BIM Connectors for interoperability between different BIM tools and with the BIM-SPEED Platform

Deliverable D5.2

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

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Colophon

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Publishable executive summary

Within the context of the BIM-SPEED project, a complete list of Use Cases had been identified to collect different actions in the domain of the Building Renovation projects based on BIM and in its different stages: design, construction/renovation, operation and maintenance of the building. Every Use Case tries to solve a specific problem by using one or several BIM tools and services. Every tool and service needs a set of data inputs to operate, and provide a specific set of outputs. In most of the cases, the static and dynamic information collected from the buildings (IFC of the building, data coming from sensors, actuators and controllers) is provided to the BIM tools and services But in general, the format of the data provided by these buildings do not conform with the data format expected by the BIM tools and services to operate, and several data sources and formats can be considered for a simple tool. Under these circumstances, the need for homogenization of the information is crucial in order to reach interoperability between the BIM tools and services.

Based on the previous motivation, this deliverable type "*Other*" describes the actions developed to ensure the communication between BIM tools in different disciplines (energy, lighting, costs, etc.) and exchange between different types of data, thus contributing to the harmonization of information and fostering interoperability. To achieve this objective, this deliverable presents a conceptual interoperability architecture based on two integration frameworks and several BIM Connectors. These Connectors are in charge of transforming the input and output data of the different BIM tools and services and make them consistent with standard formats and models. Standardised ETL processes (Extract, Transform, and Load) have been established to enable the BIM Connectors to interchange information between the authoring software and the BIM-SPEED Platform. Supporting these processes, the BIM-SPEED platform offers a workflow management that automates de use of the BIM Connectors to allow BIM tools to operate. The identified ETL processes are being detailed in Information Delivery Manuals (IDM).

Considering the large number of Use Cases defined in the project, the interoperability exercise has been developed for a representative set of Use Cases, BIM tools and pilot buildings that cover different needs regarding data (static, dynamic) and transformations (with or without ETLs). This exercise will be extended to other Use Cases and BIM tools until the end of the project to enrich the BIM-SPEED platform with usable BIM tools for the building renovation process and convert this platform into a single access point of BIM tools and services.

List of acronyms and abbreviations

API: Application Program Interface

BACN: Building Automation and Control Network

BEPS: Building Energy Performance System

BIM: Building Information Model

CityGML: City Geography Markup Language

eBIM: extended Building Information Model

EEB: Energy-Efficient Buildings

ETL: Extract, Transform, Load

dBIM: dynamic Building Information Model

DSOs: Distribution System Operators

gbXML: green building XML schema

HVAC: Heating, Ventilation and Air Conditioning

IDM: Information Delivery Manuals

IFC: Industrial Foundation Classes

IoT: Internet of Things

MVD: Model View Definition

OCR: Optical Character Recognition

TRL: Technology Readiness Level

Definitions

Requirements

A requirement is a description and specification of the functionality desired for a system. It can also collect performance features of the system, such as availability, scalability, security, etc. From the end user point of view, a requirement represents a constraint imposed by the client on the development of a software product.

Data exchange requirement

This is a kind of requirements focussed on the specification of the information to be exchanged among different software elements and possibly the end-user. In this case, more than functionality, the requirements for data exchange specify the “Who”, “What”, “Where”, “When” and “How” data is shared in a software context.

Use Case

A use case is a scenario description that describes how software is to be used in a specific situation. It can be translated as a system function (specific functionality offered by the system) which is compliant with the requirements.

End-user

An expert that interacts with the BIM-SPEED platform in order to insert, analyse or retrieve data from it or also to operate, manage and configure the system. End-users are related to the actors intervening the building renovation process.

Workflow

The workflow defines a sequence of actions to carry out a specific task from the end user point of view.

Sequence diagram

A sequence diagram represents the communication flow between modules, components or objects to obtain a result. The sequence diagram follows a specific format and it will be used directly for the software development. Therefore, these diagrams are mainly focus on components and the sequence of interactions among them in a specific temporal order.

extendedBIM (eBIM)

Extension of the original BIM that includes additional information coming from static and dynamic data sources of a building.

dynamicBIM (dBIM)

Dynamic BIM is an extension of the original BIM (it is a subset of the extendedBIM) that includes not only static data such as the geometrical characteristics of buildings but also dynamic data related to them which change over time such as building energy consumption, internal comfort conditions, external weather, etc.

Pilot

Real scenario where the technology developed is validated for different TRLs. In the case of the BIM-SPEED project, a pilot is a building where different problems and solutions related to the renovation process are demonstrated.

BIM tool and services

Tools and services that use the Building Information Model representation as the basis of their data management.

BIM Connector

Software element that acts as gateway to connect heterogeneous BIM tools and services to the BIM-SPEED platform. This connector is in charge of contributing to the harmonization of information by transforming the information to be exchanged using standard data formats and models. Every BIM Connector within the BIM-SPEED project is composed by a set of ETLs.

ETL process

Process that covers three stages of the data management: Extraction, Transformation and Load. A properly designed ETL process extracts data from the source system, enforces data quality and consistency standards, conforms data so that separate sources can be used together, and finally delivers data in a presentation-ready format so that application developers can build applications and end users can make decisions.

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List of Figures & Tables

1. Introduction

1.1 Description of the deliverable content and purpose

The purpose of this deliverable is to present the conceptual architecture for the interoperability framework of the BIM-SPEED platform, and to show how the different interoperability elements have been designed and developed to obtain the integration of a set of BIM tools. With this aim, ETL processes to enable information exchange in EEB renovation projects, the IDM (Information Delivery Manuals) for the identified ETL processes, the reference pivot model to share data, and the operable BIM Connectors and associated APIs concerning the used BIM tools in BIM-SPEED are presented and described in detail. This deliverable is ready at M24 for a representative set of Use Cases and BIM tools, yet the implemented solutions will be continuously improved during the project for other Use Cases and associated tools.

1.2 Contributions of partners

Partners' contribution to the deliverable can be divided as follows:

Table 1: Contribution of partners

#	Partner	Contribution
1	**CARTIF**	Leader of the deliverable, task 5.2 and WP5. Coordination of the overall task activity. Designer of the conceptual interoperability architecture. Data exchange requirements definition for a representative set of Use Cases, BIM tools and demo-sites. Workflow identification, ETL and BIM Connectors development. Real time data integration (ThingsBoard) and static data integration in the BIM-SPEED platform. BIM Connectors demonstration in real cases (TRL6): BIM tools as Services of the BIM-SPEED platform.
2	**TUB**	Advisors and reviewers of the activity in the task and final version of deliverable D5.2.
3	**CSTB**	Definition of an ETL for IFC enrichment on material properties, development of an associated BIM connector in the form of a web service, support in the integration of BIM Connectors within the BIM-SPEED platform.
4	**HTV**	Contribution in the definition of data imputation, data checking and data quality plans.

1.3 Relation to other activities

The activity in task 5.2: *Interoperability between multidisciplinary BIM tools and services* is directly related to different Work Packages and tasks of the BIM-SPEED project since this task offers the interoperability framework to exchange building data. These data are used by the BIM tools and the BIM-SPEED platform, where all these elements are integrated (Figure 1).

Concretely, task 5.2 is closely related to WP1: *Collecting and understanding BIM data from existing buildings* regarding all the static and dynamic data; with WP2: *Creating As-Built BIM, BIM Passport, Family & Library* regarding the BIM information ontologies to be used in the pivotal model of the interoperability framework; and WP6 (*Implementing BIM cloud platform and data management*) regarding the interoperability with and through the BIM-SPEED platform.

WP5: *Developing open-interoperability solutions and standardisation* and task 5.2 is also closely related to WP2, WP3: *Creating and calibrating Building Energy & related analytical models* and WP4: *Conducting performance simulations of renovation scenarios* where different third parties' BIM tools are created and Use Cases identified.

Finally, task 5.2 is also related to WP8: *Demonstrating best practices of BIM for renovation*, linking the use cases and BIM tools with the BIM demo-sites.

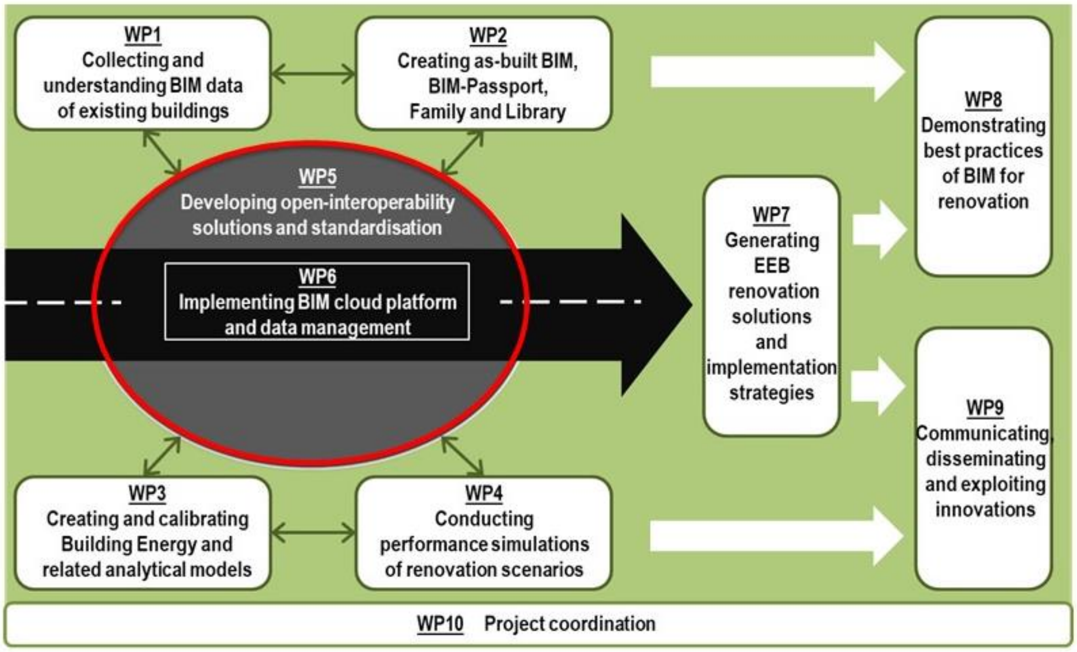

WP1
Collecting and understanding BIM data of existing buildings
WP2
Creating as-built BIM, BIM-Passport, Family and Library
WP5
Developing open-interoperability solutions and standardisation
WP6
Implementing BIM cloud platform and data management
WP7
Generating EEB renovation solutions and implementation strategies
WP8
Demonstrating best practices of BIM for renovation
WP9
Communicating, disseminating and exploiting innovations
WP3
Creating and calibrating Building Energy and related analytical models
WP4
Conducting performance simulations of renovation scenarios
WP10 Project coordination

Figure 1: WP5 relation to other WPs and activities

2. Workflow and requirements identification for data exchange

2.1 Methodology for identification of requirements for data exchange

The main objective of task 5.2: *Interoperability between multidisciplinary BIM tools and services* is to ensure the communication between the BIM tools, used and generated as part of the BIM-SPEED project and covering different disciplines (energy, lighting, acoustics, costs, etc.), and to guarantee the exchange of different types of data (static and dynamic data of the building in different formats). The purpose is to contribute to the harmonization of information and to foster interoperability.

In order to reach this objective a set of BIM Connectors, supported by different ETL processes, are proposed, able to transform and translate data from their data model and format in the data source to the data model and format in the consumer, that is, in the BIM tools.

The first action towards the development of these BIM Connectors is to identify the workflows for data exchanges between the BIM tools to be integrated into the BIM-SPEED platform and the static and dynamic data sources of a building. The definition of these workflows will help in the extraction of convenient requirements for data exchange.

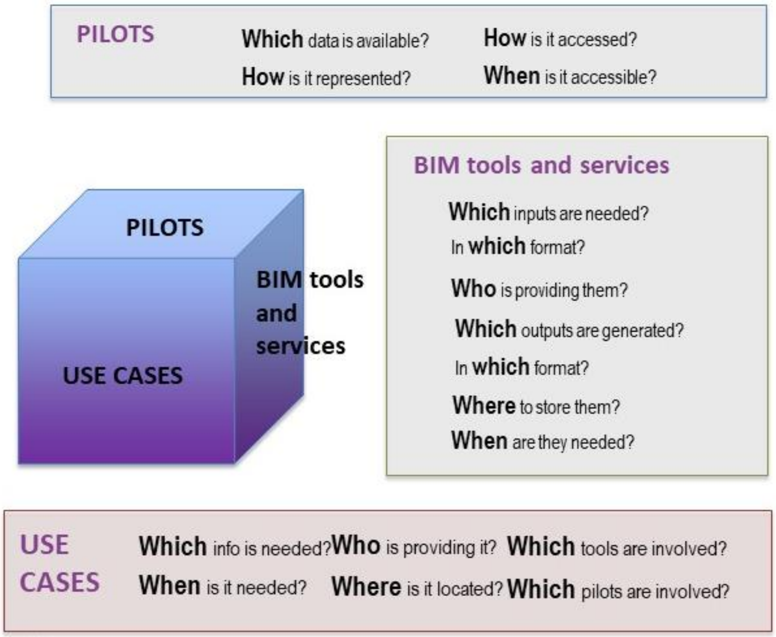


Figure 2: Questions for data exchange requirements collection

The methodology proposed to define workflows and identify the requirements for data exchange is to answer a set of questions affecting data interoperability from different perspectives (see Figure 2), and to link all these answers towards the homogenization of inputs and outputs among the three involved elements: **demo-sites or pilots**, **BIM tools and services**, and **Use Cases** defined within the BIM-SPEED project.

The ***rationale*** that relates these three worlds is:

A **Use Case** tries to cover a specific problem in the scope of the building renovation based on BIM, and to solve this problem must use one or several BIM tools and services. Each **tool and service** needs a set of data inputs to operate and provide a specific set of outputs. In most of the cases, the inputs feeding every tool and service are provided by the **pilots**, in both, their static and dynamic representation. In general, the format of the data provided by the pilots do not conform to the data format expected by the BIM tools and services to operate, and several data sources and formats can be considered for a simple tool. Under these circumstances, the need for homogenization of the information is crucial in order to reach the interoperability between the BIM tools, services and the pilots.

From the **pilots'** point of view, the requirements for data collection and exchange are obtained answering the following questions:

- Which data of the pilot is available? (covering both, static and dynamic data)
- How is it represented? (data format)
- How is it accessed? (communication protocols)
- When is it accessible? (specific moment during the flow when this info is needed)

From the **BIM tools and services**' point of view, the requirements for data collection and exchange are obtained answering the following questions:

- Which inputs are needed? (to make the tool/service operative)
- In which format are these inputs needed? (data format of the inputs)
- Who is providing them? (identification of the input data source)
- Which outputs are generated? (results of the tool/service)
- In which format? (data format of the outputs)
- Where these outputs should be stored? (BIM-SPEED platform, outputs provided directly to the user, etc.)
- When are these inputs and outputs needed? (in relation to the use case and when it is executed)

From the **Use Cases**' point of view, the requirements for data collection and exchange are obtained answering the following questions:

- Which information is needed to launch the Use Case?
- When is this information needed? (specific moment during the flow when this info is needed)
- Who is providing this information? (pilot, BIM tool/service, BIM-SPEED platform)
- Where this information is located? (pilot, BIM tool/service, BIM-SPEED platform)
- Which tools are involved in the Use Case? (one or several)
- Which pilots are involved in the Use Case? (in which pilot the Use Case will be validated)

Considering that the BIM-SPEED project counts on 14 demo-sites (or pilots), 42 Use Cases and more than 20 BIM tools/services (see Figure 3), a set of representatives Use Cases, tools and pilots have been chosen to implement the methodology for identification of requirements for data exchange.

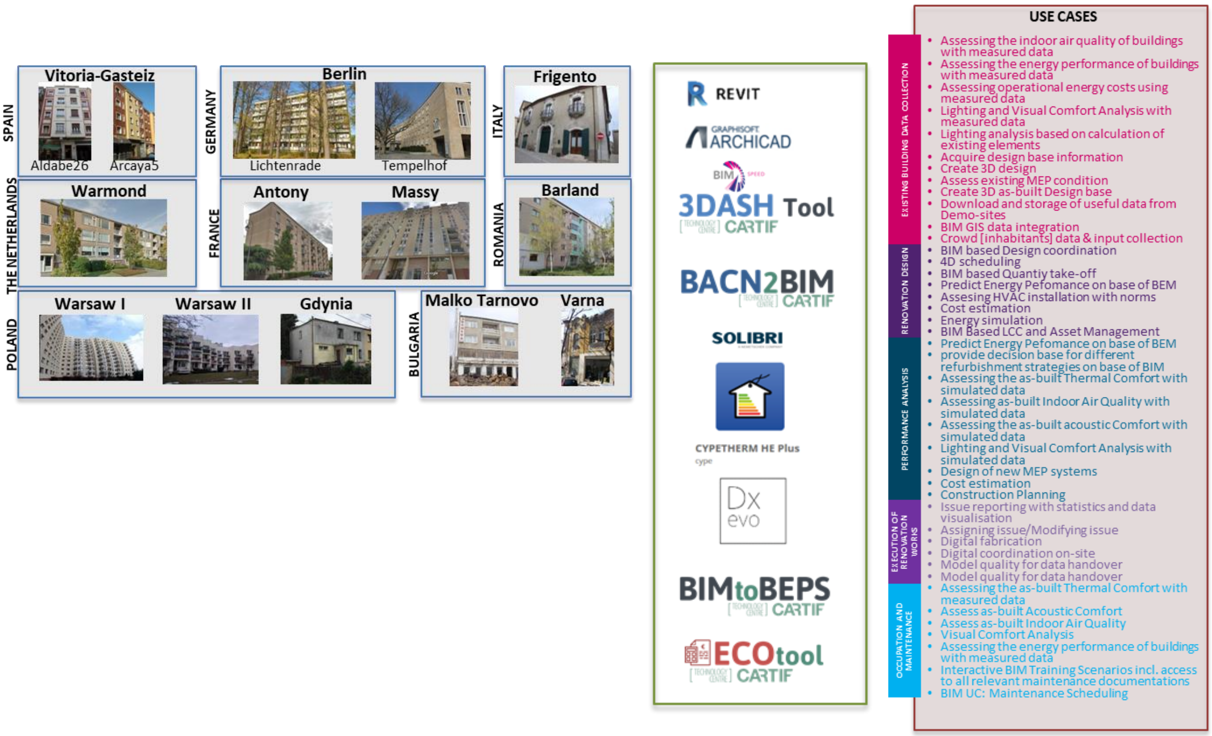

SPAIN
Vitoria-Gasteiz
Aldabe26
Arcaya5
GERMANY
Berlin
Lichtenrade
Tempelhof
ITALY
Frigento
THE NETHERLANDS
Warmond
FRANCE
Antony
Massy
ROMANIA
Barland
POLAND
Warsaw I
Warsaw II
Gdynia
BULGARIA
Malko Tarnovo
Varna
REVIT
ARCHICAD
3DASH Tool
CARTIF
BACN2BIM
SOLIBRI
CYPETHERM HE Plus
Dx evo
BIMtoBEPS
ECOtool
USE CASES
EXISTING BUILDING DATA COLLECTION
Assessing the indoor air quality of buildings with measured data
Assessing the energy performance of buildings with measured data
Assessing operational energy costs using measured data
Lighting and Visual Comfort Analysis with measured data
Lighting analysis based on calculation of existing elements
Acquire design base information
Create 3D design
Assess existing MEP condition
Create 3D as-built Design base
Download and storage of useful data from Demo-sites
BIM GIS data integration
Crowd [inhabitants] data & input collection
RENOVATION DESIGN
BIM based Design coordination
4D scheduling
BIM based Quantiy take-off
Predict Energy Pefomance on base of BEM
Assesing HVAC installation with norms
Cost estimation
Energy simulation
BIM Based LCC and Asset Management
PERFORMANCE ANALYSIS
Predict Energy Pefomance on base of BEM
provide decision base for different refurbishment strategies on base of BIM
Assessing the as-built Thermal Comfort with simulated data
Assessing as-built Indoor Air Quality with simulated data
Assessing the as-built acoustic Comfort with simulated data
Lighting and Visual Comfort Analysis with simulated data
Design of new MEP systems
Cost estimation
Construction Planning
EXECUTION OF RENOVATION WORKS
Issue reporting with statistics and data visualisation
Assigning issue/Modifying issue
Digital fabrication
Digital coordination on-site
Model quality for data handover
Model quality for data handover
OCCUPATION AND MAINTENANCE
Assessing the as-built Thermal Comfort with measured data
Assess as-built Acoustic Comfort
Assess as-built Indoor Air Quality
Visual Comfort Analysis
Assessing the energy performance of buildings with measured data
Interactive BIM Training Scenarios incl. access to all relevant maintenance documentations
BIM UC: Maintenance Scheduling

Figure 3: Demo-sites, Use Cases and some of the BIM tools of the BIM-SPEED project

Following the previous rationale, 4 Use Cases (UC) have been analysed offering different scenarios of data needs, data exchange and interoperability, as shown in Table 2 below.

Table 2: Set of representative Use Cases for data exchange requirements identification

UC_Id	BIM use case	Method	Tool/services	Data exchange
UC_1	Create 3D design	3D Modelling of existing asset based on points clouds	3DASH Tool[1]	Access to static data without ETLs
UC_2	Predict Energy Performance based on BEM	Building Information Model (BIM) to Building Energy Model (BEM)	BIMtoBEPS[1]	Access to static and semi-static data with ETLs
UC_3	Download and storage of useful data from Demo-sites	Collect data based on other API defined by device installers	BACN2BIM[1]	Dynamic data collection using static data and ETLs
UC_4	Assessing the energy performance of buildings with measured data	Assessing operational energy costs using measured data	ECOtool[1] BACN2BIM	Access to static and dynamic data using ETLs

[1] Developed by CARTIF

The selected Use Cases use four BIM tools that need different data inputs and formats to operate, starting from the simple case of accessing directly to static data of the pilot without the need of transforming this data into a specific data format, to the complex case of accessing to static and dynamic data of the pilot with the need of transforming these data to the specific data format of the BIM tools. The four Use Cases and BIM tools are validated in this task in four demo-sites: ALDABE26 and ARCAYA 5 in Vitoria-Gasteiz (Spain), WARSAWII (Poland) and Massy (France).

The workflows defined for each of the Use cases and BIM tools are described in detail in the following section.

2.2 Workflow definition

In this section, the different workflows needed to operate with the different BIM tools, according to the requirements of the specific Use Cases, are defined in a conceptual manner.

UC_1 - Create 3D design: 3DASH Tool

The Use Case 1 uses the **3DASH Tool** (developing within WP1: *Collecting and understanding BIM data from existing buildings*) to 3D modelling of existing asset based on point clouds. This 3DASH Tool (3D Automatic Surfaces Handling) is a specific tailored REVIT plug-in programmed in C++ and supported by *Point Cloud Library* (PCL). The conceptual diagram of the 3DASH Tool is shown in Figure 4.

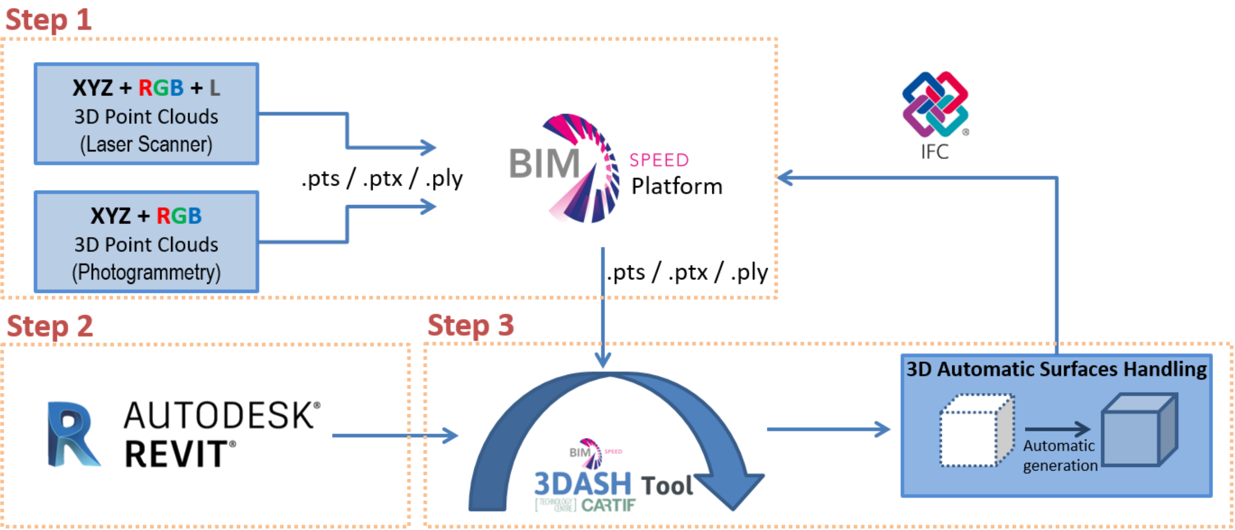


Figure 4: 3DASH Tool conceptual diagram

The 3DASH Tool uses 3D point clouds as input, which are made up of geometry (XYZ coordinates) and colour (RGB used to show a more realistic appearance). The reflectance of the object when it is incised by the laser (L) is not used in the calculations of the plug-in. Within the BIM-SPEED project, the 3D point cloud provider is the BIM-SPEED platform, from where the raw 3D point cloud of the building in .pts/.ptx/.ply format is obtained (once loaded by the user) but the 3DASH Tool can be also executed independently of the

BIM-SPEED platform. The final as-Built IFC generated as results of the process can be stored again in the BIM-SPEED Platform.

Following the concept of the 3DASH Tool defined in Figure 4, the process of the tool is illustrated in Figure 5, where the user interaction is required: obtain the point clouds by laser scanning or photogrammetry systems and transform them to a valid input format .pts/.ptx/.ply (Step1); install the 3DASH add-in in REVIT (Step2); execute the tool in REVIT (Step3), modify the BIM model after the automatic generation (it is necessary to edit the join and properties of some of the elements generated) and export the BIM model to IFC.

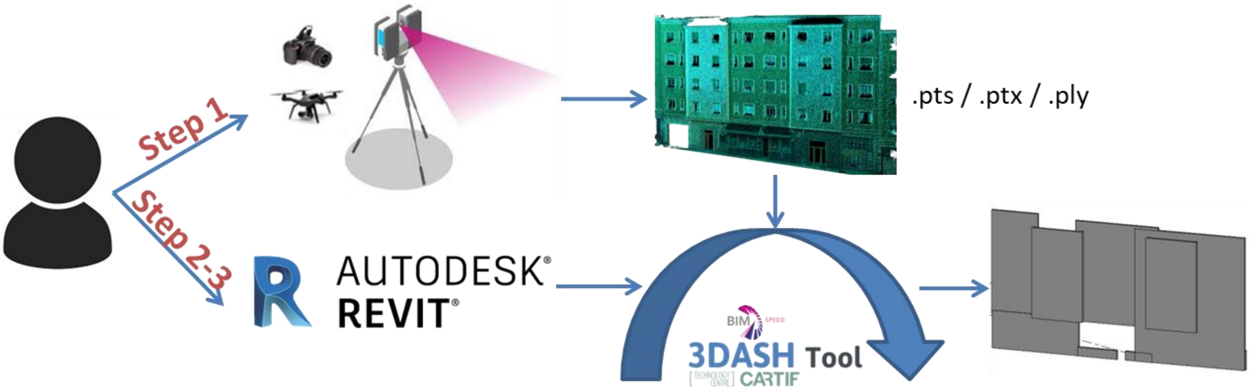


Figure 5: User interaction and process for automatic shaping into REVIT through the 3DASH tool

More specific information about the 3DASH Tool is explained in D1.1: *Methods for architectural, structural, thermal 3D data acquisition of existing buildings* of the BIM-SPEED project.

UC_2 - Predict Energy Performance on base of BEM: BIMtoBEPS

The Use Case 2 uses the BIMtoBEPS tool (developed within WP3-*Creating and calibrating Building Energy & related analytical models*) to predict the energy performance based on Building Energy Modelling. This BIMtoBEPS tool is a combination of ETL processes and BIM Connectors that have the aim to transform the IFC file into a TRNSYS-compliant simulation file, feeding it with meteorological data and using IFC enriched with some information that is not exported by BIM software. As for REVIT (which is one of the main BIM software used), thermal parameters of the materials and schedules (occupancy, lighting, etc.) are not exported to IFC using original IFC exporter. Conceptually speaking, Figure 6 shows the schema how the BIMtoBEPS tool works.

Within the BIM-SPEED project, the IFC file is obtained (once loaded by the user) from the BIM-SPEED platform repository, but the BIMtoBEPS tool can be also executed independently of the BIM-SPEED platform. As stated before, if thermal parameters are not included in the IFC file, the tool can enrich the IFC with the required user intervention (see *D3.2: A set of support tools and standardised procedures for BEM creation* for more details). Provided that the schedules (as stated above, occupancy, lighting, etc.) are correctly defined in the IFC file, the tool is able to use this information. On the contrary, default schedules from the REVIT library associated to different space types can be used. In this case, it is a requirement that each space is related to a given space type definition. Next, via existing web services and using the location/coordinates included in the IFC, weather files can be automatically generated in order to feed the TRNSYS modules with, in this case, EPW (EnergyPlus Weather) format. At this stage, the TMY service provided by the JRC has been used, while MEEREN weather service, developed in *T1.4: Environmental, climate and surroundings data* of the BIM-SPEED project and explained in *D1.4: IT solutions to couple environmental, surroundings and weather data to BIM*, will be analysed in next iterations of this Use Case. As well, for prediction, Weatherbit has been selected as initial web service for forecast, while, similar to before, MEEREN will be analysed as forecasting is under development, such as reported in D1.4. Finally, the simulation can be run and results stored again in a BIM Platform (e.g. BIM-SPEED platform repository).

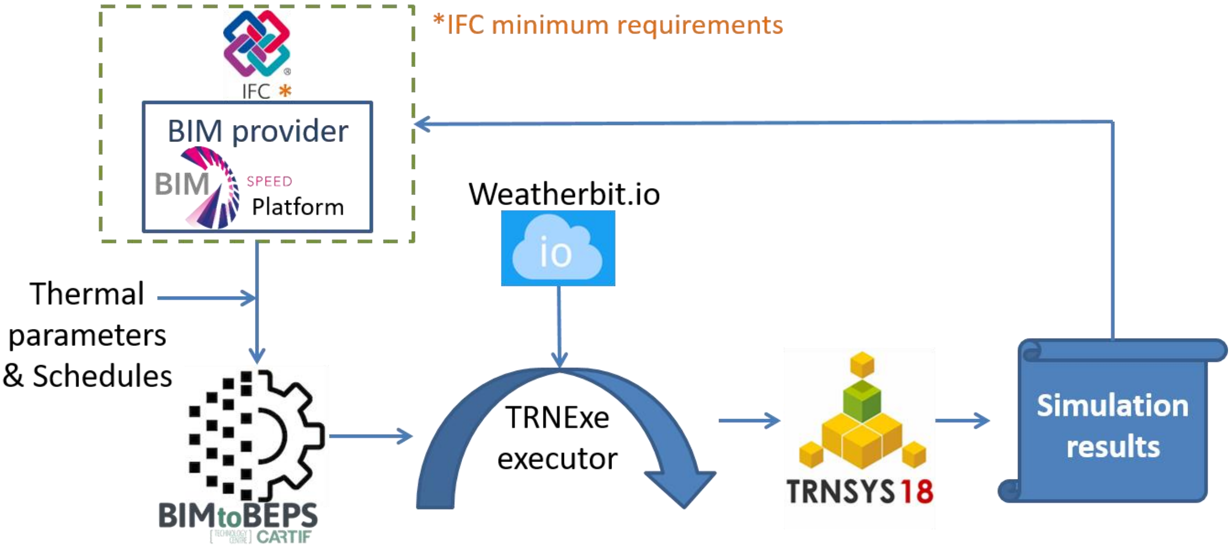


Figure 6: BIMtoBEPS tool conceptual diagram

According to this concept (Figure 6), the process is illustrated in Figure 7 where the user plays an important role because its interaction is required to execute the tool and receive the final results, as well as for defining some of the elements of the simulation model (e.g. thermal properties or windows types). It should be highlighted that the BIMtoBEPS tool is indeed developed under *WP3: Creating. And calibrating Building Energy and related analytical models*. However, it is manually fed with data and, within WP5-*Developing open-interoperability solutions and standardisation* of the BIM-SPEED project, the interoperability with data available in the multiple repositories is implemented, aiming at feeding the tool with existing information. As observed in the Figure 7, once the IFC file is specified (got it from the BIM-SPEED platform), the first step is the checking of the IFC file and the properties to determine missing properties or inconsistencies. If any is detected, then, it is needed the enrichment of such a file, whereas, in parallel, the EPW web service is executed to retrieve the climate data in .epw format (according to the TRNSYS type used). Then, the BIMtoBEPS tool can be executed to generate the simulation model. Finally, the execution of the simulation is performed via TRNExe and/or the use of weather forecast. Here, two possibilities arise. First, TRNSYS could be run with the historical weather data file generated in the previous step (EPW web service) or using forecasted data from climate services, such as Weatherbit. It is important to remark the difference among both services: one provides the historical weather file in .epw format, while the second covers the forecasting to override the original EPW file in order to simulate the predicted energy for the forecasted climate conditions.

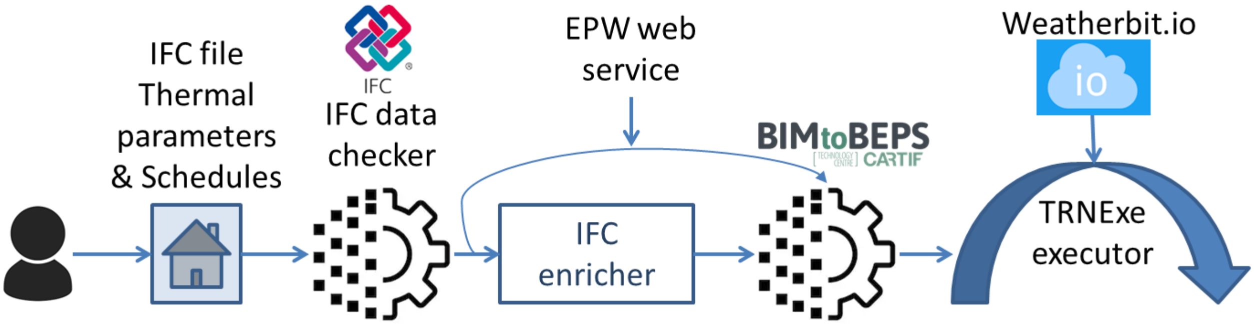


Figure 7: BIMtoBEPS tool process

More specific information about the BIMtoBEPS tool is explained in *D3.2: A set of support tools and standardised procedures for BEM creation* of the BIM-SPEED project.

UC_3 - Download and storage of useful data from Demo-sites: BACN2BIM

This use case is composed of two different uses of the same tool, BACN2BIM (developed within WP1: *Collecting and understanding BIM data of existing buildings*). This tool has been developed as part of the BIM-SPEED project to cover the need of having “real-time” data of the behaviour of the buildings (dynamic data as a result of the building operation) and their storage in an IFC compliant repository to match these data with the model of the building (BIM) and to have these data available to be used in other applications and tools of the BIM-SPEED project. This tool offers two different operations; On the one hand, the tool is able to connect to the demo projects where some monitoring systems have been deployed. In the BIM-SPEED project they are mainly based on ComfortEye[2] and ENERGOMONITOR platform (commercial solution). Then, after uploading some configurations by means of a .csv file, the tool starts retrieving data from demo projects. After these raw data are read the tool stores them into a common database that has been developed and deployed to be compliant with IFC4 (ADD2-TC1 schema version) (standard for interoperability in BIM projects). This database is part of an open-source IoT platform called ThingsBoard, which provides the users of BIM-SPEED project capabilities to connect to it and then seeing/downloading data to be used in other applications. In the BIM-SPEED project, this platform is used as the main storage system for dynamic data.

Users can to select which data they want to download from which demo project and from which monitoring systems (or installed devices). Then data can be downloaded in two different formats .csv and .json which can be used in other applications such as calibration of building energy model with real data. To both ends, the tool uses the ThingsBoard API to store in and download data from it. A representation of this operation approach is shown in Figure 8.

[2] Developed by UNIVPM

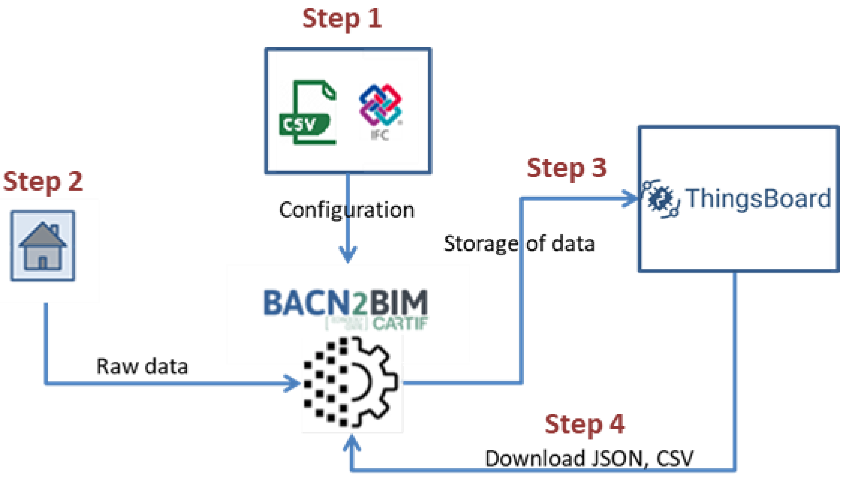


Figure 8: BACN2BIM conceptual diagram and process

More specific information about the BACN2BIM tool is explained in *D1.3: IT solutions to couple dynamic data of the existing buildings to BIM* of the BIM-SPEED project.

UC_4 - Assessing the energy performance of buildings with measured data: ECOtool

This Use Case is focussed on the calculation of economic indicators affecting the occupation and maintenance phase of the renovation process, as for example the Operational Energy Costs or the Payback Period (KPIs defined in *D4.1: Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation* of the BIM-SPEED project). In order to cover this Use Case, the ECOtool[3] is used. This tool is able to calculate several economic indicators (Operational Energy Costs, Investment, Life cycle cost, Return of Investment, Payback Period, etc.) using static and dynamic data of the building as inputs (see section 3.1). These data are collected from different data sources and with different data formats and have to be provided to the ECOtool in a .xml file. Therefore, a combination of ETLs are required for the integration and interoperability of this tool mainly to parse the information coming from the IFC, energy bills or even configuration files provided by the user, and to obtain energy carriers from already available services. The interoperability with the dynamic repository of the BIM-SPEED platform (ThingsBoard) is also needed to extract information regarding the energy (electricity and fuels) consumption of the building under consideration.

From a conceptual point of view, Figure 9 shows the schema of how the ECOtool works. Again, the IFC file is provided in the BIM-SPEED platform, where possible energy bills and other configuration information related to energy consumption and costs is also accessible. In addition, IoT information is collected from the ThingsBoard platform, when available, to obtain the real consumption measured directly in the building. Other information has to be included manually by the user, mainly related to the maintenance costs of the energy systems. Finally, the ECOtool has to be fed with the electrical and fuel prices. This information can

[3] Developed by CARTIF as part of the EU H2020 OptEEmAL project (GA 680676) and adapted in task 5.2 to comply with the KPIs defined in *task 4.1: Baseline, KPI and Use Case definition and verification* of the BIM-SPEED project

be obtained directly from the energy bills, but geo-clustering services as EUROSTAT can be also used to collect automatically (using its APIs) the energy carriers per country. Using all this information the ECOtool is able to calculate the Operational energy cost KPI. Adding other inputs like the initial investment cost or the energy price increase, the Payback Period KPI can be also obtained.

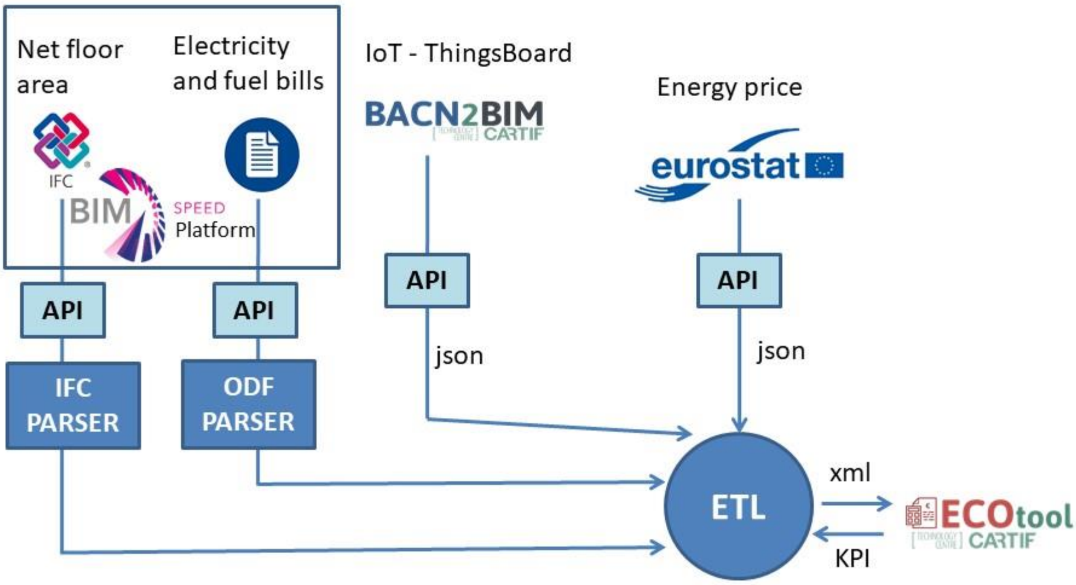


Figure 9: ECOtool conceptual diagram and process for the Operational energy cost calculation

Finally, the economic KPI calculations can be run and results stored again in the BIMSPEED platform repository.

2.3 Requirements for data exchange

According to the definition of each one of the use cases, now, it is time to determine the data requirements to allow the full operation of the Use Case. To that end, Table 3 summarises the data requirements that are illustrated in the conceptual diagrams above.

As it is observed, the use cases require a set of data in order to be capable of running the associated tools. In this sense, it **depends on the modelling of the IFC file** in some cases. For instance, looking at **UC_2**, one of the most important requirements is the materials properties, which is usually not included in the IFC due to interoperability problems between BIM software when exporting to IFC (e.g. REVIT). Besides, sometimes, the modeller does not include all the information within the specific IFC class. Hence, somehow, the material properties should be available as the energy demand of the building depends on them.

Table 3: Data requirements for the use cases

Use case	Associated tools	Data requirements
UC_1	**3DASH Tool** (REVIT plug-in)	3DASH add-in (BimSpeed.addin available to download from the BIM-SPEED platform) Point clouds in .ply, .pts or .ptx format
UC_2	**BIMtoBEPS tool**	IFC file Materials properties (.xls file if not included in the IFC)) Schedules (from internal library by default if not included in the IFC) Windows parameters (by user intervention) Weather file (.epw file)
UC_3	**BACN2BIM**	IFC file Configuration .csv file including user, password and other monitoring systems information Monitoring system/devices able to communicate data previously deployed
UC_4	**ECOtool** **BACN2BIM**	IFC file – Net floor area Final energy consumptions Energy prices Maintenance costs Other costs for energy services

3.1 Inputs and outputs identification based on BIM-SPEED Use Cases, BIM tools and services

Within this section, the data requirements previously summarised are analysed. The main aim is to identify the input and output of each dataset and their data sources. To that end, 3 possibilities to get data are specified:

- Optimistic: This data source represents the "ideal" situation in which the information can be acquired automatically (or almost automatically) in order to facilitate the execution of the ETLs.
- Realistic: This is the situation as it is being developed in the current status, which depends on data availability and accessibility.
- Pessimistic: This would reflect the worst situation and almost all the cases require the user interaction and manual loading of data.

UC_1 - Create 3D design: 3DASH Tool

Table 4 compiles the input and outputs of the 3DASH Tool in the three variants: optimistic, realistic and pessimistic. It should be noted all the data inputs are static (no changes unless user intervention).

Entering into the details of each input:

- 3DASH add-in: The first input to launch the 3DASH Tool is to download the add-in file, in .zip format. After download the file, install the 3DASH add-in in REVIT following the instruction of the *Readme.txt* file.
- Point clouds (.ply/.pts/.ptx): These point clouds made up of geometry (XYZ coordinates) and colour (RGB coordinates: real appearance) can be directly handled by the tool.

Table 4: Data inputs for the UC_1

Input	Type	Data source 1 (Optimistic)	Data source 2 (Realistic)	Data source 3 (Pessimistic)
3DASH add-in	Static	BIM-SPEED platform	External repository	Manual loading
Point Clouds (.ply/.pts/.ptx)	Static	BIM-SPEED platform	Manual loading	Manual loading

With respect to the outputs of the **UC_1**, basically, these can be summarised in one:

- .ifc file, which is the results of the automatic generation of architectonic features from a given point cloud of a building. This IFC generated shows the As-built building.

UC_2 - Predict Energy Performance base on BEM: BIMtoBEPS

With respect to the UC_2, Table 5 compiles the input and outputs of the BIMtoBEPS in the three variants: optimistic, realistic and pessimistic. It should be noted all the data inputs are static (no changes unless user intervention) with the exception of the weather file that is semi-static and depends on the selected years to generate the historical EPW file, as well as the transformation with weather forecast. The reason of being semi-static is that the input can change, but the frequency is low to be dynamic.

Entering into the details of each input:

- .ifc file: Ideally, this IFC file should be available on the BIM-SPEED platform, otherwise a repository should be accessible to obtain the IFC file, while the pessimistic situation deals with the direct uploading from the user. At the moment, and as depicted in the sequence diagram, the optimistic situation is approached, executing the tool from the BIM-SPEED platform. Nevertheless, the option to the user for uploading a different IFC file is implemented, providing both the automatic and manual possibilities.
- Materials properties: In this case, ideally, the BIM software exporters should provide the materials information. The current situation is that material properties are missing in the exported IFC file, so an enrichment functionality has been made available in the tool. The user can check if the information related to material properties is available, and in case not, the tool provides a pre-filled Excel file to include missing information. Then, the user uploads it, and the tool automatically enriches the IFC according to the official IFC standard. The pessimistic situation would be the case of providing a form to the user to input the materials data, with no IFC enrichment.

- Weather file: Both optimistic and realistic situations are similar and the Web services are used. Nevertheless, the small difference lies in the climate services to be used, while the realistic case takes data from PVGIS and Weatherbit, the optimistic case also considers MEEREN, weather service implemented as part of *T1.4: Environmental, climate and surroundings data* (which will be analysed in the next iteration). PVGIS generates the initial (historical) EPW file (TRNSYS compliant), while Weatherbit feeds with forecasted information. Pessimistic data source (not considered) is the necessity for the user to find the proper weather file in the online repositories to load it manually.
- Schedules: Similar to the materials properties, BIM exporters are not prepared for obtaining this information. However, if the BIM is modelled under the well-established requirements for the tool, the object IfcSpace and its attribute SpaceType are feasible. This class has default values for schedules for occupancy, lighting and equipment. In this sense, and based on the space type, the tool makes use of the REVIT libraries to the schedule (note the IFC must have been exported with REVIT anyway, since this information is under the "Energy Analysis" property set, which is not part of the standard). Last possibility, which is not considered, is the manual uploading via forms by the user.
- Windows: This input follows the same restrictions than the materials and schedules, with the difference that, for feeding the tool with windows properties, some windows types compliant with the windows definition in TRNSYS has been used instead of REVIT libraries. The TRNSYS windows are pre-loaded, and the user must link each glazing element from the IFC with one of them. The pessimistic situation would be when the user needs to write the input totally manually.

Table 5: Data inputs for the UC_2

Input	Type	Data source 1 (Optimistic)	Data source 2 (Realistic)	Data source 3 (Pessimistic)
.ifc file	Static	BIM-SPEED platform	Repository	Manual loading
Materials properties	Static	IFC with all data (e.g. thermal props)	Pre-filled Excel based on IFC data	Manual loading
Weather file	Semi-static	Web service (PVGIS TMY;Weatherbit service; MEEREN climate service)	Web service (PVGIS TMY and Weatherbit service)	TRNSYS-compliant weather files (manual)
Schedules	Static	IFC with all data (e.g. thermal props)	REVIT library	Manual loading
Windows	Static	IFC with all data (e.g. thermal props)	Windows types library compliant with TRNSYS	Manual loading

With respect to the outputs of the **UC_2**, basically, these can be summarised in three:

- .dck file, which is the file used by TNRSYS for the simulation. Therefore, the use case through the tool would have transformed the IFC input into the TRNSYS-compliant file.

This file constitutes the simulation model itself that the BIMtoBEPS tool retrieves after getting the input data and being executed.

- .bui file, which is a file with the description of the building including all the information required by TRNSYS to simulate the building.
- Simulation results: In order to obtain the simulation results, the UC_2 also executes the simulation via TRNExe. Then, an output file is created and the ETLs are able to read and extract the results.
- Simulation summary: With the aforementioned results, a summary with overall numbers is rendered with the aim of providing the user with global results.

UC_3 - Download and storage of useful data from Demo-sites: BACN2BIM

In the case of the UC_3, there are some considerations to keep in mind; before using this application devices and/or monitoring systems deployed on demo projects, they have to be commissioned and they need to be connected to the internet and be accessible from external ICT systems. It is assumed that in the BIM-SPEED project two different monitoring systems are going to be used, they are ENERGOMONITOR and ComforEye, both described in the deliverable *D1.3: IT solutions to couple dynamic data of the existing buildings to BIM*. Once these constraints are solved, the description of the needed inputs for this tool follows.

- .ifc file: the same as UC_2, this file should be included on the BIM-SPEED platform and accessed directly from there by the BACN2BIM application in the optimistic case. For both, realistic and pessimistic situations, the IFC file will be uploaded manually to the application. This file contains not only the geometrical and geographical information about the objects that compose the building, but also its spatial structure, which is a fundamental information used by the application.
- .csv file: this file is considered also as a static one, and same considerations as the previous one are described for it, in the optimistic case, the file should be accessible from the BIM-SPEED platform, for the realistic and pessimistic cases, this file can be uploaded by hand to the application. This .csv file contains necessary configuration for accessing the devices/monitoring system, such as type of monitoring system, username, password, address/IP to access to the monitoring system, sensor Type, Building name, and the sensor location of where devices are installed on buildings (this should match with the name of the space in the .ifc file).

Table 6: Data inputs for the UC_3

Input	Type	Data source 1 (Optimistic)	Data source 2 (Realistic)	Data source 3 (Pessimistic)
.csv File	Static	BIM-SPEED Platform	Manual loading	Manual loading
.ifc File	static	BIM-SPEED Platform	Manual loading	Manual loading

Four different outputs can be achieved by the use of the BACN2BIM tool:

- Retrieving real and dynamic data from demo projects; by using this tool, users have the capability to create a monitoring project in the ThingsBoard platform to store dynamic data from buildings.
- Dynamic database; is the common data storage system where data from buildings are stored; this database is designed and automatically developed following the IFC4 (Add2-TC1 schema version) standard regarding to the spatial structures contained on it (spatial structures defined on buildings). Sensors and monitoring systems are included also on this database with a fix identifier, which matches with the identifier of the spatial structure in the .ifc file, in order to make the identification of devices and spaces easy.
- Real time data are accessible to download by users of the BIM-SPEED platform in two different formats .csv and .json, including all the physical measurements of devices installed on buildings in a fix frequency. This frequency depends on the configuration and capabilities of devices/monitoring systems installed on buildings.
- Updated .ifc file; the original .ifc file (input of the tool) is updated with information about the sensors installed on buildings, including them in the correct space. Devices are represented as square boxes in the .ifc updated file. Then devices are located in one of the walls surrounding the space..

UC_4 - Assessing the energy performance of buildings with measured data: ECOtool

For the UC_4, Table 7 compiles the inputs and outputs of the ECOtool in the three variants: optimistic, realistic and pessimistic. In this case many of the data inputs are dynamic or semi-dynamic, that is, changing during the time (every month, every year, etc.)

The concrete inputs needed to calculate the operational energy cost using the ECOtool are:

- Net floor area (in m^2): This parameter is always included in the IFC file, so if this IFC is available on the BIM-SPEED platform, an ETL will be used to extract the information (optimistic approach). Otherwise the value should be included manually by the user (pessimistic approach). Currently these IFC files are available for all the demo-sites in the project, so the optimistic situation is applied.
- Maintenance costs (in €): These are the costs associated to the maintenance of the energy systems in the building. Normally this value is not included in the energy bill or any other data source, so in this case the user has to provide this value manually in all the approaches (optimistic, realistic, and pessimistic).
- Other costs for energy services (in €): This value is related to the cost of other possible energy services, for example, the hire of meters or other devices. Ideally these costs will be included in the energy (fuel and electricity) bills, and in this case the information will be extracted automatically using a PDF/ODF parser (if bills are in PDF format) or OCR parser (if the bills are images). This parser constitutes a new ETL for the optimistic approach. If this information is not available within the energy bills, the user should provide it manually (realistic and pessimistic approaches).
- Final energy consumption in electricity (in kWh): This parameter represents the total energy consumption in electricity in the last year, and if possible, will be collected directly from the

demo-sites when they would be monitoring this data through a BEM system. Under this circumstance the UC_4 will also make use of the BACN2BIM tool and will obtain dynamic data from the ThingsBoard IoT framework. This scenario represents the optimistic approach. When this information is not accessible or available in the demo-site, the electricity bill can be used to extract this information using the proper parser. This scenario represents the realistic approach. Finally, if no dynamic data or electricity bill is available for the building, the user should upload this information manually to the ECOtool. In this case the pessimistic approach is envisaged.

- Final energy consumption for different fuels (in kWh): Similar to the previous input, in this case the final energy consumption for different fuels is needed (gas, oil, biomass, etc.). The three approaches are also possible here: optimistic (dynamic data available in ThingsBoard), realistic (fuel bills available in the BIM-SPEED platform), and pessimistic (user uploading this parameter directly).
- Electricity price (€/kWh): This value corresponds with the price of the electricity according to the country where the demo-site is located and the prices of the DSOs (Distribution System Operators). The most accurate information regarding this value can be extracted from the electricity bill, if available. In this case we need to apply the same parser than in the final energy consumption to extract the proper information, automatizing the collection of this information (optimistic approach). If the electricity bills for the demo-site are not available, the use of EUROSTAT[4] is proposed as a second alternative of automatic data collection (realistic approach). In this case a geo-clustering service using EUROSTAT APIs will be developed to access to the energy price of every country. This service is considered as a new ETL for energy carriers' extraction. Finally, if none of the previous options are available, the user should introduce the information about the electricity cost in his/her country and for his/her demo-site manually (pessimistic approach).
- Fuel price (€/kWh): In addition to the electricity price, the price of other fuels is also needed to calculate the Operational energy cost. Similar to the previous parameter, we can obtain this value from the fuel bills, when available in the BIM-SPEED platform (optimistic approach), from the EUROSTAT service (realistic approach) or from the user directly (pessimistic approach).

[4] https://ec.europa.eu/eurostat

Table 7: Data inputs for the UC_4

Input	Type	Data source 1 (Optimistic)	Data source 2 (Realistic)	Data source 3 (Pessimistic)
Net floor area	Static	IFC (BIM-SPEED platform)	Manually	Manually
Maintenance costs	Semi-dynamic	Manually	Manually	Manually
Other costs for energy services	Semi-dynamic	Fuel/electric bills	Manually	Manually
Final energy consumption in electricity	Dynamic	IoT (ThingsBoard)	Electricity bill	Manually
Final energy consumption for different fuels	Dynamic	IoT (ThingsBoard)	Fuel bill	Manually
Electricity price	Dynamic	Electricity bill	EUROSTAT	Manually
Fuel price	Dynamic	Fuels bills	EUROSTAT	Manually

With respect to the outputs of the UC_4, basically, these can be summarised in:

- Operational energy costs KPI (BS.OEC): the total costs of the building spent on energy services (energy consumption, maintenance, etc.). More information about this KPI (BS.OEC) can be found in *D4.1: Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation* of the BIM-SPEED project.
- Other economical KPIs can be obtained from the ECOtool. For the BIM-SPEED project the Payback Period KPI (BS.PP) can be also obtained from the ECOtool indicating in addition the *Discount Rate*[5] (a 'correction' factor), the *Energy Price Increase* (energy cost of the last 5 years, including the value in the present) and the *Initial Investment Cost* (defined by the user).

3.2 Availability of data from real demo-sites

Until now, the data requirements, definition of input/outputs and demo-sites for validation have been explained. However, the objective is that the use cases are broadly applied. Therefore, within this section, the availability of data for each demo-site is analysed in order to determine where each use case would be applicable. For that purpose, Table 8 summarises the data requirements for each demo-site in compliance with the use case.

[5] Recommended 3% (Energy Performance of Building Directive 2010/31/EU of 16 January 2012)

Table 8: Availability of data for each use cases in the demo-sites

Use case	Data requirements	Vitoria (Spain)		Berlin (Germany)		(The Netherlands)	(France)		(Poland)			(Romania)	(Italy)	(Bulgaria)	
		Aldabe26	Arcaya5	Lichtenrade	Tempelhof	Warmond	Antony	Massy	WarsawII	WarsawI	Gdynia	Barland	Frigento	Malko	Varna
UC_1	Point clouds (.pts / .ptx / .ply)		X	X		X			X				X	X	X
UC_2	IFC file[6]	X	X	X			X	X	X				X	X	X
	Materials properties (if not included in the IFC file)		X	X			X	X					X		
	Weather file (downloaded from PVGIS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Weather forecast (Weatherbit.io)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
UC_3	IFC file[7]	X	X	X				X	X				X		
	CSV file[8]	X	X	X											
UC_4	Net floor area[9]	X	X	X			X	X	X				X	X	X
	Maintenance costs[10]		X					X							
	Other costs for energy services[11]		X					X							
	Final energy consumption in electricity[12]	X	X				X	X						X	X
	Final energy consumption for different fuels[13]	X	X				X	X						X	X
	Electricity price	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Fuel price	X	X	X	X	X	X	X	X	X	X	X	X	X	X

[6] Spaces (with *space type* definition) and location must be included in the IFC file. Material properties (thermal properties) are optional but material layers of the elements are mandatory.

[7] Spaces or rooms must be included in this IFC file and their name has to be the same as the one included in the .csv file.

[8] Type of monitoring system, user name, password and location (long name of the rooms or spaces) of the devices installed in the buildings must be included in the .csv file.

[9] Obtained from the IFC file with *space condition type* defined (heated, heated/cooled, unconditioned, etc.).

[10] By dwelling or by building, depends of the system to be evaluated (in €/month or €/year).

[11] For example, renting of energy supply meters (in €/month or €/year).

[12] A full year is required in residential typology, but for example, could start in March 2019 to March 2020.

[13] A full year is required in residential typology.

4. Architecture of the interoperability framework

4.1 Conceptual architecture

In this section, the conceptual architecture proposed for the BIM-SPEED interoperability framework is presented. As it is showed in Figure 10, the interoperability framework is in charge of joining three main pillars of the BIM-SPEED Platform, as it was explained in section 2:

1. The pillar of the dynamic data represented by the demonstration sites and the real and/or dynamic data provided by them.
2. The pillar of the 3rd Party services or BIM tools, existing or generated as part of the project. These tools need input data to operate and provide outputs to the BIM-SPEED platform.
3. The pillar of the static data represented by the BIM-SPEED platform repository and all the documents uploaded by the user and generated by other BIM tools integrated into the BIM-SPEED platform.

To be able to fulfil the functionality expected for every use case, these three pillars have to work together and share information. The interoperability framework will facilitate this objective by providing common communication mechanisms, common data representations and common interfaces using the elements described below.

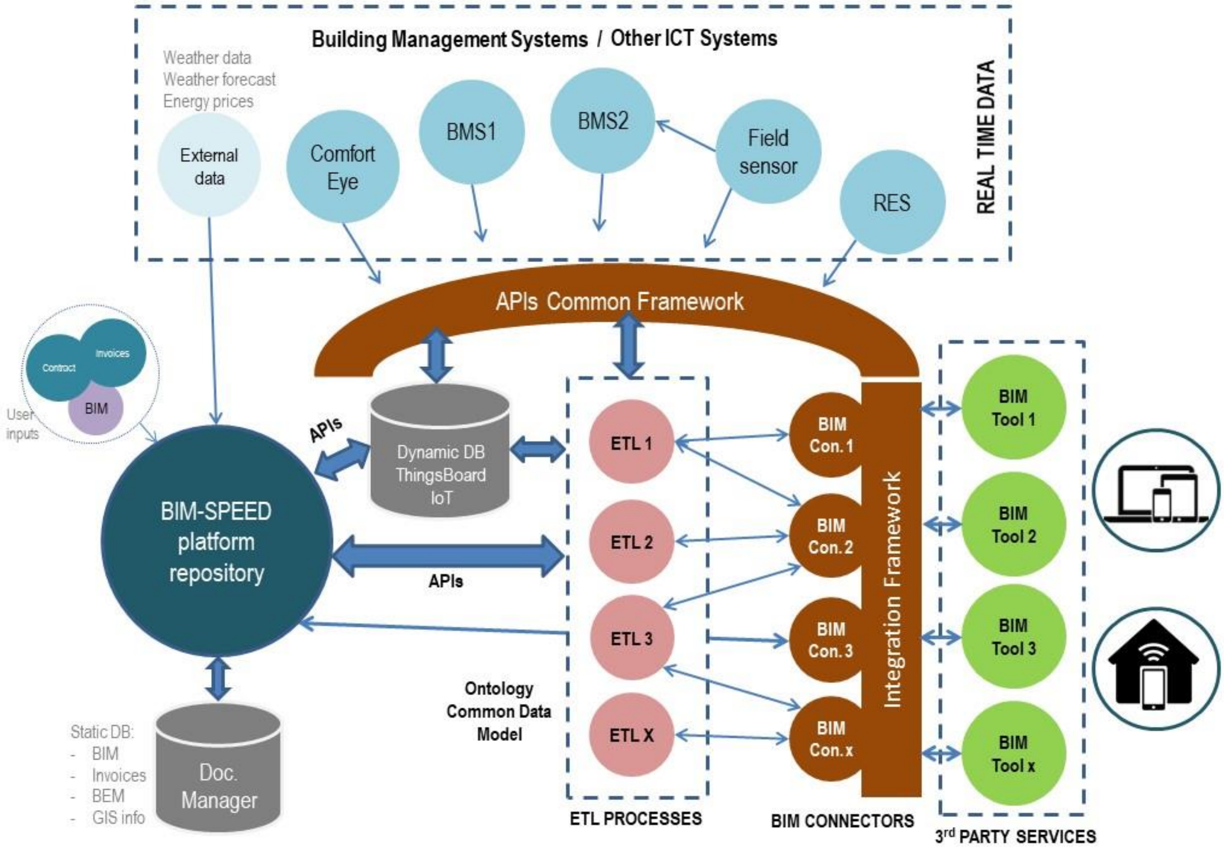


Figure 10: Conceptual architecture for the interoperability framework

In order to be able to collect the data offered by the demo-sites in a homogeneous way, an **integration framework for dynamic data** is proposed. This framework will be able to implement open communication protocols to access to specific Building Automation Networks, such as Lonworks or BACnet, and/or to use APIs able to access to existing Building Management Systems (BMS) of the demo-sites, as ENERGOMONITOR or ComfortEye. To do that, the open source IoT platform ThingsBoard is proposed. ThingsBoard counts on different communication drivers able to speak different languages, that is, able to communicate with different and heterogeneous devices, using different communication protocols and data representations, and to manage all this information in a homogeneous way. More details regarding how ThingsBoard is able to reach the integration of dynamic data, and its relation with the BIM world, is explained in section 4.2 of this document.

Secondly, the interoperability framework is in charge of providing the proper integration actions to make the BIM tools reachable and accessible by the users of the BIM-SPEED platform. To do that, an **integration framework for BIM tools and services** is envisaged, based on the implementation of a set of **BIM-Connectors** able to translate and adapt the information available in the BIM-SPEED platform to the specific inputs' needs of the BIM tools. These connectors are also in charge of implementing the appropriate **Extract-Transform-Load (ETL) processes** to collect all the information needed by every tool and adapt its representation to every BIM tool data representation model. In this case, the BIM tools' integration framework is based on the Model-View-Controller pattern, as it is explained in more detail in section 4.3.

Thirdly, the interoperability framework has to interact with **the BIM-SPEED platform** as part of the data flow and with the objective of collecting static information of the demo-sites and storing results coming from the BIM tools. In order to access this data, the BIM-SPEED platform offers its functionality through a set of endpoints in APIs. The development of the BIM-Connectors and ETL processes include these APIs to obtain files from the BIM-SPEED platform (for example the IFC files of the demo-sites), to store dynamic time series data from ThingsBoard to the BIM-SPEED platform, and to store other types of outputs coming from other BIM tools.

In addition to this, and as part of the T5.2 activity, the BIM-Connectors and ETLs are also prepared to integrate the BIM tools into the BIM-SPEED platform to offer their functionality. In this sense, the BIM-Connectors offer the BIM tool functionalities by publishing the tool in a web server through a Graphical User Interface and the backend implementing the set of ETLs. The URLs of these tools are later used in the BIM-SPEED platform to offer every BIM tool as a BIM-SPEED service linked to a specific file of the static repository, normally the IFC file of the demo-site.

As part of the interoperability, not only common communication mechanism and well-defined interfaces has to be implemented, but also a **common data representation framework** has to be defined in order to homogenize the heterogeneity of data sources and BIM tools' needs. A common data model (or ontology) is proposed in this case to fulfil this requirement. In that sense, the interoperability framework is totally compliant with BIM-IFC for the static data and with the model created in ThingsBoard to link IoT data with BIM-IFC objects.

Base on this conceptual architecture for the interoperability framework, the elements involved in the four Use Cases and the workflow (in purple) can be easily represented:

1. **UC_1 – Create 3D design (3DASH Tool)**: Access to static data without the need of ETLs (Figure 11).

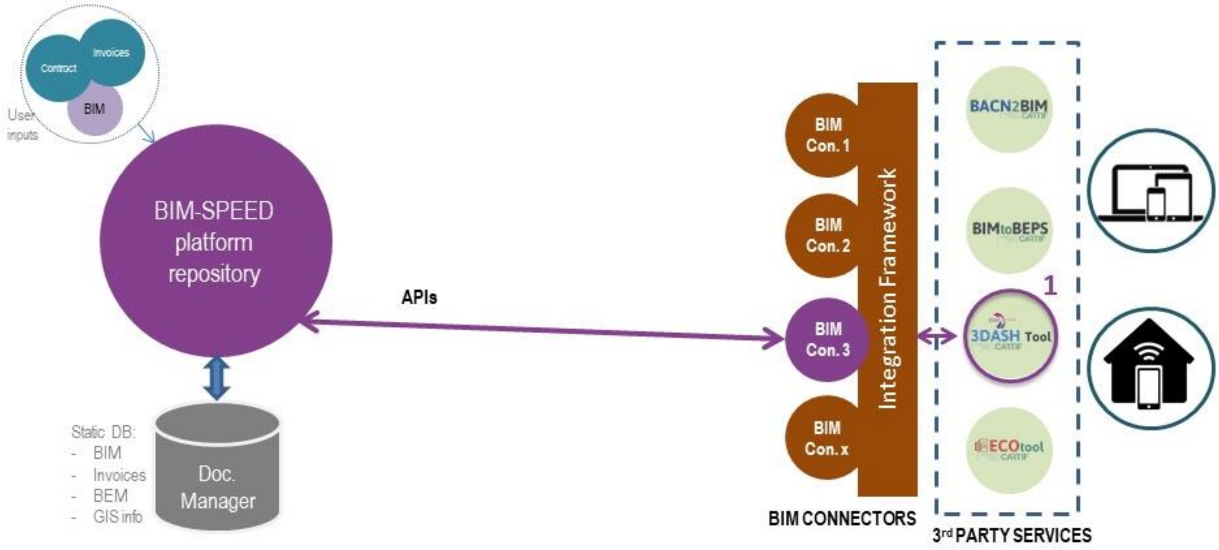


Figure 11: Components of the architecture participating in UC_1

2. **UC_2 – Predict Energy Performance on base of BEM (BIMtoBEPS)**: Access to static data with the need of ETLs (Figure 12).

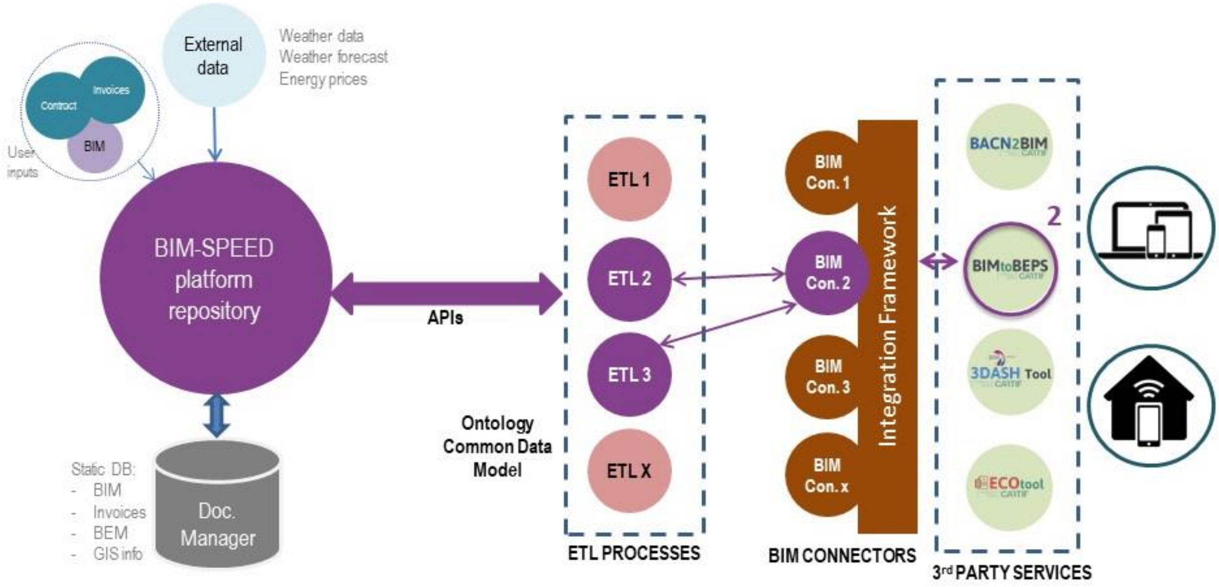


Figure 12: Components of the architecture participating in UC_2

3. **UC_3 – Download and storage of useful data form Demo-sites (BACN2BIM)**: Dynamic data collection using static data and ETLs (Figure 13).

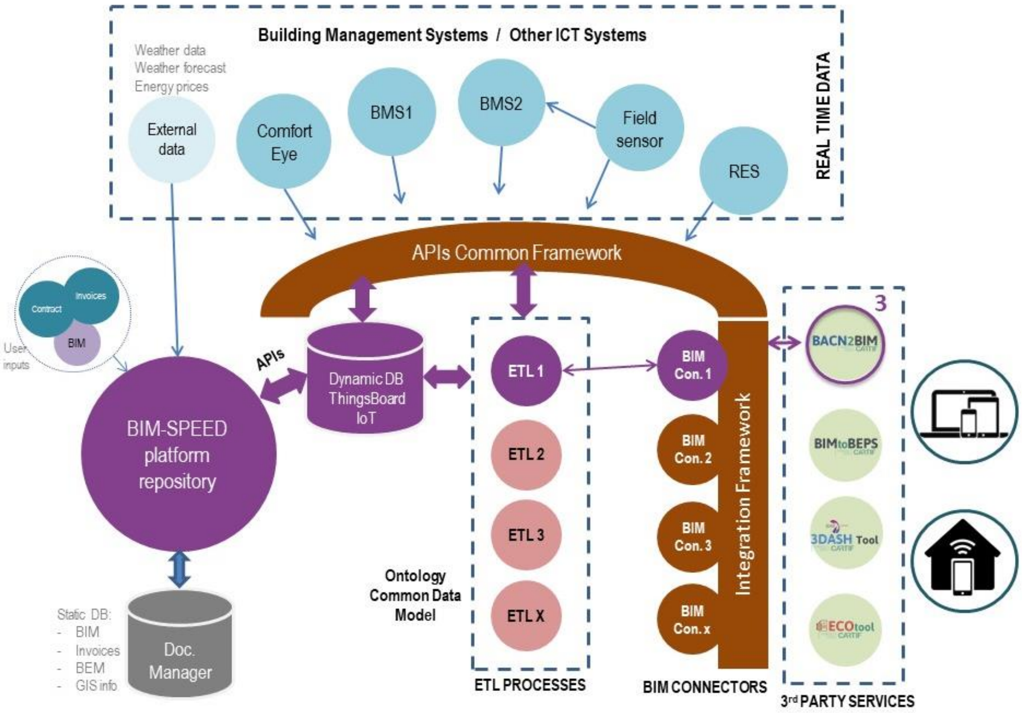


Figure 13: Components of the architecture participating in UC_3

4. **UC_4 – Assessing the energy performance of buildings with measured data (ECOtool)**: Access static and dynamic data with the need of ETLs (Figure 14).

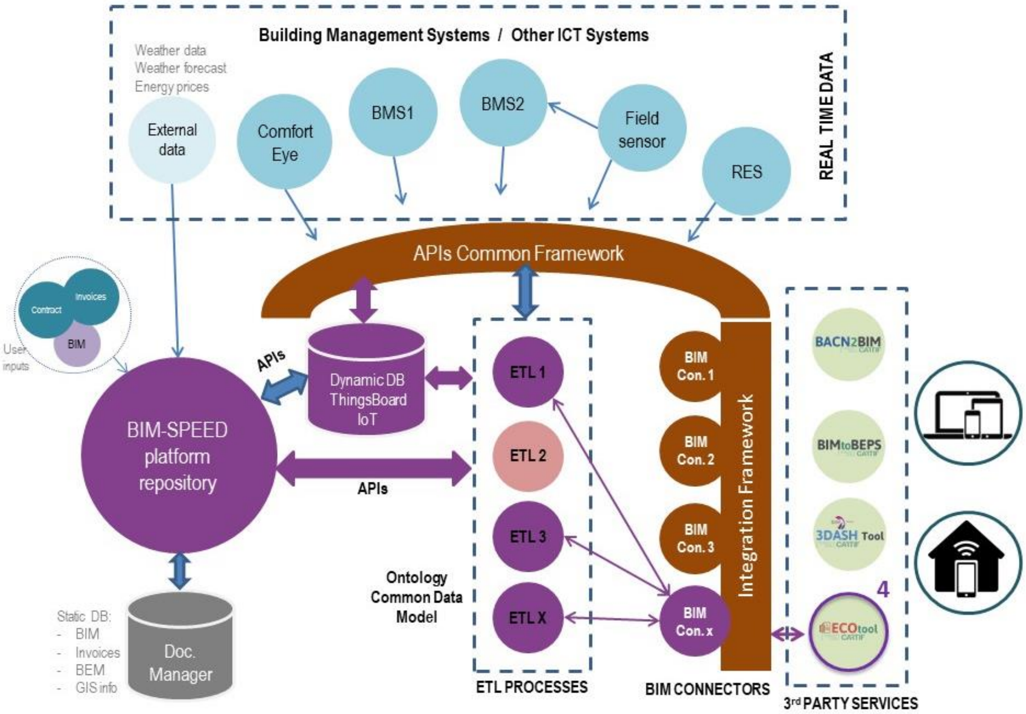


Figure 14: Components of the architecture participating in UC_4

Although this deliverable covers the interoperability and integration of a representative set of Use Cases and BIM tools, the integration framework for dynamic data, the integration framework for BIM tools and services, and the ontology of the interoperability framework will be adapted to the needs of other tools in an iterative and incremental process until month 48 (end of task 5.2).

4.2 Integration framework for dynamic data: ThingsBoard

This topic is necessary to make the reader understand how dynamic data (coming from real monitoring systems) are linked to static information models (BIM), more specifically, linked to IFC4 (Add2-TC1 schema version). The deliverable D1.3: *IT solutions to couple dynamic data of the existing buildings to BIM* includes an explanation of how the BACN2BIM tool has been designed, developed, and deployed.

The first constraint that can be found in the integration framework for dynamic data is the existence of many communications protocols used to perform the Control Automation Network. Some examples of protocols areLonWorks, Bacnet.Also other newer protocols used in both industrial and domestic Control Networks based on Http clients which use APIs to access data. Following is the need of having these data stored in a common data model and in a way able to ensure the compatibility between parts, the one in the static building model (IFC) and the other one in the “real-time” dynamic conditions and building operation (Building Automation Control Network). As explained in D1.3: *IT solutions to couple dynamic data of the existing buildings to BIM* every protocol and device used as gateway (to connect fieldbus protocols to the internet) are quite similar and allow us to develop a group of different drivers for accessing real data in a similar way. Then raw data are stored in a database (part of the ThingsBoard platform) following the standard IFC4 (Add2-TC1 schema version). (See D1.3: *IT solutions to couple dynamic data of the existing buildings to BIM* for more specifications).

The main idea for the integration of dynamic data is described in Figure 15. The user creates a new monitoring project, and then, data coming from sensors (using specific drivers) are stored in a database which is compliant with the IFC4 (Add2-TC1 schema version) standard. Then data can be downloaded and used in other applications.

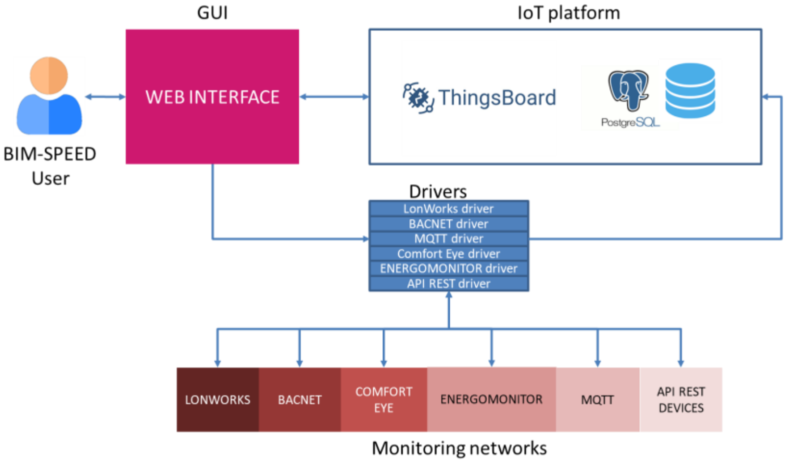


Figure 15: Integration of dynamic data

4.3 Integration framework for BIM tools and services

The way how the integration framework has been designed and developed follows the pattern Model-View-Controller (MVC), whose architecture is shown in Figure 16. In short, the architecture is composed of 4 main parts:

- User that interacts with the tools (e.g. BIMtoBEPS or BACN2BIM).
- Model that manages the information that should be accessed and exchanged with the controller to perform the different actions that should be rendered.
- View that is the final visualisation to present the results to the user.
- Controller, which is in charge of the management and orchestration of the user requests.

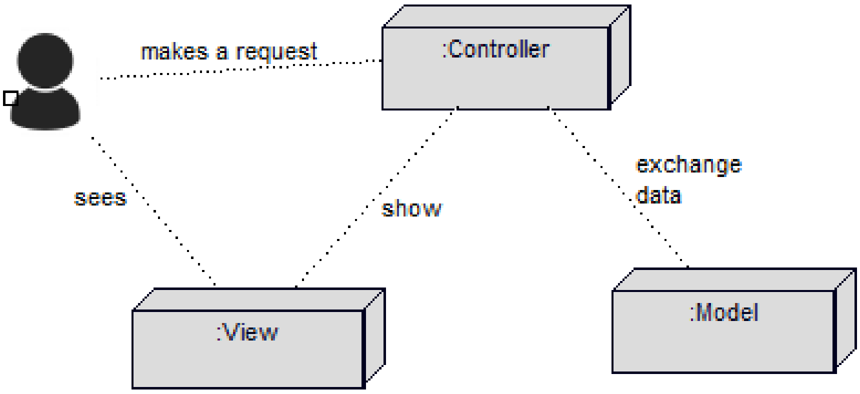


Figure 16: Model-View-Controller architecture

Under this approach, the BIM-SPEED and, thus, the tools have been implemented where the view is the Graphical User Interface (ad-hoc and/or existing like Revit panel), the controller is the APIs through which the requests and responses are performed and the model represents the BIM-SPEED platform in terms of data storage/accessibility.

Then, adapting the MVC pattern or architecture to the specific context of BIM-SPEED and the conceptual architecture as stated in section 3.1, Figure 17 groups the model-view-controller concepts within the elements of the conceptual architecture. In short:

- Model side includes the data repositories within the BIM-SPEED platform (i.e. BIM-SPEED platform repository, dynamic database from ThingsBoard IoT, document manager and user inputs).
- View side is the tools themselves and the accessibility to them via graphical user interfaces (ad-hoc as happening in the BIMtoBEPS tool or through existing software like REVIT in the 3DASH plug-in).
- Controller is the layer between the view (tool) and the model (BIM-SPEED repositories) in order to provide the ETL processes and APIs for external sources. Moreover, via the ETLs and APIs, it orchestrates the communication with the BIM-SPEED repositories and tools.

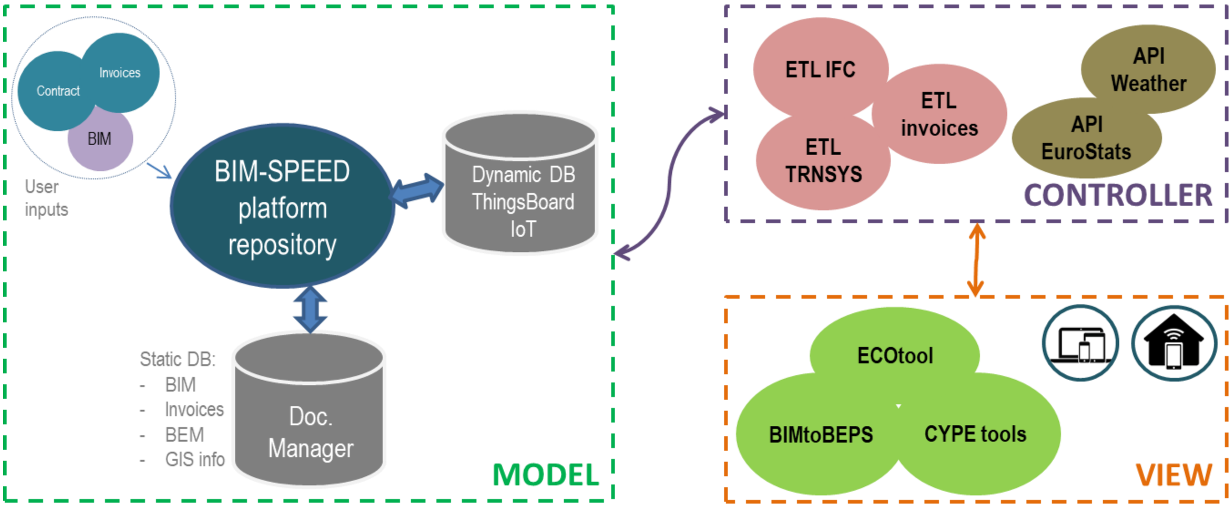


Figure 17: MVC architecture for BIM-SPEED integration framework

5. Data management and reference pivot model

5.1 Standards of application

The projects developments using BIM methodology should follow the recommendation provides by the EN-ISO 19650 [4] (*Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling*) to have a common framework to exchange information in the whole life cycle of the built asset. This recommendation has been adapted for each country with the transposition of these with its corresponding recommendations.

The application of the EN-ISO 19650 can be summarize in:

- The information requirements and data models should be defined at the beginning by contracting partners/owners to define the needs.
- Information development planning: when and where
- Development of information: development and delivery
- Approval of information: validation

The information management is carried out in the development (design and construction) and operational (use and maintenance) phases.

A Common Data Environment (CDE) and workflow definition should be defined/implemented to manage the information in the development of the project following the recommendation of the EN-ISO 19650. In this deliverable has been shown the approach followed in task *5.2: Interoperability between multidisciplinary BIM tools and services* to be compliant with these recommendations. The workflow followed for data access and exchange for the different BIM tools has been described in section 2.2. The use of a CDE improve the management and exchange data in the development and operational phases.

5.2 Ontology / Common data model

5.2.1 extendedBIM (eBIM)

The extendedBIM is defined as an extension of the original BIM whose objective is to include additional information from different domains coming from static and dynamic data sources of a building. In the context of the BIM-SPEED project, this extension allows to reach the 10 dimensions (10D) of the BIM applied to EEB renovation with the BIM tools implemented in the BIM-SPEED platform.

The incorporation of the dynamic data (8D) will be defined as dynamicBIM (dBIM), a subset of eBIM, and will be explained more in detail in the next section.

5.2.2 dynamicBIM (dBIM)

A dynamic BIM is defined as a BIM that integrates dynamic data. BIM is just static information of a building, including not only 3D visualization, but also properties and parameters of the building elements. However, operational and performance data are not included. That is the reason why extending the BIM with dynamic data deals with the dynamicBIM (dBIM) concept [1]. To that end, it is necessary to link data between the static information, in this case based on IFC, and the dynamic data-samples [3]. Within BIM-SPEED, the way to extend the BIM with dynamic data has been through a SQL-based database that follows the IFC4 (Add2-TC1 schema version). Databases are represented by entity-relationship diagram, which, in the case of BIM-SPEED, is depicted in Figure 18.

As it is observed, the hierarchy of the IFC4 (Add2-TC1 schema version) classes is maintained. The “Building” contains “BuildingStorey” that, at the same time, contains “Zones”. From the zones, these could be formed by “Elements”, “Spaces” and/or “SpaceBoundary”. Each of them might contain “Sensor” to measure data via “TimeSeries”. Moreover, all these IFC classes (translated into entities or tables of the database) are also fed with metadata, such as “TimeSeriesDataType”, “DataOrigin” and “SensorType”. These are enumerations that support the classification of the information. To illustrate with an example, “DataOrigin” [5] five types of data origin: Measured, Predicted, Simulated, Userdefined and Notdefined. Therefore, to make the database compliant to the IFC standard, the same lists have been followed.

Apart from it, the database is extended with other storage possibilities, which are very common in buildings. For instance, the calculation of Key Performance Indicators (KPIs), whose values are stored following the same structure than the IfcTimeSeries for sensor data storage. This means it is a replication from sensors, but under the aim of KPIs and they are related to a building directly instead of, for instance, the zones. Besides, a table for alarms has been designed. Anyway, the fields and properties from IFC have been followed to make the database IFC-compliant.

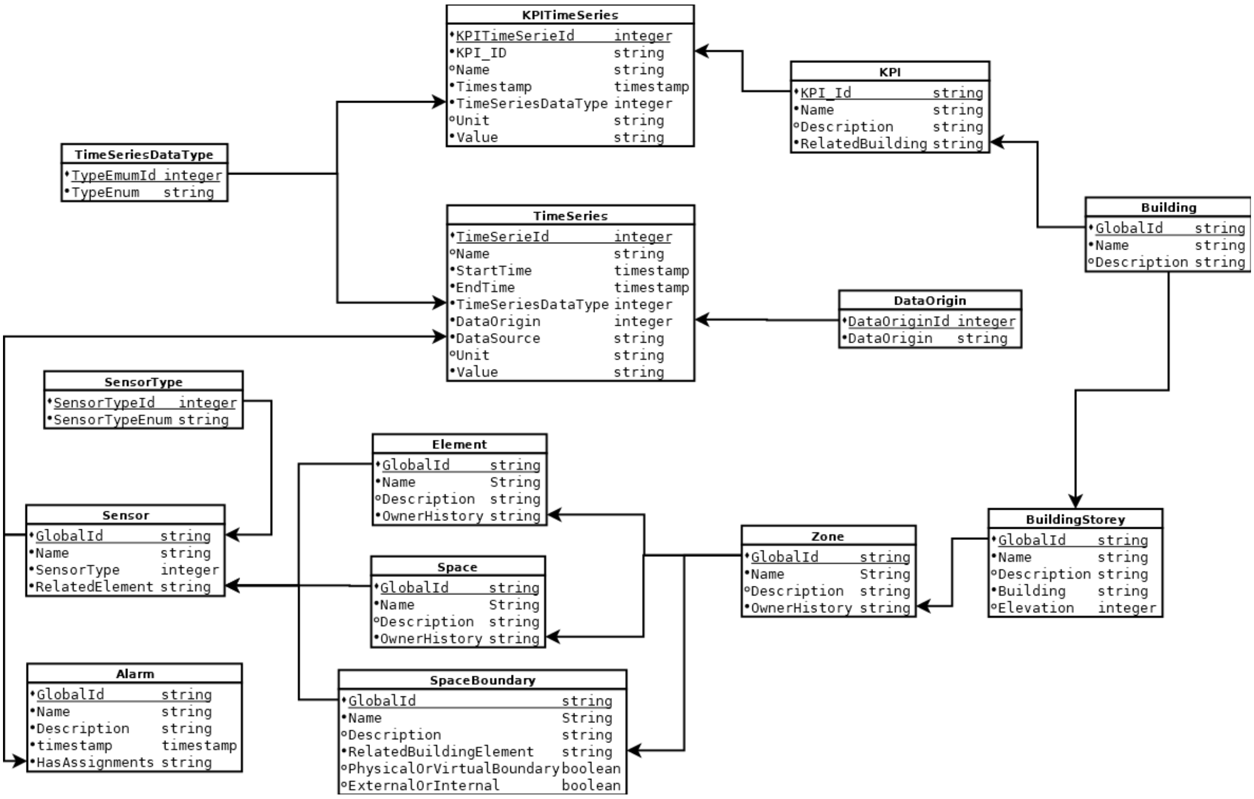


Figure 18: Entity-relationship database diagram

The implementation of the aforementioned database has been performed into the ThingsBoard IoT platform related to the BACN2BIM tool for the insertion of IoT data (see deliverable *D1.3*: *IT solutions to couple dynamic data of the existing buildings to BIM*). In this sense, the entities are directly translated into tables, while the relationships are implemented as additional tables. These persistently save the relationships between the IFC classes, for instance, a building storey and a building. Besides the relationships, a second level of relationship, although abstract, is the link with the IFC file itself. In this case, all the tables contain the attribute GlobalId, which corresponds with the IfcGloballyUniqueId in the IFC file, a Globally Unique Identifier (GUID). To show it with an example, a space with the GUID '3YI72L$Lz3$etU8o59PChV' must be reflected with the same identifier in the table "Space". The reason why using this value is because it represents the unique identifier of the elements in the BIM model, therefore, keeping the coherency and consistency between dynamic database and BIM.

5.2.3 Model View Definitions

Generally speaking, a MVD, or "Model View Definition", is a subset of the overall IFC schema to describe a data exchange for a specific use or workflow"[14]. The main purpose of the MVD is to support BIM interoperability across multiple software applications and/or industry domains. A MVD covers from nearly the entire IFC to specific data sets (e.g. wall properties).

[14] https://technical.buildingsmart.org/standards/ifc/mvd/

Under this definition, MVD has been used in the BIM-SPEED tools to extract specific information of the IFC model in order to foster the interoperability. In this sense, the implementation of the MVD is dynamic, obtaining the information for each request instead of a pre-loaded approach. The major advantage of this way is the capability of retrieving the information independently of the IFC model. That is to say, for each request, the information can be extracted based on the IFC classes and property sets. The disadvantage is the requirement for running queries each time the tool is executed. Nevertheless, in case of a pre-defined MVD, if the IFC file does not contain the specific information (e.g. MVD for the curtain walls, while these walls are not modelled as such), the information could not be loaded. In this sense, with the dynamic approach, if information is not found, code automatically adapts the response not to block the correct execution of the tool, providing specific warns to the user.

For BIM-SPEED, two categories of MVDs are established: static and dynamic. The first one is related to the IFC data, while the second one is related to dBIM. This dynamic MVD differs from which the term MVD is initially conceptualised, although with the same philosophy (i.e. providing a specific set of information). Instead of providing a subset of the IFC model, the MVD reflects a dataset related to building elements (such as IfcSpaces, IfcBuilding or any other). Then, the different MVDs that are implemented are summarised in the bullet points below:

Static MVDs

- Area: This MVD is very specific and simply extracts the area of each heated and/or cooled zone of the building, sums all these areas (transform) and obtains the total heated/cooled area of the building.
- Coordinates: This second MVD is also very specific and extracts the location of the building (latitude and longitude) to link the climate conditions to the building location.
- Wall properties: This MVD is related to the walls and their property-sets, as well as other related useful characteristics such as elements (e.g. materials), which, although are not used within the tools explained in this deliverable, they are necessary for the building pathologies diagnosis tool developed within WP7: *Generating EEB renovation solutions and implementation strategies* and explained in D7.2: *Machine-learning for As-Built diagnostics and enrichment of design rules for deep renovation* of BIM-SPEED project. The properties of the walls are listed below:
  - Absorptance
  - Thermal parameters: ThermalResistance, HeatTransfer, ThermalMass, ThermalTransmittance
  - IsExternal
  - Dimensions: Area, Volume, Level, Length, Width
  - Related elements composed by RelatedOpeningElement y RelatedElement
  - Materials, including MaterialLayerSet, IsInsulated, AirThickness
- Roof properties: Very similar to the previous one, but related to roof elements, but also Thickness, Slope and Perimeter.
- Slabs: The parameters that are obtained in this MVD are Area, Volume, Level, Perimeter and HeatTransferCoefficient.

- Spaces: It includes all the spaces of the building and their area, volume and level. Similar to wall properties, the usage of the MVD is related to the tool described in D7.2: *Machine learning for as-built diagnostics and enrichment of design rules for deep renovation*.
- Windows: Subset of IFC mode to collect windows information, in particular, IsExternal, Area, Level, Dimensions, Length, Width and Heat Transfer Coefficient (U).

Dynamic MVDs

- Building energy: This dMVD contains the total energy consumption, electrical and thermal, related to the building (i.e. IfcBuilding). Then, the dataset is composed by the IfcGlobalId of the building and two parameters: electrical and thermal consumptions. Independently from the data-source (i.e. IoT ThingsBoard and/or .csv files), this MVD groups the same data.
  - A sub-MVD (it can be considered as a sub-MVD) is the one that consists of the building and the energy bills. It is true that data are the same (energy consumptions), but also extended with energy prices and other information that is not collected through sensors and meters, but they are available on the invoices (e.g. the aforementioned prices). This extension would be represented as a new property set in the IfcBuilding.

5.3 Data persistency, imputation and data quality

As part of the interoperability framework, one important aspect is to guarantee that the data being exchanged is properly defined, elaborated and stored, that is, to ensure that the data models of the renovation projects driving on the BIM-SPEED platform are compliant to the standards and technical rules. The requirements for the correct formulation of this data are fixed by the specific needs of the BIM tools that are integrated into the BIM-SPEED platform.

The correctness and quality of this information is also affecting the data model representation of the interoperability framework since it is based on BIM. Therefore, in this section the need for counting on verification methods and processes is highlighted, since it enables to guarantee that the BIM created for the renovation project is compatible to be used by the BIM tools for authoring/modelling, calculation, configuration, decision making, etc. To achieve this objective, task *5.3: Rule-based model checking and validation of data interoperability* is in charge of validating the information collected by the BIM-SPEED platform against modelling specifications, regulations and definitions to avoid errors.

To drive this activity, task *5.3: Rule-based model checking and validation of data interoperability* is defining an inventory of information (used by the BIM tools) to be validated and is also analysing the available model checker tools as NavisWorks, Desite MD and Solibri Model Checker. The demonstration of the verification methods (based on the inventory and model checker tools) will be launched in the different Use Cases and BIM tools, depending on the inputs defined in this deliverable that require model checking and validation to guarantee proper interoperability. Outcomes of this activity will be found in deliverable *D5.3: Methods and tools for rule-based model checking and data validation*.

6. Identification of ETL processes and BIM connectors

The core elements of the interoperability framework are the BIM Connectors and the ETL processes. As explained before, the BIM Connectors are in charge of transforming the information of the BIM-SPEED platform to make it consistent with standard data formats and models. At the same time, these Connectors provide the proper interfaces for the integration of the BIM tools into the BIM-SPEED platform. Standardized ETL processes are established to enable the BIM Connectors to extract the information from static, dynamic data sources, and also from the BIM tools, and transform it into a format that can be handled by the BIM-SPEED platform. The practical interoperability solutions are applied in this deliverable to four BIM tools: 3DASH Tool, BIMtoBEPS, BACN2BIM and the ECOtool. In this section the detailed description of both, the BIM Connectors and ETL processes for the four BIM tools, is presented. An introduction to the Information Delivery Manual (IDM) is also offered.

6.1 Development of Information Delivery Manuals (IDM)

An IDM offers a methodology to bring together different companies and authorities to know which and when different kind of digital information has to be communicated within a project. The standard ISO 29481-1:2010 - “Building information modelling - Information delivery manual - Part 1: Methodology and format” -has been developed by buildingSMART and covers the methodology to capture and specify processes and information flow during the lifecycle of a facility.

The main purpose of an IDM is to make sure that the relevant data are communicated in such a way that they can be interpreted by software at the receiving side.

In the context of the BIM-SPEED project, the objective of the IDMs in task 5.2: *Interoperability between multidisciplinary BIM tools and services* is to document the ETL processes used in the BIM Connectors and describe the associated information that has to be exchanged between the different pillars described in the conceptual architecture (Figure 10) of the interoperability framework. The output of this activity serves as the basis for the software development process. Thus, in order to make an IDM operational, it has to be supported by software.

To define the IDMs within this task, the data-exchange requirements and workflows defined in section 2 are considered as starting point. The specification of the different ETL processes, for the four Use Cases under consideration, to cover the IDM of every ETL and its software development, is presented in sections 6.2 and 6.3.

The definition of these IDMs covers for the moment the ETLs identified for the generation of BIM Connector of the 3DASH tool, BIMtoBEPS, BACN2BIM and ECOtool, but will continue during the task 5.2 execution, and until month 48, for the integration of other BIM tools into the BIM-SPEED platform.

The standard templates provided by buildingSMART [5] for the documentation of the Exchange Requirements, Functional Parts and Process Map of the IDM will be used in next iterations to formalize the IDM documentation.

6.2 ETL processes definition

Four different BIM Connectors have been defined to assure the interoperability with the BIM-SPEED platform of the four BIM tools analysed in this deliverable. In order to identify the ETLs needed within every BIM Connector, in this subsection different sequence diagrams are used to present, from a software point of view, the different software elements (objects) that conform every BIM Connector and the sequence of interactions among them. Using these BIM Connectors, the BIM tools are converted into services to be offered through the BIM-SPEED platform.

6.2.1 ETL process definition for the 3DASH Tool

The sequence diagram of the 3DASH Tool is shown in Figure 19 where it is described how the data exchange processes take place. In this specific Use Case, the tool itself could be considered as an ETL in the sense that it transforms raw 3D point clouds obtaining from laser scanners and photogrammetry systems into BIM elements and displays the detected features in a unique working project in REVIT.

The steps to follow are listed below:

1. The first step is to obtain the point clouds:
    a. The user has to obtain the 3D point clouds from laser scanner or photogrammetry systems.
    b. The user transforms the point clouds to a valid input format .pts/.ptx/.ply.
    c. The user uploads the point cloud into the BIM-SPEED platform.
2. The second step is the installation of the 3DASH Tool:
    a. The user launches the 3DASH Tool service through the BIM-SPEED platform using the 3D point clouds located in the BIM-SPEED platform repository.
    b. The user downloads the 3DASH Tool add-in.
    c. The user installs the 3DASH Tool add-in following the readme.txt file.
3. The third step is the automatic generation of the elements from point clouds by using the 3DASH Tool:
    a. The user launches the 3DASH Tool in REVIT software.
    b. The 3DASH Tool firstly loads the point clouds available.
    c. The 3DASH Tool analysed the point clouds and, following different steps in which the user has to define different parameters, generate 3D automatic surfaces handling from them.
    d. Finally, once the elements detected by the tool have been generated, the user has to modify them to solve possible problems of element joints or properties that may be missing from the model.
4. The last stage is the extraction of the results by exporting the generated BIM model to IFC and loading the information into the BIM-SPEED Platform.

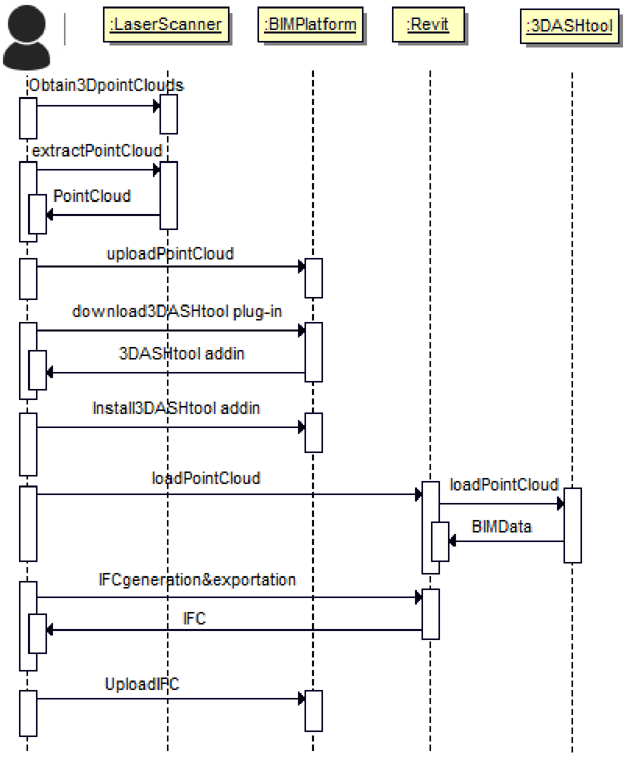


Figure 19: Sequence diagram of the 3DASH Tool

6.2.2 ETL process definition for the BIMtoBEPS tool

The way how the BIMtoBEPS tool operates is summarized in Figure 20. Here, it is observed how the data exchange processes take place. Basically, in "big blocks":

1. The user launches the BIMtoBEPS service through the BIM-SPEED platform using the IFC file located in the BIM-SPEED platform repository. In this sense, in order to preserve security, the user needs to *log in* in the first step of the tool's interface, otherwise, users without privileges cannot execute the service.
    a. The BIMtoBEPS tool firstly extracts the location (coordinates) from the IFC file.
    b. With the previous location, it calls the TMY generator non-interactive service published by the JRC[15] within the PVGIS tools. It allows downloading an EPW weather file (readable by TRNSYS) in the corresponding coordinates (latitude and longitude). As stated before, this is the current status, while MEEREN will be considered in the next stage.
    c. The BIMtoBEPS engine (that includes an additional ETL for the extraction of all the elements into the IFC model, not included in the sequence diagram as being part of WP3) then checks the data that are missing, e.g. thermal properties and/or schedulers. In the case of the thermal properties, default databases are used, such as the Revit one from BIM families (although in future versions, the user will be able to provide new materials). Schedulers are separately exported and fed in the BIMtoBEPS engine.

[15] https://ec.europa.eu/jrc/en/PVGIS/docs/noninteractive

d. Finally, the most important phase within this step, the BIM connector that extracts the information of the BIM, combines with the thermal properties and schedules so as to, lastly, transform all the data into the TRNSYS dck file via the ETL_TRNSYS module.

2. The second step is the simulation by using the TRNSYS engine (TRNExe). This step is split into two more phases:
    a. Simulation according to the actual EPW weather file, which contains historical statistical data for weather conditions. Therefore, actual energy demand would be obtained.
    b. Simulation of the prediction, where forecasting weather services (like WeatherBit) are used. The great difference with the previous phase is that the forecasting can be only performed for the next 24-48 hours as the weather forecast only covers this period of time. Same than before, MEEREN (and its module under development for forecasting) will be analysed.
3. The last stage is the extraction of results by the ETL_SimulationResults that is able to read the output file from TRNSYS, format the data and either show information to the user or load the information into the BIM Platform (e.g. BIM-SPEED platform data repository).

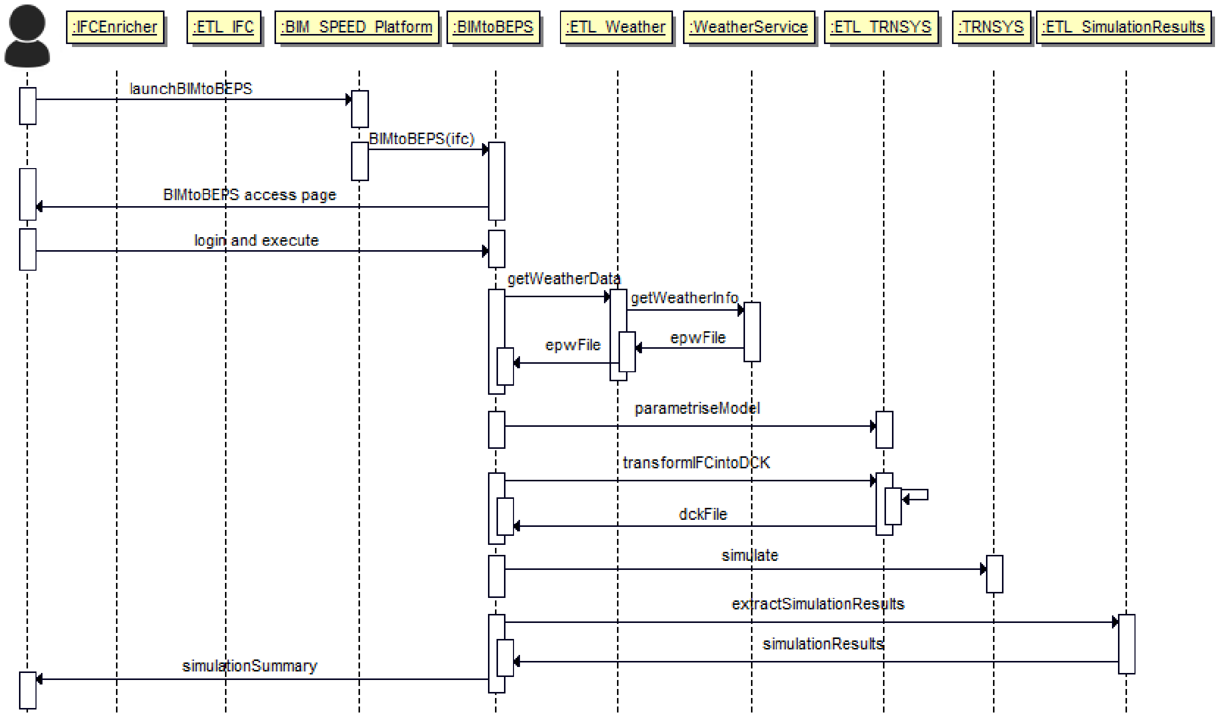


Figure 20: Sequence diagram of the BIMtoBEPS tool

6.2.3 ETL process definition for the BACN2BIM tool

The following sequence diagram (Figure 21) shows how the tool BACN2BIM runs in the two operation mode options available: getting data from demos and store them into ThingsBoard, and download data from common database/platform (ThingsBoard). In this specific Use Case, the tool itself could be considered as an ETL in the sense that it transforms raw data coming from sensors in a particular format into time series data coded in standard format files such as .csv and .json, and also stores these data in a common data repository using the ThingsBoard platform.

Following the description of the process for getting data from demos will be described.

1. The Demo project installer commissions the monitoring devices on the demo site, and gives the platform user the necessary configuration parameters to access the devices.
2. With previous information included in a .csv file, the user goes into the BIM-SPEED platform and executes the BACN2BIM tool uploading the .csv and the IFC file of the building.
3. Users need to configure a new user account filling a form in the application and accepting the new account link that the platform automatically sends to the provided email. Then the user also selects a proper password to access ThingsBoard, needed in the case user wants to download data.
4. The tool now defines the structure of the database into ThingsBoard platform following the IFC4 (Add2-TC1 schema version) standard and deploys it automatically.
5. BACN2BIM tool is able to upload the IFC4 file including information about monitoring devices, and this is made for each space that contains devices. Information about geometrical and geographical information of devices is also updated in the IFC file in a simple way, modelling them as square boxes.
6. Depending on the kind of monitoring system installed on the building, configuration included in the .csv file, the platform launches a specific driver to connect devices and get data from them, in a fixed frequency.
7. These data are stored on the database, which is defined in the picture as uploading telemetry.

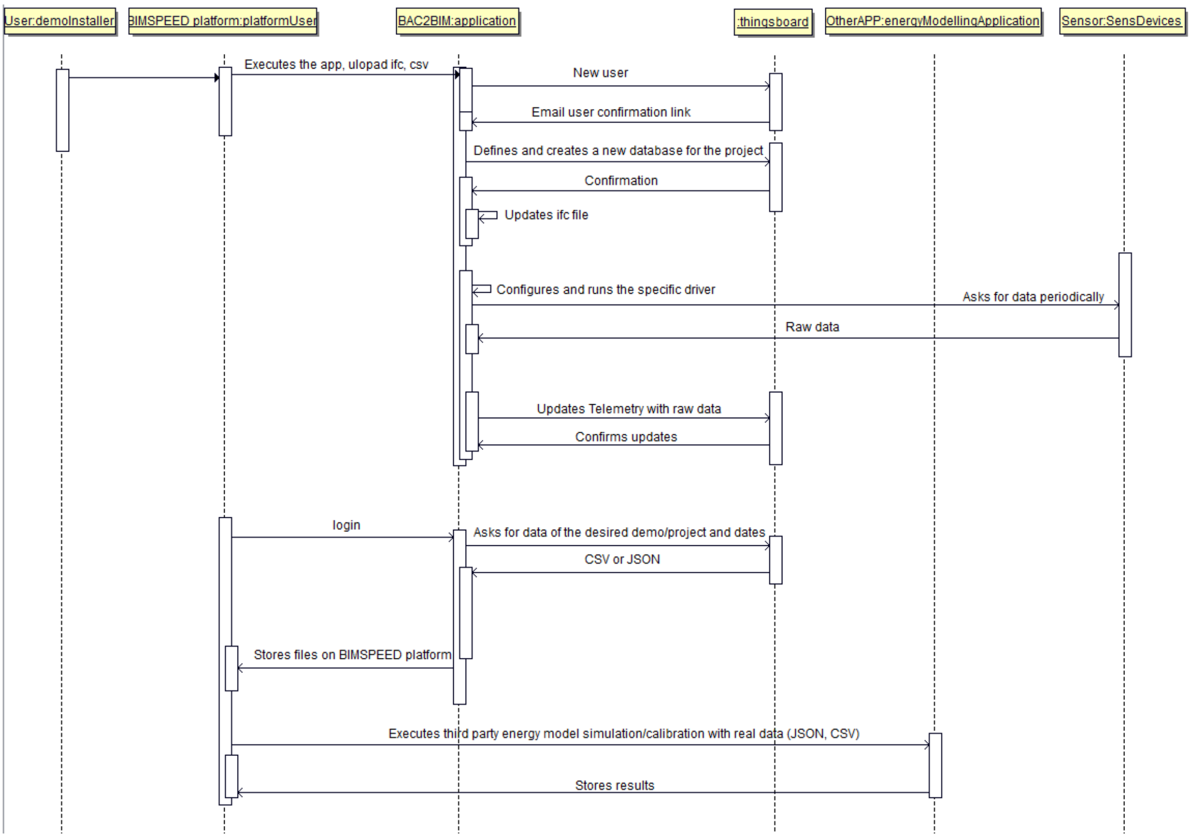

User:demoInstaller
BIMSPEED platform:platformUser
BAC2BIM:application
:thingsboard
OtherAPP:energyModellingApplication
Sensor:SensDevices
Executes the app, ulopad ifc, csv
New user
Email user confirmation link
Defines and creates a new database for the project
Confirmation
Updates ifc file
Configures and runs the specific driver
Asks for data periodically
Raw data
Updates Telemetry with raw data
Confirms updates
login
Asks for data of the desired demo/project and dates
CSV or JSON
Stores files on BIMSPEED platform
Executes third party energy model simulation/calibration with real data (JSON, CSV)
Stores results

Figure 21: Sequence diagram of the BACN2BIM tool

The process for downloading data once they are available on the BIM-SPEED platform follows the next steps.

1. The user logs in into the BIM-SPEED platform and select several options from the form in the screen, which cover, type of downloaded file (format .csv or .json), the desired demo site and sensors, and finally the “from” and “to” dates of desired data.
2. User downloads this file and uses it on other third-party applications if required (i. e. calibration of building energy performance models).

6.2.4 ETL process definition for the ECOtool

The sequence diagram of Figure 22 shows the different software elements that conforms the BIM Connector to offer the ECOtool as a Service within the BIM-SPEED platform. As explained previously, the ECOtool needs as inputs a set of parameters coming from different and heterogeneous data sources. The Manager component is in charge of managing the collection of all these parameters and to provide all these inputs to the main ETL. Before achieving this point, the manager has to launch other processes:

1. The manager obtains the Net floor area parameter from the IFC file using the ETL_IFC process, able to parse the IFC file to extract the total area of a specific surface, concretely from the Qto_SpaceBaseQuantities property of every heated/cooled spaces. The IFC file is stored in the repository of the BIM-SPEED platform, thus, the platform’s API has to be used to obtain this file first.

2. The manager obtains information from the energy bills using the ETL_OCR process, able to parse the scanned bills to extract specific fields. If the energy bills of the demo-site are available, the information about the energy price included in them is more accurate than the information available in the EUROSTAT service. Thus, the energy prices extracted from the bills has priority.
3. After this, the manager access to the ThingsBoard IoT framework to obtain the energy consumption of the demo-site in electricity and other fuels, if available. To do so, a client is used to access ThingsBoard and obtain this information in a json format. The ETL_IoT (or ETL_BACN2BIM) process is developed to extract and transform this information, according the the ECOtool needs. If these dynamic data are not available in ThingsBoard for the building, a csv provided by the end user will be analysed also in the IoT_ETL.
4. If the demo-site does not count on available energy bills, where the energy prices can be extracted, the information would be obtained from other services as EUROSTAT (a geo-clusering service which provides the average price of the energy for a specific location). The ETL_EUROSTAT process is used here to implement the client accessing the EUROSTAT server, extract information and transform it according to the ECOtool needs.
5. Finally, the user has to insert manually the maintenance cost of the energy systems.
6. The manager, using all the previous extracted and transformed information, provides these inputs to the main ETL_process to generate an .xml file as input of the ECOtool. The manager executes the ECOtool with this xml file and obtains the Operational Energy Cost (or the Payback period, depending on the inputs).
7. Finally, the economic indicators obtained from the ECOtool can be stored in the BIM-SPEED platform using its APIs. These KPIs can be also considered as semi-dynamic information of the demo-site, so they could be also stored in the repository of ThingsBoard.

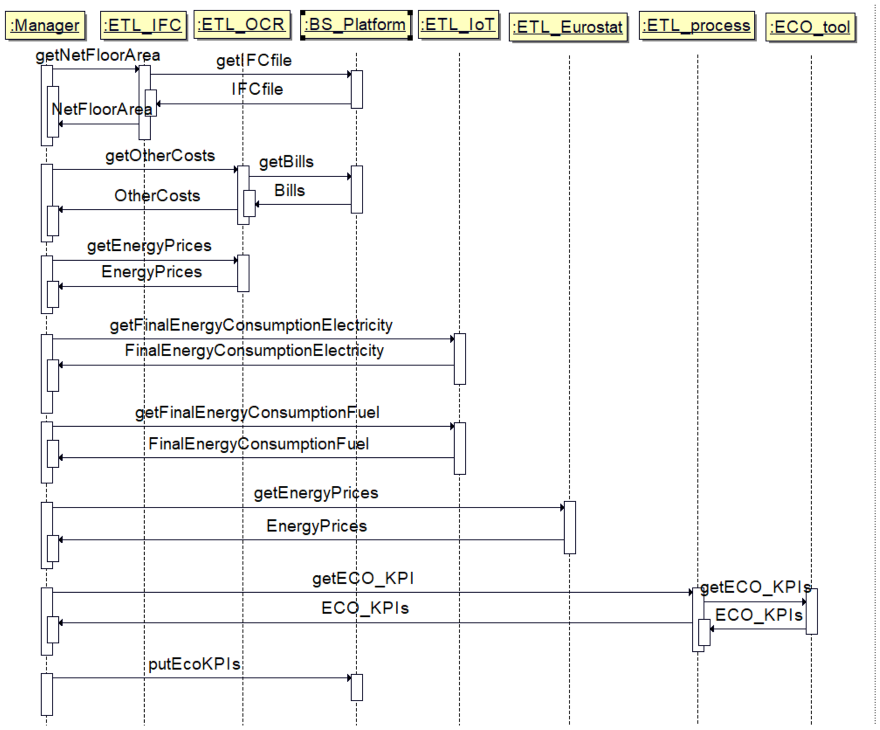


Figure 22: Sequence diagram of the ECOtool

The GUI and the public URL for the ECOtool is under development. Once it is ready, the user would be able to launch the ECOtool service through the BIM-SPEED platform using the IFC file or the energy bills located in repository of the BIM-SPEED platform for a specific demo-site.

6.2.5 Summary of ETLs

As conclusion of the sections before, the needed ETLs are identified, which are illustrated in the use cases/tools diagrams. Table 9 compiles all the ETLs and the use case that uses them.

Table 9: Summary of the ETLs identified per use case

ETL	ETL1 IFC	ETL2 Weather	ETL3 TRNSYS	ETL4 Sim. Results	ETL5 BACN2BIM	ETL6 OCR	ETL7 EUROSTAT	ETL8 Process
UC_1								
UC_2	X	X	X	X				
UC_3					X			
UC_4	X				X	X	X	X

6.3 Development of ETLs and BIM connectors

6.3.1 ETL1 – IFC information extraction

This first ETL is the related to the IFC information extraction, which is also linked to the MVDs. Indeed, the ETL dynamically creates the aforementioned MVDs (see section 5.2.3) by extracting and transforming the information. For that end, IfcOpenShell library in python[16] has been used. Then, the concept of the ETL is very simple, just using the functions of the library to navigate across the IFC elements, relationships and property sets to extract data and transform whenever necessary.

The ETL is a python class with multiple functions, one per each MVD, for instance, extractCoordinates or extractWallProperties. The return of each of the functions depends on the function, summarized below:

- MVD coordinates → It returns a tuple with the latitude and longitude. Here, it should be noted that the ETL also transforms data because the IfcSite object provides the information as 4 numbers (degrees, minutes, seconds, milliseconds), which, under the aim of weather services, require the transformation into one single decimal number for the longitude and another one for the latitude that form the tuple.
- MVD area → It is just a single number for the total area of the specific space.
- MVDs walls, roof, slabs, spaces and windows → It returns a dictionary, which is just a pair key-value. The key is the GlobalId of the element and the value is another dictionary. This second dictionary contains the pair "name of the property-value of the property" (e.g. [ThermalTransmittance, 2.45]).

In principle, the ETL retrieves the information, but also transformations are feasible (at the moment, not applied) for the conversion of the units. The reason why it is not implemented yet is because the current units are based on the international system.

Finally, the ETL provides an extra function to wrap up the information and transform it into a DataFrame python object, which sometimes facilitates the use of the information (for instance, in the building pathologies diagnosis tool in *D7.2: Renovation design using building and HVAC components in BIM libraries*).

Moreover, it should be noted that, within the BIMtoBEPS tool, an IFC extractor is also developed. However, in contrast to the WP5 ETL, the one for this tool (developed in WP3) obtains all the information from the IFC file. That is why the ETL is not reflected in the sequence diagram and it is part of the BIMtoBEPS element.

6.3.2 ETL2 – Weather files

Next ETL is the weather services, which connects to the service available on the PVGIS TMY site of the JRC. In particular, the service points https://re.jrc.ec.europa.eu/api/tmy, being necessary a set of parameters to call the service. Then, the ETL automatically builds the request URL according to:

a) Coordinates (latitude and longitude) as extracted in the ETL for IFC parameters to provide the location to the weather service.

b) Start and end years, which, according to the documentation of the Web service, should differ at least 10 years because the weather file is filled depending on the availability of the temporal coverage of the database. The default value is the last year of the chosen database.

c) Output format, which is EPW, readable by TRNSYS, although also .csv and .json are available.

[16] http://ifcopenshell.org/python

d) Browser, which is a parameter to indicate the service if it is being accessed from a browser or an external application, which is the case of this ETL as data is downloaded and not visualised in the browser..

The ETL does not only load the EPW file, but also transforms it. It should be noted that the weather file contains the information from historical registers. However, under the goal of increasing the functionality, the ETL also connects with a weather forecast services, in particular, WeatherBit[17]. In this sense, the ETL provides a set of functions:

- Get forecast data for the next 48 hours, which is returned as a list of DataPoint objects. This object is a python class that contains all the elements that are retrieved by the weather service, like temperature, pressure, relative humidity, etc.
- Get current data, which, in contrast to the forecast data, is just a single value with the current weather condition. Similar to before, it is one python object, but, in this specific case, the class is named SingleDataPoint with some differences with respect to DataPoint because some of the weather parameters are slightly different (the API documentation provides all the details).
- Get historical data, but it is not operative because it requires a subscription fee that is not covered within the project.

The request is also automatically filled according to certain parameters, such as:

- key: API key for accessing the service.
- lang: language of the response.
- units: either metric, scientific or Fahrenheit.
- granularity: hourly by default.

Others like the ones included in Table 10.

Table 10: Parameters of the weather forecast service call

Objective	Parameters
Get observation by lat/lon	lat, lon
Get observation by city name	city, state(optional), country (optional)
Get observation by postal code	postal_code, country (optional)
Get observation by city id's	city_id
Get observation by airport ICAO, or station id	station
Get observation hours	Hours (48 by default)

Having the JSON response by the weather service, the information tags are transformed into the aforementioned python classes. Once this process is ended, then, next step is the transformation of the original EPW file by loading the forecast information. Then, the ETL would build an EPW file that

[17] https://www.weatherbit.io/

contains certain hours (in fact, 48 hours) with forecast data to allow the simulation with prediction values.

In short, the ETL has two objectives:

1) Obtain and load the historical EPW data to provide the weather file to the simulation model.
2) Extract, Transform and Load forecast data into the EPW to run prediction simulations.

6.3.3 ETL3 – TRNSYS

TRNSYS ETL is not part of the WP5 itself. The reason is, as already stated, the development of the BIMtoBEPS tool belongs to WP3 where this ETL has been really developed. Basically, the objective of the ETL is to make use of the IFC data to transform it into TRNSYS-compliant (i.e. dck file). Then, this ETL makes also use of the IFC ETL (but the full one implemented under WP3) to get the input from the IFC file. Then, the IFC classes and objects are transformed into the DCK format and loaded into a file to be run in the TRNSYS simulation engine.

6.3.4 ETL4 – Simulation results

This ETL dedicated to extract the simulation results. TRNSYS, after running the simulation, generates an output file, which is readable. The results are grouped in columns, being the first row the header and following the values of the simulation result.

Then, the ETL loads the output file in order to read the results with the aim at providing a summary to the user, allowing also downloading the original file.

6.3.5 ETL5 – BACN2BIM

BACN2BIM ETL is the one that allows the users of BIM-SPEED project to have real and dynamic data of the building operation. The ETL uses IFC4 (Add2-TC1 schema version) to define the structure of the database where data are inserted and maintains its compatibility with the BIM model. Raw data are the main inputs of the ETL as well, and as outputs users have time series data in .csv or .json formats. Then these files can be used in other applications and tools (also ETLs) as inputs such as calibrating of energy models or the ECOtool.

On the other hand, as output, the BACN2BIM tool also generates a new .ifc file including information about sensors installed on buildings, which are represented on the new .ifc file on the correspondent spatial structure of the building, this makes the representation of the building more accurate and similar to reality. A more extended description of this tool and its development and deployment can be found in Deliverable *D1.3: IT solutions to couple dynamic data of the existing buildings to BIM*.

6.3.6 ETL6 – Information extraction using OCR

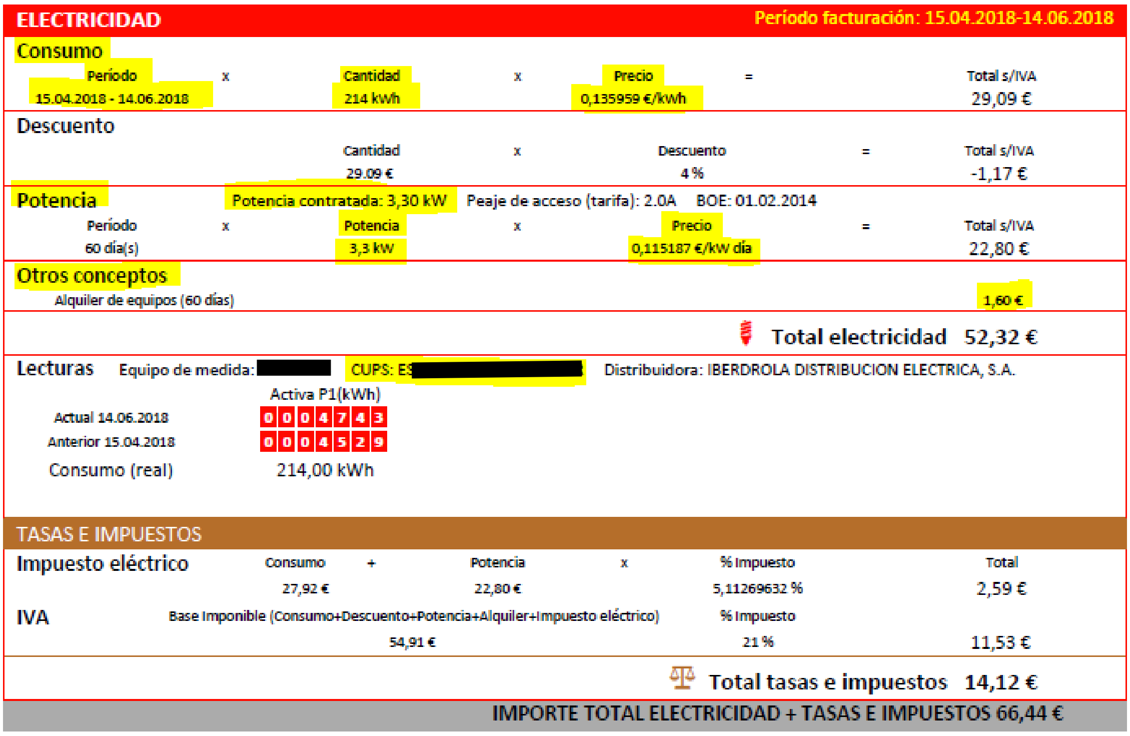
Historical consumer information is not always computerized, but it can be helpful for analytical purposes. Scanned documents or photos can contribute in this scenario, and the goal is to avoid the effort that is often required to store such data manually. The OCR (Optical Character Recognition) module extracts information from scanned images / files and transforms it into text. The ETL for OCR using in the

UC_4 (ECOtool) is written in Python and can provide information about the billing period, the amount of energy consumed, and the total cost, and associate it with an identifier automatically.

An **example of information to be extracted** from energy bills, for one apartment in the demo-site **Arcaya 5 (Vitoria -Spain)**, is presented below. For this demo-site, there are two energy providers: EDP and Iberdrola, and depending on the dwelling the energy provider is different.

In the case of EDP, it includes electricity and gas consumption bills. In the case of the electricity bill, the concepts included in the bill and useful for the ECOtool are highlighted in yellow in Figure 23 . They correspond with:

- Electricity billing period [Initial billing date – Final billing date].
- Electricity consumption [kWh].
- Electricity price [€/kWh].
- Power contracted [kW].
- Electricity power price [€/kW·day].
- Other concepts [€]. Equipment rental.
- CUPS: Idenfier of the electricity supply point.



ELECTRICIDAD Período facturación: 15.04.2018-14.06.2018

Consumo

Período	x	Cantidad	x	Precio	=	Total s/IVA
15.04.2018 - 14.06.2018		214 kWh		0,135959 €/kWh		29,09 €

Descuento

		Cantidad	x	Descuento	=	Total s/IVA
		29.09 €		4 %		-1,17 €

Potencia Potencia contratada: 3,30 kW Peaje de acceso (tarifa): 2.0A BOE: 01.02.2014

Período	x	Potencia	x	Precio	=	Total s/IVA
60 día(s)		3,3 kW		0,115187 €/kW día		22,80 €

Otros conceptos

Alquiler de equipos (60 días)	1,60 €

Total electricidad 52,32 €

Lecturas Equipo de medida: [redacted] CUPS: ES[redacted] Distribuidora: IBERDROLA DISTRIBUCION ELECTRICA, S.A.

	Activa P1(kWh)
Actual 14.06.2018	0004743
Anterior 15.04.2018	0004529
Consumo (real)	214,00 kWh

TASAS E IMPUESTOS

	Consumo	+	Potencia	x	% Impuesto	Total
Impuesto eléctrico	27,92 €		22,80 €		5,11269632 %	2,59 €

	Base Imponible (Consumo+Descuento+Potencia+Alquiler+Impuesto eléctrico)	% Impuesto	
IVA	54,91 €	21 %	11,53 €

Total tasas e impuestos 14,12 €

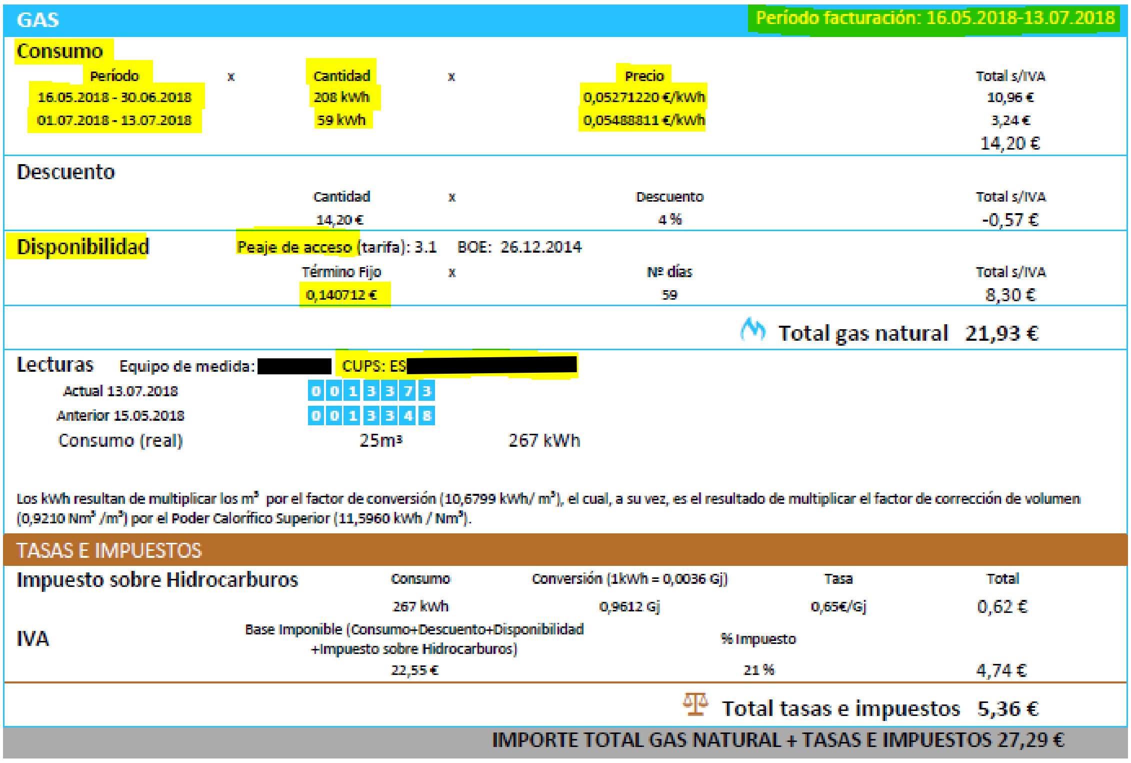
IMPORTE TOTAL ELECTRICIDAD + TASAS E IMPUESTOS 66,44 €

Figure 23: Electricity bill of a dwelling in Arcaya 5 (Vitoria – Spain)

In the case of natural gas, the concepts included in the bill and useful for the ECOtool are highlighted in yellow in Figure 24. They correspond with:

- Natural gas billing period [Initial billing date – Final billing date].
- Natural gas consumption [kWh].

- Natural gas price [€/kWh].
- Gas access toll [€/day].
- Other concepts [€]. Incldued only in some bills. Equipment rental.
- CUPS: Idenfier of the natural gas supply point.



GAS Período facturación: 16.05.2018-13.07.2018

Consumo

Período	x	Cantidad	x	Precio	Total s/IVA
16.05.2018 - 30.06.2018		208 kWh		0,05271220 €/kWh	10,96 €
01.07.2018 - 13.07.2018		59 kWh		0,05488811 €/kWh	3,24 €
					14,20 €

Descuento

Cantidad	x	Descuento	Total s/IVA
14,20 €		4 %	-0,57 €

Disponibilidad Peaje de acceso (tarifa): 3.1 BOE: 26.12.2014

Término Fijo	x	Nº días	Total s/IVA
0,140712 €		59	8,30 €

Total gas natural 21,93 €

Lecturas Equipo de medida: [redacted] CUPS: ES[redacted]

Actual 13.07.2018	0 0 1 3 3 7 3	
Anterior 15.05.2018	0 0 1 3 3 4 8	
Consumo (real)	25m³	267 kWh

Los kWh resultan de multiplicar los m³ por el factor de conversión (10,6799 kWh/ m³), el cual, a su vez, es el resultado de multiplicar el factor de corrección de volumen (0,9210 Nm³ /m³) por el Poder Calorífico Superior (11,5960 kWh / Nm³).

TASAS E IMPUESTOS

	Consumo	Conversión (1kWh = 0,0036 Gj)	Tasa	Total
Impuesto sobre Hidrocarburos	267 kWh	0,9612 Gj	0,65€/Gj	0,62 €

	Base Imponible (Consumo+Descuento+Disponibilidad +Impuesto sobre Hidrocarburos)	% Impuesto	
IVA	22,55 €	21 %	4,74 €

Total tasas e impuestos 5,36 €

IMPORTE TOTAL GAS NATURAL + TASAS E IMPUESTOS 27,29 €

Figure 24: Natural gas bill of a dwelling in Arcaya 5 (Vitoria – Spain)

The other energy provider, Iberdrola, only provides gas to the dwellings. The information provided in the bill is very similar to the one of EDP.

6.3.7 ETL7 – Energy prices (EUROSTAT)

This ETL is in charge of developing a geo-clustering service able to access the EUROSTAT[18] database of the European Commission to obtain the energy cost in a specific country. The EUROSTAT database provides energy price data as required in € KWh per country.

To retrieve data programmatically EUROSTAT provides several REST services that can be called following the format depicted in Figure 25.

[18] http://ec.europa.eu/eurostat

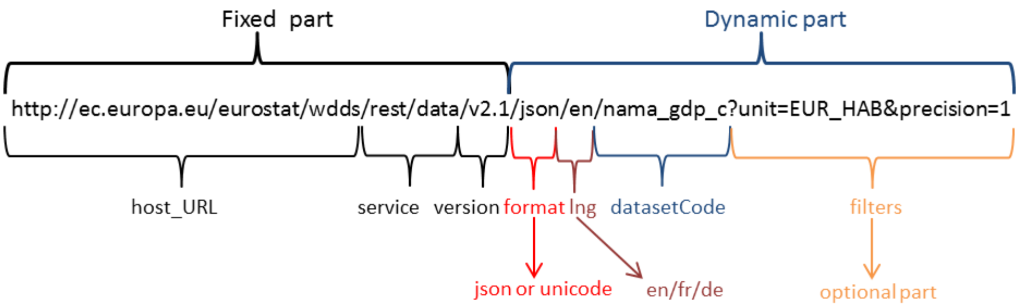
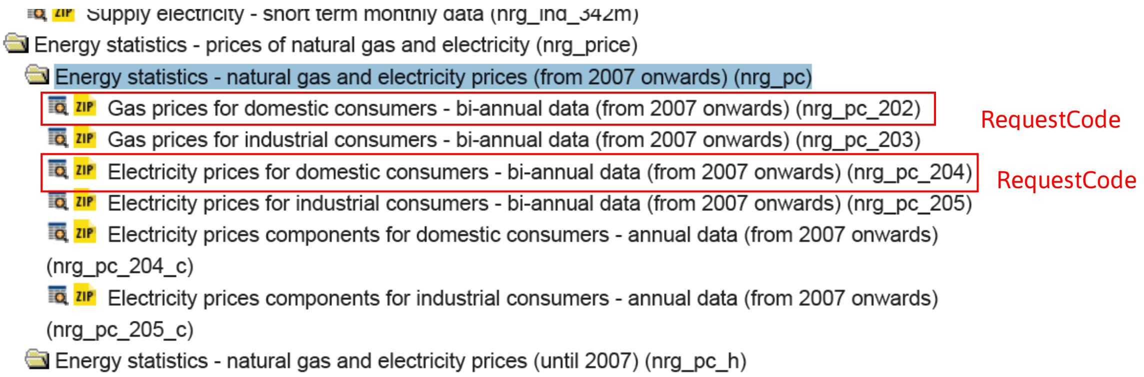


Figure 25: EUROSTAT REST request

A detailed explanation of this request can be found at link below: http://ec.europa.eu/eurostat/web/json-and-unicode-web-services/getting-started/rest-request.

To retrieve energy prices, the information to be gathered is the price of gas and electricity for domestic consumers. It is also necessary to know the country where the demo-site is located. The query format for countries requires the following ISO 3166-1 alpha-2 code representation. The datasets to query energy price are (see Figure 26):

1. Gas Price for domestic consumers (datasetCode: nrg_pc_202)
2. Electricity Price for domestic consumers (datasetCode: nrg_pc_204)



Supply electricity - short term monthly data (nrg_ind_342m)

Energy statistics - prices of natural gas and electricity (nrg_price)

Energy statistics - natural gas and electricity prices (from 2007 onwards) (nrg_pc)

Gas prices for domestic consumers - bi-annual data (from 2007 onwards) (nrg_pc_202)

Gas prices for industrial consumers - bi-annual data (from 2007 onwards) (nrg_pc_203)

Electricity prices for domestic consumers - bi-annual data (from 2007 onwards) (nrg_pc_204)

Electricity prices for industrial consumers - bi-annual data (from 2007 onwards) (nrg_pc_205)

Electricity prices components for domestic consumers - annual data (from 2007 onwards) (nrg_pc_204_c)

Electricity prices components for industrial consumers - annual data (from 2007 onwards) (nrg_pc_205_c)

Energy statistics - natural gas and electricity prices (until 2007) (nrg_pc_h)

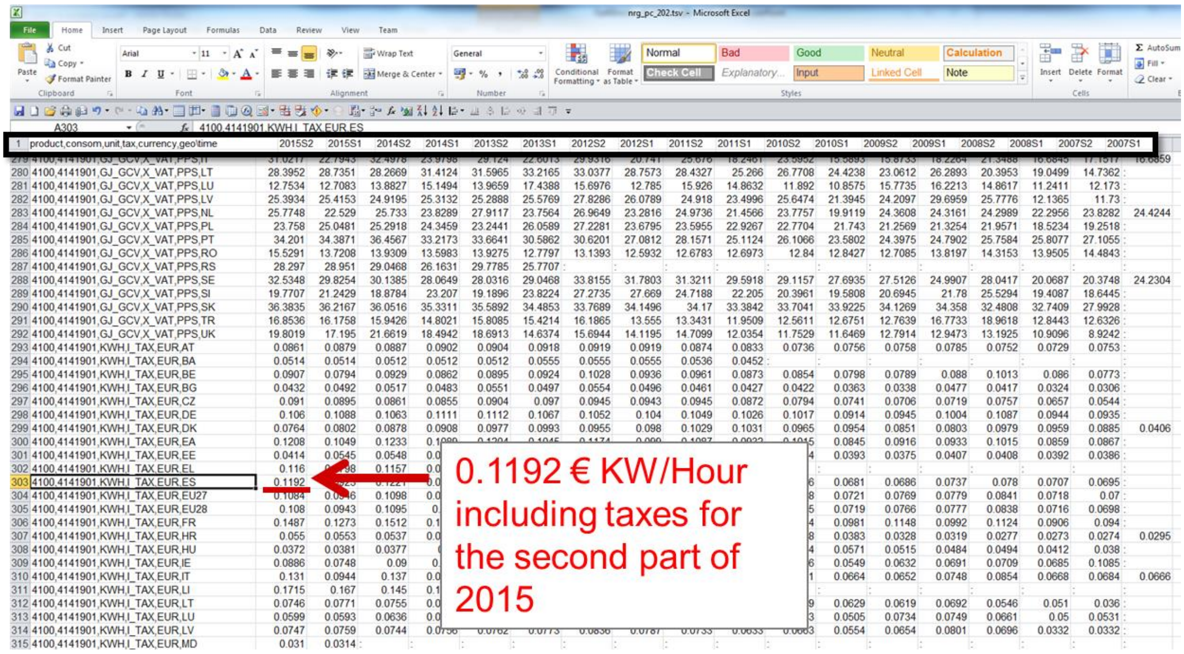
Figure 26: Capture of datasets list – Energy Statistics

The simplest possible query where only the dataset is specified (no filters applied) is:

http://ec.europa.eu/eurostat/wdds/rest/data/v2.1/unicode/en/nrg_pc_204

http://ec.europa.eu/eurostat/wdds/rest/data/v2.1/unicode/en/nrg_pc_202

The response received follows the format shown in Figure 27.



4100,4141901,KWH,I_TAX,EUR,ES

1	product,consom,unit,tax,currency,geo\time	2015S2	2015S1	2014S2	2014S1	2013S2	2013S1	2012S2	2012S1	2011S2	2011S1	2010S2	2010S1	2009S2	2009S1	2008S2	2008S1	2007S2	2007S1
279	4100,4141901,GJ_GCV,X_VAT,PPS,IT	31.0217	22.7943	32.4978	23.9798	29.124	22.6013	29.9316	20.741	25.676	18.2461	23.5952	15.5893	15.8733	18.2264	21.3488	16.6845	17.1517	16.6859
280	4100,4141901,GJ_GCV,X_VAT,PPS,LT	28.3952	28.7351	28.2669	31.4124	31.5965	33.2165	33.0377	28.7573	28.4327	25.266	26.7708	24.4238	23.0612	26.2893	20.3953	19.0499	14.7362	:
281	4100,4141901,GJ_GCV,X_VAT,PPS,LU	12.7534	12.7083	13.8827	15.1494	13.9659	17.4388	15.6976	12.785	15.926	14.8632	11.892	10.8575	15.7735	16.2213	14.8617	11.2411	12.173	:
282	4100,4141901,GJ_GCV,X_VAT,PPS,LV	25.3934	25.4153	24.9195	25.3132	25.2888	25.5769	27.8286	26.0789	24.918	23.4996	25.6474	21.3945	24.2097	29.6959	25.7776	12.1365	11.73	:
283	4100,4141901,GJ_GCV,X_VAT,PPS,NL	25.7748	22.529	25.733	23.8289	27.9117	23.7564	26.9649	23.2816	24.9736	21.4566	23.7757	19.9119	24.3608	24.3161	24.2989	22.2956	23.8282	24.4244
284	4100,4141901,GJ_GCV,X_VAT,PPS,PL	23.758	25.0481	25.2918	24.3459	23.2441	26.0589	27.2281	23.6795	23.5955	22.9267	22.7704	21.743	21.2569	21.3254	21.9571	18.5234	19.2518	:
285	4100,4141901,GJ_GCV,X_VAT,PPS,PT	34.201	34.3871	36.4567	33.2173	33.6641	30.5862	30.6201	27.0812	28.1571	25.1124	26.1066	23.5802	24.3975	24.7902	25.7584	25.8077	27.1055	:
286	4100,4141901,GJ_GCV,X_VAT,PPS,RO	15.5291	13.7208	13.9309	13.5983	13.9275	12.7797	13.1393	12.5932	12.6783	12.6973	12.84	12.8427	12.7085	13.8197	14.3153	13.9505	14.4843	:
287	4100,4141901,GJ_GCV,X_VAT,PPS,RS	28.297	28.951	29.0468	26.1631	29.7785	25.7707	:	:	:	:	:	:	:	:	:	:	:	:
288	4100,4141901,GJ_GCV,X_VAT,PPS,SE	32.5348	29.8254	30.1385	28.0649	28.0316	29.0468	33.8155	31.7803	31.3211	29.5918	29.1157	27.6935	27.5126	24.9907	28.0417	20.0687	20.3748	24.2304
289	4100,4141901,GJ_GCV,X_VAT,PPS,SI	19.7707	21.2429	18.8784	23.207	19.1896	23.8224	27.2735	27.669	24.7188	22.205	20.3961	19.5808	20.6945	21.78	25.5294	19.4087	18.6445	:
290	4100,4141901,GJ_GCV,X_VAT,PPS,SK	36.3835	36.2167	36.0516	35.3311	35.5892	34.4853	33.7689	34.1496	34.17	33.3842	33.7041	33.9225	34.1269	34.358	32.4808	32.7409	27.9928	:
291	4100,4141901,GJ_GCV,X_VAT,PPS,TR	16.8536	16.1758	15.9426	14.8021	15.8085	15.4214	16.1865	13.555	13.3431	11.9509	12.5611	12.6751	12.7639	16.7733	18.9618	12.8443	12.6326	:
292	4100,4141901,GJ_GCV,X_VAT,PPS,UK	19.8019	17.195	21.6619	18.4942	18.6913	14.6374	15.6944	14.1195	14.7099	12.0354	11.7529	11.6469	12.7914	12.9473	13.1925	10.9096	8.9242	:
293	4100,4141901,KWH,I_TAX,EUR,AT	0.0861	0.0879	0.0887	0.0902	0.0904	0.0918	0.0919	0.0919	0.0874	0.0833	0.0736	0.0756	0.0758	0.0785	0.0752	0.0729	0.0753	:
294	4100,4141901,KWH,I_TAX,EUR,BA	0.0514	0.0514	0.0512	0.0512	0.0512	0.0555	0.0555	0.0555	0.0536	0.0452	:	:	:	:	:	:	:	:
295	4100,4141901,KWH,I_TAX,EUR,BE	0.0907	0.0794	0.0929	0.0862	0.0895	0.0924	0.1028	0.0936	0.0961	0.0873	0.0854	0.0798	0.0789	0.088	0.1013	0.086	0.0773	:
296	4100,4141901,KWH,I_TAX,EUR,BG	0.0432	0.0492	0.0517	0.0483	0.0551	0.0497	0.0554	0.0496	0.0461	0.0427	0.0422	0.0363	0.0338	0.0477	0.0417	0.0324	0.0306	:
297	4100,4141901,KWH,I_TAX,EUR,CZ	0.091	0.0895	0.0861	0.0855	0.0904	0.097	0.0945	0.0943	0.0945	0.0872	0.0794	0.0741	0.0706	0.0719	0.0757	0.0657	0.0544	:
298	4100,4141901,KWH,I_TAX,EUR,DE	0.106	0.1088	0.1063	0.1111	0.1112	0.1067	0.1052	0.104	0.1049	0.1026	0.1017	0.0914	0.0945	0.1004	0.1087	0.0944	0.0935	:
299	4100,4141901,KWH,I_TAX,EUR,DK	0.0764	0.0802	0.0878	0.0908	0.0977	0.0993	0.0955	0.098	0.1029	0.1031	0.0965	0.0954	0.0851	0.0803	0.0979	0.0959	0.0885	0.0406
300	4100,4141901,KWH,I_TAX,EUR,EA	0.1208	0.1049	0.1233	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0845	0.0916	0.0933	0.1015	0.0859	0.0867	:
301	4100,4141901,KWH,I_TAX,EUR,EE	0.0414	0.0545	0.0548	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0393	0.0375	0.0407	0.0408	0.0392	0.0386	:
302	4100,4141901,KWH,I_TAX,EUR,EL	0.116	[illegible]	0.1157	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	:	:	:	:	:	:	:
303	4100,4141901,KWH,I_TAX,EUR,ES	0.1192	[illegible]	0.1221	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0681	0.0686	0.0737	0.078	0.0707	0.0695	:
304	4100,4141901,KWH,I_TAX,EUR,EU27	0.1084	[illegible]	0.1098	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0721	0.0769	0.0779	0.0841	0.0718	0.07	:
305	4100,4141901,KWH,I_TAX,EUR,EU28	0.108	0.0943	0.1095	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0719	0.0766	0.0777	0.0838	0.0716	0.0698	:
306	4100,4141901,KWH,I_TAX,EUR,FR	0.1487	0.1273	0.1512	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0981	0.1148	0.0992	0.1124	0.0906	0.094	:
307	4100,4141901,KWH,I_TAX,EUR,HR	0.055	0.0553	0.0537	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0383	0.0328	0.0319	0.0277	0.0273	0.0274	0.0295
308	4100,4141901,KWH,I_TAX,EUR,HU	0.0372	0.0381	0.0377	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0571	0.0515	0.0484	0.0494	0.0412	0.038	:
309	4100,4141901,KWH,I_TAX,EUR,IE	0.0886	0.0748	0.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0549	0.0632	0.0691	0.0709	0.0685	0.1085	:
310	4100,4141901,KWH,I_TAX,EUR,IT	0.131	0.0944	0.137	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0664	0.0652	0.0748	0.0854	0.0668	0.0684	0.0666
311	4100,4141901,KWH,I_TAX,EUR,LI	0.1715	0.167	0.145	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	:	:	:	:	:	:	:
312	4100,4141901,KWH,I_TAX,EUR,LT	0.0746	0.0771	0.0755	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0629	0.0619	0.0692	0.0546	0.051	0.036	:
313	4100,4141901,KWH,I_TAX,EUR,LU	0.0599	0.0593	0.0636	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0505	0.0734	0.0749	0.0661	0.05	0.0531	:
314	4100,4141901,KWH,I_TAX,EUR,LV	0.0747	0.0759	0.0744	0.0756	0.0762	0.0773	0.0836	0.0787	0.0733	0.0633	[illegible]	0.0554	0.0654	0.0801	0.0696	0.0332	0.0332	:
315	4100,4141901,KWH,I_TAX,EUR,MD	0.031	0.0314	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:

0.1192 € KW/Hour including taxes for the second part of 2015

Figure 27: EUROSTAT gas price response

In addition to these elements, additional filters should be included in the optional part of the request to ensure the retrieving of the relevant data, such as the type of energy, kind of consumer, precision, geography (country code based on ISO 3166-1 alpha-2 code), currency, product, unit, time and taxes.

Example of requests for the gas price and the electricity prices in Spain are:

Gas price

http://ec.europa.eu/eurostat/wdds/rest/data/v2.1/json/en/nrg_pc_202?consom=4141902&precision=1&geo=ES&lastTimePeriod=1&currency=EUR&product=4100&unit=KWH&tax=I_TAX

Electricity price

http://ec.europa.eu/eurostat/wdds/rest/data/v2.1/json/en/nrg_pc_204?consom=4161903&precision=1&geo=TR&currency=EUR&product=6000&unit=KWH&time=2016S1&tax=I_TAX

The results of these requests are provided in JSON files. The ETL has to extract from this file the information needed for the ECOtool.

6.3.8 ETL8 – Process for the ECOtool

Finally, this ETL is in charge of generating the XML expected by the ECOtool to operate and to receive the socio-economic KPIs calculated by this tool. In order to do that, the ETL has to compile all the inputs collected both, manually from the Graphical User Interface, and automatically form other ETLs (ETL_IFC, ETL_IoT, ETL_OCR, etc.) to create the XML according to the format needed by the ECOtool. An example of this XML is shown below:

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<economicModel>
        <evaluationModel>true</evaluationModel>
        <districtInformation>
                <refurbishmentSurface>2000.0</refurbishmentSurface>
        </districtInformation>

        <contextualData>
                <gasEnergyCost>0.0536</gasEnergyCost>
                <biomassEnergyCost>0.0129</biomassEnergyCost>
                <electricityEnergyCost>0.1051</electricityEnergyCost>
                <gasEnergyCost_1>0.0526</gasEnergyCost_1>
                <biomassEnergyCost_1>0.0135</biomassEnergyCost_1>
                <electricityEnergyCost_1>0.104</electricityEnergyCost_1>
                <gasEnergyCost_2>0.0516</gasEnergyCost_2>
                <biomassEnergyCost_2>0.0123</biomassEnergyCost_2>
                <electricityEnergyCost_2>0.1029</electricityEnergyCost_2>
                <gasEnergyCost_3>0.0506</gasEnergyCost_3>
                <biomassEnergyCost_3>0.0111</biomassEnergyCost_3>
                <electricityEnergyCost_3>0.1018</electricityEnergyCost_3>
                <gasEnergyCost_4>0.0496</gasEnergyCost_4>
                <biomassEnergyCost_4>0.0107</biomassEnergyCost_4>
                <electricityEnergyCost_4>0.1007</electricityEnergyCost_4>
        </contextualData>

        <configurationData>
                <discountRate>0.03</discountRate>
                <timeForAnalysis>50</timeForAnalysis>
        </configurationData>

        <ecms>
                <ecm>
                        <buildingID>1</buildingID>
                        <ecmId>PA.FA.EX.VE.01</ecmId>
                        <endOfLifeCost>1.91525</endOfLifeCost>
                        <estimatedServiceLife>25.0</estimatedServiceLife>
                        <installationCost>54.5</installationCost>
                        <maintenanceCost>30.35</maintenanceCost>
                        <quantity>720.0</quantity>
                        <salePrice>106.5</salePrice>
                </ecm>

                <ecm>
                        <buildingID>1</buildingID>
                        <ecmId>PA.OP.DG.DE.03</ecmId>
                        <endOfLifeCost>2.445</endOfLifeCost>
                        <estimatedServiceLife>40.0</estimatedServiceLife>
                        <installationCost>42.12</installationCost>
                        <maintenanceCost>22.55</maintenanceCost>
                        <quantity>36.0</quantity>
                        <salePrice>281.0</salePrice>
                </ecm>
        </ecms>
</economicModel>
```

6.3.9 ETL9 – IFC material enrichment

In addition to the previous ETLs, generated as part of the four Use Cases under study, other horizontal ETL has been created for the IFC material enrichment that can be of application in those BIM tools needing an enhanced version of the IFC.

Digital simulation always needs a pre-processing step on the building numeric model by setting/correcting different kind of information like:

- Geometry
- Material properties definition
- Boundary conditions
- Calculation parameters (depending used algorithm, etc.)

The geometry management is always the first step and calculation tools have been able to read CAD files for many years (describing the 2D and / or 3D geometry), particularly in the automotive or aeronautical sector. The construction industry has long remained oriented towards 2D formats representing floor or facade plans (especially Autodesk formats: DWG, DXF) making these formats de facto standards. The description of the material characteristics and other parameters (boundary conditions, etc.) was generally done directly inside the simulation tools.

With the rise of BIM, in particular openBIM (i.e. the IFC standard) which paves the way for interoperability, it becomes possible to prepare input data for simulation tools by considering the entire information contained in the BIM models, in particular material properties. Unfortunately, despite CAD tools (architect tools like Autodesk REVIT, Graphisoft ArchiCAD, etc.) that allow the user to manage these properties, they are not exported in the IFC file.

To tackle the matter, we propose to develop a specific ETL that enables enriching an IFC file by adding the material properties needed for a thermal simulation. In this context, it is first necessary to build a specific dictionary (according to the thermal simulation use cases) in order to describe the properties needed (name, unit, default value, etc.) and the involved objects (materials in our case).

In a second step, a web interface will be developed to set the right material properties for a given BIM/IFC model.

To finish, the initial IFC file will be enriched with these additional properties (we chose the version 4 of IFC).

Dictionary

In the dictionary, each material is identified by a Universally Unique Identifier (UUID) and:

- Has just one usual name and several synonyms in a given language
- Is defined in several languages (English is the default language)
- Has a set of properties

Then, it is possible to search materials defined in an IFC file into the dictionary by inputting a name. If the name is found (or one of the synonyms), the corresponding properties are retrieved. If the name is missing, the user is notified that the database must be updated with this new material description.

The user can then request the database administrator to add the new material and its properties.

Once all materials are added into the database, the user can launch again the process in order to enrich the IFC file.

Properties

The properties described in the database are:

- Specific Heat Capacity [J/kg/°K]
- Thermal Conductivity [W/m/°K]
- Mass Density [kg/m3]
- Emissivity [without unit]
- Compressibility [without unit]

IFC enrichment

If all materials contained in the IFC file have been found in the database, the file is then enriched with the given properties. It means that for each material defined in the IFC file (line #n), some new lines will be added as shown below (lines #n+1 to #n+6):

```
#n = IFCMATERIAL ('Name','Description','Category');
#n+1=IFCPROPERTYSINGLEVALUE('SpecificHeatCapacity',$,IFCSPECIFICHEATCAPACITYMEASURE(REAL),$);
#n+2=IFCPROPERTYSINGLEVALUE('ThermalConductivity',$,IFCTHERMALCONDUCTIVITYMEASURE(REAL),$);
#n+3=IFCPROPERTYSINGLEVALUE('MassDensity',$,IFCMASSDENSITYMEASURE (REAL),$);
#n+4=IFCPROPERTYSINGLEVALUE('Emissivity',$,IFCREAL(REAL),$);
#n+5=IFCPROPERTYSINGLEVALUE('Compressibility,$,IFCREAL(REAL),$);
#n+6=IFCMATERIALPROPERTIES('MaterialProperties',$,(#n+1,#n+2,#n+3,#n+4,#n+5),#n);
```

This specific ETL can be also offered as a service in the BIM-SPEED platform, in a similar manner as the model checker developed by CSTB. In section 7.5 it is explained how this ETL is validated.

7. Integration and demonstration in relevant environment (TRL6)

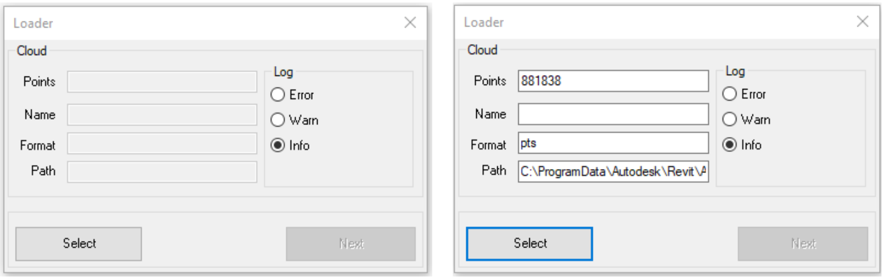
This section shows the current status of the integration of the tools explained above with the BIM-SPEED platform. Some of these tools have already demonstrated in relevant environment (TRL6) on BIM-SPEED demonstration case (3DASH Tool and BACN2BIM tool). These initial integrations and demonstrations TRL6 are summarized in this section.

7.1 3DASH Tool as a service of the BIM-SPEED platform

The 3DASH Tool is currently in a prototype phase. The integration of the 3DASH Tool as a service with the BIM-SPEED platform is ongoing at time of writing this deliverable. The validation status of the tool is TRL6 and has been demonstrated in the context of the BIM-SPEED project using three BIM-SPEED cases: Aldabe26 and Arcaya5 demos in Vitoria-Gasteiz (Spain) and WarsawII demo (Poland). The validation of the 3DASH Tool has been demonstrated with the results of the Arcaya5 demo-site of the BIM-SPEED project, as shown below:

- Upload point cloud:

The *Loader* menu is deployed when the 3DASH Tool is launched to upload the point clouds. After point cloud has been loaded and analysed, the number of points loaded appears in the *Loader* menu (Figure 28).



Loader

Cloud

Points:
Name:
Format:
Path:

Log: ○ Error ○ Warn ● Info

Loader

Cloud

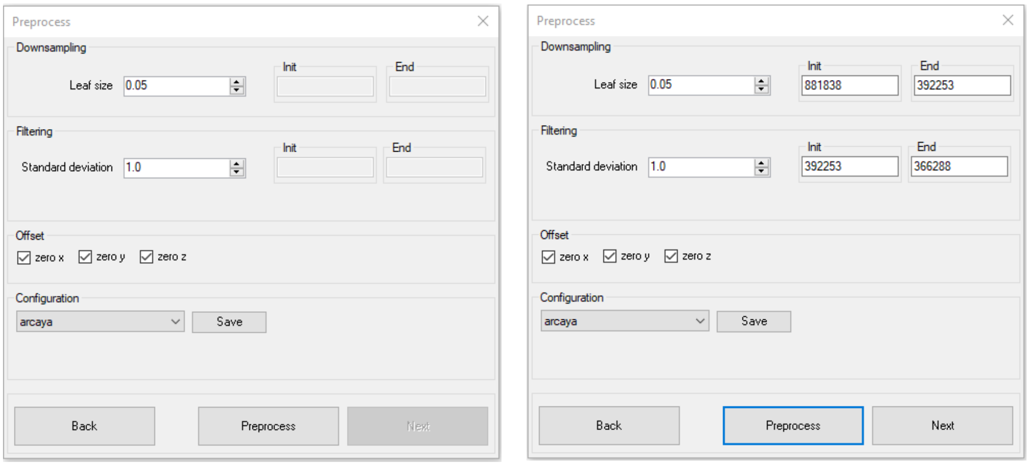
Points: 881838
Name:
Format: pts
Path: C:\ProgramData\Autodesk\Revit\A

Log: ○ Error ○ Warn ● Info

Figure 28: Loader menu (left). Information of the points displaying in the loader menu after upload the point clouds (right).

- Pre-processing options:

The *Preprocess* menu is shown after selecting the button *Next*, in the *Loader* menu. After defining the values of the pre-processing of the points, the results are shown in the *Preprocess* menu (Figure 29).



Downsampling: Leaf size 0.05; Init; End

Filtering: Standard deviation 1.0; Init; End

Offset: ☑ zero x ☑ zero y ☑ zero z

Configuration: arcaya; Save

Downsampling: Leaf size 0.05; Init 881838; End 392253

Filtering: Standard deviation 1.0; Init 392253; End 366288

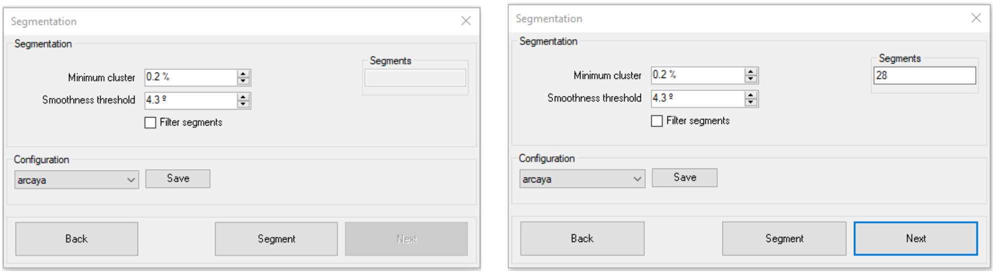
Offset: ☑ zero x ☑ zero y ☑ zero z

Configuration: arcaya; Save

Figure 29: *Preprocess* menu (left). Pre-processing results displaying in the *Preprocess* menu (rigth)

- <u>Segmentation options:</u>

The *Segmentation* menu is shown after selecting the button *Next*, in the *Preprocess* menu. After launching the execution with the *Segment* button the number of segments detected using the point clouds and the values selected before are shown in the *Segmentation* menu (Figure 30).



Segmentation: Minimum cluster 0.2 %; Smoothness threshold 4.3 º; □ Filter segments; Segments

Configuration: arcaya; Save

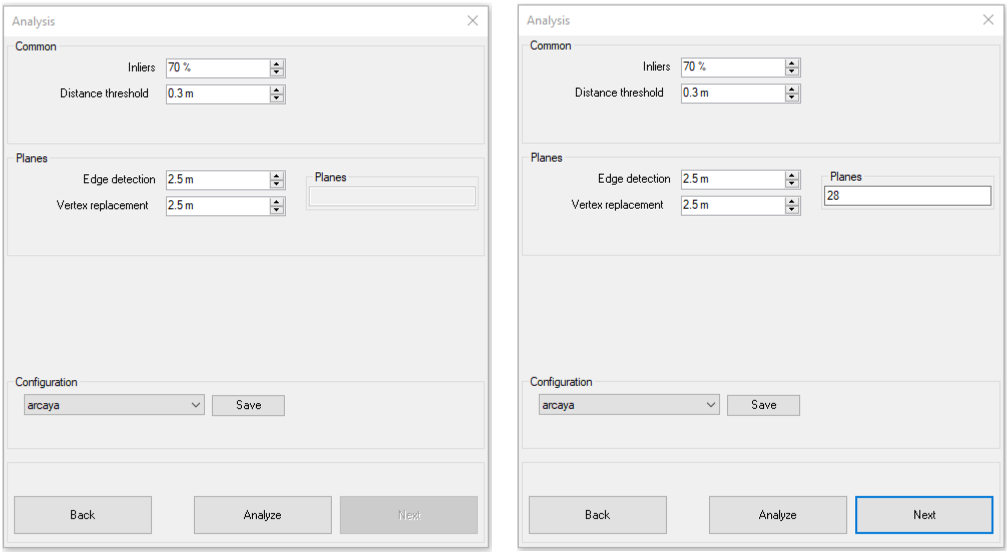
Segmentation: Minimum cluster 0.2 %; Smoothness threshold 4.3 º; □ Filter segments; Segments 28

Configuration: arcaya; Save

Figure 30: *Segmentation* menu (left). Information of the segments detected displaying in the *Segmentation* menu (right)

- <u>Analysis options:</u>

The *Analysis* menu is shown after selecting the button *Next*, in the *Segmentation* menu. After the execution of the *Analysis*, the information of the planes is displaying in the interface (Figure 31).



Left:

Inliers 70 %
Distance threshold 0.3 m
Edge detection 2.5 m
Vertex replacement 2.5 m
Planes
Configuration: arcaya

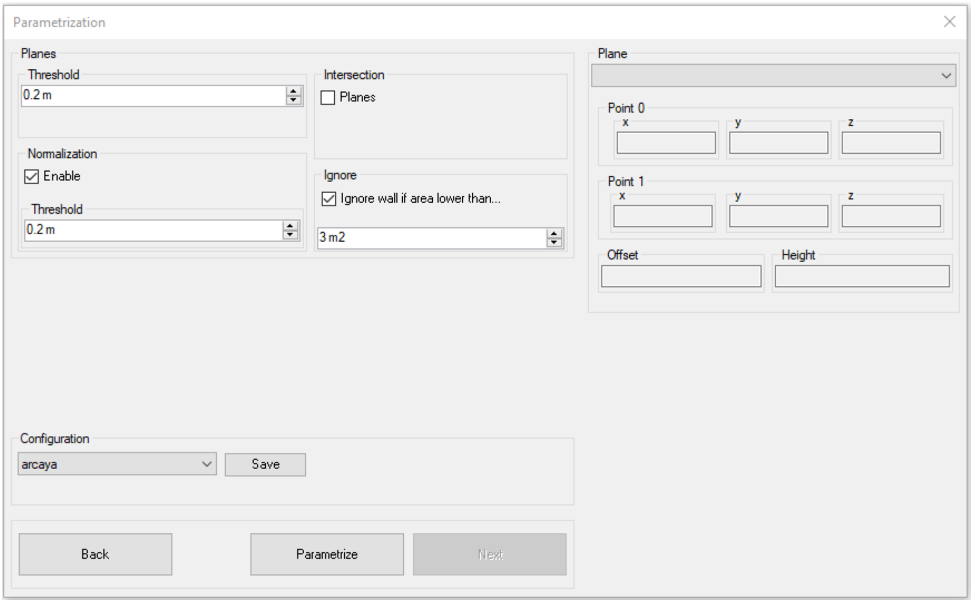
Right:

Inliers 70 %
Distance threshold 0.3 m
Edge detection 2.5 m
Vertex replacement 2.5 m
Planes 28
Configuration: arcaya

Figure 31: *Analysis* menu (left). Information of the planes detected displaying in the *Analysis* menu (rigth).

- <u>Parameterization options:</u>

The *Parameterization* menu is shown after selecting the button *Next*, in the *Analysis* menu. In this step, the parameterization settings can be configured (Figure 32).

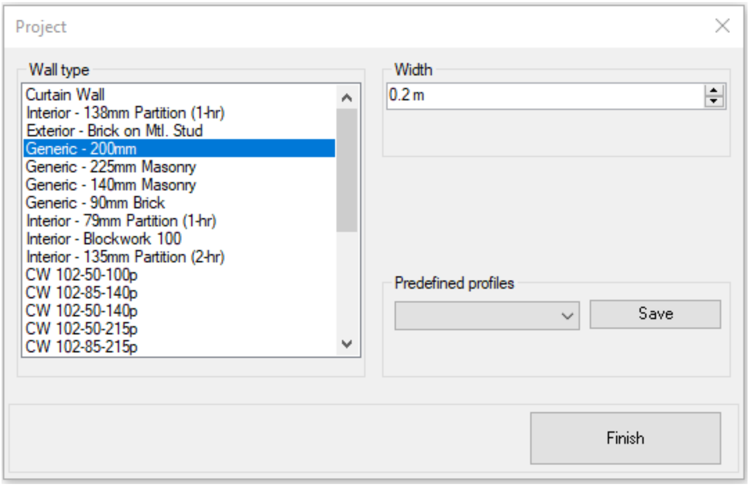


Threshold 0.2 m
☐ Planes
☑ Enable
Threshold 0.2 m
☑ Ignore wall if area lower than...
3 m2
Configuration: arcaya

Figure 32: *Parameterization* menu of the 3DASH Tool.

- <u>Project options:</u>

After selecting the button *Next*, the family wall type menu is shown in the 3DASH Tool to select the desired type of wall for the final generation of the elements (Figure 33) and the walls generated are added to the REVIT project (Figure 34).



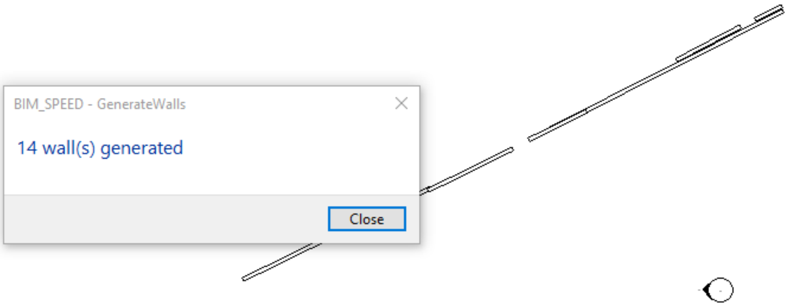
Project

Wall type

Curtain Wall
Interior - 138mm Partition (1-hr)
Exterior - Brick on Mtl. Stud
Generic - 200mm
Generic - 225mm Masonry
Generic - 140mm Masonry
Generic - 90mm Brick
Interior - 79mm Partition (1-hr)
Interior - Blockwork 100
Interior - 135mm Partition (2-hr)
CW 102-50-100p
CW 102-85-140p
CW 102-50-140p
CW 102-50-215p
CW 102-85-215p

Width: 0.2 m

Figure 33: *Project* menu to select the wall type.



BIM_SPEED - GenerateWalls

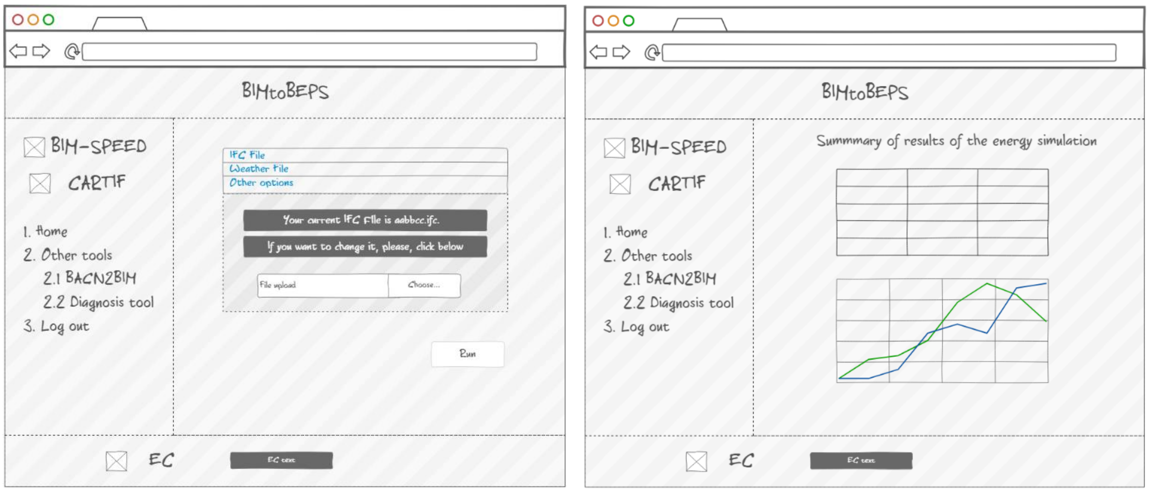
14 wall(s) generated

Figure 34: The results of the generated walls are shown in REVIT

More details of the results obtained in the demonstration in TRL6 with the Arcaya5 and WarsawII demos are available in *D1.1: Methods for architectural, structural, thermal 3D data acquisition of existing buildings of the BIM-SPEED project*.

7.2 BIMtoBEPS tool as a service of the BIM-SPEED platform

At this stage of the project, the BIMtoBEPS tool is in prototype version and initial tests have been carried out, while the development will continue until the end of the project (T5.2 finishes in M48). In this sense, the mock-ups of the human-machine interaction are shown in Figure 35. Initially, previous to these screens, the user needs to log in or requests an access key to the administrator of the tool, otherwise, he/she cannot execute the tool. The way to launch it is via the BIM-SPEED platform services by selecting the IFC file.



Your current IFC File is aabbcc.ifc.

If you want to change it, please, click below

Summmary of results of the energy simulation

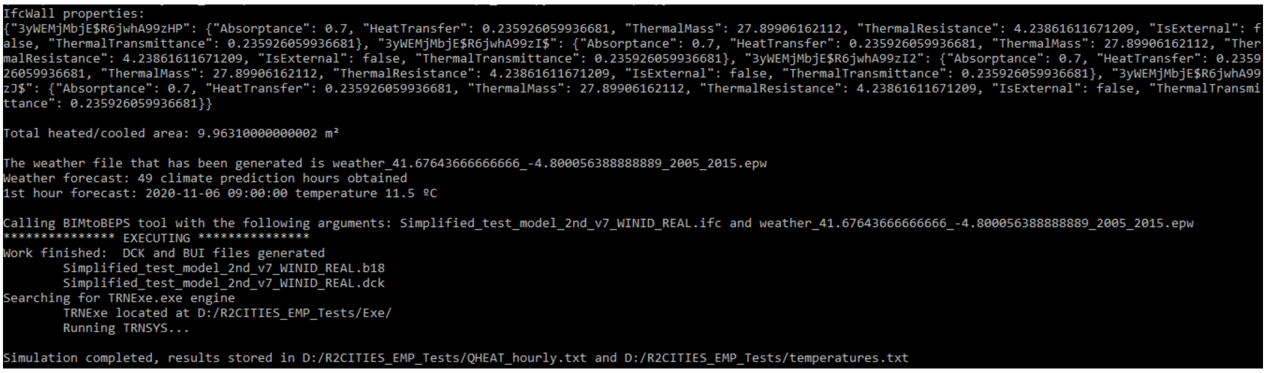
Figure 35: BIMtoBEPS tool mock-ups

Once logged-in, there is an intermediate validation. Although the execution has been done with the IFC file, it could be a mistake and loading again the file could be necessary. Then, the user can check the name of the IFC file to determine if it needs to be re-loaded. If everything is correct, then the tool can be launched. In this sense, the ETLs start to work. Figure 36 shows the log that is obtained. First of all, the wall properties are printed with some of the thermal parameters, like thermal resistance or heat transfer. Secondly, the total heated/cooled area is extracted. This information is mainly used by the ECOtool, but the BIMtoBEPS tool makes also use of it to provide results in kWh/m^2 to the user.

Next, the weather file that is generated from the weather service, whose name (in the example, weather_41.67643666666666_-4.800056388888889_2005_2015.epw) is composed of various parts:

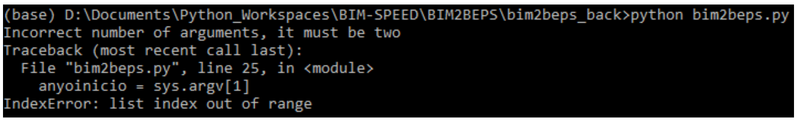
- Tag “weather” to identify the weather file.
- Coordinates, i.e. latitude, in the example 41.6764 and longitude, in the example -4.80, which corresponds to Valladolid, Spain.
- Years from which the file is built, in this case between 2005 and 2015. According to the documentation of the web service, “the data are selected from hourly data in a longer time period (normally 10 years or more)”. Then, the TMY generator takes the last year with available data from the database of the location established in the coordinates. It should be noted that the user is able to select these years when executing and, if they are not selected, an error message is printed as Figure 37.

To check that the weather file is correctly created, the number of prediction points is printed (in the example 49 hours are downloaded). As well, the next forecasted data is shown, which is the first value of the array of data, being, in this case, 11.5°C.



```
IfcWall properties:
{"3yWEMjMbjE$R6jwhA99zHP": {"Absorptance": 0.7, "HeatTransfer": 0.235926059936681, "ThermalMass": 27.89906162112, "ThermalResistance": 4.23861611671209, "IsExternal": f
alse, "ThermalTransmittance": 0.235926059936681}, "3yWEMjMbjE$R6jwhA99zI$": {"Absorptance": 0.7, "HeatTransfer": 0.235926059936681, "ThermalMass": 27.89906162112, "Ther
malResistance": 4.23861611671209, "IsExternal": false, "ThermalTransmittance": 0.235926059936681}, "3yWEMjMbjE$R6jwhA99zI2": {"Absorptance": 0.7, "HeatTransfer": 0.2359
26059936681, "ThermalMass": 27.89906162112, "ThermalResistance": 4.23861611671209, "IsExternal": false, "ThermalTransmittance": 0.235926059936681}, "3yWEMjMbjE$R6jwhA99
zJ$": {"Absorptance": 0.7, "HeatTransfer": 0.235926059936681, "ThermalMass": 27.89906162112, "ThermalResistance": 4.23861611671209, "IsExternal": false, "ThermalTransmi
ttance": 0.235926059936681}}

Total heated/cooled area: 9.96310000000002 m²

The weather file that has been generated is weather_41.67643666666666_-4.800056388888889_2005_2015.epw
Weather forecast: 49 climate prediction hours obtained
1st hour forecast: 2020-11-06 09:00:00 temperature 11.5 ºC

Calling BIMtoBEPS tool with the following arguments: Simplified_test_model_2nd_v7_WINID_REAL.ifc and weather_41.67643666666666_-4.800056388888889_2005_2015.epw
*************** EXECUTING ***************
Work finished:  DCK and BUI files generated
        Simplified_test_model_2nd_v7_WINID_REAL.b18
        Simplified_test_model_2nd_v7_WINID_REAL.dck
Searching for TRNExe.exe engine
        TRNExe located at D:/R2CITIES_EMP_Tests/Exe/
        Running TRNSYS...

Simulation completed, results stored in D:/R2CITIES_EMP_Tests/QHEAT_hourly.txt and D:/R2CITIES_EMP_Tests/temperatures.txt
```

Figure 36: Execution of the ETLs for the BIMtoBEPS tool



```
(base) D:\Documents\Python_Workspaces\BIM-SPEED\BIM2BEPS\bim2beps_back>python bim2beps.py
Incorrect number of arguments, it must be two
Traceback (most recent call last):
  File "bim2beps.py", line 25, in <module>
    anyoinicio = sys.argv[1]
IndexError: list index out of range
```

Figure 37: Error message for wrong arguments

After having prepared the data to feed the BIMtoBEPS tool, it is time to run the tool. In the same snapshot before, it is illustrated the log with the call to the tool, including the parameters. As explained in D3.2, the tool requires the IFC file (which is enriched with the pre-filled data for the thermal properties of the materials) and the aforementioned EPW weather file. Then, the tool starts the process, which, when finished, provides the b18 (TRNSYS 18 file of the building) and the .dck.

The last stage of the BIMtoBEPS use case consists of the execution of the simulation. For that end, the TRNExe execution file is used, which is the TRNSYS engine. Then, the service looks for the location of such an engine and run TRNSYS with the DCK file. The user knows the execution is being correctly executed because the screen of TRNSYS is launched as Figure 38. It should be noted that the screen is just shown to inform the user about the simulation, but it is automatically closed.

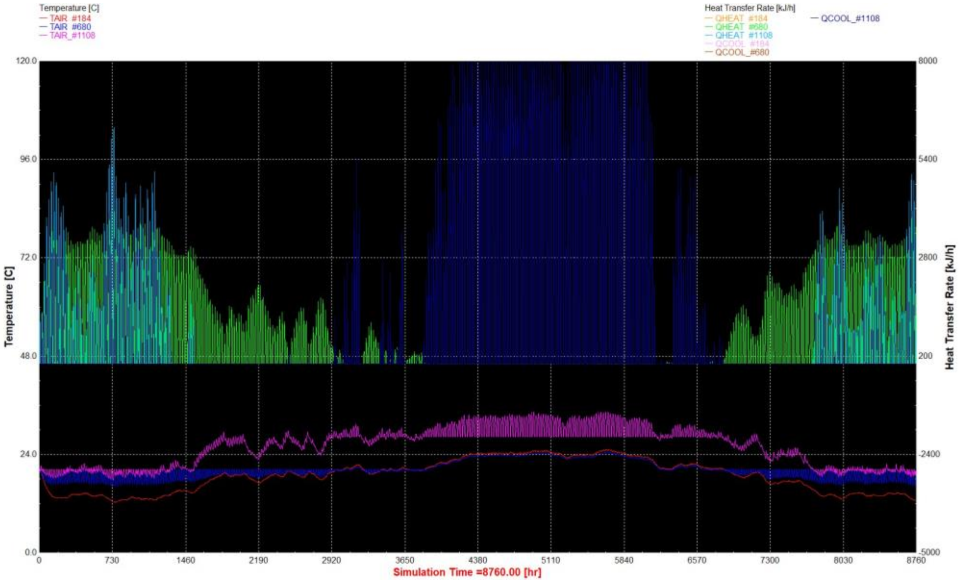
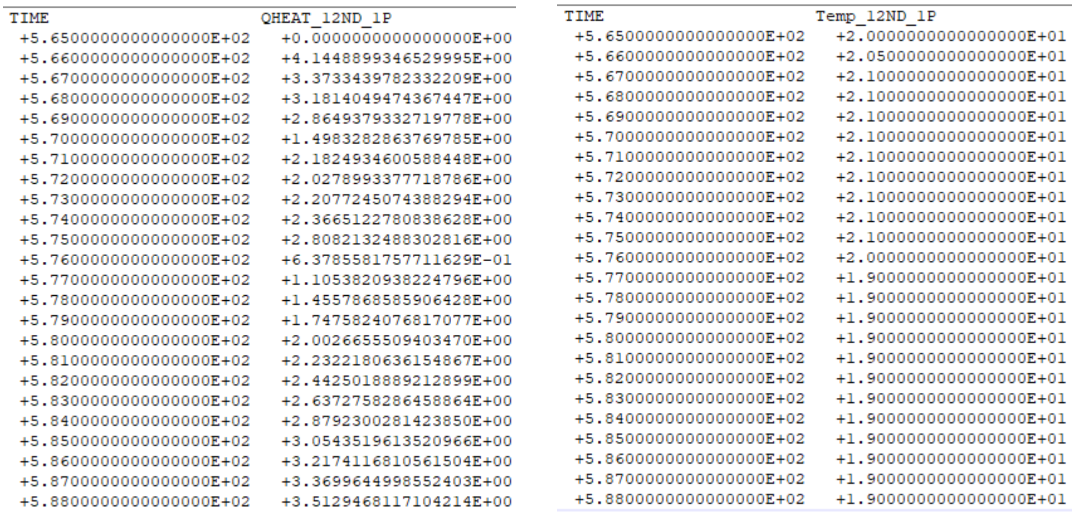


Figure 38: TRNSYS execution for BIMtoBEPS

With the finalisation of the execution of the tool, the BIMtoBEPS use case is able to read the result. The files where TRNSYS has written are also observed in the previous log. Both heating and temperatures are obtained. To show an example of the file executed, Figure 39 depicts both the energy and temperature files. In this sense, the time step and the total energy or indoor temperature is shown. Also, the use case, under the aim of showing user-friendly information to the user, extracts some graphs about the results similarly to TRNSYS. The example is illustrated in Figure 40.



```
TIME                              QHEAT_12ND_1P
  +5.6500000000000000E+02    +0.0000000000000000E+00
  +5.6600000000000000E+02    +4.1448899346529995E+00
  +5.6700000000000000E+02    +3.3733439782332209E+00
  +5.6800000000000000E+02    +3.1814049474367447E+00
  +5.6900000000000000E+02    +2.8649379332719778E+00
  +5.7000000000000000E+02    +1.4983282863769785E+00
  +5.7100000000000000E+02    +2.1824934600588448E+00
  +5.7200000000000000E+02    +2.0278993377718786E+00
  +5.7300000000000000E+02    +2.2077245074388294E+00
  +5.7400000000000000E+02    +2.3665122780838628E+00
  +5.7500000000000000E+02    +2.8082132488302816E+00
  +5.7600000000000000E+02    +6.3785581757711629E-01
  +5.7700000000000000E+02    +1.1053820938224796E+00
  +5.7800000000000000E+02    +1.4557868585906428E+00
  +5.7900000000000000E+02    +1.7475824076817077E+00
  +5.8000000000000000E+02    +2.0026655509403470E+00
  +5.8100000000000000E+02    +2.2322180636154867E+00
  +5.8200000000000000E+02    +2.4425018889212899E+00
  +5.8300000000000000E+02    +2.6372758286458864E+00
  +5.8400000000000000E+02    +2.8792300281423850E+00
  +5.8500000000000000E+02    +3.0543519613520966E+00
  +5.8600000000000000E+02    +3.2174116810561504E+00
  +5.8700000000000000E+02    +3.3699644998552403E+00
  +5.8800000000000000E+02    +3.5129468117104214E+00
```

```
TIME                              Temp_12ND_1P
  +5.6500000000000000E+02    +2.0000000000000000E+01
  +5.6600000000000000E+02    +2.0500000000000000E+01
  +5.6700000000000000E+02    +2.1000000000000000E+01
  +5.6800000000000000E+02    +2.1000000000000000E+01
  +5.6900000000000000E+02    +2.1000000000000000E+01
  +5.7000000000000000E+02    +2.1000000000000000E+01
  +5.7100000000000000E+02    +2.1000000000000000E+01
  +5.7200000000000000E+02    +2.1000000000000000E+01
  +5.7300000000000000E+02    +2.1000000000000000E+01
  +5.7400000000000000E+02    +2.1000000000000000E+01
  +5.7500000000000000E+02    +2.1000000000000000E+01
  +5.7600000000000000E+02    +2.0000000000000000E+01
  +5.7700000000000000E+02    +1.9000000000000000E+01
  +5.7800000000000000E+02    +1.9000000000000000E+01
  +5.7900000000000000E+02    +1.9000000000000000E+01
  +5.8000000000000000E+02    +1.9000000000000000E+01
  +5.8100000000000000E+02    +1.9000000000000000E+01
  +5.8200000000000000E+02    +1.9000000000000000E+01
  +5.8300000000000000E+02    +1.9000000000000000E+01
  +5.8400000000000000E+02    +1.9000000000000000E+01
  +5.8500000000000000E+02    +1.9000000000000000E+01
  +5.8600000000000000E+02    +1.9000000000000000E+01
  +5.8700000000000000E+02    +1.9000000000000000E+01
  +5.8800000000000000E+02    +1.9000000000000000E+01
```

Figure 39: TRNSYS execution results both heating and temperature

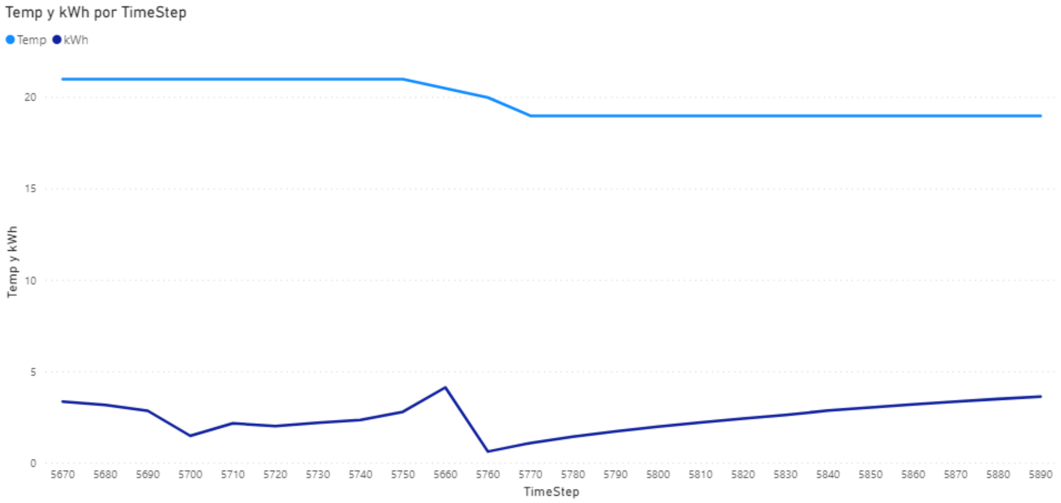
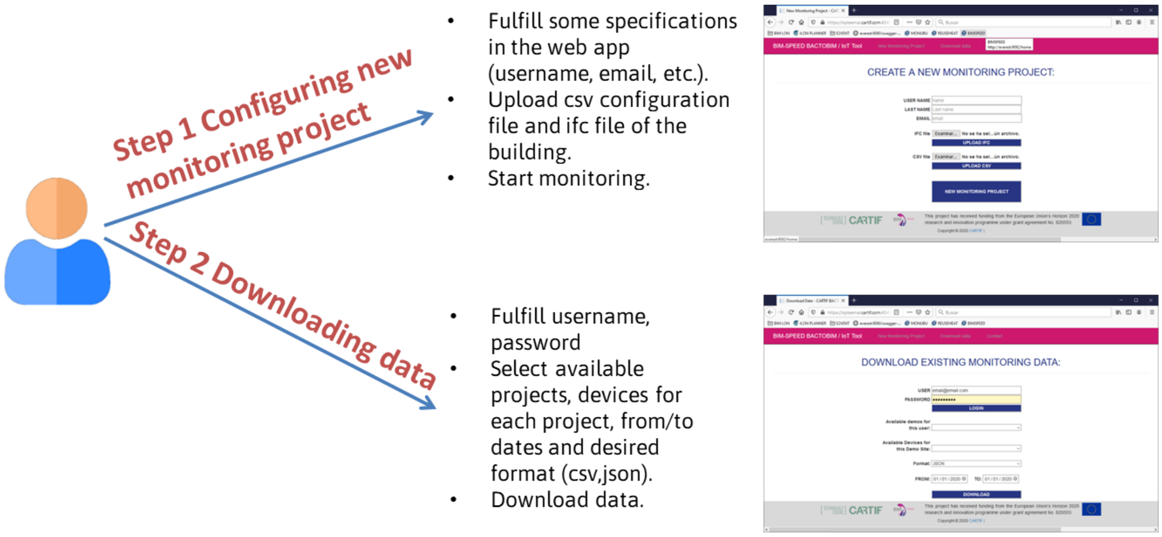


Figure 40: Graphical representation of the results

7.3 BACN2BIM as a service of the BIM-SPEED platform

Currently, BACN2BIM tool is correctly running in a dedicated server on the CARTIF premises, and the first steps to be included in the general BIM-SPEED platform has been done having good results. In fact there is communication with the general platform and the tool can be run from it. The Figure 41 shows the BACN2BIM operation modes, the first one, used to configure and create a new monitoring project of a building, and the second one used to download data from buildings after the monitoring project has been created.



Step 1 Configuring new monitoring project

- Fulfill some specifications in the web app (username, email, etc.).
- Upload csv configuration file and ifc file of the building.
- Start monitoring.

CREATE A NEW MONITORING PROJECT:

USER NAME Name
LAST NAME Last name
EMAIL email
IFC file Examinar... No se ha sel...ún archivo.
CSV file Examinar... No se ha sel...ún archivo.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 820553.
Copyright © 2020 CARTIF |

Step 2 Downloading data

- Fulfill username, password
- Select available projects, devices for each project, from/to dates and desired format (csv,json).
- Download data.

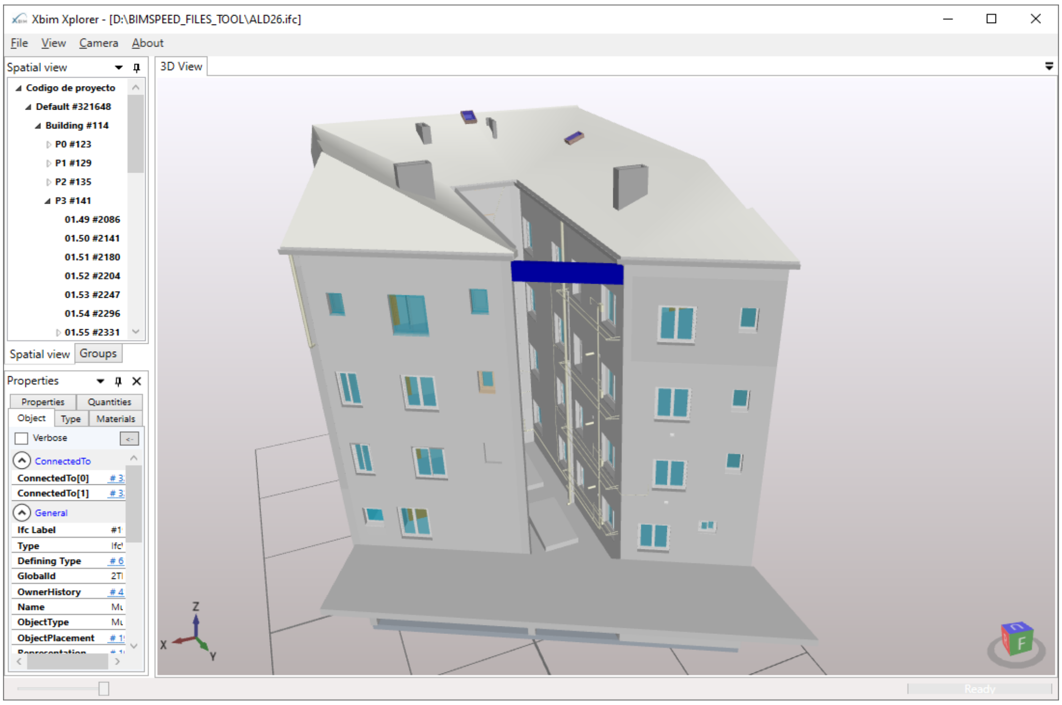
DOWNLOAD EXISTING MONITORING DATA:

USER email@email.com
PASSWORD ••••••••••
Available demos for this user:
Available Devices for this Demo Site:
Format: JSON
FROM: 01/01/2020 TO: 01/01/2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 820553.
Copyright © 2020 CARTIF |

Figure 41: BACN2BIM tool operation modes

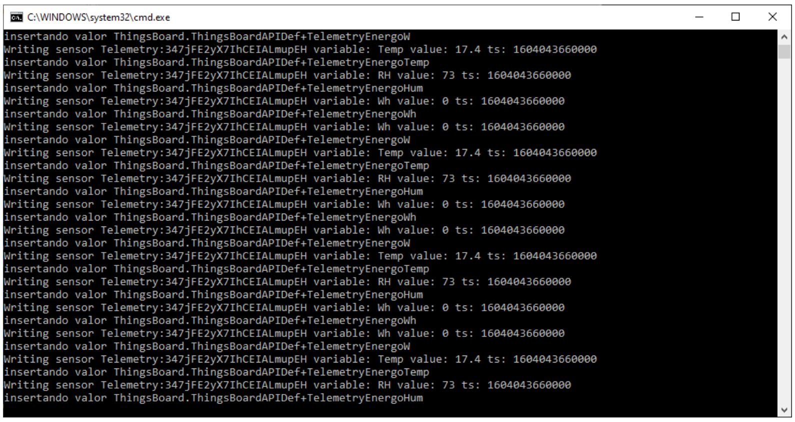
The tests performed to check the correct behaviour of the tool have been carried out using the IFC of a single familiar house shown in the Figure 42 which is a proper BIM-SPEED building model (it is a demo project located in Vitoria Spain, named Aldabe26). The connection with data from buildings has been carried out using the devices which are installed on the buildings that are available in the Energomonitor platform (described in *D1.3: IT solutions to couple dynamic data of the existing buildings to BIM*).



Xbim Xplorer - [D:\BIMSPEED_FILES_TOOL\ALD26.ifc]

Figure 42: Example model for testing BACN2BIM tool

Firstly, users have to fulfil the form and necessary parameters (.csv file, .ifc file, user, password and user email) shown in Figure 41, step 1. Then, the BACN2BIM application starts configuring the ThingsBoard database and modifying the Input .ifc file adding information about measurement devices. Also, a dedicated driver for connecting to the ENERGOMONITOR platform is automatically deployed. This driver starts asking for real data (in this example the frequency has been set to one minute) (see Figure 43). Once these data are received, they will be stored in the database using the ifcSpace Global ID as the name of the device. Doing this, devices are directly linked to spaces, using a random identification which is defined in the .ifc file.



```
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoW
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Temp value: 17.4 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoTemp
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: RH value: 73 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoHum
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoWh
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoW
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Temp value: 17.4 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoTemp
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: RH value: 73 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoHum
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoWh
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoW
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Temp value: 17.4 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoTemp
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: RH value: 73 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoHum
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoWh
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Wh value: 0 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoW
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: Temp value: 17.4 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoTemp
Writing sensor Telemetry:347jFE2yX7IhCEIALmupEH variable: RH value: 73 ts: 1604043660000
insertando valor ThingsBoard.ThingsBoardAPIDef+TelemetryEnergoHum
```

Figure 43: ENERGOMONITOR driver asking for data

Secondly, following the step 2 shown in Figure 41, the BACN2BIM tool allows the users to download data from the general repository. Both .json and .csv formats can be downloaded by users as can be seen in the Table 11.

Table 11 Extracts of .json and .csv files

JSON	CSV
{"ts":1595570280000,"value":"0"}],"Temperature":[{"ts":1595594880000,	1595570280000;0
"value":"23.3"},{"ts":1595594820000,"value":"23.28"},{"ts":159559476000	Temperature;
0,"value":"23.28"},{"ts":1595594700000,"value":"23.3"},{"ts":1595594640	ts;value
000,"value":"23.27"},{"ts":1595594580000,"value":"23.3"},{"ts":15955945	1595594880000;23.3
20000,"value":"23.27"},{"ts":1595594460000,"value":"23.28"},{"ts":15955	1595594820000;23.28
94400000,"value":"23.28"},{"ts":1595594340000,"value":"23.28"},{"ts":15	1595594760000;23.28
95594280000,"value":"23.28"},{"ts":1595594220000,"value":"23.29"},{"ts"	1595594700000;23.3
:1595594160000,"value":"23.27"},{"ts":1595594100000,"value":"23.27"},{	1595594640000;23.27
"ts":1595594040000,"value":"23.23"},{"ts":1595593980000,"value":"23.2	1595594580000;23.3
1"},{"ts":1595593920000,"value":"23.22"},{"ts":1595593860000,"value":"2	1595594520000;23.27
3.2"},{"ts":1595593800000,"value":"23.22"},{"ts":1595593740000,"value":	1595594460000;23.28
"23.23"},{"ts":1595593680000,"value":"23.22"},	1595594400000;23.28

7.4 ECOtool as a service of the BIM-SPEED platform

The generation of the BIM Connector and the ETLs for the integration of the ECOtool into the BIM-SPEED platform is ongoing at the time of writing this deliverable. Thus, the demonstration of the usability of this tool in the context of the project is still pending to be developed.

The generation of the BIM Connector for the ECOtool is based on the description of the ETLs presented in sections 6.3.1 (ETL for IFC information extraction), 6.3.5 (ETL for IoT data collection), 6.3.6 (ELT for OCR data extraction from energy bills), 6.3.7 (ETL for collection of energy prices from EUROSTAT) and 6.3.8 (ETL for processing inputs and outputs of the ECOtool).

Once these ETLs are finalized and orchestrated as part of the ECOtool BIM Connector, the tool will be offered as a web service published in a URL. This URL will be provided to BIM-SPEED platform in order to link the ECOtool service with the IFC or energy bills of the demo-sites, similarly to the exercise done with the BACN2BIM or BIMtoBEPS services demonstrated previously.

7.5 IFC material enrichment as a service of the BIM-SPEED platform

The principle of the process is shown on the following diagram. Actions are:

- In a first step, for the demonstration prototype, a specification is established in order to identify a list of materials generally used in the construction sector. At conception time, each partner is expected to use the names of the materials from this list.
- To do this, the end user can check the materials names in the database to see which names can be used.
- Then, the user uploads its IFC file in a BIM-SPEED-platform-electronic-document-management system (EDMS) folder.
- The user can launch the IMES service (IFC Material Enricher Service) after having displayed the BIM-SPEED IFC-related service panel where IMES is referenced (Figure 44).

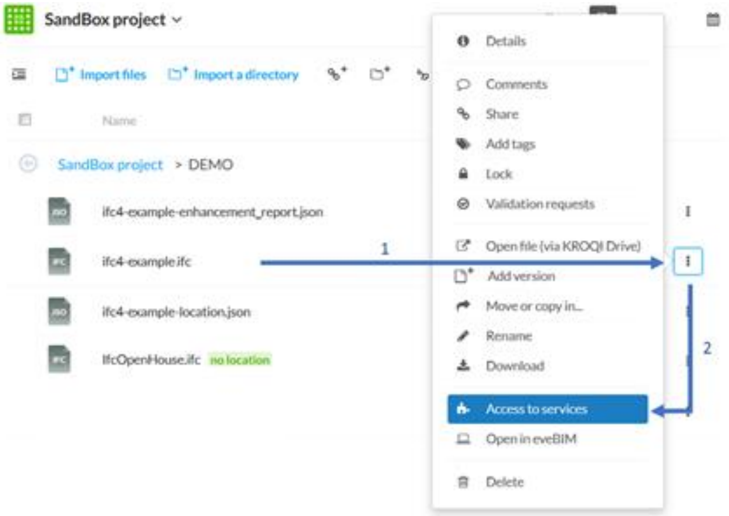
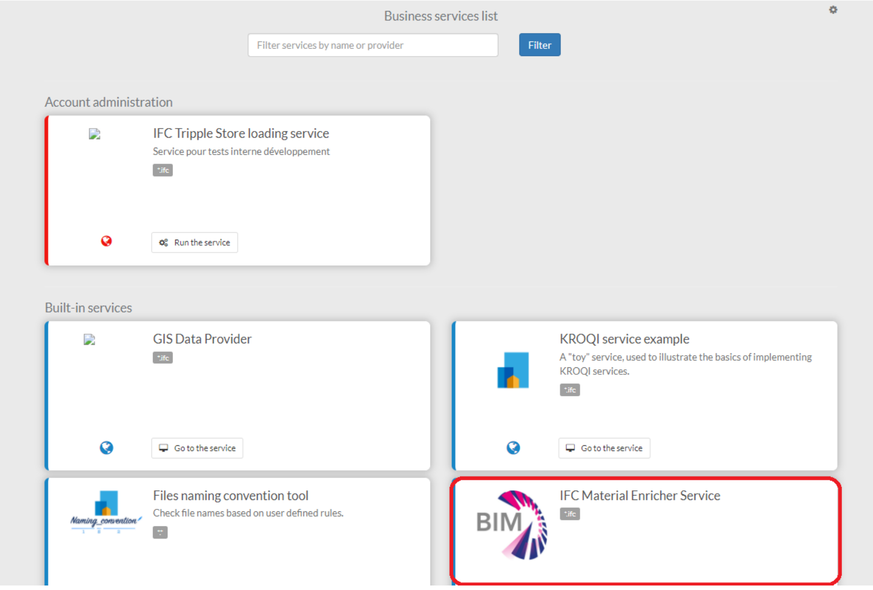


Figure 44: How to launch services on an IFC file



Business services list

Account administration

IFC Tripple Store loading service

Service pour tests interne développement

Built-in services

GIS Data Provider

KROQI service example

A "toy" service, used to illustrate the basics of implementing KROQI services.

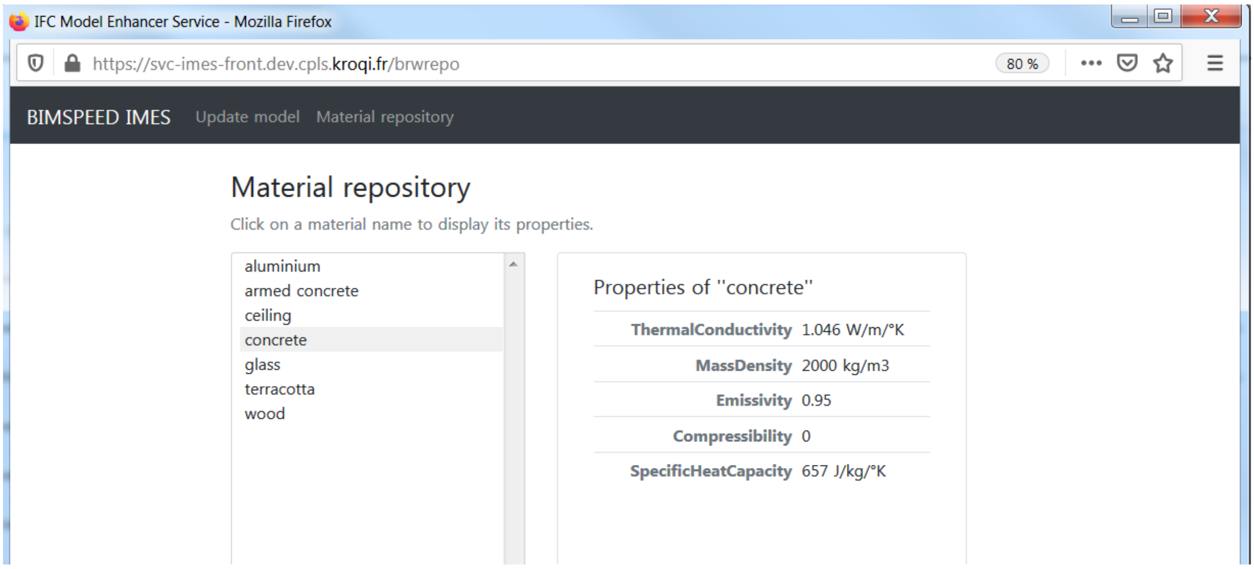
Files naming convention tool

Check file names based on user defined rules.

IFC Material Enricher Service

Figure 45: List of available services

Then, the user clicks on the button *“Use Tool” of the Material repository brow*ser. The next form shows to the user the name of all materials contained in the database so he can check if the names he has used for materials in the processed IFC file or correct before launching the updating process. By clicking on a material, the user can display the attached properties of a given material (Figure 46):



IFC Model Enhancer Service - Mozilla Firefox
https://svc-imes-front.dev.cpls.kroqi.fr/brwrepo
80 %
BIMSPEED IMES
Update model
Material repository

Material repository

Click on a material name to display its properties.

- aluminium
- armed concrete
- ceiling
- concrete
- glass
- terracotta
- wood

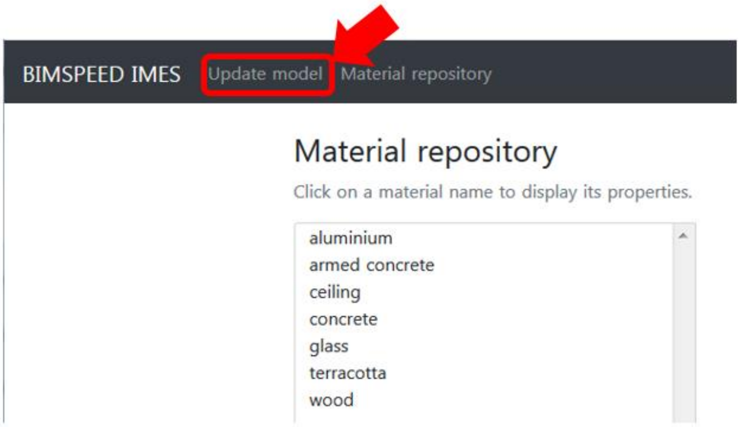
Properties of "concrete"

ThermalConductivity	1.046 W/m/°K
MassDensity	2000 kg/m3
Emissivity	0.95
Compressibility	0
SpecificHeatCapacity	657 J/kg/°K

Figure 46: Display of material names and their properties

The names of materials shown in the database are expressed in the same language as the one configured in the current BIM-SPEED account.

If the user is confident about the material names he has used in the conception phase, he can now launch the service in order to update the model (Figure 47):



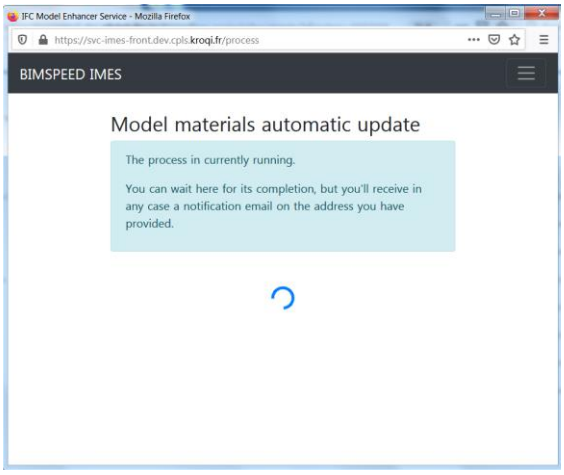
Material repository

Click on a material name to display its properties.

aluminium
armed concrete
ceiling
concrete
glass
terracotta
wood

Figure 47: How to launch the IFC model enrichment

The process is running. The user can wait for the result, but he will also receive an email notifying him that the enriched IFC file is ready (Figure 48).


IFC Model Enhancer Service - Mozilla Firefox
https://svc-imes-front.dev.cpls.kroqi.fr/process
BIMSPEED IMES

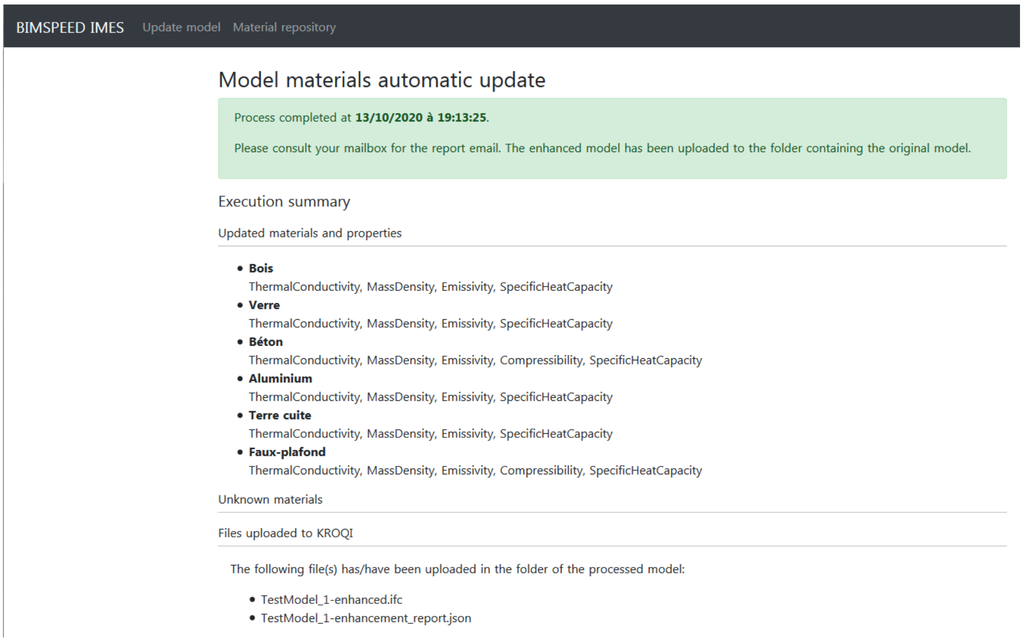
Model materials automatic update

The process in currently running.

You can wait here for its completion, but you'll receive in any case a notification email on the address you have provided.

Figure 48: Process is running

When the process is finished, the service displays a summary page (Figure 49).



Model materials automatic update

Process completed at **13/10/2020 à 19:13:25**.

Please consult your mailbox for the report email. The enhanced model has been uploaded to the folder containing the original model.

Execution summary

Updated materials and properties

- **Bois**
  ThermalConductivity, MassDensity, Emissivity, SpecificHeatCapacity
- **Verre**
  ThermalConductivity, MassDensity, Emissivity, SpecificHeatCapacity
- **Béton**
  ThermalConductivity, MassDensity, Emissivity, Compressibility, SpecificHeatCapacity
- **Aluminium**
  ThermalConductivity, MassDensity, Emissivity, SpecificHeatCapacity
- **Terre cuite**
  ThermalConductivity, MassDensity, Emissivity, SpecificHeatCapacity
- **Faux-plafond**
  ThermalConductivity, MassDensity, Emissivity, Compressibility, SpecificHeatCapacity

Unknown materials

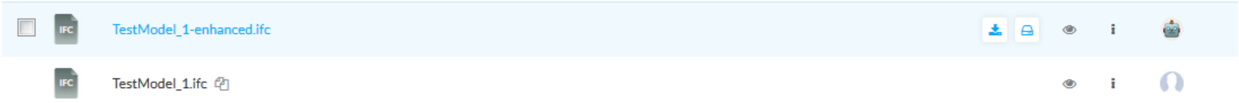
Files uploaded to KROQI

The following file(s) has/have been uploaded in the folder of the processed model:

- TestModel_1-enhanced.ifc
- TestModel_1-enhancement_report.json

Figure 49: Summary page of the process done

The generated materials-extended file will be placed in the same EDMS folder as the one from the input IFC file (Figure 50).



□ IFC TestModel_1-enhanced.ifc

IFC TestModel_1.ifc

Figure 50: New enriched IFC file

The following diagram (Figure 51) presents the integration of IMES with a possible BIM-SPEED workflow guiding the end-user through the simulation process.

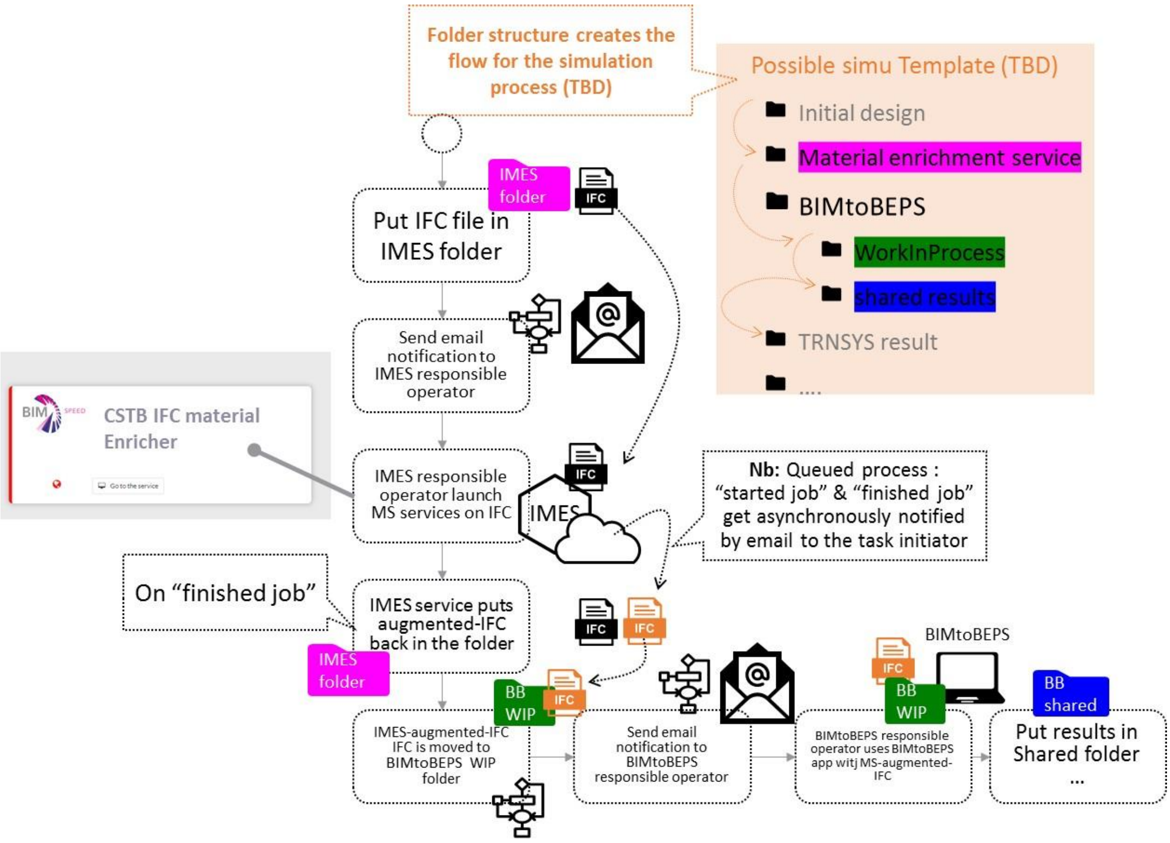

Folder structure creates the flow for the simulation process (TBD)
Possible simu Template (TBD)
Initial design
Material enrichment service
BIMtoBEPS
WorkInProcess
shared results
TRNSYS result
....
IMES folder
IFC
Put IFC file in IMES folder
Send email notification to IMES responsible operator
CSTB IFC material Enricher
Go to the service
IMES responsible operator launch MS services on IFC
IMES
Nb: Queued process : "started job" & "finished job" get asynchronously notified by email to the task initiator
On "finished job"
IMES service puts augmented-IFC back in the folder
IMES folder
IFC
IFC
BB WIP
IFC
IMES-augmented-IFC IFC is moved to BIMtoBEPS WIP folder
Send email notification to BIMtoBEPS responsible operator
BIMtoBEPS
IFC
BB WIP
BIMtoBEPS responsible operator uses BIMtoBEPS app witj MS-augmented-IFC
BB shared
Put results in Shared folder
...

Figure 51: IMES diagram.

8. Conclusion and future work

Interoperability is one of the major issues in digitalisation processes where datasets come from multiple, diverse and heterogeneous sources. In this sense, within the building sector, the lack of standard procedures or, at least, the lack of their applicability in a homogeneous way provokes time-consuming interactions from the users in order to adapt, transform and use the available data. Moreover, standards like IFC4 (Add2-TC1 schema version), even though they provide a great basis to represent data, do not cover the entire life-cycle of buildings. For instance, operation and maintenance require the storage of dynamic data, while IFC is thought to represent static (or semi-static) data of the building.

For that end, ETL (Extraction, Transformation and Loading) procedures become essential for the interoperability. Thanks to them, the traditional intervention of the user can be minimised because the heterogeneous data models converge to a homogeneous data representation to be able to feed tools and services that form the BIM 10D concept. All of them start from the BIM and IFC4 (Add2-TC1 schema version) standard model as fundamental, extending the information that is available in IFC to other building-related data, such as energy consumption (BACN2BIM), energy performance simulation models (BIMtoBEPS), transformation of point clouds to IFC (3DASH Tool) or economic information (ECOtool).

Within *D5.2: BIM Connectors for interoperability between different BIM tools and with the BIM and with the BIM-SPEED Platform*, a set of ETLs have been developed to allow data transformations so that tools and services can interact and exchange data, fostering interoperability in the building sector. Four main use cases have served to demonstrate this interoperability and capability to interconnect tools, data, services, BIM, etc. These are summarised in the bullets below:

- 3DASH Tool, whose main objective is the transformation of point clouds into BIM model in order to be able to obtain an IFC model. The use case is implemented as a REVIT plug-in that loads the 3D point clouds, obtained by laser scanner or photogrammetry systems, and generate BIM elements automatically from these point clouds.
- BIMtoBEPS that makes use of multiple ETLs, such as the extraction of IFC data, weather climate files and weather forecast services in order to transform the BIM model in form of IFC4 (Add2-TC1 schema version) to a TRNSYS-compliant file able to run simulations. This use case reduces the human efforts required to create both the BIM and the simulation models, being only needed the first one.
- BACN2BIM is in charge of extending the IFC data model with dynamic data coming from sensors and, thus, providing with IoT (Internet of Things) data to the building. The capability of ingesting multiple data sources allows the integration of data from comfort, energy consumption and other to complement the BIM.
- ECOtool, whose main aim is the evaluation of the building performance from the economic point of view by considering energy. Therefore, the use case needs to use multiple data sources, such as energy consumption or energy prices in order to combine all this information and provide the users with a tool to analyse some economic indicators by integrating data.

Under these use cases that are described, implemented and validated within the D5.2, interoperability between data, BIM, tools and services is demonstrated. Nevertheless, as lesson learnt, there are some challenges that need to be solved before ensuring interoperability:

- IFC data export from BIM modelling tools. At the current stage, many of the BIM modelling tools do not export the complete data stock into IFC. For instance, REVIT, one of the most used softwares, does not export thermal parameters related to materials, being required for some of the building phases within the life-cycle (e.g. simulation).
- Vendor lock-in, which is more related to dynamic data, but also other sources. In this sense, some vendors deploy the services under proprietary protocols and data models, being unable to be read, hence, not interoperable.
- Heterogeneity of data models, existing a diversity of data models without a clear convergence. IFC seems to be the most widely used, but there exist others like gbXML. Another example could be the simulation engines, TRNSYS or Energy+, among others. They do not use the same data formats, which complicates a broad uptake of interoperability aspects.
- User procedures. Establishing common procedures among users is a very complex task, where different users make models in multiple ways. There is neither standard nor consensus about the guidelines how to model to foster interoperability. In this sense, maybe this is the most complex challenge to be solved, but rules and guidelines are necessary for interoperable contexts.

Finally, as future work, the main one is the finalisation of the Use Cases explained in this deliverable. Some of them are more advanced such as 3DASH Tool or BACN2BIM, while BIMtoBEPS and ECOtool need to be completed. Therefore, the current prototype versions will be continuously improved to have functional versions at M48, when the T5.2 finishes. Regarding the 3DASH Tool and BACN2BIM, mainly, their bugs will be polished and refined. Secondly, the Use Cases that are currently fed with testing data or single demonstrators will be extended with other demonstrators within the project. In this sense, it will be demonstrated the feasibility and replicability of the Use Cases in different contexts and buildings whenever it complies with the data requirements that were established in this deliverable. Additionally, further Use Cases will be explored and their feasibility, as well as the integration of the current Use Cases (when possible because the 3DASH Tool is not feasible) in a "one-stop-shop" in order to provide a single access point to all of them. Finally, the integration of MEREEN service into the BIMtoBEPS Use Case will be analysed.

9. References

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[3] Hernández, J.L., Martín Lerones, P., Álvarez, S., Bonsma, P., van Delft, A., Deighton, R., Braun, J.D., (2018) "An IFC based interoperable framework for building linked data", 6th Linked Data in Architecture and Construction Workshop (LDAC 2018), London, UK, 19 21 June 2018.

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