the main problems detected in the process of converting BIM models to BEM models.

**Open BIM Analytical Model:** Open BIM Analytical model solves the problem of lack of geometric accuracy and heterogeneity of definition of IFC files generated by different major BIM tools (Revit, ArchiCad, Allplan, etc). From any IFC containing the geometric definition of spaces, this application is able to recalculate its geometry and redefine all the edges and vertices of all the enclosures of the model received as input, so that it is ready to be calculated by subsequent thermal analysis tools.

**Open BIM Construction Systems:** Open BIM Construction Systems is capable of defining the materials of all the geometric elements of the project, including the thermal characterization of all the layers that compose the construction systems. This allows to import IFC files with any level of detail (LOD) and prepare it for subsequent thermal calculation and analysis. The definition of entities can be stored in libraries that can later be imported automatically, so that the definition of construction systems of BIM projects is automated. More details about these functionalities are specified later in the report.

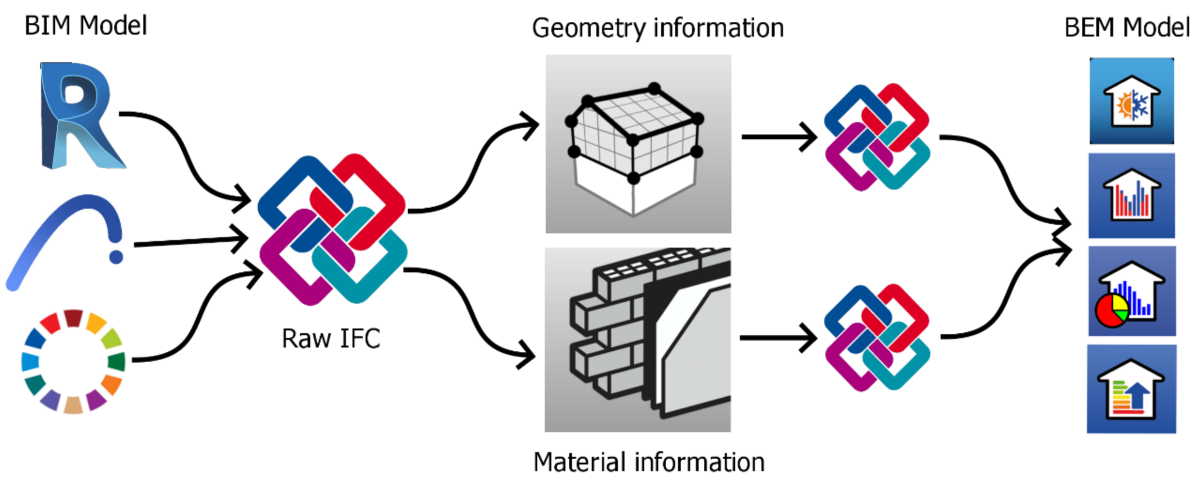



Figure 1. BIM to BEM workflow by CYPE

**BIMtoBEPS based on TRNSYS**

This tool addresses the interoperability between BIM models contained in IFC4 files and building energy modelling using TRNSYS 18[1] as simulation engine. Specifically, the building energy model is generated according to the data input file (*.b18) structure associated to the TRNSYS Type 56 that can be manually generated using the TRNBuild user interface in a process that tends to be time consuming and error prone.

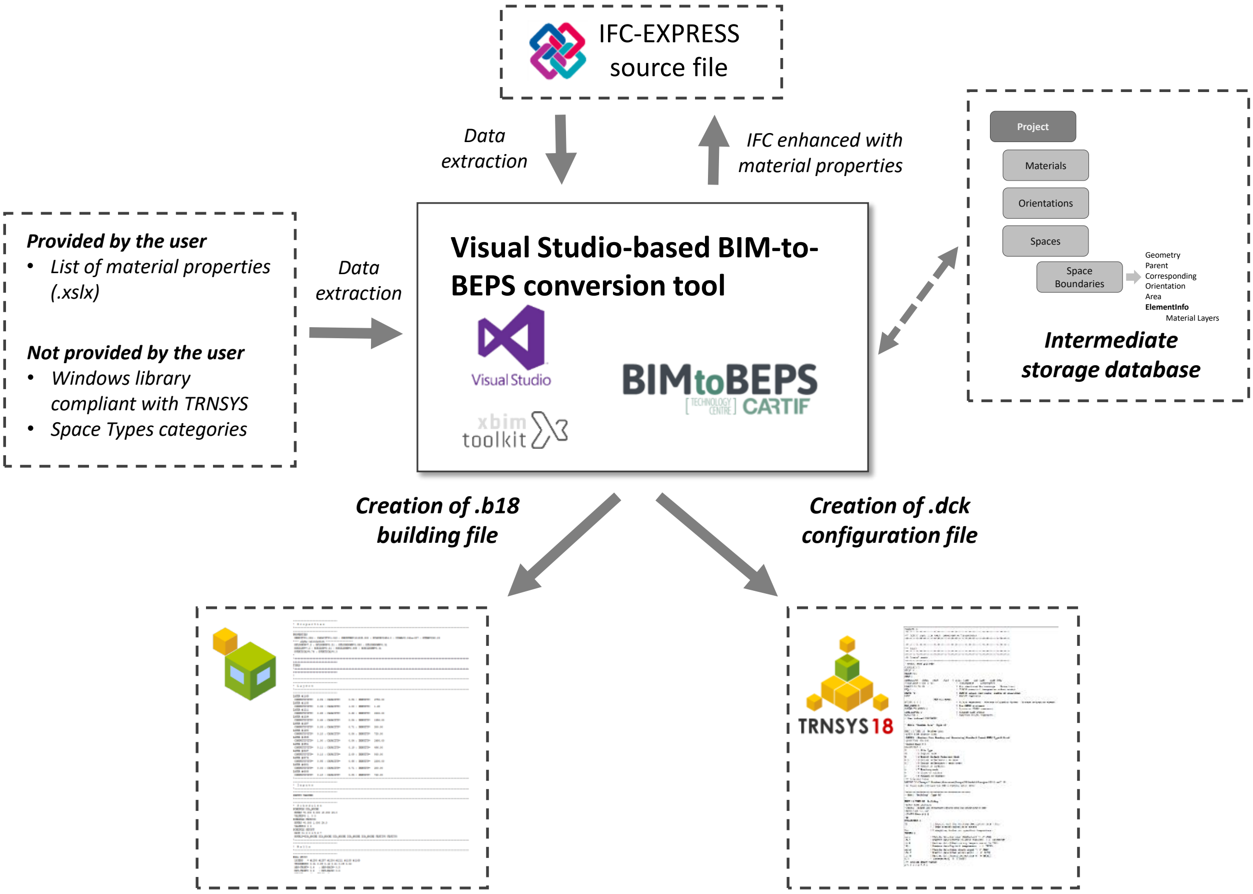



Figure 2. BIMtoBEPS methodology

Figure 2 shows the concept and methodology under the BIMtoBEPS tool. The steps are the following:

- The tool reads the IFC model and is able to check if all the materials have associated thermal properties. In case it's not, an Excel file is provided and the user must fill-in all the missing values. When the file is uploaded, the tool automatically enriches the IFC making it available for download, and ready for starting the information extraction.
- As the information needed in TRNSYS for the definition of windows properties exceeds the one supplied by the IFC, the tool also allows the user to link the glazing elements from the model with windows types from an internal library.

[1] http://www.trnsys.com/

- Then, a dedicated algorithm extracts all the information available in the IFC of all the instantiated IFC classes: geometry, attributes, property sets, relations, etc. All the operations needed to extract explicit information are carried out, and the results are stored in an intermediate database.
- Last, from this database, the .b18 file is created and ready for being used in the TRNSYS model.
- Additionally, it is possible to calculate the building energy demand calling TRNSYS engine including the building energy model generated into a predefined module.

This tool is in continuous development, aiming also at allowing the extraction of all the information related to the energy systems. Though, it must be noted that the information that the IFC considers is not sufficient to build complex energy models and for the moment, many assumptions must be done. The tool will be adapted to new versions of the IFC standard.

**Simple BEM generator**

Using open data, the Simple BEM generator is a tool to create a BEM that can be simulated without the input of an existing BIM. It can especially be useful to conduct initial fast simulations and optimization procedures to create an overview for such projects, where a BIM does not exist yet. As creating a detailed BIM is often a lengthy process, these initial results can help decide whether a specific project is worth the effort or whether another project might have a greater potential for improvement. It contributes to the interoperability and extends the field of application of Metabuilds optimization tool with the BIM-SPEED platform. More details about the process are shown later in the report.

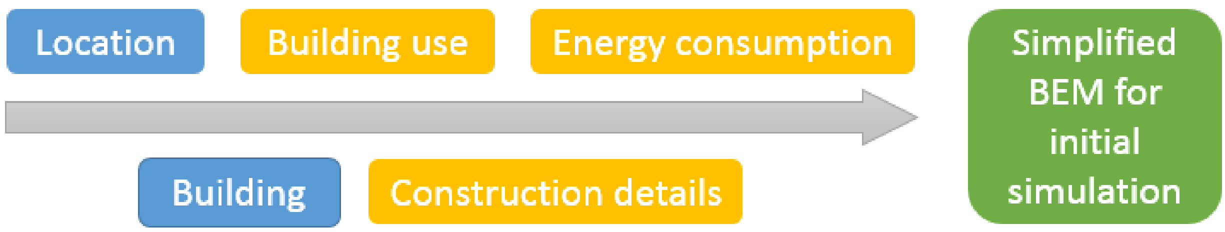



Figure 3. Simple BEM generator workflow – Creation of a simplified BEM using mandatory (blue) and optional (yellow) basic information

## 3.1 Simple Box Tool and Full BIM-BEM approach

In the analyses carried out it has been detected that there are different profiles of professionals who need to create BEM models in a BIM workflow. The tools developed allow both the non-expert user (architects, managers, etc) and the professionals specialized in energy to work. This is possible thanks to the development of several pipelines that allow to define the models with more or less detail and with the help or not of external BIM tools.

The construction of energy models is a non-trivial task that goes beyond the basic knowledge of the construction sector. The automation of the calculation with the digitalization of the discipline brings an implicit knowledge of the three-dimensional geometry and its internal definition in the construction of the model. However, not all users who need to perform BEM energy analysis from BIM models have such specialized knowledge of the subject. For this reason, the tools allow two fundamental workflows:

**Simple box tool**

The definition of an energy model with hardly any user intervention. Tools under this category will allow the user to convert BIM models following open standards such as IFC to BEM models without the need of being an expert. This procedure does not allow the user to change the model parameters; however, the obtaining of the BEM model is instantaneous. As of today, a slight manual intervention is still needed due to lack of data in the IFC, but with proper evolution of the standards and BIM software exporter tools modification, it will be possible to directly obtain BEM models.

**Full BIM-BEM advanced approach**

The automatic generation of models from BIM models generated with any tool. The use of open formats approved as IFC allows the automatic generation of BEM models from a BIM model created with tools such as Revit, ArchiCad or OB Architecture. In addition, it is possible to define custom libraries that map IFC types with native elements of BEM applications, so that the BIM - BEM transition is completely automatic after the first definition of elements.

## 3.2 Support BEM related analysis using 2D Floor plans

Despite the rapid process of digitization in the construction sector, there are still many entities not integrated into the BIM workflow for project development. This creates a digital gap that would discriminate against those non-integrated professionals if only the generation of a BEM model from a previous BIM model was allowed. Since BIM integration of stakeholders is always a gradual and iterative process, the integration of traditional (non-BIM) workflow into the tools presented is an imperative use case. Therefore, the software developed also allow the loading of two-dimensional reference drawings for the elaboration of the BEM model, including its zone definition, so that later it can be read by specific energy calculation applications capable of reading IFC models. The supported formats include DWG and DXF and can be elaborated with any software compatible with them. The layers included in the models will be recognized and support advanced features such as edge and vertex capture for drawing three-dimensional geometric entities and the layer visibility filter.

Once these files are loaded into the project, they can be associated with specific levels of the model, so that they are automatically displayed when that level is viewed. In addition, if there are any changes to any of the two-dimensional files loaded into the project, they will be automatically updated within the applications, maintaining the visibility and mapping settings defined by the user. This will ensure consistency between the CAD drawings and the generated BEM model. Additionally, other hybrid workflows are also possible. If a BIM model is created with tools capable of creating IFCs where the floors of the building (IfcBuildingStorey) are associated to 2D drawings in CAD or DXF format (e.g. IFCBuilder), the tools will show the 2D drawings associated to the floors of the building automatically.

# 4. Open BIM Analytical Model

Open BIM Analytical model is free software developed to generate the analytical building geometry in order to compute its energy and acoustic analysis. The application allows to introduce all the analytical elements manually, including spaces, surfaces, edges and joints between entities. It is also possible to introduce an existing IFC BIM model as input, automatically generating all the missing information to be able to run the subsequent analyses in other specific applications. The algorithm in charge of this process is based on the definition of spaces and information of the architectural elements of the IFC. However, it should be noted that users have full control over the definition of the elements of the final result, being able to make manual adjustments and corrections to the automatically generated model.

In addition, in order to perform various analyses through the generated model, the application allows for the multiple grouping / zoning of the building's spaces. In this way, a BEM model could be created that not only serves to perform thermal analysis, but also acoustic analysis, ensuring the geometric correspondence of all automatically generated calculation models.

The output of this application is an IFC with all the necessary information to perform precision calculations in specific applications such as CYPETHERM or AcoubatBIM.

**Languages**

Available languages: English, French, Italian and Portuguese, Spanish, Catalan

**Getting started**

To start a new project with Open BIM Analytical Model, the first step is to download the latest version of Open BIM Analytical Model from BIMserver.center:

https://bimserver.center/es/store/259/open_bim_analytical_model.

Once installed, the first step is to open Open BIM Analytical Model. Then, connect to BIMserver.center on the far right and log in, if necessary, following the steps above. Once logged in, it is possible to start using Open BIM Analytical Model.

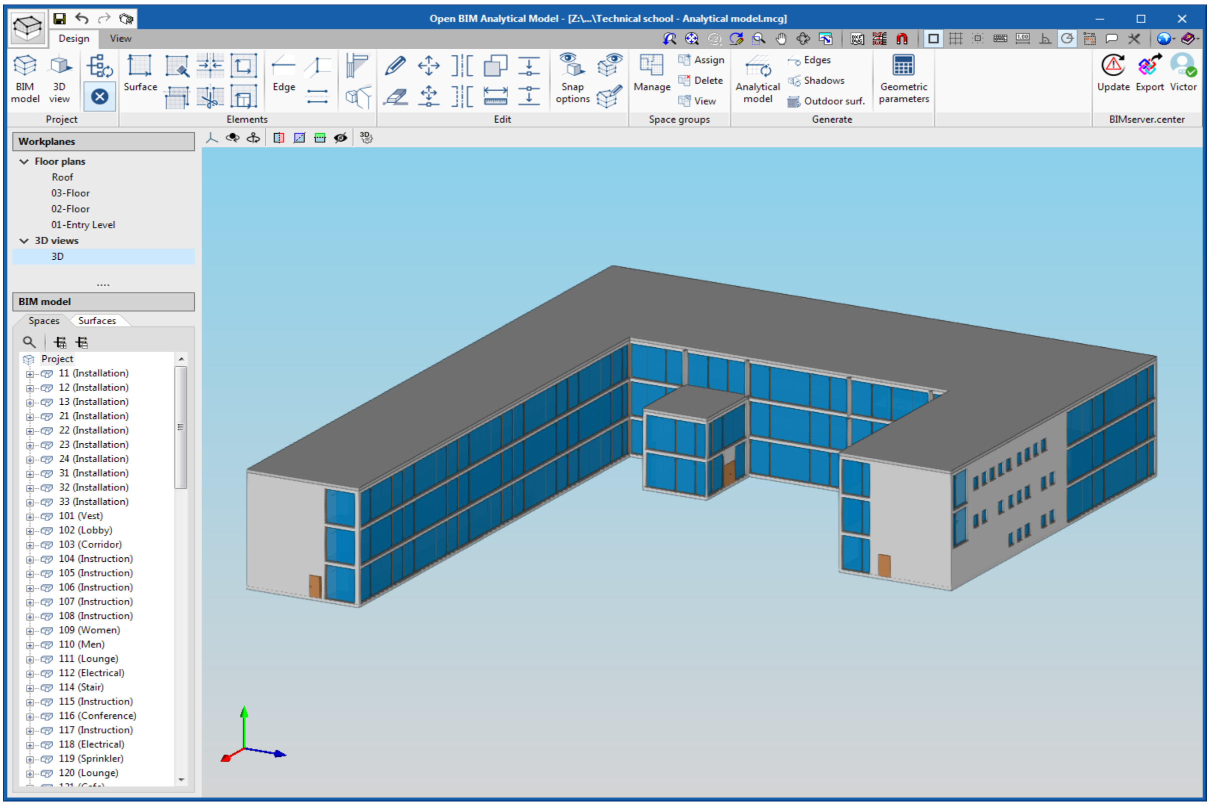


Figure 4. Open BIM Analytical Model GUI

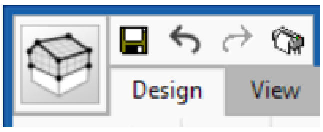



Figure 5. Top toolbar

The top toolbar, as in other CYPE applications, has the following options (in order from left to right): Program file button. When pressed, a tab is displayed offering the user to create a new file, open an existing one, save, save as, change the description of the work, print plans, select the last files opened and exit.

- **Save**. Save the changes in the specified file.
- **Undo.** Undo the last action.
- **Redo.** Undo the last undo.
- **Plans.** Plot the plans of the current project in 2D CAD / PDF format.

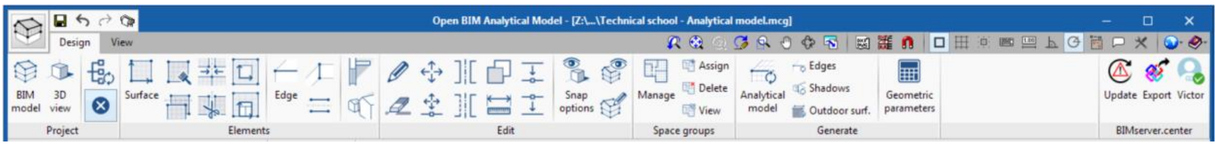



Figure 6. Application toolbar

The application toolbar is divided into two tabs: **Design** and **View**. The **Design tab** has options that allow the user to enter and modify the elements that make up the analytical model. The **View tab** contains the tools necessary to configure the different project view modes. To the left of the work area there is a list with the different views of the project and a panel with two tabs that allows you to show the space and surface trees of the analytical model. When a space or surface is selected, it will be illuminated in the work area.

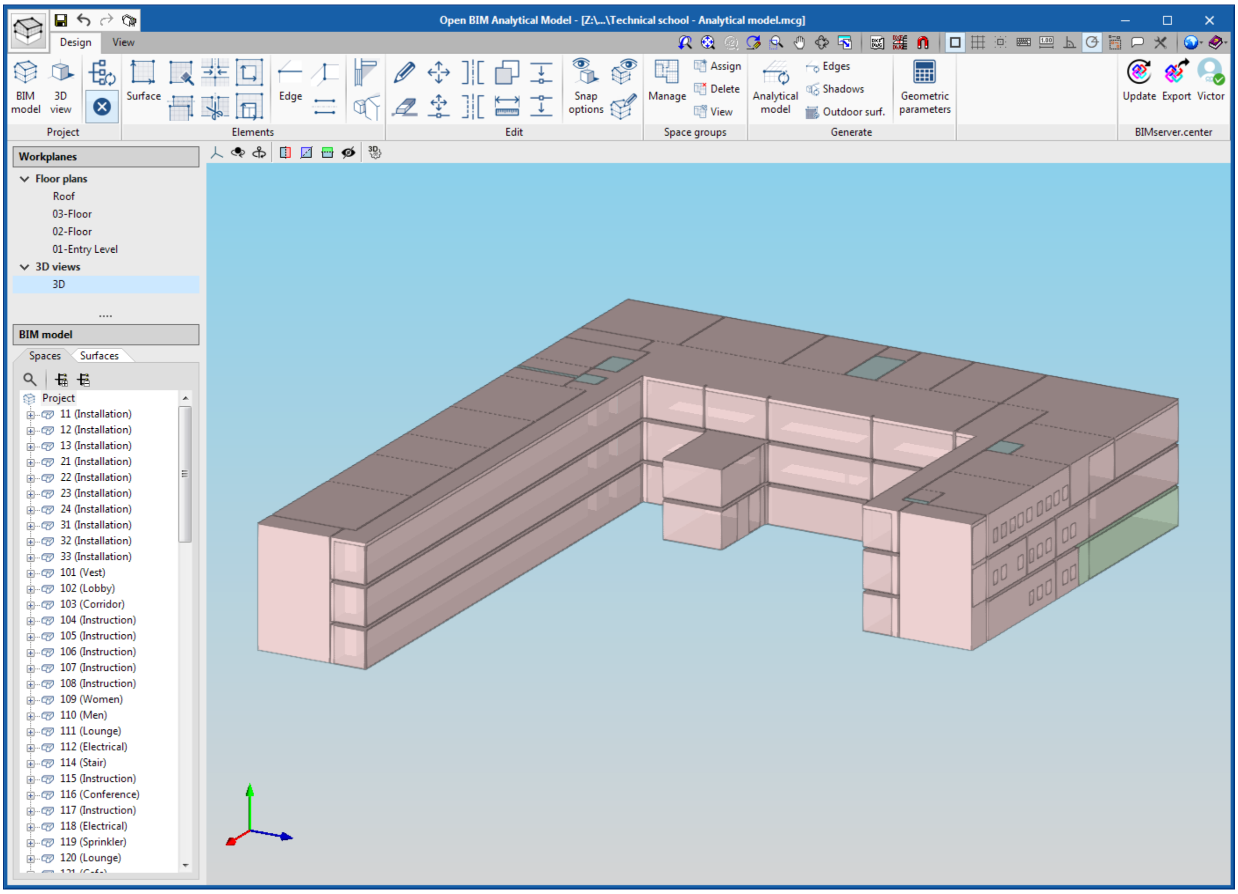



Figure 7. Space selection

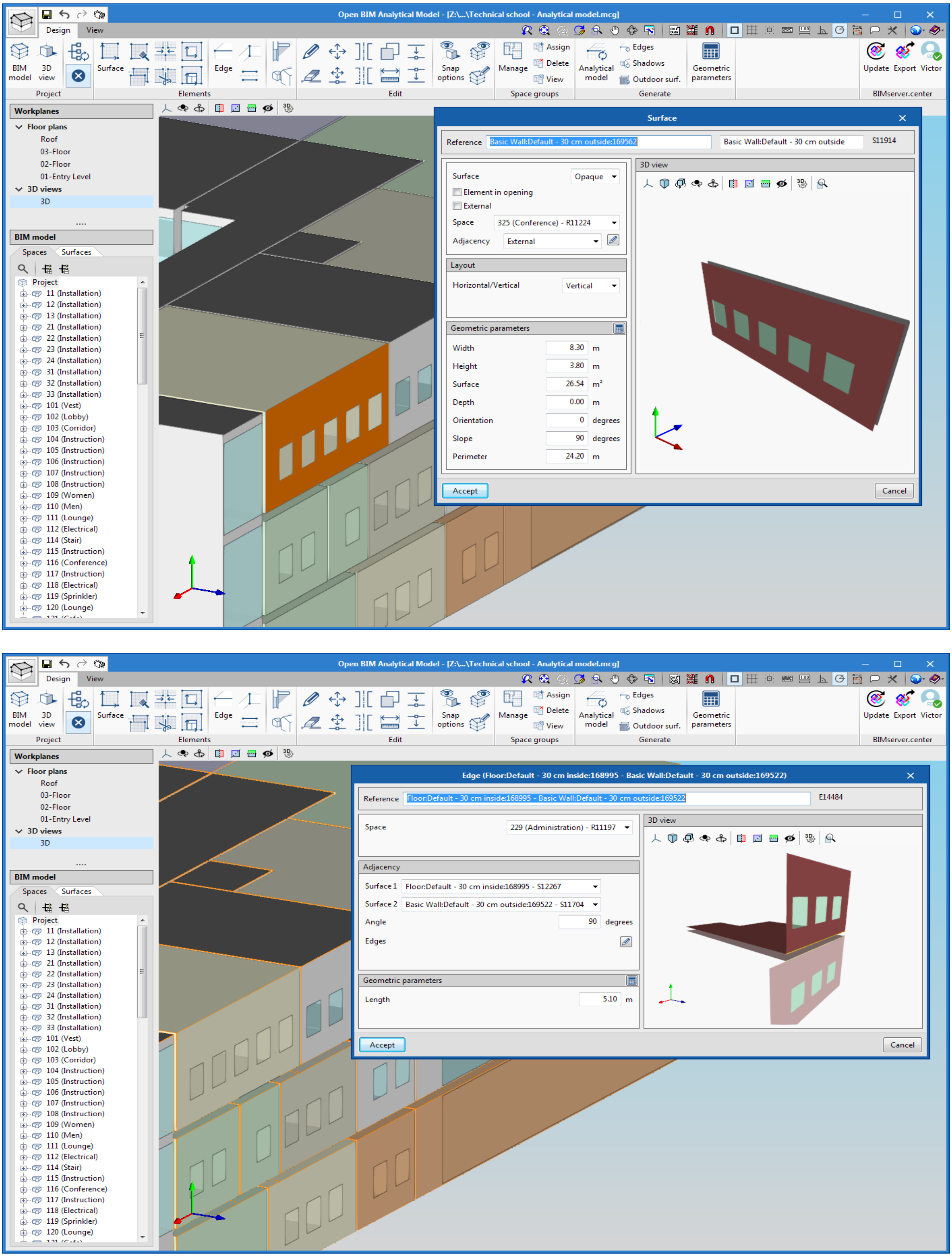



Figure 8. Open BIM Analytical Model element definition

# 5. Open BIM Construction Systems

"Open BIM Construction Systems" is a tool aimed at defining the technical characteristics corresponding to the construction solutions that make up the building's envelope and interior partitioning system.

The definition of the constructive characteristics in a free software makes possible the decoupling of the development level of the BIM project with the energetic definition of the building, being able to create mappings as the ones described previously, so that the energetic model synchronizes its geometry with the one of the BIM model, guaranteeing the coherence and automation of the passage from BIM to BEM. The definition can be based on preloaded libraries (some of them obtained directly from manufacturers) or define customized libraries that allow to define all the thermal characteristics of each material and create customized walls with only those layers or combining them with the preloaded ones.

As with the "Open BIM Analytical Model", the software can be downloaded free of charge from BIMserver.center.

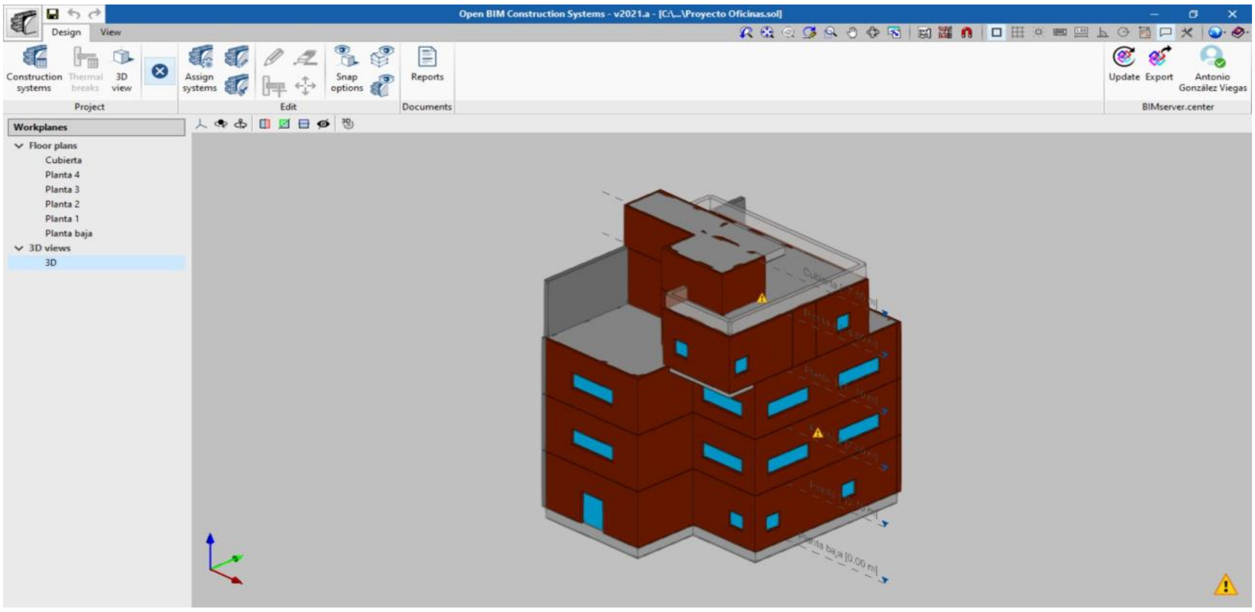



Figure 9. Open BIM Construction System GUI

**Application toolbar**

The application toolbar is divided into two tabs: **Design** and **View**.

The **Design tab** specifies the constructive solutions involved in the project. For this purpose, the program has a library of typologies where the properties of all types of systems are defined in order to be applied to each of the building's components at a later date.

The **View tab** contains the tools needed to set up the different project display modes. It is possible to generate different types of 2D and 3D views of the building. Each one is oriented to facilitate the user's interaction with the model in a different way. All the views generated are listed on the left of the application's work area.

For each construction solution it is possible to indicate its general properties using the fields "Description" and "Construction characteristics". In addition, in the case of elements composed of several layers, the application allows you to specify the characteristics of the materials in each one of them. Each layer has a description and a group of parameters related to its physical properties such as thickness and density. We can also indicate the presence of a perimeter elastic band in the layer.

Optionally, it is possible to enter the value of the parameters related to its thermal properties. In order to be able to represent the system in the 3D view and in the supporting lists, it is possible to indicate a colour for the complete solution and a colour and a pattern for the material of each layer. All the information of a construction solution or of a layer of it can be exported in a file in order to be able to use it in multiple projects. The application includes, by default, several libraries of building solutions and materials for the layers based on standards or other official documents.

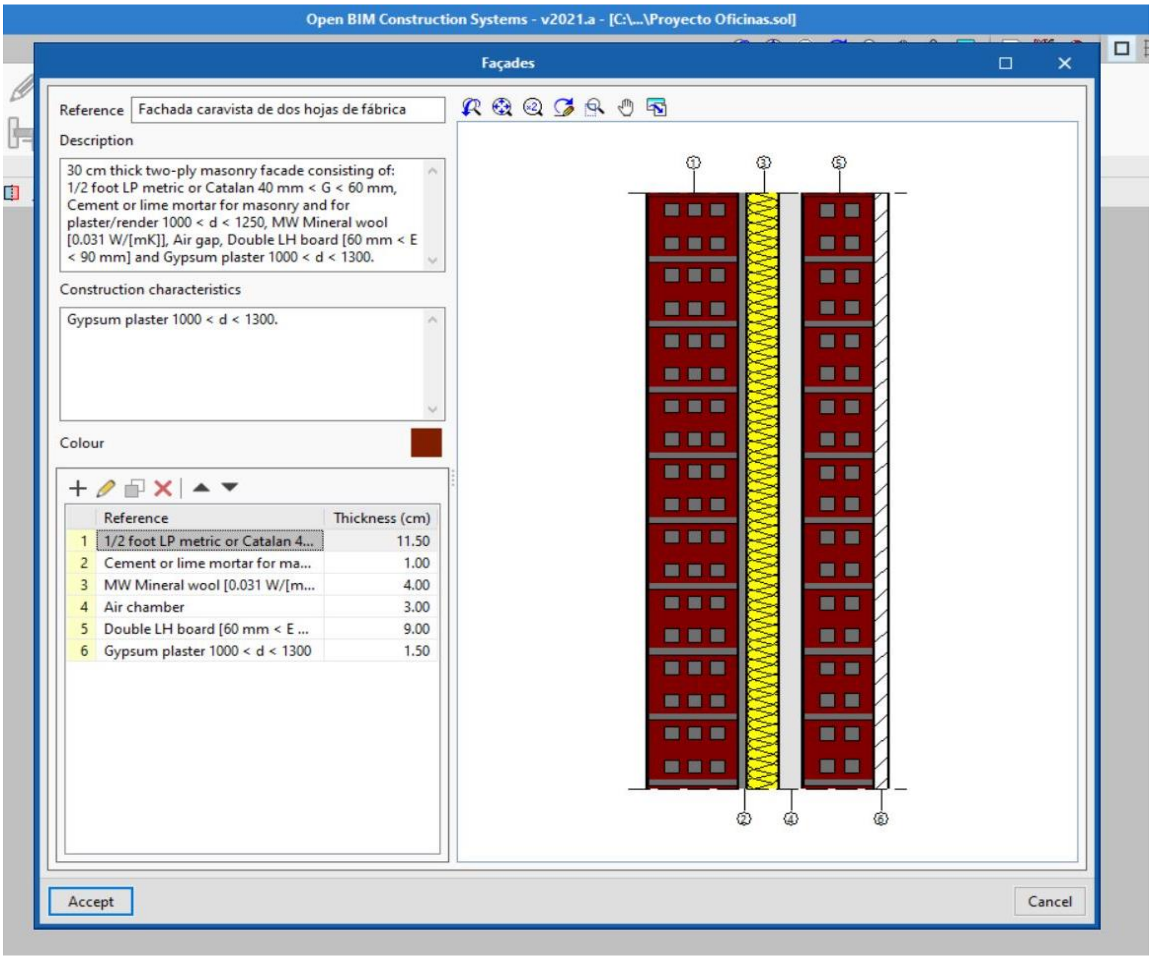



Figure 10. Open BIM Construction Systems layer definition.

# 6. Conversion tool from .ifc to TRNSYS

The BIMtoBEPS tool based on TRNSYS has been created to bridge the gap between BIM and BEM models, and allow for a straight conversion from the IFC file to the TRNSYS building model under the shape of .b18 extension and its corresponding structure.

As it has been previously mentioned, at present this conversion is not a trivial matter, since some of the information needed for the generation of building energy models is not still exported in the IFC file provided by any BIM software.

Being the case that the IFC provided contains all the required information, this tool is able to automatically generate the BEM. However, it also includes some functionalities that enables to make this conversion in case some information is missing. All the details are explained throughout this section in the corresponding steps.

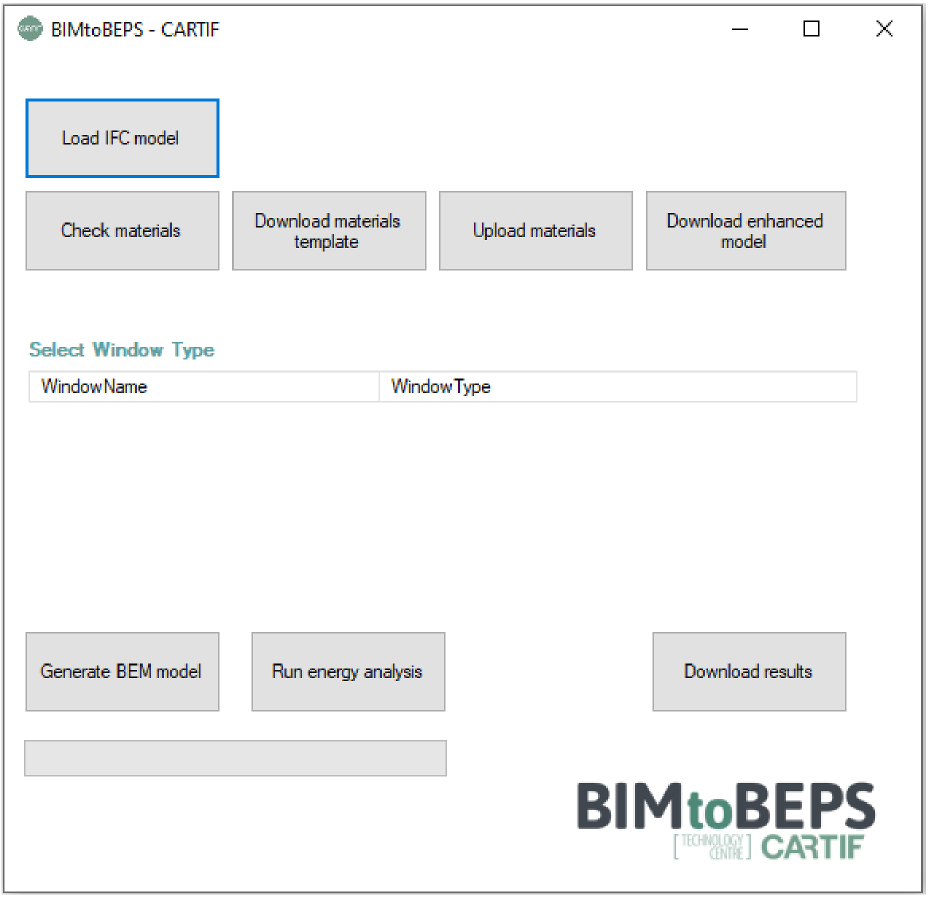



Figure 11. General view of the BIMtoBEPS tool based on TRNSYS

## 6.1 Use of the tool

**Step 1: Load IFC model**

First of all, Figure 11 shows the general aspect of the tool. It is a simple application with which the user can interact. The first step is to Load the IFC model.

It must be noted that the model must be geometrically correct both in terms of building elements but also spaces and zones defined in the BIM software, meaning that all the physical spaces must be properly bounded. OptEEmal guidelines [4] are recommended to be followed.

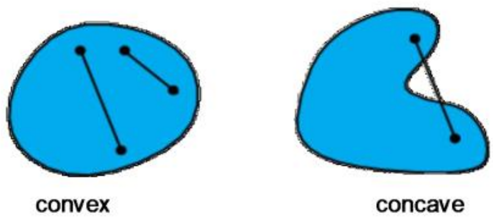



Figure 12. TRNSYS definition of convex and concave geometries.

In addition to this, it is worth clarifying that TRNSYS does not recognise concave spaces, so that if any of them does not meet this condition, it must be divided into a set of convex spaces, as showed in Figure 13, where the hall has a "T" shape that is has been divided into two rectangles.

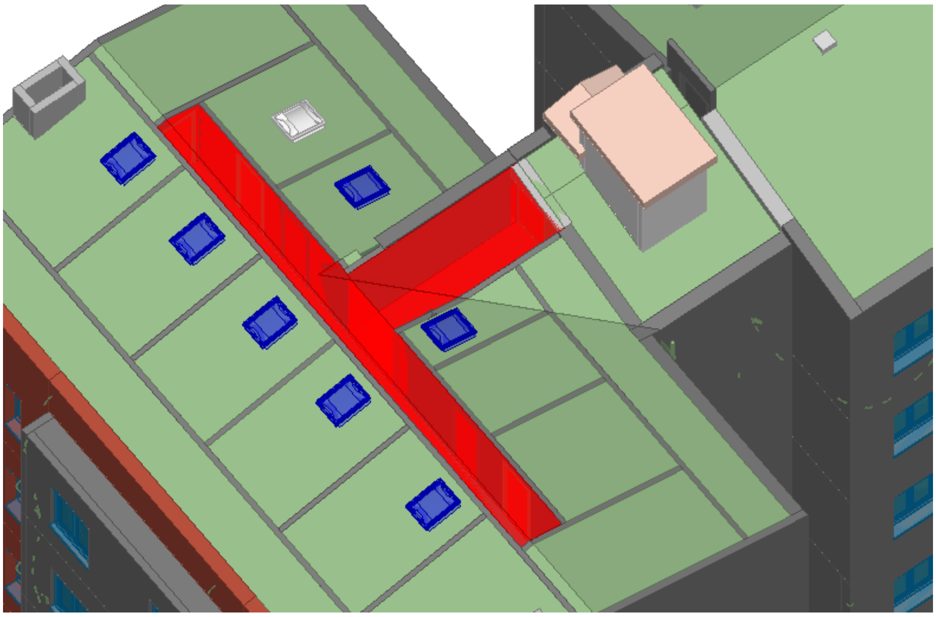


Figure 13. BIM of Vitoria demo. Division of a concave real thermal zone into two convex spaces.

**Step 2: Check and update material properties**

Once the model is loaded, it is possible to check if all the materials contained in it are associated with their material properties and respective values, in particular density, thermal conductivity and heat capacity. If the model does not contain this information, the user can download a custom Excel template (Figure 14), fill in (Figure 15) and upload it through the different buttons.

| Material name | Mass Density [kg/m3] | Thermal Conductivity [W/mK] | Heat Capacity [kJ/kgK] or [J/g°C] |
|---|---|---|---|
| LKS_Mortero cemento | | | |
| LKS_Ladrillo hueco CE3 | | | |
| LKS_Yeso | | | |
| LKS_Ladrillo hueco interior | | | |
| LKS_Ladrillo hueco CE4 | | | |
| LKS_Frondosas | | | |
| LKS-Generico | | | |
| LKS_Ladrillo hueco CE2 | | | |
| LKS_Ladrillo hueco CE7 | | | |
| Rubber | | | |
| Aluminium | | | |
| Titanium | | | |
| LKS-Cristal | | | |
| LKS_Hormigon forjado | | | |
| LKS_HORMIGON | | | |
| Metal - Cromo | | | |
| Por defecto | | | |
| Steel-Kohler-NA-Stainless | | | |
| IS_RenderMaterial_Chrome - Polished | | | |
| ISI_pipework | | | |
| Silicon Nitride - Polished | | | |
| LKS_Cristal | | | |

Figure 14. Material template for the demonstration case of Vitoria (only part of the materials).

| Material name | Mass Density [kg/m3] | Thermal Conductivity [W/mK] | Heat Capacity [kJ/kgK] or [J/g°C] |
|---|---|---|---|
| LKS_Mortero cemento | 1650 | 1.2 | 0.92 |
| LKS_Ladrillo hueco CE3 | 1650 | 0.369 | 0.84 |
| LKS_Yeso | 1650 | 0.26 | 0.92 |
| LKS_Ladrillo hueco interior | 1650 | 0.369 | 0.84 |
| LKS_Ladrillo hueco CE4 | 1650 | 0.385 | 0.84 |
| LKS_Frondosas | 2750 | 0.21 | 0.84 |
| LKS-Generico | 1100 | 0.65 | 0.84 |
| LKS_Ladrillo hueco CE2 | 1650 | 0.298 | 0.84 |
| LKS_Ladrillo hueco CE7 | 1650 | 0.2373 | 0.84 |
| Rubber | 930 | 0.138 | 2.092 |
| Aluminium | 2700 | 230 | 0.897 |
| Titanium | 4510 | 16.44 | 0.523 |
| LKS-Cristal | 2480 | 1.1 | 0.84 |
| LKS_Hormigon forjado | 2300 | 0.63 | 0.657 |
| LKS_HORMIGON | 2300 | 1.046 | 0.657 |
| Metal - Cromo | 7160 | 87.87 | 0.449 |
| Steel-Kohler-NA-Stainless | 8000 | 16.2 | 0.5 |
| IS_RenderMaterial_Chrome - Polished | 7160 | 87.87 | 0.449 |
| ISI_pipework | 1400 | 0.251 | 1.004 |
| Silicon Nitride - Polished | 8900 | 87.9 | 0.4435 |
| LKS_Cristal | 2480 | 1.1 | 0.84 |

Figure 15. Material template for the demonstration case of Vitoria filled in.

**Step 3: Download enhanced model**

The internal algorithm reads the new information and updates the IFC file, associating each material with its properties following the IFC standard[2]. An example can be seen in Figure 16, where the materials *LKS_Frondosas* and *LKS_Genérico* have been associated with the material properties given in the previous template. The rest of materials have been also updated so that not only the final model is usable by this tool, but also by any other tool able to work with IFC files (viewers, tools for interoperability or data extraction, etc.).

[2] BuildingSMART: IfcMaterialProperties class.

```
#808827=IFCPROPERTYSINGLEVALUE('MassDensity',$,IFCMASSDENSITYMEASURE(2750.),$);
#808828=IFCPROPERTYSINGLEVALUE('ThermalConductivity',$,IFCTHERMALCONDUCTIVITYMEASURE(0.21),$);
#808829=IFCPROPERTYSINGLEVALUE('SpecificHeatCapacity',$,IFCSPECIFICHEATCAPACITYMEASURE(0.84),$);
#808830=IFCMATERIALPROPERTIES($,$,(#808827,#808828,#808829),#73743);
#73743=IFCMATERIAL('LKS_Frondosas',$,'Materials');
#808831=IFCPROPERTYSINGLEVALUE('MassDensity',$,IFCMASSDENSITYMEASURE(1100.),$);
#808832=IFCPROPERTYSINGLEVALUE('ThermalConductivity',$,IFCTHERMALCONDUCTIVITYMEASURE(0.65),$);
#808833=IFCPROPERTYSINGLEVALUE('SpecificHeatCapacity',$,IFCSPECIFICHEATCAPACITYMEASURE(0.84),$);
#808834=IFCMATERIALPROPERTIES($,$,(#808831,#808832,#808833),#74019);.
#74019=IFCMATERIAL('LKS-Generico',$,'Materials');
```

Figure 16. Example of snippets generated in the enriched IFC file for the case of Vitoria.

**Step 4: Select Window Type**

Figure 17 shows how the tool automatically detects all the elements with glazing components when an IFC is provided, and enables a drop-down list section to select a windows type for each.

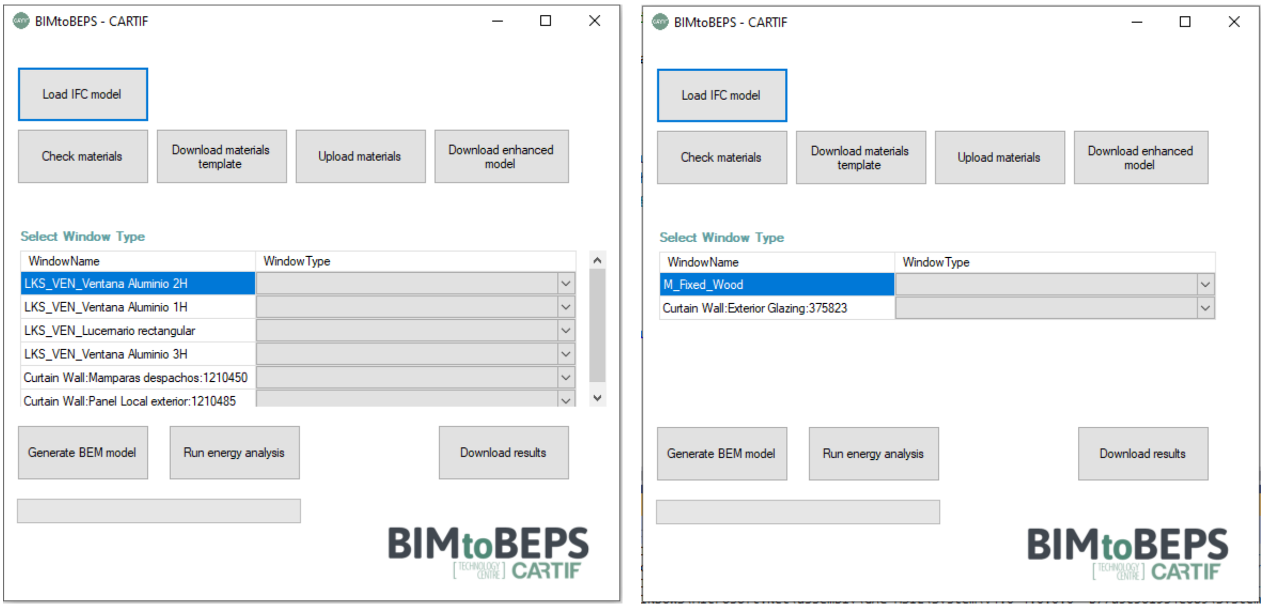



Figure 17. View of the tool when a model is loaded. Left: Vitoria demo. Right: smaller case study.

The reason under this is that in TRNSYS very detailed information is needed for the definition of windows. To overcome this interoperability issue, the tool provides a list of window types (Figure 18) that can be selected and associated with the real elements, attending to U-value and g-value parameters, and glazing configuration (simple, double or triple). Each window type proposed is linked with an internal library that provides the required information that includes frame features, and different parameters that depends on the solar radiation incidence angle, such as absorptance, among others.

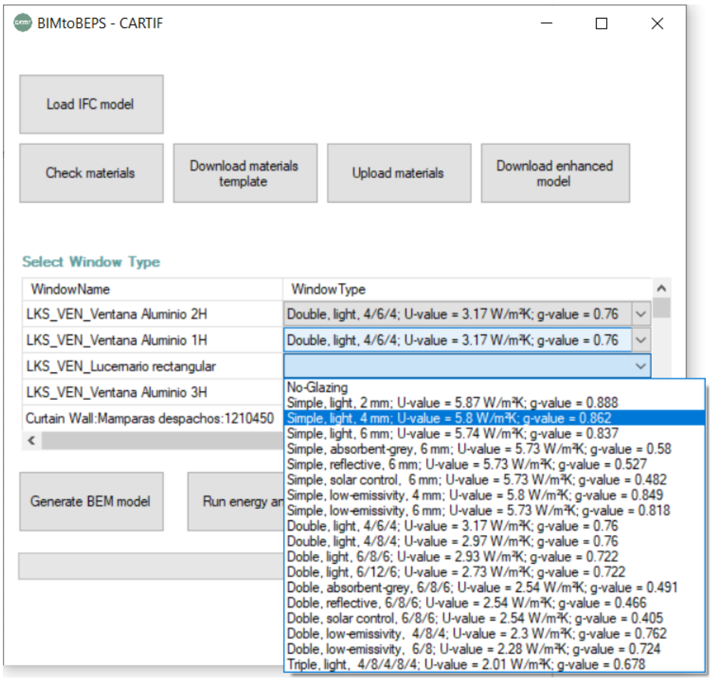



Figure 18. Windows type options

**Step 5: Generate BIM model**

Once all the required information is completed, generating the BEM model based on the .b18 format structure it is just question of "one click". Some relevant parts of the BEM model are shown in the following figures[3].

```
*------------------------------------------------------------------------
*       L a y e r s
*------------------------------------------------------------------------
LAYER #11646
 CONDUCTIVITY= 0.14 : CAPACITY= 1 : DENSITY= 1700 : PERT= 0 : PENRT= 0
LAYER #13495
 CONDUCTIVITY= 0.05 : CAPACITY= 2.385 : DENSITY= 630 : PERT= 0 : PENRT= 0
LAYER #14130
 CONDUCTIVITY= 0 : CAPACITY= 0 : DENSITY= 0 : PERT= 0 : PENRT= 0
LAYER #16284
 CONDUCTIVITY= 63.89 : CAPACITY= 0.897 : DENSITY= 2700 : PERT= 0 : PENRT= 0
```

Figure 19. Material layers definition.

```
* -----------------------------------------------------------------------
* S c h e d u l e s
* -----------------------------------------------------------------------
SCHEDULE DAILY_OCCUPANCY_Plenum
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 13.000
14.000 15.000 16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000
VALUES = 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0
SCHEDULE WEEKLY_OCCUPANCY_Plenum
DAYS = 1 2 3 4 5 6 7
```

[3] Figure 20 shows the generated schedules of occupancy, lighting and power (electrical equipment). Since the IFC does not include this information, the relation has been done through the attribute "Space Type" from the Revit library that contains predefined gains and schedules for those categories. Regarding the values, the assumption of having the 100% of the maximum gain value when the schedule is activated has been made, since it is not still possible to obtain this information from the IFC.

```
VALUES = DAILY_OCCUPANCY_Plenum DAILY_OCCUPANCY_Plenum DAILY_OCCUPANCY_Plenum
DAILY_OCCUPANCY_Plenum DAILY_OCCUPANCY_Plenum DAILY_OCCUPANCY_Plenum DAILY_OCCUPANCY_Plenum
SCHEDULE DAILY_LIGHTING_Plenum
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 13.000
14.000 15.000 16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000
VALUES = 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0
SCHEDULE WEEKLY_LIGHTING_Plenum
DAYS = 1 2 3 4 5 6 7
VALUES = DAILY_LIGHTING_Plenum DAILY_LIGHTING_Plenum DAILY_LIGHTING_Plenum DAILY_LIGHTING_Plenum
DAILY_LIGHTING_Plenum DAILY_LIGHTING_Plenum DAILY_LIGHTING_Plenum
SCHEDULE DAILY_POWER_Plenum
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 13.000
14.000 15.000 16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000
VALUES = 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0
SCHEDULE WEEKLY_POWER_Plenum
DAYS = 1 2 3 4 5 6 7
VALUES = DAILY_POWER_Plenum DAILY_POWER_Plenum DAILY_POWER_Plenum DAILY_POWER_Plenum
DAILY_POWER_Plenum DAILY_POWER_Plenum DAILY_POWER_Plenum
```

Figure 20. Schedules generated for a given space.

```
*----------------------------------------------------------------------
*  C O N S T R U C T I O N (Wall, Floor, Ceiling,..)
*----------------------------------------------------------------------
CONSTRUCTION #53314
 LAYERS = #7114 #7101 #7088 #7070 #7057 #7044 #7018
 THICKNESS = 0.013 0.0005 0.152 0.019 0.0005 0.076 0.09
 ABS-FRONT= 0.4   : ABS-BACK= 0.5
 EPS-FRONT = 0.9   : EPS-BACK = 0.9
 HFRONT = 11 : HBACK = 64
CONSTRUCTION #53317
 LAYERS = #7114 #7101 #7088 #7070 #7057 #7044 #7018
 THICKNESS = 0.013 0.0005 0.152 0.019 0.0005 0.076 0.09
 ABS-FRONT= 0.4   : ABS-BACK= 0.5
 EPS-FRONT = 0.9   : EPS-BACK = 0.9
 HFRONT = 11 : HBACK = 64
```

Figure 21. Definition of building elements.

```
*----------------------------------------------------------------------
*  Z o n e   #4596  /  A i r n o d e  #4596
*----------------------------------------------------------------------
ZONE #4596
RADIATION MODE
 BEAM=STANDARD : DIFFUSE=STANDARD : LONGWAVE=STANDARD : GEOMODE=3D_DATA : FSOLAIR=0
DAYLIGHTMODE
  DLSHADE =-1
AIRNODE #4596
FLOOR =#53357 : SURF= 120 : AREA= 34.4847749999998 : ADJACENT=#962 : ADJ_SURF= 30 : BACK
FLOOR =#53371 : SURF= 121 : AREA= 70.9570999999996 : ADJACENT=#1291 : ADJ_SURF= 42 : BACK
WALL = #53425 : SURF= 122 : AREA= 0.8775 : ADJACENT=#2456 : ADJ_SURF=85 : BACK
WALL = #53435 : SURF= 123 : AREA= 0.883124999999993 : ADJACENT=#2930 : ADJ_SURF=98 : BACK
WALL = #53450 : SURF= 124 : AREA= 33.1036316694532 : ADJACENT=#3484 : ADJ_SURF=107 : BACK
WALL = #53469 : SURF= 125 : AREA= 33.1036316694532 : ADJACENT=#4013 : ADJ_SURF=119 : BACK
WALL =#53477 : SURF= 126 : AREA= 37.9541980842332 : EXTERNAL : ORI=N_195_90 : FSKY=0.5
WINDOW = #53479 : SURF = 127 : AREA = 0.744199999999999 : EXTERNAL: ORI = N_195_90 : FSKY = 0.5 :
GEOSURF = 0
WALL =#53481 : SURF= 128 : AREA= 30.2435412109858 : EXTERNAL : ORI=E_285_90 : FSKY=0.5
WINDOW = #53482 : SURF = 129 : AREA = 0.7442 : EXTERNAL: ORI = E_285_90 : FSKY = 0.5 : GEOSURF =
0
WINDOW = #53484 : SURF = 130 : AREA = 0.744199999999999 : EXTERNAL: ORI = E_285_90 : FSKY = 0.5 :
GEOSURF = 0
```

```
ROOF =#53486 : SURF= 131 : AREA= 109.161461605277 : EXTERNAL : ORI=N_195_15 : FSKY=0.5
WALL = #53488 : SURF= 132 : AREA= 16.2467743709109 : ADJACENT=#5189 : ADJ_SURF=141 : FRONT
WALL = #53489 : SURF= 133 : AREA= 1.95261 : ADJACENT=#5189 : ADJ_SURF=142 : FRONT
WALL = #53491 : SURF= 134 : AREA= 12.2361418400749 : ADJACENT=#5189 : ADJ_SURF=136 : FRONT
 REGIME
 GAIN     = Occ_4596 : SCALE= SCHEDULE 1*WEEKLY_OCCUPANCY_DormitoryBedroom : GEOPOS= 0 : SCALE2 =
1*1 : FRAC_REFAREA= 1
 GAIN     = Light_4596 : SCALE= SCHEDULE 1*WEEKLY_LIGHTING_DormitoryBedroom : GEOPOS= 0 : SCALE2
= 1*1 : FRAC_REFAREA= 1
 GAIN     = Light_4596 : SCALE= SCHEDULE 1*WEEKLY_POWER_DormitoryBedroom : GEOPOS= 0 : SCALE2 =
1*1 : FRAC_REFAREA= 1
 HEATING = HEATING4596
 COOLING = COOLING4596
 CAPACITANCE = 394.6 : VOLUME = 328.831984476262 : REFAREA = 105.441874999999 : TINITIAL= 20 :
PHINITIAL= 50 : WCAPR= 1
```

Figure 22. Definition of a thermal zone.

**Step 6: Run energy analysis**

Additionally, the tool allows to perform an energy analysis to calculate the energy demand of the building. As Figure 23 shows the basic model generated. It consists on:

- Type15-3: for the definition of the weather file.
- Type56: that contains the building model generated by the tool.
- Type65: displays the results.

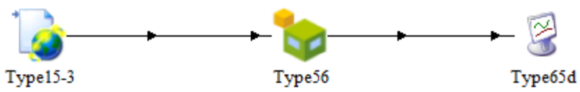



Figure 23. Basic simulation model in TRNSYS generated by the tool.

To this end, the generated BEM includes ideal heating and cooling system defined by default. This means that the ideal systems would give all the thermal power needed to reach a given temperature set point instantaneously for each defined thermal zone, which can be identified as the building energy demand. This configuration can be then modified manually through the Simulation Studio and TRNBuild interfaces.

## 6.2 Considerations

- The BIMtoBEPS tool allows to generate BEM models compliant with TRNSYS through a minimum interaction by the user.
- The BIM model must be built in a correct way, taking into account the guidelines for its design.
- For the moment, the tool addresses the conversion from the BIM to a building analytic model.
- Energy systems are still not considered, since the information provided by IFC is not sufficient for the definition on TRNSYS. More investigation must be done here in order to overcome this interoperability gap (need of knowing flows direction, parameters of the different technologies and equipment, performance maps, etc. in a standardized way).
- As the extraction of the information and the generation are different modules, the tool can be adapted to the generation of BEM models using other open formats such as *.idf*.

# 7. Simple BEM generator - Tool for BEM generation without an existing BIM

## 7.1 Background

Creating a detailed BEM of an existing building is a lengthy process, especially if a high level of detail and accuracy is desired. An initial cost-benefit analysis to renovation potential should already commence at an earlier stage where no BIM or BEM model may exist at all.

In many cases building owners and other stakeholders have an interest in assessing renovation potentials even before they have gathered any BIM or BEM information. This can be helpful e.g. for portfolio analysis when the owner wants to compare potentials of multiple projects as an initial step – before even collecting BIM information and/or running calibration procedures.

For this purpose, Metabuild makes available a “simple box” tool that allows generation of a simplified BEM without a BIM being available or required. It creates preconditions and will at a later stage enhance interoperability of Metabuild optimization tool with the BIM-SPEED platform. It will allow e.g. use of the optimisation tool for an initial overview without having an existing BIM.

## 7.2 Tool for simplified BEM generation

The tool allows a user to create a BEM without having an existing BIM. The model is created by usage of data from OSM Buildings (OSM Buildings uses geometry data from OpenStreetMap, the free wiki world map which is available under OpenDatabase License (ODbL)). The as-is building setup is derived from standardized building typologies based on building type and built year. This setup can be modified by the user. The generated BEMs are simplified. They take the existing data that is available. This includes a buildings location and its gross floor area. Some information available may not be reliable, as it is the case with building height. All these data can be modified by the user. Surrounding buildings can be selected in order to be integrated in the BEM as shading surfaces (ongoing development). Zoning is automatized. Initially, a simplified one-zone model per floor is applied to create a valid BEM that will be improved later.

The tool does not require any modelling skills by its user, so it is accessible also for non-energy-experts. The model produced is simplified but it allows an initial evaluation of a building without a lot of initial work effort. The following exploitation can then comprise evaluation of the current status as well as of renovation alternatives. Especially for obtaining a comparative overview of the renovation potential of different buildings, this tool is intended as an easy to use first step. This initial evaluation may then justify the use of more extensive procedures to create a detailed BIM and BEM.

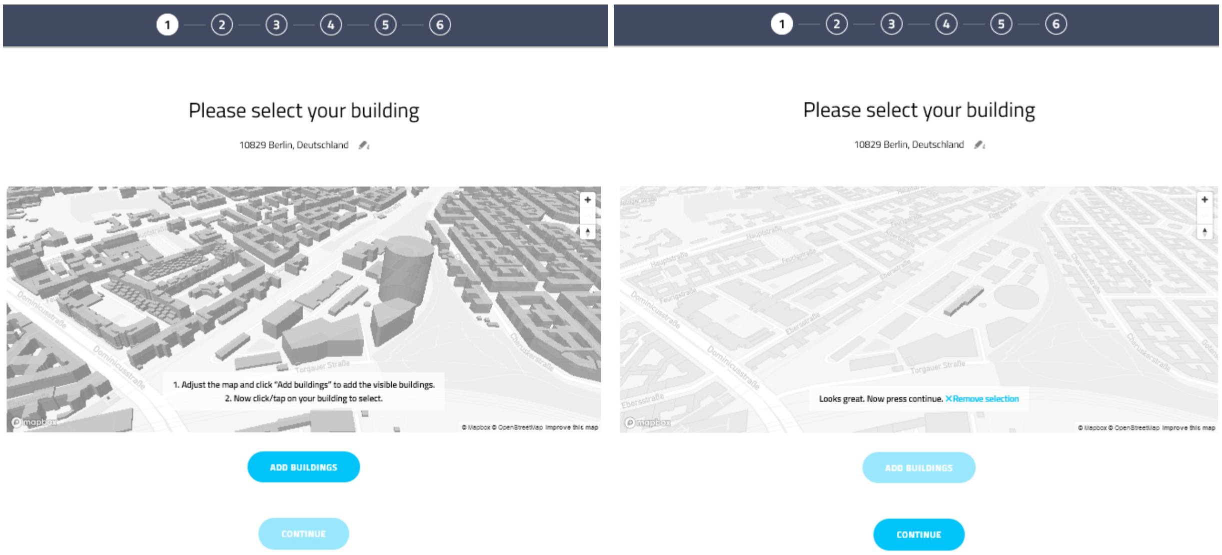



Figure 24: The location is defined via map search and the building is selected from the open database

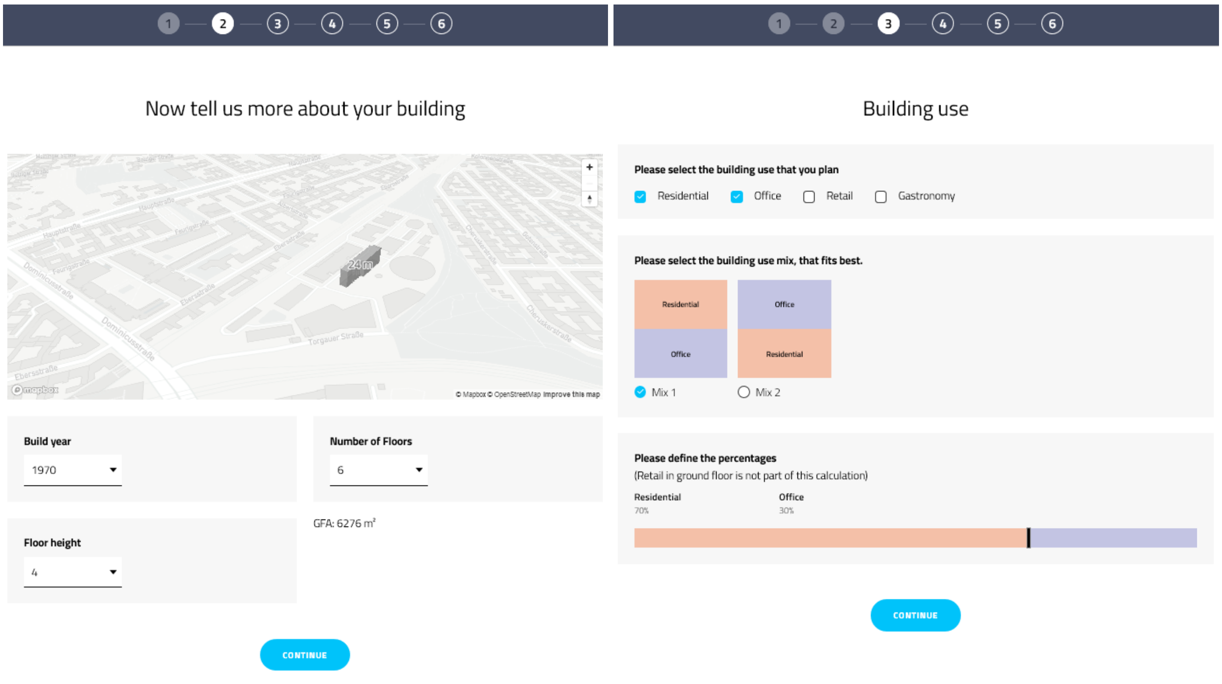



Figure 25: Building height is manually corrected and the model is enriched by information of built year, floor number and building height (left). The building use is defined, as a basis for the definition of schedules (right).

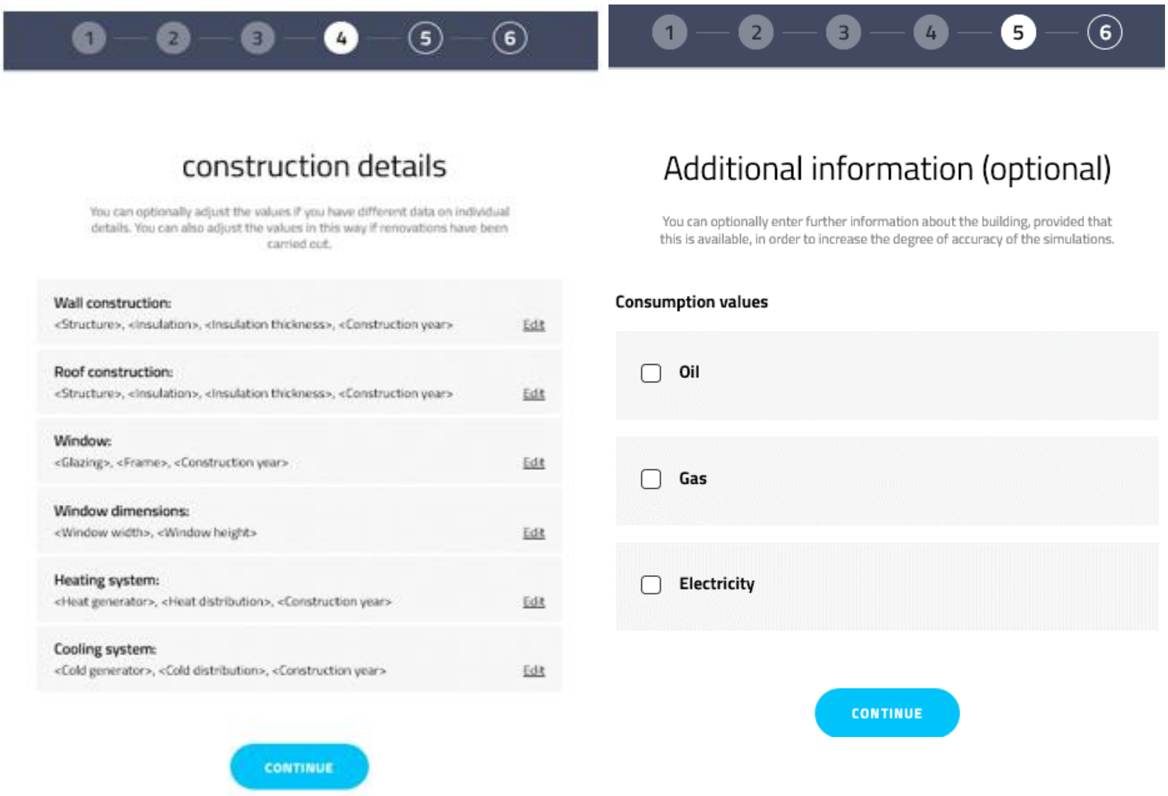



Figure 26: General information about construction details (left) and energy consumption (right) can be added to increase the degree of accuracy for energy simulations.

## 7.3 The aim of the tool

**Enabling interoperability with Optimization tool:** The simple BEM generation tool allows an early interoperability with optimization. The later use of the Metabuild's optimization tool requires a parametric BEM, i.e. where the relevant design parameters in the model can be modified by automated procedures, e.g. extraction and modification of Window-to-wall ratios, replacement of insulation (keeping the building geometry but modifying the structures/components). The tool fulfills this requirement.

**Creating alternative scenarios:** The tool can be used to create sets different renovation scenarios without the need of using a BIM software (that has a GUI – Graphical User Interface). These can be used in the process of the "Multi-criteria decision-making method" (corresponding with requirements from WP 7.1 & 4.5). This enables BIM-SPEED partners to use those renovation setups as a starting point for detailed analysis once a calibrated BEM model is available.

**Energy code compliance:** For projects in Germany and Austria, generated solutions will be checked for energy code requirement compliance (German EnEV and Austrian ÖNORM) using the officially required calculation methods.

# 8. Advanced procedures

There will be cases in which the accuracy offered by the automatic generation of Open BIM Analytical Model is not sufficient; for example, in the case of construction technology laboratories, where very high precision simulations are required which are later compared with real data measured in real buildings. In these cases, OB Analytical Model offers extended functionality to create much more accurate energy models, requiring in return much more knowledge by the user who makes the model and much more time, since this workflow is primarily manual.

The annex 1 contains a step-by-step guide of the procedure to follow to develop a fully detailed BEM model using Open BIM Analytical Model and Open BIM Construction Systems. This will serve as reference for future work packages that involve the development of BEM models.

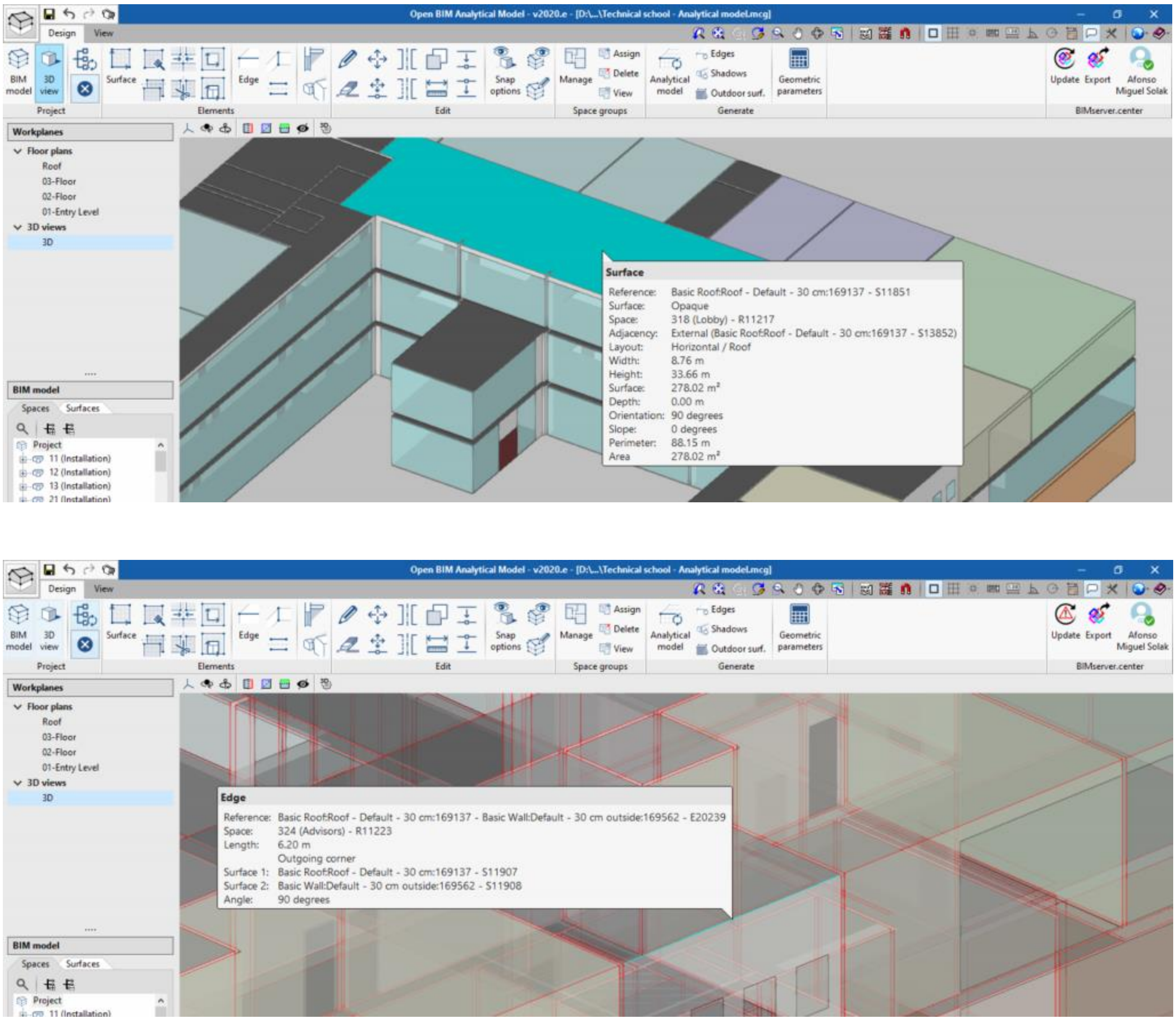



Figure 27: Open BIM Model Checker detailed definition

# 9. Connection with other software and platforms

## 9.1 Connection with BIM modeling applications

The biggest advantage of using IFC technology is the interoperability with all the tools integrated in the Open BIM workflow, which includes all the majority tools and almost all the minority ones present in the market. These tools include generalist BIM modelling tools such as Revit, ArchiCad, Open BIM Architecture, Allplan and AECOSim.

The applications can also communicate with specialized software such as CYPETHERM, or TRNSYS, which allows energy calculations and precision analysis from the output of the developed applications. This means that the developed BEM model not only has an informative use of the building's energy condition, but also serves to perform sizing of building installations (such as HVAC machines, radiators, floor heating, etc.), so that all BEM information automatically travels to the specific applications to perform these calculations.

This connection is in real time and parametric. In the case of the CYPE tools suite, this means that if the BIM model is updated (e.g. change the geometry, create or delete spaces or their properties, change some type of building element, etc) the application will notify the user that there have been changes in the model; the user can then synchronize the BEM model with the BIM model, defining a set of parameters that control the process of mass synchronization of all entities in the model. For example, you can configure whether or not to delete the deleted entities, or to create the new detected entities.

It is this parametric configuration that includes the loading of saved mapping libraries that allow the automatic definition of BIM entities in BEM, as described above. This means that once the BIM-BEM bridge is built, it is able to support changes of the BIM model and take them directly to the BEM model, so that the energy calculations are updated accordingly. This one-click synchronization allows the use of these tools as iterative meters in the design phase of the project, so that energy simulations can help optimize early decisions and the shape of the building, which would be impossible in later development phases.

The BIMtoBEPS based on TRNSYS tool, however, gives the user the possibility to generate a new BEM model any time he or she needs it. This means that there is no an automatic update of the BEM model, but it is possible to create a different one at any stage of the project in a fast way. However, the use of IFC parsing as a bridge between tools from different developers does not prevent IFCs generated with different applications from not following exactly the same geometric definition criteria and parameters. This is one of the fundamental reasons for errors and problems when exporting a BIM model to an application capable of generating a BEM model like those presented in this report. It is for this reason that the tools developed fit well in the workflow of any BIM process; they serve as a buffer between a definition model and arbitrary LOD and an energy model capable of being calculated and measured, and whose geometry is capable of being updated with the changes in the original BIM model.

## 9.2 Connection with BIM-SPEED Platform: recommended solutions

**OB Analytical Model and OB Construction System**

The BIM-SPEED platform is based on microservices that users can use on the files of a project. Following this philosophy, and since the applications developed for this project are based on BIMserver.center, the communication between the BIM-SPEED Platform and the applications OB Analytical Model and OB Construction System will be, in fact, a communication between both platforms. In this way, the workflow will be based on the cloud and not on local files, and a user will be able to access his project at all times through the web.


The solution developed is a desktop application capable of containing BIM-SPEED Platform and BIMserver.center data simultaneously, and which will be able to exchange files between platforms easily. The name of the tool is **BIM-Speed2BIMserver** and it is free to use. The procedure to follow to integrate the mentioned tools in the platform will be the following (starting from a BIM model that has been previously modelled):

1. Start a project in BIMserver.center.
2. Elaboration of the BEM model according to one of the two workflows described above. Once the BEM model has been created, the BIMserver.center project should contain at least 3 IFCs: the original architecture IFC, the OB Analytical Model IFC and the OB Construction Systems IFC.
3. (Optional) Energy calculation and simulation with specific software (e.g. CYPETHERM suite), creating additional IFCs with the results.
4. Login to the BIM-SPEED Platform from any browser.
5. Use of the BIMserver.center service available to activate the desktop synchronization application (BIM-Speed2BIMserver).
6. Once the platform selection application is open, we can decide which BIMserver.center projects we want to synchronize to the BIM-SPEED Platform project. This will allow us to synchronize a folder we have created on the BIMSpeed Platform with the files in BIMserver.center.

This will allow any user of the BIM-SPEED Platform to ensure that the files they are uploading are synchronized with the latest version of the information uploaded to BIMserver.center. In addition, this procedure can be iterative, so that the desktop application will serve to update the files as the project progresses. The procedure to bring information from BIMSpeed Platform to BIMserver.center will be analogous, creating a two-way data bridge between both platforms. It is important to point out that the user who wants to work in this way will have to have an account in both platforms to have access to the information he wants to synchronize. Generally, this user will be the architect or energy specialist who wants to synchronize BIMSpeed Platform services with BIMserver.center's energy analysis and calculation applications. This application is integrated with the BIMserver.center synchronizer and is complementary to the communication procedure described in the following point. This will be further developed in work package 5.

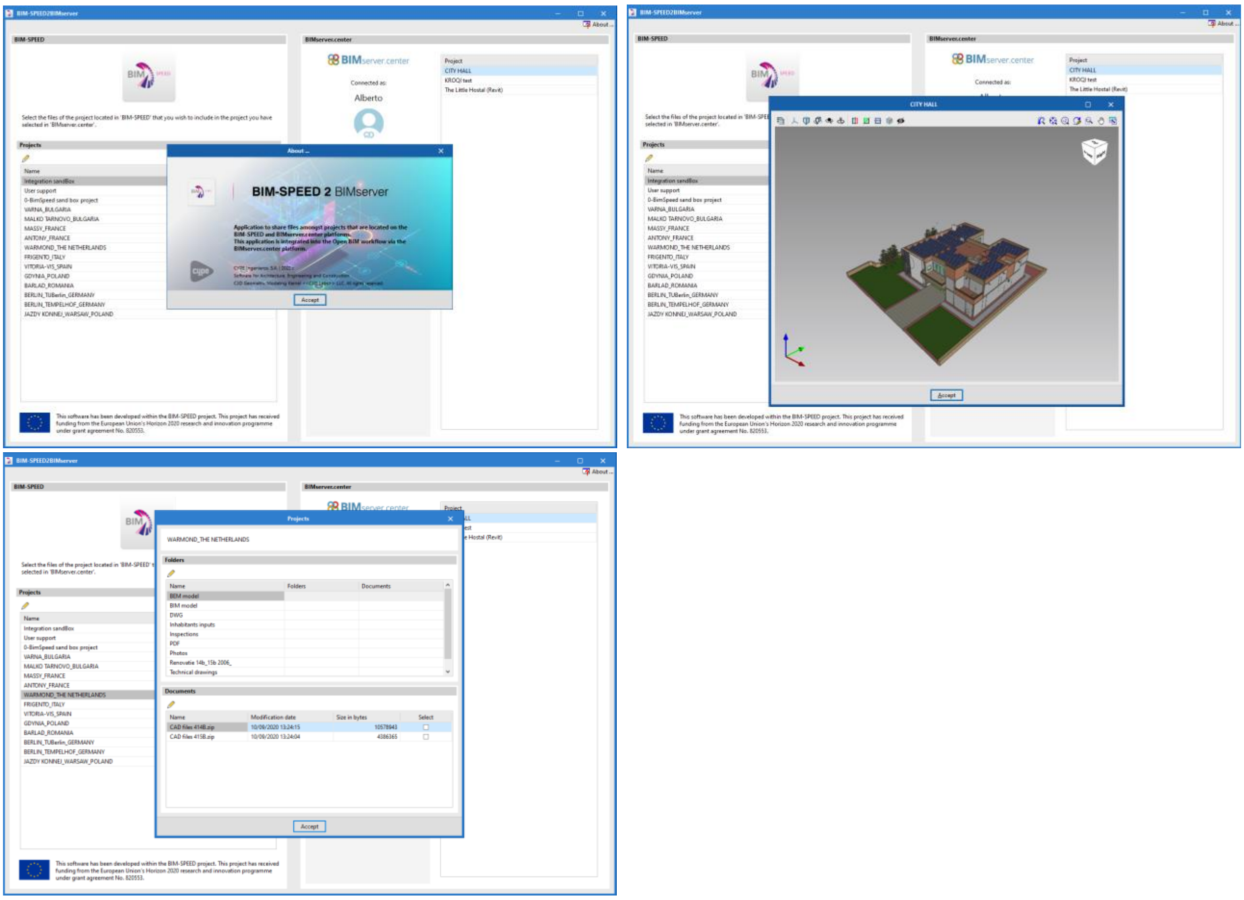



Figure 28. BIMSpeed2Bimserver tool.

**BIMtoBEPS tool**

The BIMtoBEPS tool based on TRNSYS will be adapted to be integrated with BIM-SPEED platform through a dedicated API whose workflow is shown in Figure 29. In summary, this API will connect the BIMtoBEPS tool with the platform, but also with a web service dedicated to generate weather files based on the building location, extracted from the IFC. More specifications can be found in D5.2 BIM Connectors for interoperability between different BIM tools.

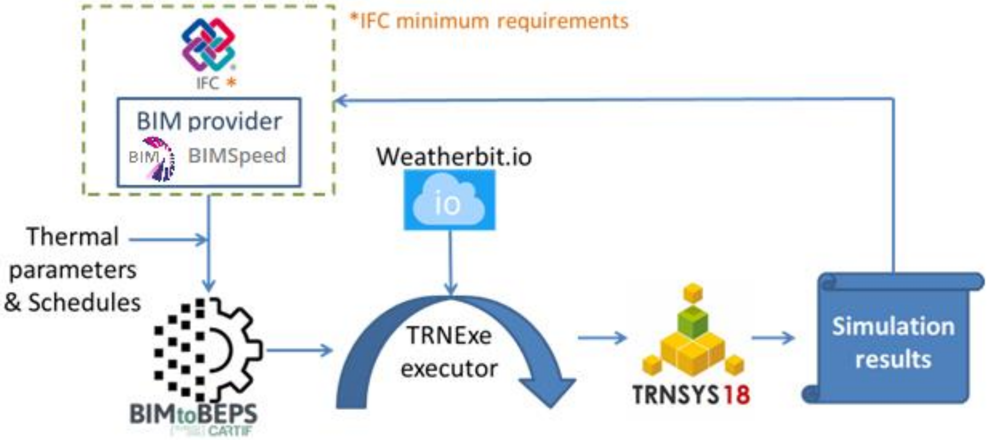



Figure 29. Integration of the BIMtoBEPS tool with BIM-SPEED platform.

**BEM Generator**

The simplified BEM, which can be created as a user result of this BEM Generator tool, is tailored for further use in the optimization procedure, which is part of Metabuilds contribution of T4.5. The connection of the BEM generator to the BIM-SPEED platform will be done in conjunction with making accessible the optimization tool.

## 9.3 Connection with BIMserver.center

The tools developed not only communicate with the BIM-SPEED platform, but also with BIMserver.center. BIMserver.center is free and compatible with all BIM tools capable of generating IFC, including Revit, Archicad, Open BIM Architecture, etc. This allows the use of the platform in a complementary way to the BIM-SPEED platform, guaranteeing the federation of BIM and BEM models generated in the development of a project. In addition, BIMserver.center has an automatic notification system, so that registered users will know when there have been changes in the project, which can be reviewed through the multiplatform application of BIMserver.center or in virtual reality or augmented reality through free applications. In addition, the platform will automatically manage the requirements and incidents detected manually and automatically in the project.  For example, the thermal calculations carried out with the BEM model created with the developed tools will upload a series of data to the platform that will be imported as input in other applications connected to BIMserver that can use those data for their own calculations (e.g. CYPETHERM HVAC will import the data from the energy simulation to dimension HVAC equipment). This guarantees the consistency of the BIM model and the BEM model and creates a continuous communication bridge with all stakeholders. Each participant in the project will be assigned a role, so that the development of the entire project and the authorship of all modifications will be recorded on the platform. Any project can be made visible to the outside (without having an account on the platform), and can share 3d models of projects via a navigable web viewer.

## 9.4 Connection with automated calibration procedure

In building energy simulation, BEMs should be accurate enough to allow achieving reliable performance predictions in renovation design, advanced control of renovated building operation and reliable energy/environmental/economic assessment. However, even when an accurate energy modeling of the building is carried out though an accurate BIM-BEM modeling approach, a high discrepancy between predicted energy consumption and actual energy consumption can be found in the practice (up to 250%), mainly due to the uncertainties in physical models and BEM assumptions (Baglivo et al. 2014).

In order to overcome this problem, a BEM calibration is generally carried out, with the aim of minimizing the differences between simulated and measured building performance (e.g. energy consumption) by tuning BEM input parameters (Coakley D, Raftery P, Keane M (2014) A review of methods to match building energy simulation models to measured data. Renewable and Sustainable Energy Reviews 37:123–141. doi: 10.1016/j.rser.2014.05.007). A BEM is generally considered calibrated when the adopted calibration indexes (generally represented by error functions) fall under a threshold defined by a relevant Standard (e.g. ASHRAE 14, IPMVP, FEMP, etc) or literature (Martinez et al. 2020). BEM calibration processes are generally classified in manual and automated approaches. The manual ones, which involve manual trial-and-error processes, have the main drawbacks of being time-consuming and highly dependent on the experience and expertise of the analysts (Chaudhary G, New J, Sanyal J, et al (2016) Evaluation of "Autotune" calibration against manual calibration of building energy models. Applied Energy 182:115–134. doi: 10.1016/j.apenergy.2016.08.073 et al 2016). Automated calibration approaches, instead, developed in the last decades, try to overcome these issues seeking sets of good-fit simulation inputs only by using mathematical and statistical techniques (Coakley D, Raftery P, Keane M (2014) A review of methods to match building energy simulation models to measured data. Renewable and Sustainable Energy Reviews 37:123–141. doi: 10.1016/j.rser.2014.05.007).

In the BIM-SPEED project, an artificial-intelligence-based automated calibration procedure, harmonized with the current BIM-to-BEM approach, will be developed to achieve in short time a reliable BEM performance prediction. Different levels of BEM accuracy, defined based on a prior state-of-the-art on BEM calibration, will be considered and implemented in order to allow a wide-ranging functioning of the procedure. These accuracy levels are those already implemented in the "Simple box" and the full BIM-BEM tools described in Section 3.1. In the following, the BIM-SPEED calibration procedure workflow is synthetically reported. The extensive description of the developed calibration procedure and the links with the new developed BIM-to-BEM approaches proposed with this deliverable will be reported in D3.4. The BIM-SPEED automated BEM calibration procedure will be mainly based on:

- a parameter screening needed to reduce parameter search dimensionality and to speed up the calibration process;

- an automated calibration process using artificial intelligence (AI) algorithms, carried out by tuning the most important input parameters to minimize the difference between simulated and real building performance.

The calibration procedure will be connected to the BEM as created with the new BIM-to-BEM workflows and, in particular, with the CYPETHERM-based procedure, since linked to EnergyPlus engine and working with open source standards. It will involve four main phases, i.e. monitoring, parameter screening, model optimization, and model evaluation, each of which is briefly described in the following. In the monitoring phase, the data related to calibration target (e.g. monthly or hourly energy consumptions) and to BEM boundary conditions (climate data to be included in weather file), both related to a specific year, are collected. Generally, monthly energy consumption determined from bills and/or smart meters are considered enough for purposes of calibration of BEM models used to predict the energy consumption. The building operating schedules by the occupants (related to the year in which climate data are collected) are also determined in this phase. An automatic screening of the most important parameters is then carried out to reduce the parameter space search dimensionality of the calibration problem and computation time (Zuhaib et al. 2019).

The automatic screening is based on BEM expertise and literature review, as well as on the outcomes of sensitivity and uncertainty analysis, carried out to define which input parameters mostly impact on BEM simulation results. Non-influential parameters will be not considered in the following phases. At the end of this phase, a variable range of variation and a probability distribution is applied to each identified parameter. In the model optimization, AI optimization algorithms are adopted to define the best set of inputs that minimizes one (single-objective) or more error functions (multi-objectives) computed between experimental and numerical energy consumptions. Finally, an evaluation of the optimized models is performed to define if the optimized BEM can be considered calibrated or not according to generally accepted criteria. A calibration index (that usually corresponds to the error function adopted in the optimization process) is calculated for each optimized model and compared to a predefined accuracy threshold. Expert judgment should also be used in this phase to discard unreasonable calibrated solutions (e.g. with unreasonable input values).

# 10. Exploitation results

**BIMtoBEPs:**

The BIMtoBEPS tool shown in this deliverable is a result of developments carried out in task 3.2-Advanced procedures and tools for creating BEM and related analytical models in BIM-SPEED project and is currently in a prototype phase. The validation status of the tool is in TRL5.

The objective is to reach TRL6 at the end of the BIM-SPEED project. The tool will be available directly through the BIM-SPEED platform for the consortium, Project Officer (PO) and Project Technical Advisor. The commercial exploitation of the software is not explored at time of writing the report due the actual developments are focused on a research and development phase and will be considered at the end of the BIM-SPEED project.

**Open BIM Analytical Model and Open BIM Construction Systems:**

Both tools have already been uploaded to the BIMserver.center store and can be downloaded for free. Both tools have been tested by several real users and have been very well received: each one has already added up to more than 1000 downloads, which is considered a very positive indicator of its usefulness. The idea is to continue developing them indefinitely, taking advantage of the use of open formats to build connections with other tools and form part of the Open BIM ecosystem.

Open BIM Analytical Model: https://bimserver.center/en/store/259/open_bim_analytical_model

Open BIM Construction Systems: https://bimserver.center/en/store/287/open_bim_construction_systems

**Simple BEM generator**

The Simple BEM generator in this deliverable, based on works carried out in WP3, is one of the development branches of Metabuild that will allow for usage via the BIM-SPEED platform. Currently in a prototype phase of TRL5, the objective is to reach TRL6 at the end of the BIM-SPEED project. The tool will be available for the consortium, Project Officer (PO) and Project Technical Advisor. It shall be usable as one possible entry point into the BIM-SPEED platform for potential projects without an existing BIM, e.g. for pre-analysis to decide whether the effort of a detailled BIM is justified.

The commercial exploitation of another development branch of this tool is being pursued but has not yet been published, also depending on the results of Metabuilds ongoing work packages.

# 11. Conclusions and future works

The development work presented in this report is a milestone in the development of BEM projects, since for the first time it will be possible to take advantage of the information from a BIM model to generate a functional BEM model not only automatically, but also in a synchronised manner.

This means that any architectural/engineering project developed in BIM (of which there are more and more) will have all the facilities to add energy balance to the project's BIM uses. This will greatly facilitate the consideration of environmental energy parameters in any type of BIM project (both new projects and renovation projects) not only in the final phase of the project, but in an iterative way throughout its development, being able to use this information to choose more efficient and less polluting construction systems, energy systems or building design elements in terms of energy consumption.

Before these tools, anyone who wanted to know the energy dimension of a BIM building was forced to model it almost entirely using specific precision tools, or else to settle for estimates and imprecise calculations whose results are neither significant nor relevant to the expected level of precision of an energy balance. In other words, any relevant analysis required the investment of many extra hours and the necessary collaboration of an expert energy team that was able to correctly model the building. This working system did not tolerate any kind of iteration and was usually done at the end of the design process with a mere justification for the regional regulations or requirements (e.g. for the issuance of an energy certificate for the building). There was also no guarantee that the energy model corresponded to the final state of the BIM model, as any changes to the BIM model would have to be reflected "manually" in the energy model.

Furthermore, this democratizes access to energy criteria in project development. Since the tools developed incorporate internal calculation engines with a simple and intuitive interface, even an architect or engineer who is not an expert in the field of energy will be able to determine how much your building consumes in a few clicks. In short, the time required to produce a BEM model has been drastically reduced, fully automating the definition of the model from pre-existing information. Proof of the usefulness of some of the tools developed is that they have already accumulated more than 1000 downloads from real users in their first months of publication in the case of Open BIM Analytical Model and Open BIM Construction Systems, and user feedback is really positive.

In an increasingly digitalised and instrumentalised world, project development has to be linked to the development of tools that make use of today's technology. The work presented in this report, which will continue to be developed in the future as free tools for the public, represents a radical change in the way BEM models are developed and maintained in ACS projects.

# 12. References and downloads

[1] Baglivo C, Congedo PM, Fazio A (2014) Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate. Building and Environment 82:467–480. doi: 10.1016/j.buildenv.2014.09.019

[2] Chaudhary G, New J, Sanyal J, et al (2016) Evaluation of “Autotune” calibration against manual calibration of building energy models. Applied Energy 182:115–134. doi: 10.1016/j.apenergy.2016.08.073

[3] Coakley D, Raftery P, Keane M (2014) A review of methods to match building energy simulation models to measured data. Renewable and Sustainable Energy Reviews 37:123–141. doi: 10.1016/j.rser.2014.05.007

[4] G.I. Giannakis, K. Katsigarakis, G.N. Lilis, S. Álvarez-Díaz. GUIDELINES for OptEEmAL BIM Input Files. OptEEmal Horizon 2020 project. Available from: https://www.opteemal-project.eu/files/guidelines_for_opteemal_bim_input_files_v11.pdf

# APPENDIX 1 – creation of a BEM model from a BIM model

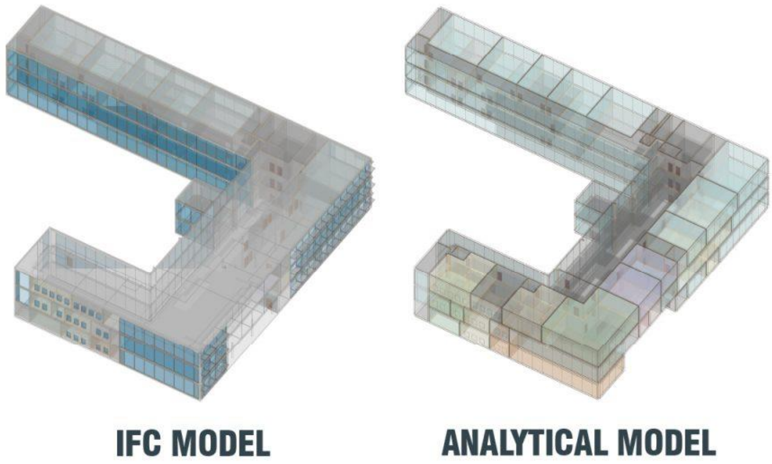



Figure 30. Generation of BEM Model from BIM

**STEP 1: Upload the BIM model to BIMserver.center**

The first step to create a BEM model from a BIM model is to create a new project in BIMserver.center and upload the mode. This can be done in several ways.

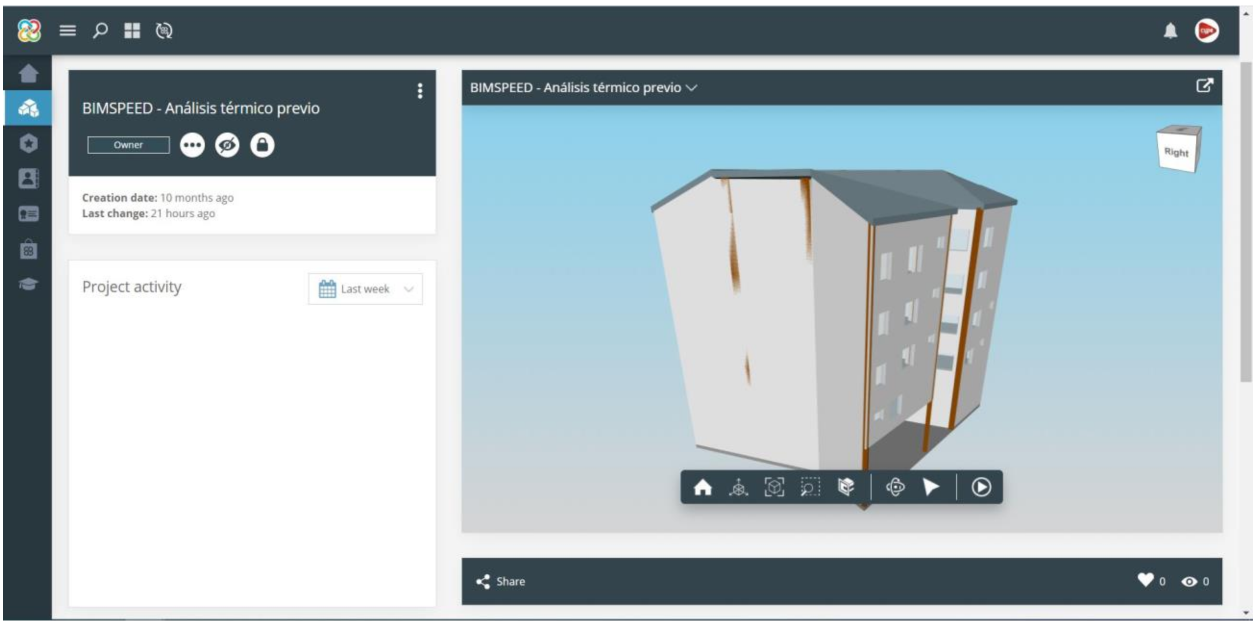



Figure 31. BIMserver.center project

### STEP 1 – Method 1: Upload the BIM model to BIMserver.center using Ifc Uploader

Ifc uploader is a tool developed by CYPE that is capable of processing any IFC model and uploading it to BIMserver.center. This application also generates a gtlTF model that allows the model to be viewed in the web browser, also from mobile devices and tablets.

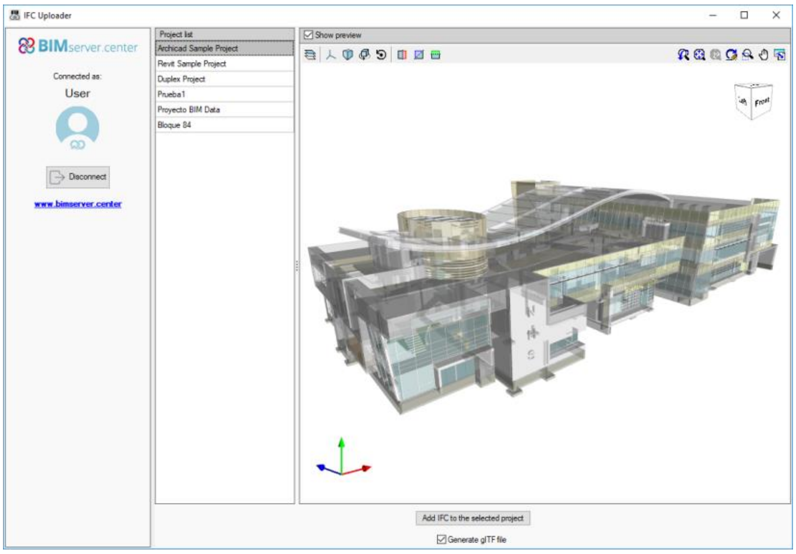



Figure 32. IFC Uploader

### STEP 1 – Method 2: Upload the BIM model to BIMserver.center using BIMserver.center's Revit addin

BIMserver.center also offers a free addin for Revit that allows the automatic upload of any Revit project to BIMserver.center. This pluggins support synchronization features, notifying the user of the changes that have occurred in the platform and even convert IFC entities into Revit native elements.

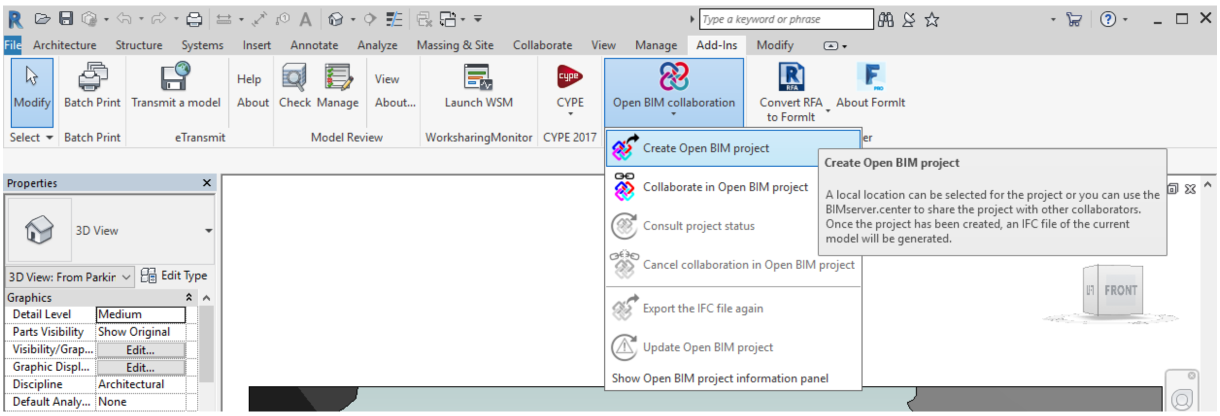
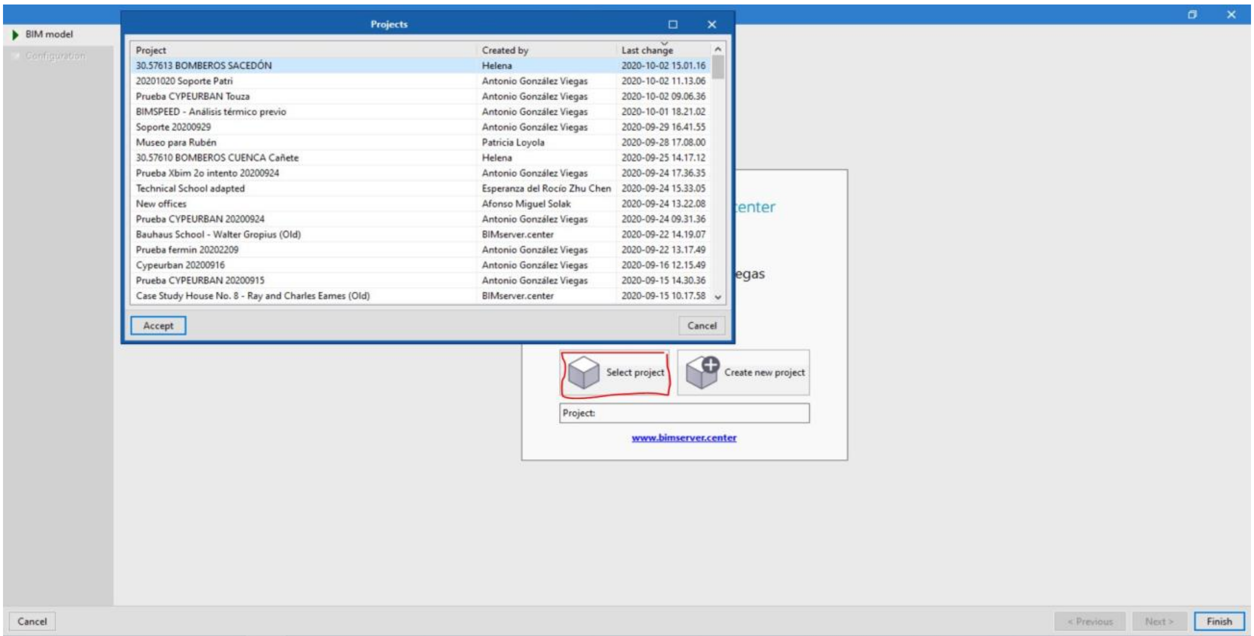



Figure 33. BIMserver addin for Revit

**STEP 2: Generate the geometry with Open BIM Analytical Model**

Now that the model is in BIMserver, it can be easily connected with the different tools that make use of BIMserver.center API. Any user that is part of this project will be able to open Open BIM Analytical Model and import the architectural model directly from the cloud. When Open BIM Analytical Model starts up, the user can either create a new project in BIMserver.center or use the information of an existing project; this last option is the most likely scenario, and allows the user to select any of the projects in which they is participating.



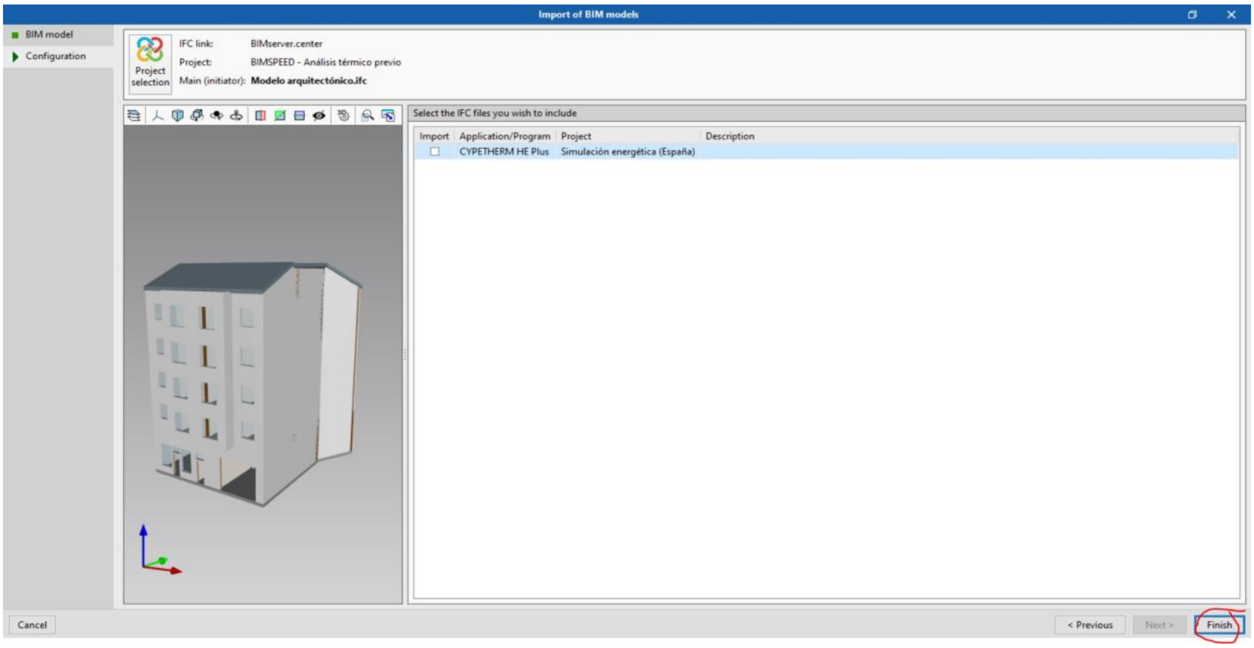
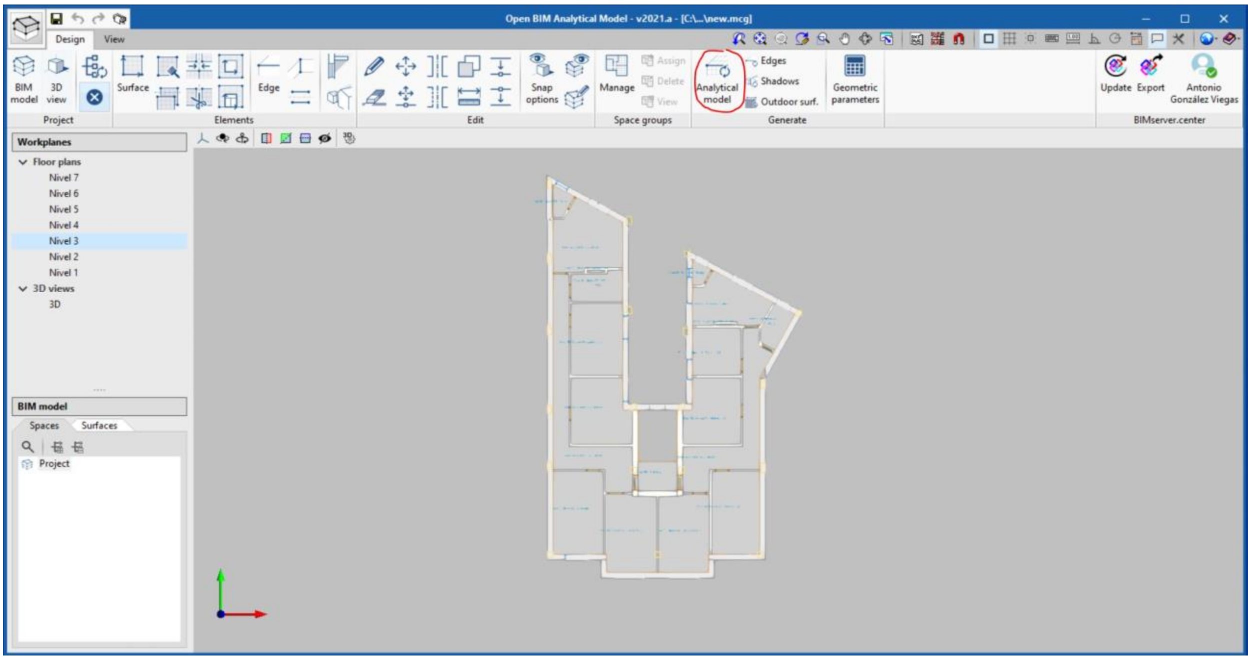



Figure 34. OB Analytical Model import process

Optionally, the user can bring additional layers of information from the project; this will make other information of the project (such as structure, MEP systems, etc) visible in OB Analytical Model 3d view. Once the project is loaded, the analytical model can be generated with the Analytical Model Generation button (highlighted below). This will open a new window with the calculation options.



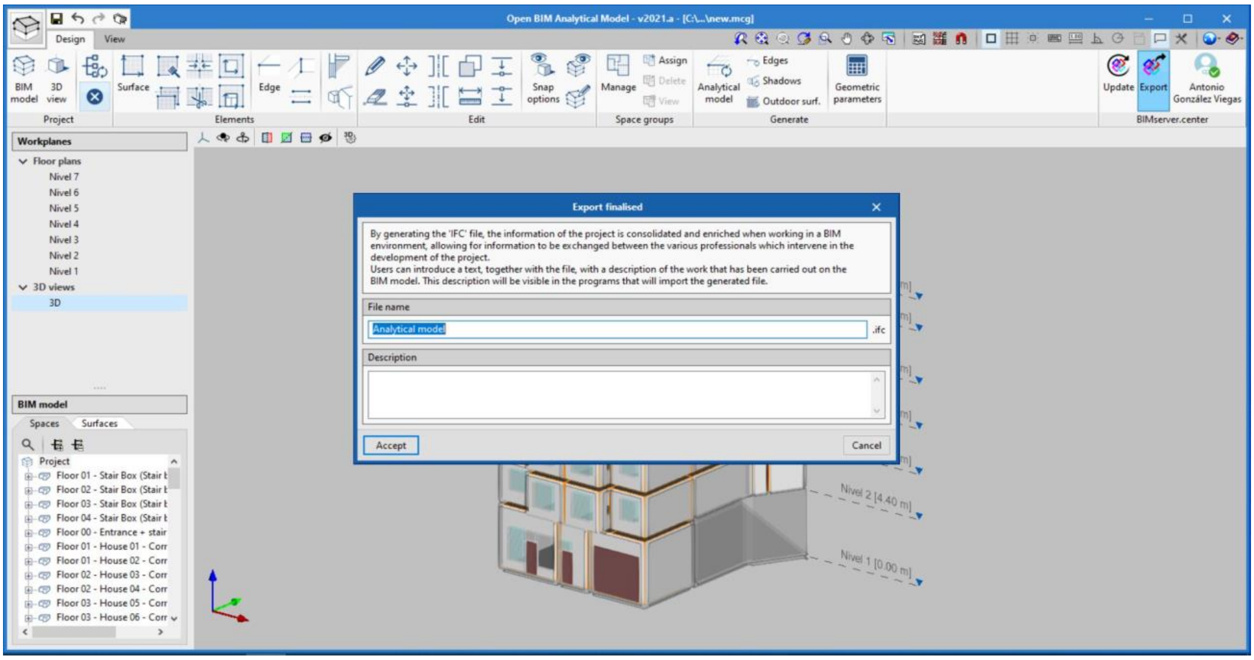
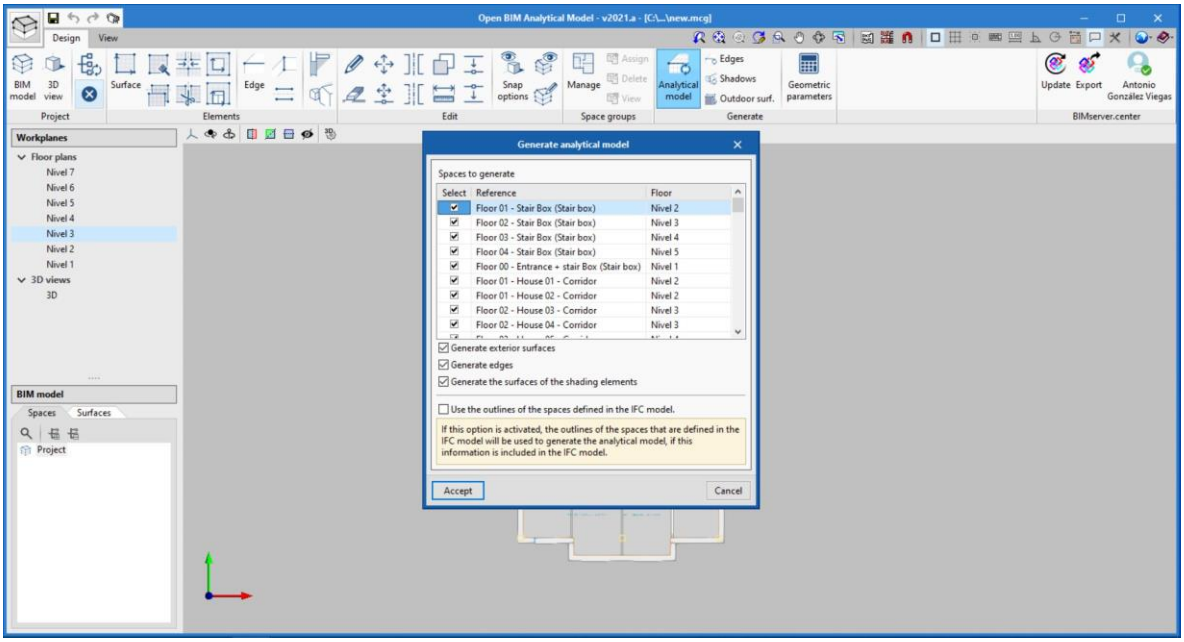



Figure 35. OB Analytical Model edge generation

The default options are suitable for the majority of the cases. Nonetheless, more information about these can be found in the official software documentation. By clicking “Accept”, the calculation and generation of analytical geometry will start. This process can take a couple of minutes depending of the hardware specifications of the user.



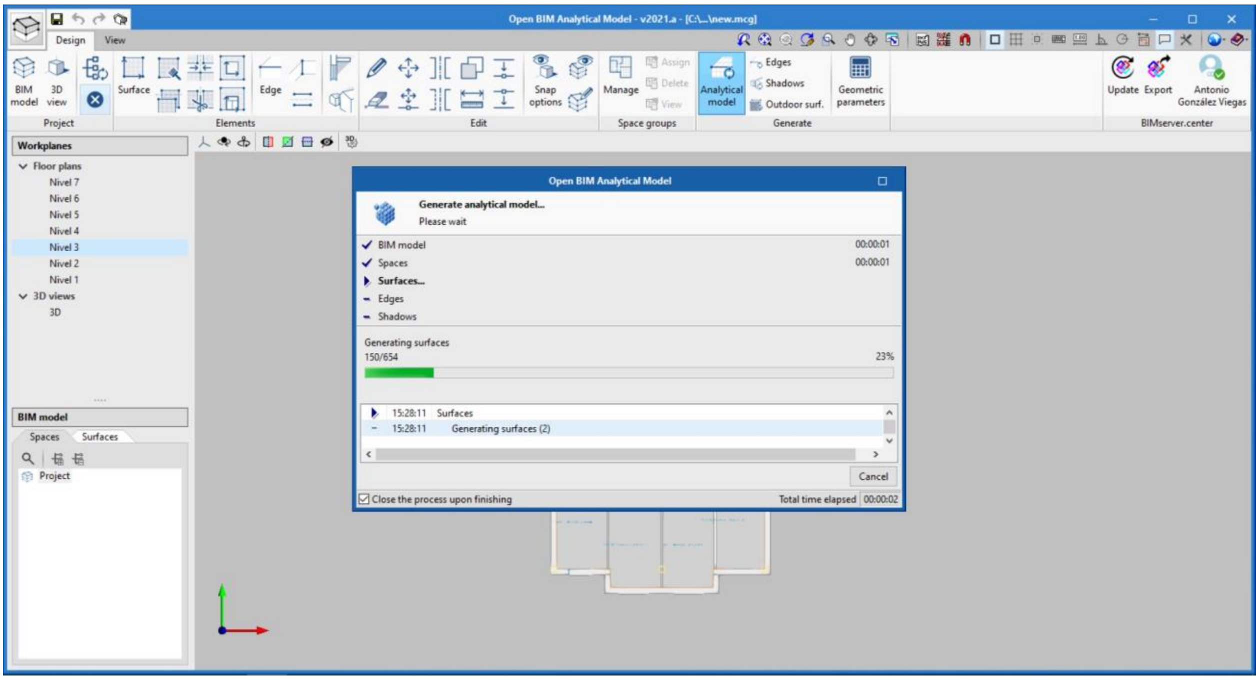



Figure 36. OB Analytical Model computation

Once the calculation has finished, the generated analytical model is visible pressing the visibility button highlighted above. This model includes the detailed definition of surfaces, edges and vertexes, as well as their geometric relationship. This information can be exported back to BIMserver.center using the Export button, allowing other collaborators of the project (or this user) to use it for later thermal analysic with specific tools such as CYPETHERM suite.

**STEP 3: Generate the constructive definition with**

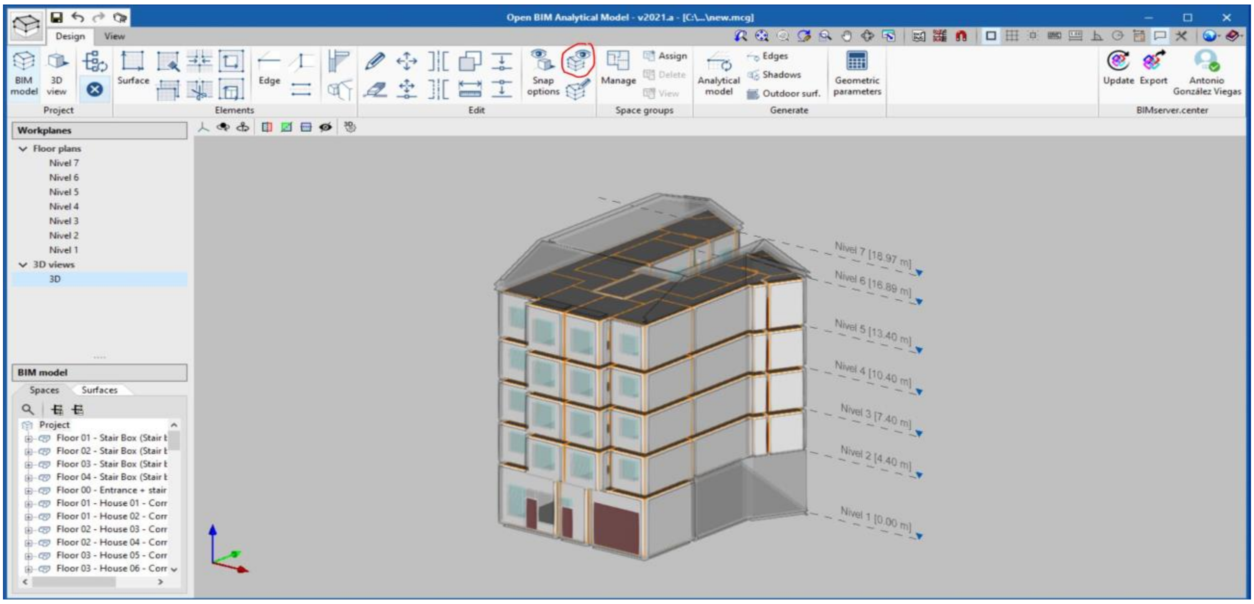



Figure 37. OB Analytical Model result

**STEP 4: Open BIM Construction Systems**

The import process in Open BIM Construction System is similar to the process of any other tool connected to the BIMserver.center API. Once the model has been imported, the user will be able to create construction systems by layers.

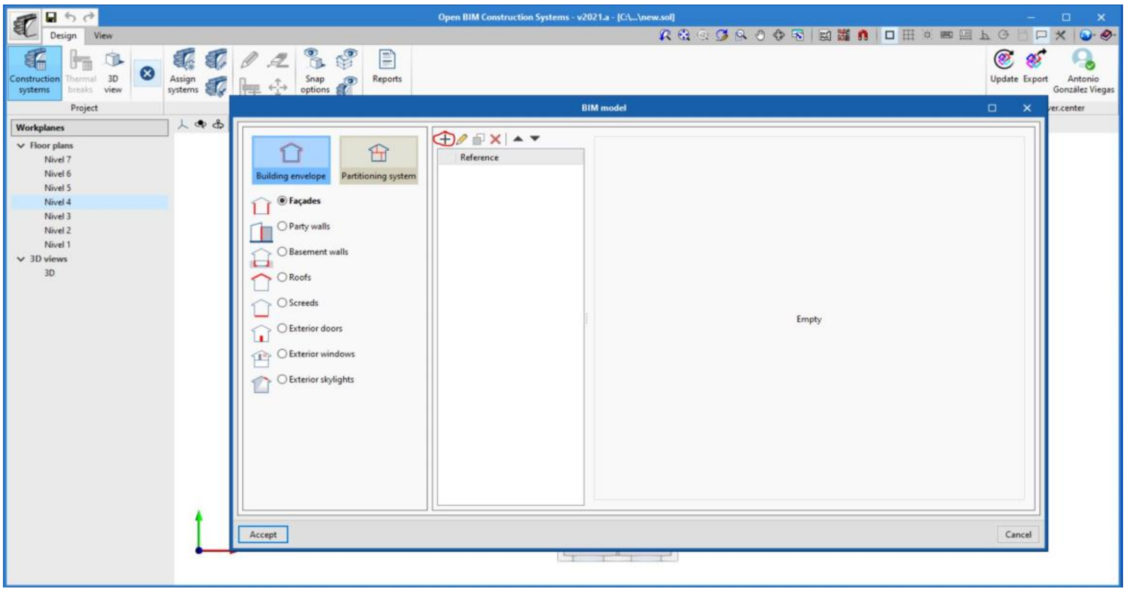



Figure 38. OB Construction systems entity creation

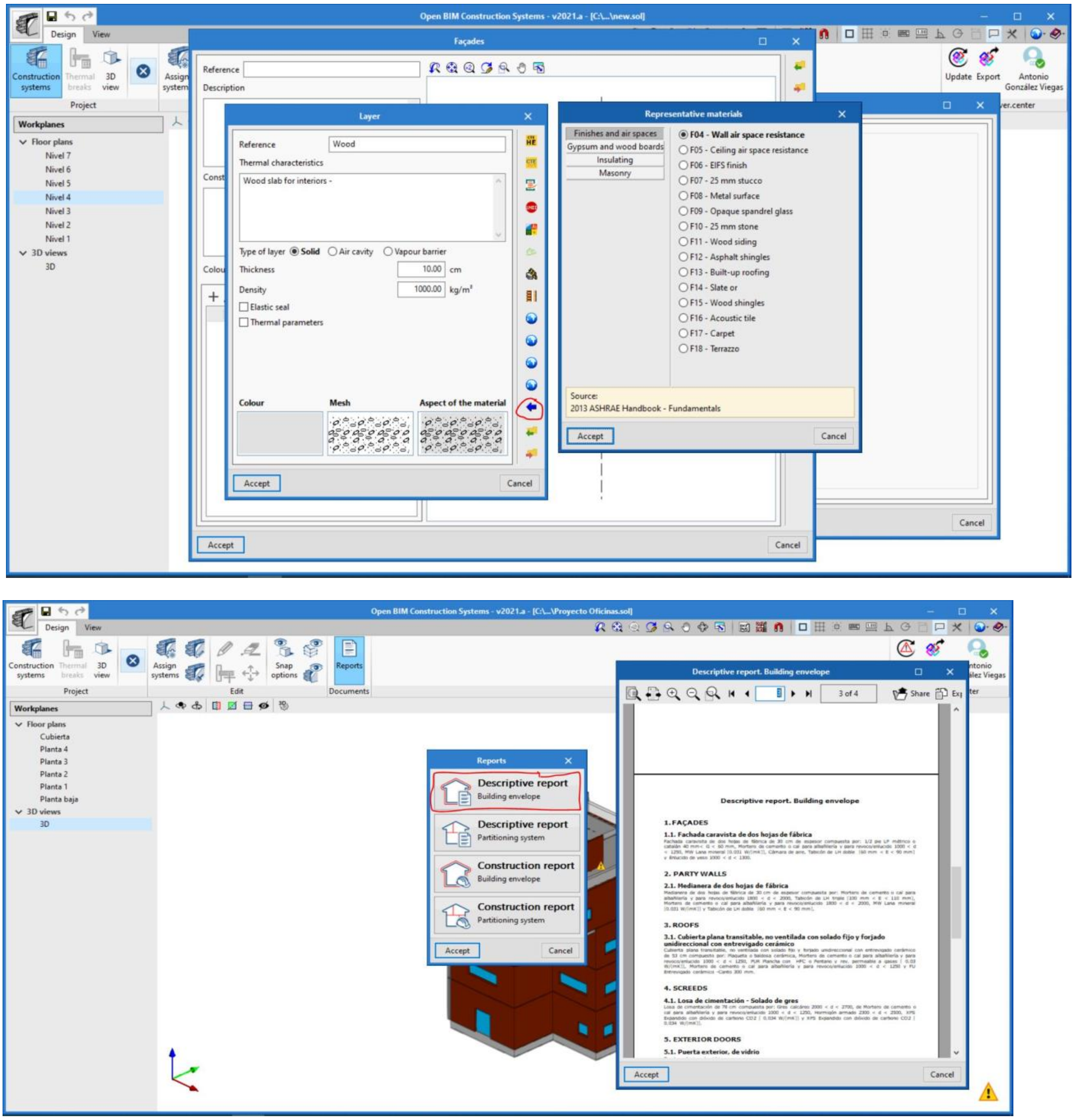



Figure 39. OB Construction Systems result export

There are two methods to define the systems;

- Defining all the properties of every layer by hand, using values from catalogues / studies.
- Using predefined values from one of the libraries included with the software.

The software will be able to generate automatic reports for the chosen systems in PDF. This information can be exported using the Export button, similarly to OB Analytical Model. Now, the BEM model is complete, composed by both exported models (geometry and construction). The BEM model is now ready for later calculation using specific analysis tools (f.e. CYPETHERM suite).

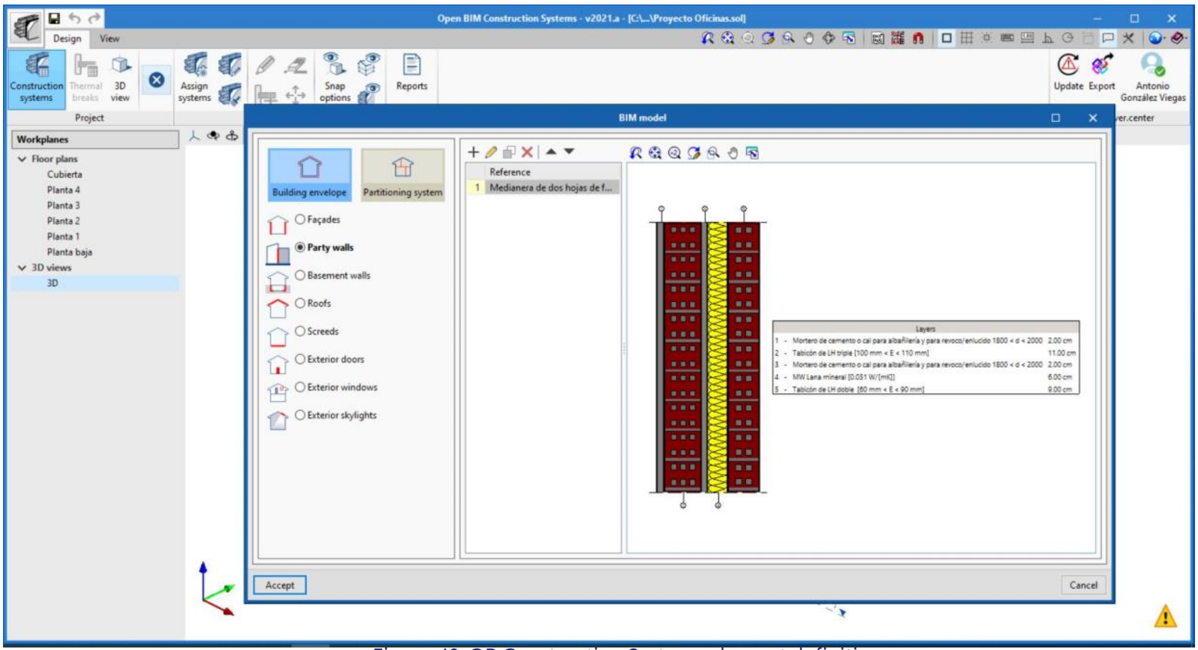



Figure 40. OB Construction Systems element definition