SPHERE

BIM DIGITAL TWIN PLATFORM

WP4 – Design & Construction Tools Development and Interaction

D4.1 MicroServices developed and validated in laboratory conditions

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DISCLAIMER

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Contents

List of acronyms

Acronym	Meaning
API	Application Programming Interface - a software intermediary that allows two applications to talk to each other.
BCF	BIM Collaboration Format - a standard for communication about issues with assets in a 3D model.
BPE	Baseline Period Energy
C	Capacitors
CAD	Computer Aided Design
CMDB	Configuration Management Database - CMDBs are used to keep track of the state of assets such as products, systems, facilities as they exist at specific points in time, and the relationship between all assets. A CMDB helps to understand the relationship between the components of a system.
COBie	Construction Operations Building Information Exchange - a non-proprietary data format for the publication of a subset of building information models (BIM) focused on delivering asset data as distinct from geometric information.
COINS	Constructieve Objecten en de Integratie van Processen en Systemen - Dutch, non-proprietary data format for the publication of a subset of building information models (BIM) focused on delivering asset data.
DMS	Document Management System
DT	Digital Twin
DTCM	Digital TWin Configuration Manager
DTM	Digital Twin Manager
ECM	Energy Conservation measure
EE	Energy Efficiency
EM	Energy Model
EPC	Energy Performance Contracting
ESCO	Energy Service Companies
EU	European Union
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
GRAPHQL	graph query language - a query language for APIs and a runtime for fulfilling those queries with your existing data.
GUI	Graphical User Interface
GUID	Global Unique Identifier - a 128-bit integer (16 bytes) that can be used across all computers and networks wherever a unique identifier is required.
HIL	Hardware In the Loop
HVAC	Heating Cooling and Ventilation
IEQ	Indoor Environment Quality
IEQM	Indoor Environment Quality Model
IFC	Industry Foundation Classes - a standardized, digital description of the built asset industry.w
IOT	Internet of Things
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data
KPI	Key Performance Indicator

LCA	Life Cycle Assessment - systematic analysis of the potential environmental impacts of products or services during their entire life cycle.
M&V	Measurement and Verification
MEP	Mechanical, Electrical & Plumbing
OPC UA	Open Platform Communications Unified Architecture
OTL	Object Type Library - a structured and meaningful standardized dataset of objects.
QA/QC	Quality Assurance /Quality Control
R	Resistors
RDF	Resource Description Framework - a standard model for data interchange on the Web.
REST	Representational state transfer - defines a set of constraints for how the architecture of an Internet-scale distributed hypermedia system, such as the Web, should behave
ROBMOS	Reduced Order Building - A simulation tool that calculates Key Performance Indicators (KPIs) for buildings based on a model obtained through the use of BIM data and sensor data available for the building.
ROM	Reduced Order Model
RPE	Reporting Period Energy
SaaS	Software as a Service
SBS	System Breakdown Structure - a logical decomposition of the system
SHACL	Shape Constraint Language- a World Wide Web Consortium (W3C) specification for validating graph-based data against a set of conditions
SIL	Software In the Loop
SIMBOT	Simulation Bot in EcosimPro
UI	User Interface
UML	Unified Modeling Language- a general-purpose, developmental, modeling language in the field of software engineering that is intended to provide a standard way to visualize the design of a system
XML	eXtensible Markup Language, a set of codes, or tags, that describes the text in a digital document.

Executive Summary

The SPHERE project's overarching goal is to advance digital tools to support the construction of new buildings and for improvement of existing buildings across their entire life-cycle. To enable better energy design, improved construction, reduced construction cost, better operational performance, ease of management, and better overall energy performance that is fit for a low carbon future. The novelty of the SPHERE project is the demonstration and validation of one of the world's first Building Digital Twin ecosystems with cross-cutting tools for architects, engineers, construction managers, and building facility managers, to name just a few, applied to both new building and retrofit cases.

Within the SPHERE project there are several work packages. In Work Package 4 *Design & Construction Tools development and interaction* a number of digital services, called Microservices are under development. These are primarily aimed at the design and construction phase of a building. The services are to be used by, among others, architects, Mechanical, Electrical & Plumbing (MEP) experts, and contractors.

This report is the final result of task 4.1: *BIMBots development for design and construction*. This task within the SPHERE project started in month 7 and ran until month 36. The report describes the BIMBots or MicroServices developed, their validation under laboratory conditions and the route towards integration into the SPHERE ecosystem. The aspects covered are energy use, indoor environmental quality and water management. The following MicroServices are described in this report.

MicroService Energy Prediction RobMOS (TNO)

This tool predicts the energy use for heating and cooling of a building. It can be used in the new building or renovation design phase as well as in the operational phase, where actual performance can be compared to predicted performance. The tool is based on schedules of occupancy, standardised weather patterns, and a combined ventilation and heat transfer model. It uses these components to simulate the building's energy consumption and energy supply during the whole year.

MicroService EcoSimpro SIMBOT (EAI)

EcosimPro is used for the simulation of a building including its HVAC (Heating Cooling and Ventilation) system to obtain insights in energy and ventilation use. The tool represents the building's envelope and heating and cooling system as sets of components, such as parts of HVAC systems. Together these form 'building blocks' that are assembled in the model into more complex simulated components. Resulting in an elaborate representation of a whole building with its HVAC installation with information to simulate the building. The components are based on an HVAC library consisting of models of pumps, fans and compressors with user-defined or generic performance maps. The building library includes thermal models of walls, windows, radiation and irradiation and also options to select weather data types.

In the design phase of a building, EcosimPro allows the analysis of different HVAC implementations to improve the energy and ventilation lifecycle of residential buildings. In the operational phase of the building, the simulation will provide a complete picture of every parameter of the building, enabling maintenance teams and inhabitants to make better decisions.

MicroService IEQ RobMOS (TNO)

This tool predicts the Indoor Environment Quality (IEQ) of a building, in particular indoor temperature and ventilation rates. The goal is to achieve early insights in promising building designs from a better prediction of the thermal comfort for the occupants. RobMOS does this by identifying ways to improve the design or the robustness of the design in various weather conditions.

MicroService iESD-W Water Recycling Management (EUT)

The purpose of iESD-W is to recommend the most suitable water treatment technology for a particular building and its sizing. Both in new construction and in retrofit local legislation requirements for water management must be met, and the developer may want to go further than legal requirements for water reuse and conservation. The iESD-W tool supports the selection of water treatment technology that fits with particular technical and user criteria, including the available space of the building.

MicroService ModSCO web based support tool for quantification of energy savings (NUIG)

The ModSCO tool comprises a calibrated computer simulation model that supports detailed analysis of various Energy Conservation Measures (ECM's) to reduce the energy use of the building. The main goal is to predict the energy saving after the ECM measures are in place, based on a before and after scenario. Thereby the best renovation scenario from an energy perspective to apply to a building can be identified. The ModSCO tool uses the Reduced Order Grey Box Models (ROM) developed with the MODELICA ® language. The BPE generated by the ModSCO application can be used for (i) systematically quantifying the monthly energy savings achieved through standardised ECM's and for (ii) estimating directly the monthly energy savings for different building retrofit scenarios. It is expected that tools like ModSCO that can provide accurate predictions will lower the barrier for the uptake of Energy Performance Contracting in Europe.

Structure of the Report

Chapter 2 first describes the SPHERE Ecosystem, into which all the microservices are being integrated. Subsequently each of the MicroServices is described in more detail in Chapters 3 to 7.

Conclusions

The work leads to the following conclusions.

- The development of the Microservices is well on track, with a delay in the validation, mainly because of a lack of data at this stage from the SPHERE pilot sites.
- For several Microservices a functional test has been performed to show that they work and that they yield plausible results.
- The integration into the SPHERE ecosystem including data exchange and IFC data import and result exports functionality has started but it is not yet functional.
- The exploitation of the SPHERE platform and the microservices described in this report will be taken up by a SPHERE spin-off called the Building Digital Twin Organisation. It will explore market interests by initially providing a SPHERE demonstration mode for free.

1 Introduction

The SPHERE project's overarching goal is to advance digital tools to support the construction of new buildings and the improvement of existing buildings across their entire life-cycle. To enable better energy design, improved construction, reduced construction cost, better operational performance, ease of management, and a better overall energy performance fit for a low carbon future. The novelty of the SPHERE project is the demonstration and validation of one of the world's first Building Digital Twin ecosystems with cross-cutting tools for architects, engineers, construction managers, and building facility managers, to name just a few roles, applied to both new building and retrofit cases.

SPHERE as a special innovation project assembles and integrates different information streams needed to make these improvements happen. SPHERE partners bring together close to 20 existing software technologies, advancing them from laboratory level or small pilots to large scale demonstrations, as a key step towards real use by companies. Another socio-technical innovation that SPHERE tries to accomplish is to bring as many actors in the life cycle of a building together by creating a Digital Twin of the building across its entire life cycle. To increase collaboration and create co-benefits. For example, for building facility managers to bring relevant insights on operational energy use to building designers, so as to help them with improving the design of the building to use less energy from the outset. . This is achieved by advancing the idea of a fully systematic, collaborative and integrated framework for setting up and managing a building construction or renovation project called Integrated Design and Delivery Services (IDDS).

1.1 Purpose and Target Group

This report is the final result of task 4.1 as part of Work-Package 4: *BIMBots development for design and construction*. This task within the SPHERE project started in month 7 and ran until month 36. The report describes the BIMBots or MicroServices developed, their validation under laboratory conditions and the route towards integration into the SPHERE digital ecosystem. The aspects covered are energy use, indoor environmental quality and water management. The report is for public consumption for general dissemination and for internal reporting purposes. .

In WP3 the SPHERE architecture has been set for an integrated ecosystem infrastructure that allows synchronisation, handling and processing of large-scale building data, information and knowledge. This integrated system is called an ecosystem. Using this ecosystem, building architects, MEP experts, contractors and other stakeholders can analyse, estimate and predict different performance indicators of the building life cycle using the required, specialised tools that are part of the SPHERE ecosystem based on the standardised SPHERE OPEN API. . By bringing together different services and experts, the SPHERE digital ecosystem will allow detailed analyses of specific features like energy efficiency, energy technology design, indoor environmental quality and environmental indicators related with circular economy concepts. The overall objective of task 4.1 is to develop specific plug-ins realised as BIMBots/MicroServices that implement functions that are important during the design and construction phase of the building's life cycle.

This report gives a description of each individual MicroService, its current status and what has been done under Task 4.1 to validate, and the way forward from the current situation. For all the MicroServices the integration with the SPHERE ecosystem is described. The MicroServices as outlined in Table 1 below are reported for validation in this report. The overall SPHERE digital ecosystem in which the MicroServices are integrated is described in Chapter 2.

Table 1. Overview of MicroServices reported for validation in this report

MicroService	Chapter (this report)	Related SPHERE task
RobMOS Energy Prediction (TNO)	3	Task 4.1 – Subtask 4.1.2
EcoSimpro Building simulation (EAI)	4	Task 4.1 – Subtask 4.1.2
RobMOS Indoor Air Quality (TNO)	5	Task 4.1 - Subtask 4.1.1
iESD-W Water Recycling (EUT)	6	Task 4.1 - Subtask 4.1.3
ModSCO Energy savings (NUIG)	7	Task 4.1 – Subtask 4.1.2

1.2 Contributions of partners

The report is based on contributions from TNO, EUT, NUIG, EAI as tool developers and NEANEX as the ecosystem developer. It has been drafted by TNO as the beneficiary responsible for the milestone, and it has been reviewed by EKO and by VTT.

1.3 Relations to other activities

The overall objective of WP4 is to develop specific plug-ins into the SPHERE digital ecosystem, realised as BIMBots/MicroServices, that implement functions that are important during the design and construction phase of the building's life cycle. The context of BIMBots and MicroServices is further described in section 2.2. The WP4 MicroServices primarily focus on carrying out energy simulations in the design and construction phase of the building. Simulations can be improved by calibration and studying of real-life operational data.

To this end there is a strong relation to WP5 in SPEHRE. The overall objective of WP5 is to set up, install and develop other MicroServices required by the digital twin ecosystem for the operational phase of the building. The IoT sensor component of SPHERE developed under WP5 will allow the use of a range of data-streams, such as real-life building energy use. And this IoT data from WP5 tools can also be used by the simulation tools described in this deliverable. As such the tools from task 4.1, primarily energy simulations, and the IoT capability delivery under WP5 need to be considered and the related tools. For example, to provide feedback between design and operation of the building to bridge the energy gap (the difference between predicted energy performance and actual performance).

The relation to WP6 which covers the pilot demonstration, is that all elements of the SPHERE project will come together in real use cases, the SPHERE pilot projects delivered by partners TNO, CAV, DE5 and CREE in the Netherlands, Italy, Luxembourg and Finland. The MicroServices developed in task 4.1 will be implemented and validated for digital twin prototypes during design, procurement, construction and during use in work package 6. Thereby after work package 4 ends in month 36 the works will be carried on in using and improving the tools described here as part of work package 6.

2 Description of the SPHERE Ecosystem

In WP3 of this project the SPHERE architecture was designed for an integrated ecosystem infrastructure that allows synchronisation, handling and processing of large-scale building data, information and knowledge. This integrated system is called a Digital Twin ecosystem. To understand the context of the SPHERE MicroServices as described in chapter 3 to 8, the SPHERE digital ecosystem is described briefly in this chapter, in which the MicroServices form plug-ins.

The main driver to choose for an ecosystem approach rather than a rigid platform as described in deliverable “D3.3 - DT platform implementation Services and useability”, is the robustness in a fast-changing environment compared to a rigid platform.

The SPHERE ecosystem offers a number of specialised services developed under task 4.1, called Microservices, for the analysis of energy efficiency, energy technology design, indoor environmental quality, water management and environmental indicators related with circular economy concepts.

2.1 SPHERE digital ecosystem

The idea of such a digital ecosystem is that the responsible party or person for a construction or renovation project can ’assemble’ their IT landscape with tools as building blocks based on the needs of their project. To enable this, an open SPHERE API is built on top of a Digital Twin ontology network, regulating the data flows within the ecosystem. This is needed to enable data and information exchanges between MicroServices. For example, for sending IoT sensor energy data from an IoT MicroService to an energy simulation MicroService. This has several advantages compared to a rigid platform:

- The project responsible can choose the most relevant and/or favoured tools for the project based on the best-of-breed principle.
- The stakeholders can work in their tool of choice and hence be more efficient.
- IT Landscape stays lean as tools are communicating efficiently with each other and there are no redundant tools.
- Optimised, fine-grained data transactions & delivery instead of different tools exchanging the same type of data in different manners, or exchanging entire IFC-files that contain too much information.
- No fixed dependencies are put in place from an IT development perspective. The end product is no longer a single tool, but rather a framework to allow tools to communicate. If a tool does not comply with the open API, it can be substituted by another tool or simply left out of the IT landscape.
- New tool providers can join the ecosystem simply by complying with the open SPHERE API. By integrating with a single standardised API, a range of integrations become available.

Figure 1 displays the necessary components in red to facilitate the desired ecosystem approach. Other items include the core services (light blue) to comply with the building Digital Twin definition, and optional services (dark blue) depending on the project context and needs.

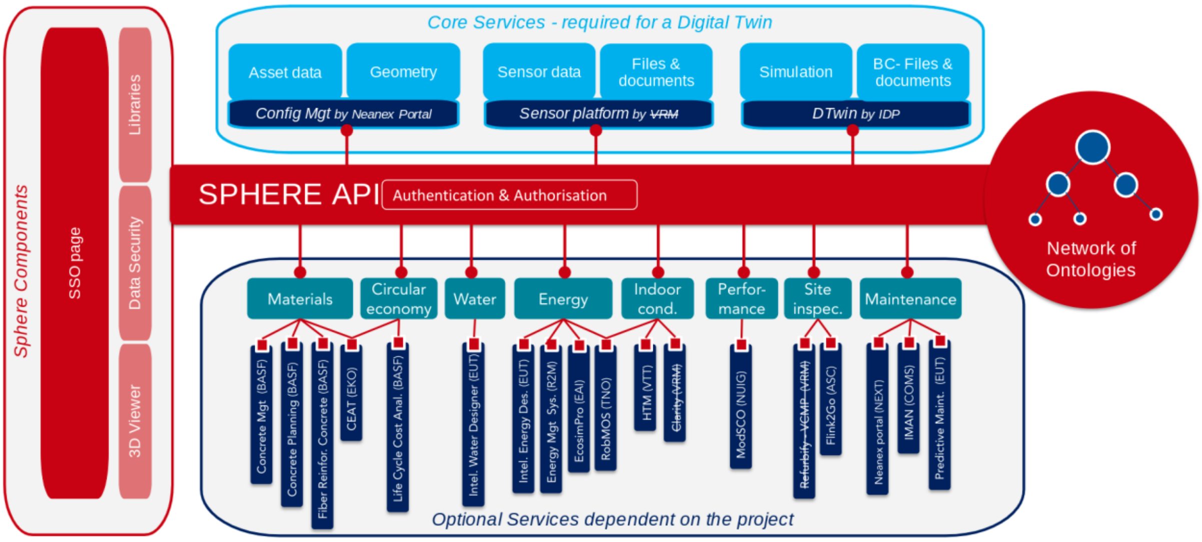


Figure 1. Concept for SPHERE ecosystem and Microservices.

2.2 SPHERE MicroServices Framework

During the proposal stage this milestone and the related Task 4.1 was fully focussed on the development of BIMBots. The core concept of a BIMBot as developed by TNO is an intelligent, online system as a form of a microservice that autonomously performs actions based on Building Information Modelling (BIM) data, e.g. performing calculations, simulations or analysis. In the course of task 4.1 it emerged that other standalone applications were covered that are not specifically designed for autonomous operation, nor for using BIM information per se. This meant that the naming of BIMBots does not cover the full scope of services developed under Task 4.1 anymore. Therefore, it was decided to use the term MicroServices instead of BIMBots, given that a BIMBot is a form of a microservice. In the rest of the document we will use the new naming MicroServices.

The definition of a MicroService is the following: **A MicroService refers to a standalone application that gives modern developers a way to design highly scalable, flexible ecosystems by decomposing the ecosystem into discrete services that implement specific business functions**. These services, often referred to as “loosely coupled,” can then be built, deployed, and scaled independently to create an agile ‘’container’’, referred to in SPHERE as the SPHERE Ecosystem, with easier integration of different services.

Each MicroService in SPHERE, including those reported within this report, communicates with other MicroServices through standardised application programming interfaces (APIs). This enables services to be written in different programming languages and/or using different IT technologies. This differs completely from software systems built as monolithic structures where services are inextricably interlinked and can only be scaled together. The MicroServices approach is highly suitable to IT developments such as SPHERE where a large number of parties collaborate to bring in their services into a single platform.

2.3 Network of Ontologies

The SPHERE consortium defined a Network of Ontologies in deliverable 3.1[1] to describe the "common language" for applications to exchange information in a consistent and standardised way. The API built on top of this Ontologies Network (methodology in D3.3) defines the technical aspects to enable smooth exchanges of information between all the different tools within a Building Digital Twin.

Next to the SPHERE OPEN API and corresponding Ontologies Network, other components have been set up within the SPHERE project such as an SSO page, a common 3D viewer, a data security & authentication approach, and a set of libraries to enable different simulation processes. These services are optional, in contrast to the Ontology Network and SPHERE OPEN API, and could be encapsulated within tools offering other core or optional services, depending on the configuration of the IT-landscape.

2.4 SPHERE open API

The SPHERE OPEN API enables two or more applications to exchange information within vendor neutral and unambiguous data transactions. The defined Ontology Network only operates as a common language **between** applications. It is completely decoupled from the applications themselves as conceptually shown in the figure 2 below. Besides the SPHERE Ontology Network and the SPHERE open API concepts, optional IT artefacts are considered useful to make the implementation of the API easier in practice. These additional IT artefacts or IT components can be grouped in (1) ontology alignments to formally tighten the ontology network, (2) application profiles for the definition of a relevant subset of the ontology network and validation (SHACL shapes) and (3) mapping files to connect application-specific concepts to shared concepts defined in the Ontology Network (JSON-LD contexts or other).

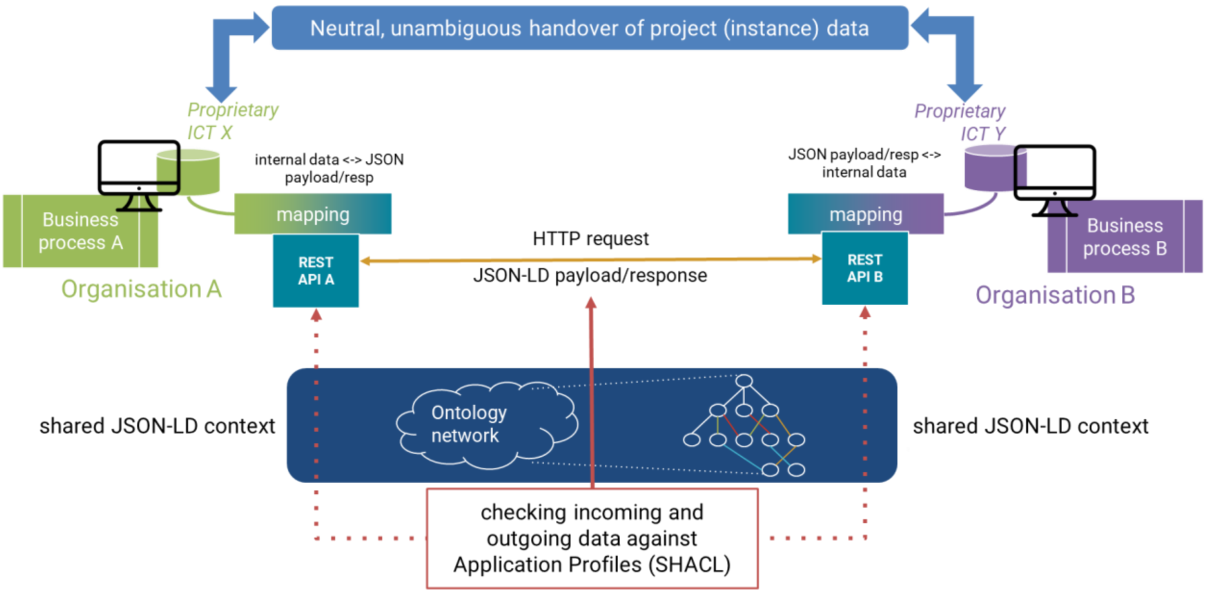


Figure 2. Concept for data exchange using SPHERE Ontology Network and API. (see D3.3, chapter 3.1.2)

[1] See D3.1 Digital_Twin_requirements, chapter 5

2.5 Interface Agreement

To facilitate the process of integrating tools like RobMos (Chapter 3) and Modsco (Chapter 7) in the ecosystem, an *Interface Agreement* template was set up by Neanex (see Figure 3 below). The goal of this template is to capture the types of incoming and outgoing data in a standardized manner. Using this template for every tool, we can expand the API iteratively while keeping a clear overview of the different integrations (and their respective API interactions) already present.

The template consists of two main parts: the functional analysis and the design integration.

- The functional analysis defines the use cases for the integration, each (optionally) consisting of different user stories, complemented with (UML) activity and data flow diagrams. It describes what data a MicroService needs to exchange, with which other MicroServices and when. It is vital to clearly define and document these workflows before any development is done. Not only to keep the development efficient but also to make sure that the SPHERE OPEN API stays lean, as many different tools might be interested in the same information.
- The design integration documents the technical implementation of the functional analysis. The technical implementation is documented in three (UML) diagrams: A class diagram, a data flow diagram and an activity diagram.

During the software development process issues are likely discovered, either from a technical or functional perspective. The technical implementation might also impose restrictions upon the user workflows. These issues and decisions can also be documented in the *Interface Agreements*. The templates for Interface Agreement have been described in WP3, while the specifications prepared in collaboration with WP4 (Design and Construction tools) and WP5 (Use and Operation tools).

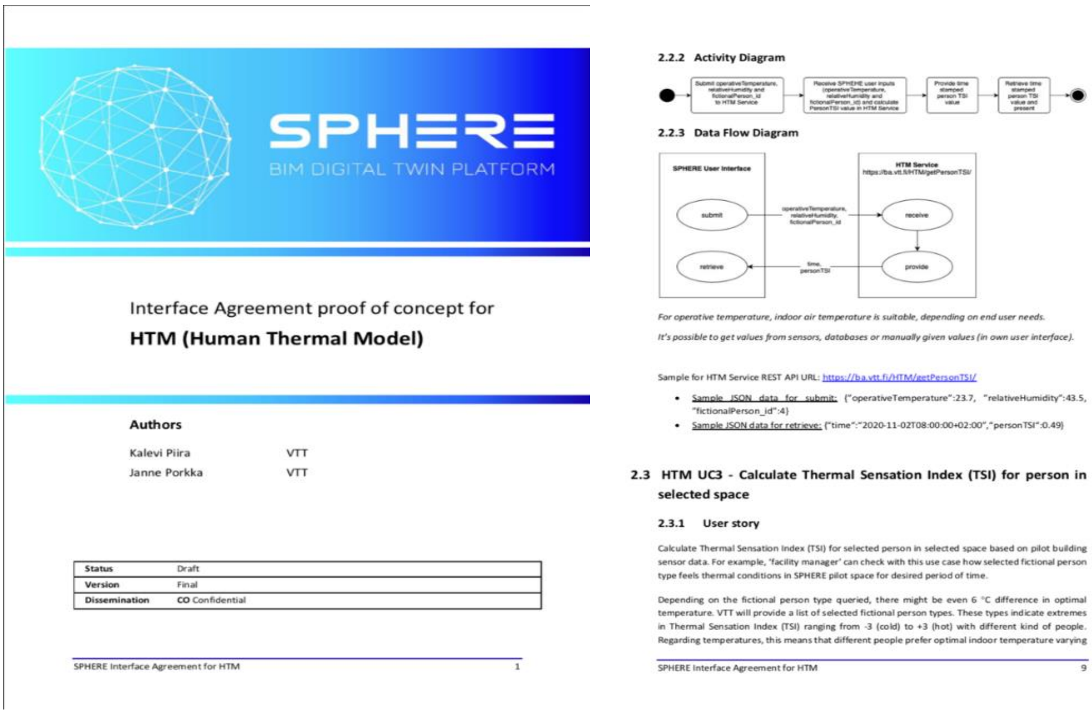


Figure 3. Screenshots from Interface Agreement specification.

3 MicroService Energy Prediction RobMOS (TNO)

3.1 Purpose, User Needs, Requirements

Purpose

The purpose of the RobMOS tool is to predict the energy use and energy supply of a building in relation to heating and cooling services both in the design phase as in the operational phase. The tool combines building occupancy schedules, standardised weather patterns, and a model of ventilation and heat transfer to simulate the energy consumption and energy supply across a whole year. Based on these results RobMOS calculates Key Performance Indicators (KPIs) for building energy use.

The aim of RobMOS is to get a better prediction of the energy consumption in the design phase, compared to existing models and methods. This is realised by using different user building occupancy profiles, giving insight into the resulting variation in energy consumption.

Furthermore, the RobMOS models can be calibrated during operation using measurement data. This allows the models to get closer to the real behaviour of a building while it is in use, in terms of understanding what drives a building's energy use.

In the operational phase of a building often a significant gap emerges between the predicted energy use and the real energy use of a building. Typically this energy performance gap is around a 35% difference, as described in the SPHERE proposal. In the operational phase the RobMOS MicroService can be used to reduce this performance gap between model outcomes and reality. The RobMOS MicroService does this by calibrating building energy models (EMs) using monitoring data. This leads to socalled data driven building models. In particular, RobMOS evaluates the predicted energy use and energy supply and compares these with the measured performance. Subsequently, the feedback from RobMOS can be used to also improve the predicted energy use for the next newbuild or renovation project, to reduce the energy performance gap.

While our RobMOS MicroService for calibration requires several other components, amongst others a building energy model, it is set up to run independently of which model it is tuning or how that model is implemented. RobMOS thus works to support the performance of building energy models used in the design phase based on information from the building operational phase.

User Needs

The user needs for RobMOS are in the design and in the operational phase of the building. In the design phase there is a user need by project managers, design teams, DT configuration managers, and architects to predict the energy use and energy supply needs of a building in relation to heating and cooling services.

In the operational phase there is a user need by consultancy companies, architects, real estate developers, housing corporations and home owners to validate the KPIs for energy performance.

For a good validation it is needed to use calibrated building Energy Models (EMs). Calibration is carried out using RobMOS by using energy monitoring data from the building. This needs to be done by the building owners and/or the real estate developers.

Requirements

The RobMOS MicroService requires information about the building and heating, cooling and ventilation installations, to be able to create and run reduced order models. This MicroService requires data from different sources available in the SPHERE ecosystem, because usually not all required information is available in a single source such as a BIM IFC datafile.

Status development

At this point of the project the coupling within RobMOS between two of its subcomponents, the heat transfer model (RC model) and the ventilation model, is ready. A simulation of a whole year with hourly timesteps takes about 1.5 minutes for a two-story residential building with three heating/cooling zones. The testing of the programme is in progress with initial pilot data from the Netherlands pilot.

Based on the calculation or algorithm core additional modules have been developed in SPHERE. On the input side a module has been written to generate a wide variety of building user types and their occupancy behaviour. This influences the internal heat gain, the usage of the ventilation system, the opening of windows and the thermostat setpoint. On the output side of the core a module calculating the KPIs for energy performance has been added. This module not only calculates the KPIs for heating and cooling, but also for thermal comfort including temperature and adaptive comfort.

3.2 Tool Technical Description

The RobMOS tool consists of 6 layers, shown in Figure 4, starting with the inputs and ending with the service KPI results. A layer can contain files, modules, models or solvers. In this paragraph a step-by-step description of each of the layers of the tool is provided.

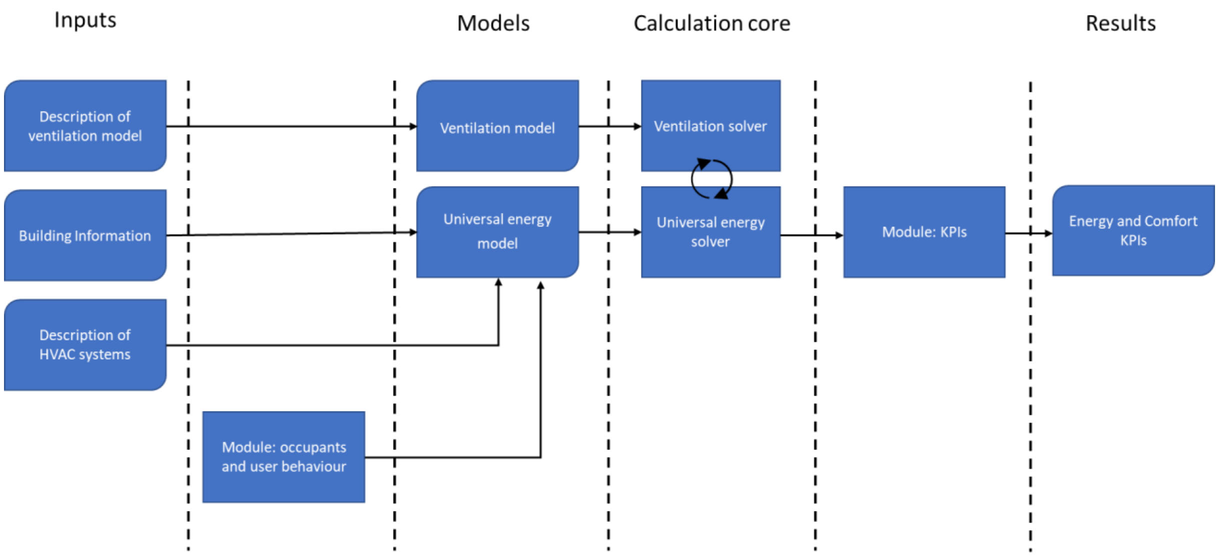


Figure 4. Overview of the RobMOS architecture

Layer 1 – user inputs:

The tool has three inputs which need to be provided by the user. The description of the ventilation model contains all the parameters of the windows, doors, ventilation grids and mechanical exhaust. The building information must contain all information about the geometry, the building materials and their thermal properties. The third input is the description of the HVAC systems. However, because the ventilation model is already described in the ventilation model description, only the heating and cooling systems need to be described in this input.

Layer 2 – generated inputs:

The module occupancy and user behaviour generates a large set of occupancy schedules and schedules for user behaviour. All the combinations of these schedules are automatically generated and fed to the models and to the RobMOS calculation core. The schedules are built from a combination of occupancy and user behaviour. Table 2, Table 3 and Table 4 below show examples of used schedules. In total there are 7 occupancy schedules, 3 schedules for window usage, which also depends on the occupancy schedule, and 3 schedules for mechanical ventilation. This gives a total number of 63 combinations of schedules that can be considered in the tool.

Table 2. RobMOS occupancy schedules.

Occupancy schedules
1 adult
2 adults
1 adult + 1 child
1 adult + 2 children
2 adults + 1 child
1 senior
2 seniors

Table 3. RobMOS window usage schedules

Usage of windows
Always
Never
Occupancy depended

Table 4. RobMOS mechanical ventilation usage schedules

Usage of mechanical ventilation
Low
Mid
High

Layer 3 - Models:

Based on the input information, both a ventilation and a universal energy model are created. As an example, the pilot project in the Netherlands is used here, which consists of 18 single-family row houses. An overview of the developed universal energy model (RC) for RobMOS with the various thermal resistances (R’s) and various thermal capacities (C’s) is given in Figure 5. In the RC model a separate heating/cooling zone is considered for the ground floor, while on the first floor two zones are considered, one at each side (front and rear side) of the dwelling. These zones on the first floor represent the bedrooms including the bathroom and a storage space. The approach enables the number of parameters (heat resistances and capacities) to remain limited for fast simulations, whilst the detail is still sufficient to obtain the dynamics of a typical single-family house.

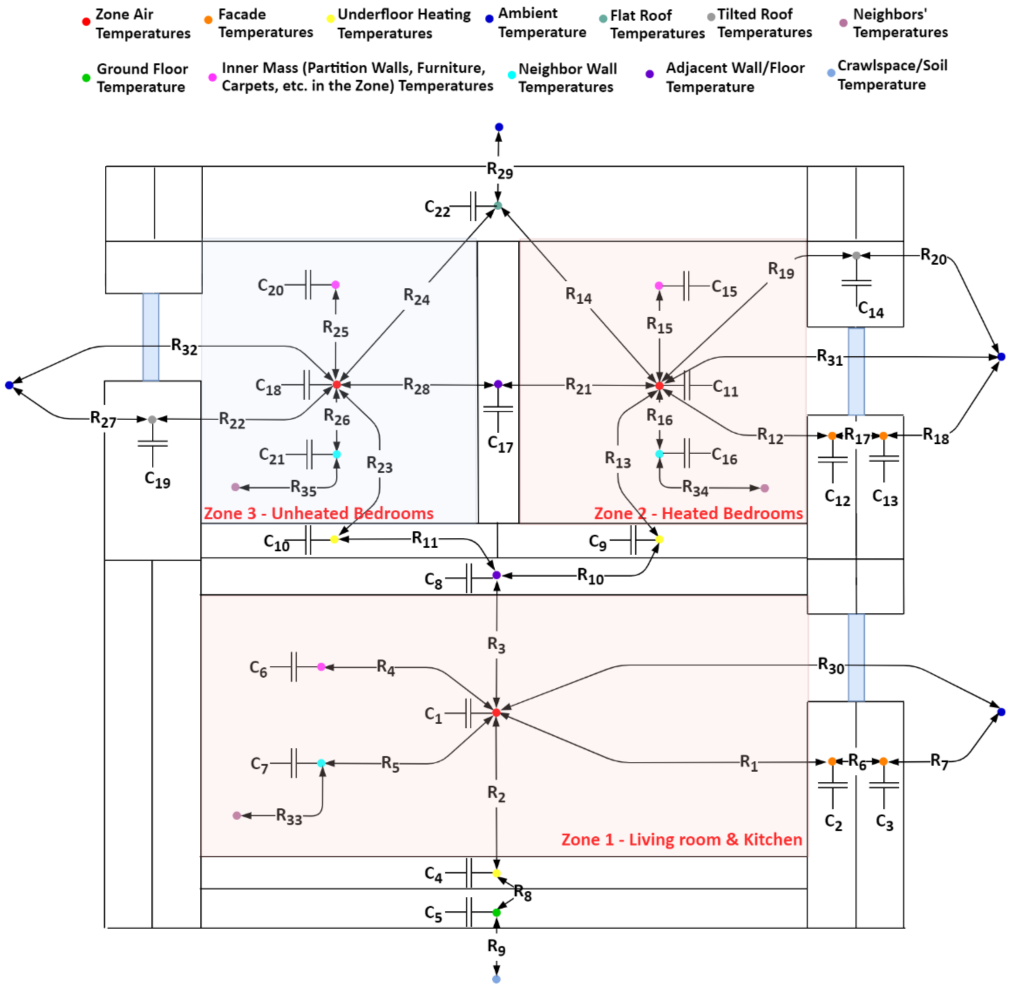


Figure 5. Schematic of the RC-model of the Dutch Demo

Beside the universal energy model also a ventilation model is created based on available input data. In Figure 6 the ventilation model is schematically shown. The nodes represent zones, the outer conditions including temperature, wind speed and direction, and additional zones which are not present in the universal energy model (referred to as plenums). The connection between the nodes represents windows, doors, grids, and ducts.

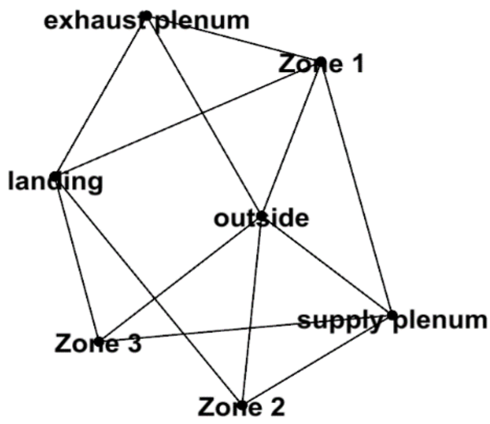


Figure 6. Schematic of the ventilation model of with zones are linked to the zones in the RC model.

Layer 4 - Calculational core:
In the calculation core the ventilation solver and universal energy solver are running in a coupled calculation. The results from the ventilation solver will influence the energy solver and vice versa. Both of the models run using hourly timesteps.

Layer 5 - KPI calculation and results:
The results are the last layer of the RobMOS tool. The results of the calculation are the delivered heating or cooling by the HVAC system. The KPI's module will also return the annual energy used for heating and cooling.

Layer 6 - Data driven calibration
An important part of the RobMOS tool is calibration through data. Part of this means the energy demand will be compared with measurement data. However, the construction of the houses for the Dutch Pilot in SPHERE has only recently been completed due to COVID-19 pandemic restrictions delaying the completion. The monitoring campaign in these houses started in July 2021. When sufficient monitoring data has become available, TNO will be able to compare between predicted energy and actual energy use, and between IEQ performance predicted and measured.

Once a long enough time-series from monitored data is available, it is also possible to start with the model calibration. To illustrate the possibilities Figure 7 presents the results from a manual calibration on a single-family house dataset. In this figure, the measured and predicted energy signature is given. The energy signature shows the heating power versus the outside temperature, in this case averaged over weekly periods. The green circles represent the predicted thermal power and the red circles the (average) measured thermal power. With the green and red lines, the linear regression is shown for the predicted and measured heating power. The data in the figure shows an excellent correlation between predicted and measured heating power (at a 1.1% average performance difference).

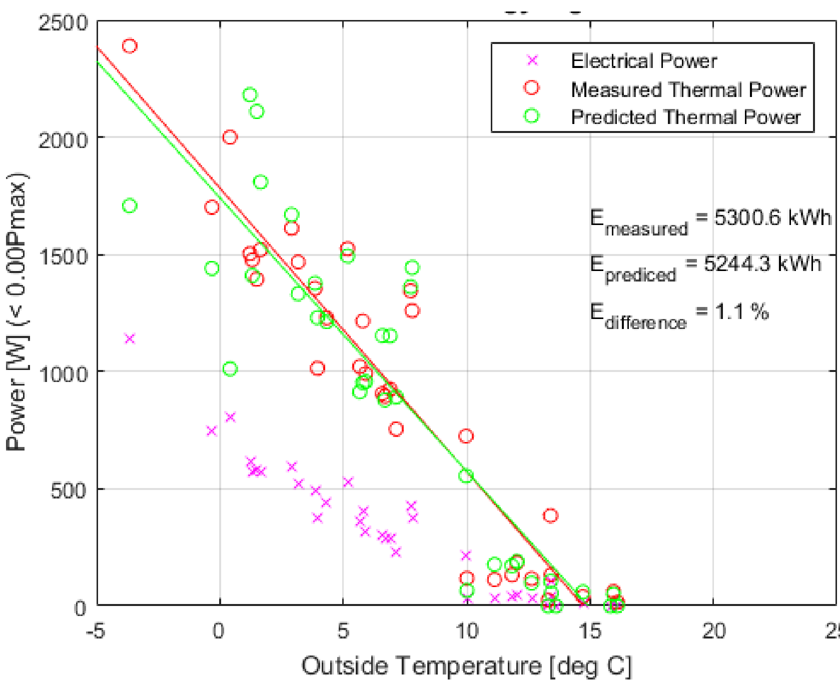


Figure 7. Energy signature evaluation using RobMOS with comparison with actual measurement

3.3 User Stories and Use Examples

The RobMos tools have been developed with the user needs in mind. To this end specific user stories have been developed based on the standard approach used in software product development.[2] User stories are expressed in a simple sentences as follows :

As an [actor], I want to [carry out a task] using the [tool name] so as to achieve [an insight/result decision]

The user stories were developed for different actors based on the life cycle of the construction/renovation works as defined in SPHERE task 2.1 based on the seven different life cycle phases: 1) Strategic definition, 2) Preparation and Brief, 3) Concept Design, 4) Technical Design, 5) Construction, 6) Handover and closeout, 7) In Use.

The following user stories were developed for RobMOS to guide the development works:

- 1 - Concept Design – As an architect or real estate developer, I want to estimate the energy use of a building using RobMOS so as to achieve early insights in feasible/good designs.
- 2 - In Use – As an owner or real estate developer, I want to know how the actual performance of the building w.r.t. energy consumption for heating and cooling.
- 3 - In Use – As an owner or real estate developer, I need to calibrate the model to be able to have good results for the actual performance.

The user stories guide the implementation of the testing approach for the tool, as for each user story the steps to utilise the tool have been defined in a flow-schematic as per the steps that need to be

[2] https://www.atlassian.com/agile/project-management/user-stories

taken to implement it. The flow-schematics for the user stories can be found in Figure 8, Figure 9 and Figure 10 below.

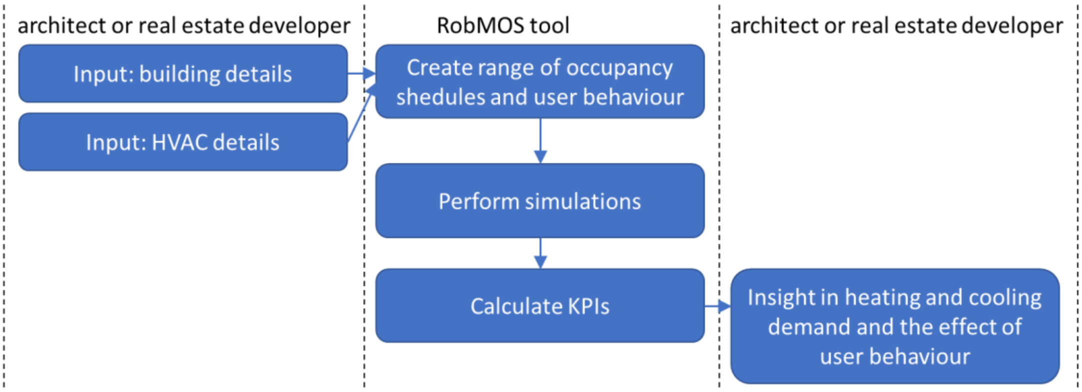


Figure 8. User Story 1 flow of user steps in carrying out the user story tasks

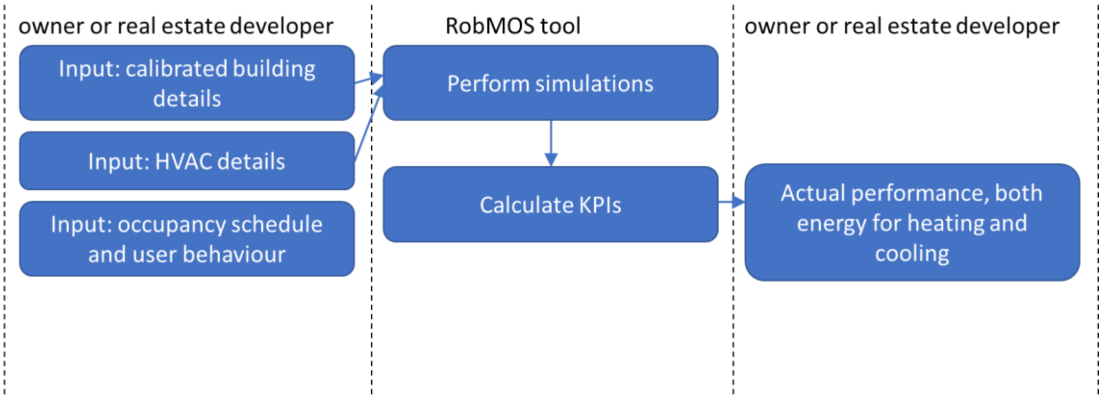


Figure 9. User Story 2 flow of user steps in carrying out the user story tasks

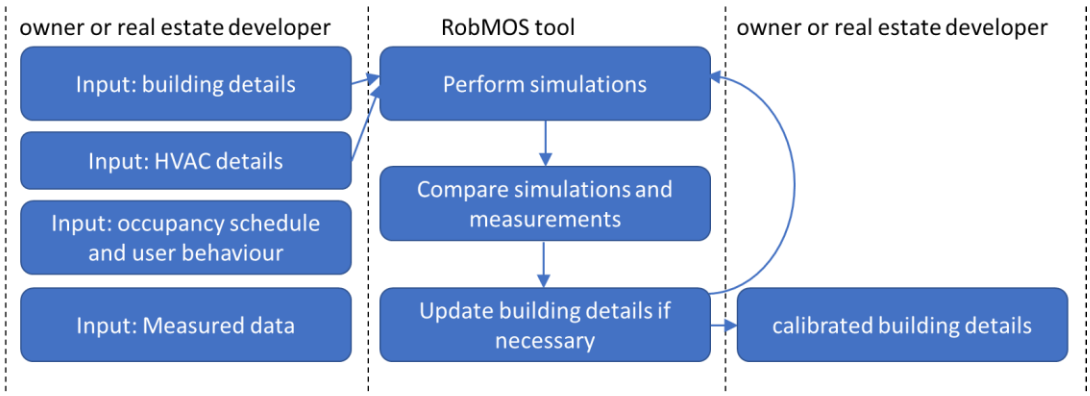


Figure 10. User Story 3 flow of user steps in carrying out the user story tasks

3.4 Integration in the SPHERE ecosystem

The works on the integration of the tools within the SPHERE ecosystem are envisioned in the pilot testing phase of the project (M24-M36 period). RobMOS will have its own user interface that will be linked to the SPHERE ecosystem using the single sign-on principle as developed in WP3. As depicted in Figure 11 below, RobMOS will receive building project data, BIM data and IoT data from SPHERE, carry out its energy calibration services, and send the simulated assessment back to the SPHERE ecosystem for results viewing purposes.

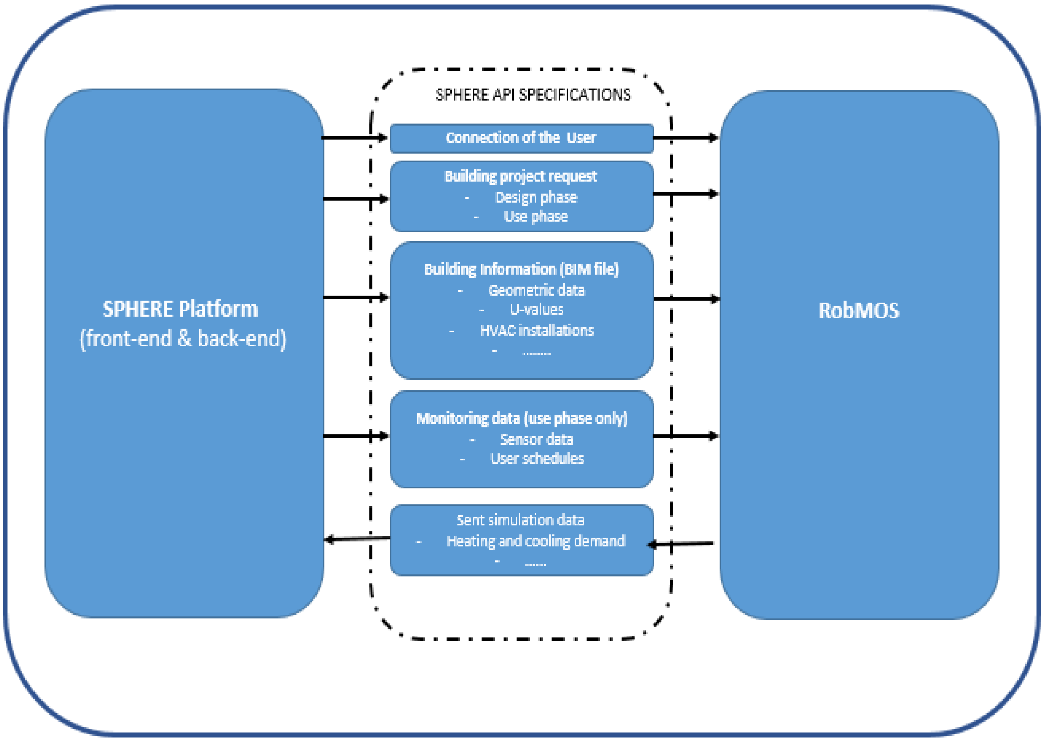


Figure 11. Interaction between SPHERE Ecosystem and MicroService RobMOS

In the current phase of the project, the interface between the RosMOB tool and the SPHERE ecosystem is envisioned to be mostly run between NEANEX and RobMOS. The NEANEX portal allows the visualisation of results generated by RobMOS. The inputs required for the simulations of RobMOS (building, installation and user details) have been generated based on information provided around the Dutch pilot. Currently, the results from RobMOS simulations can be obtained through an API that is accessible through https JSON requests. For a specified building, the energy for cooling, heating and heating hours can be requested for a given time period.

Data from the Dutch pilot that is used by the RobMOS tool will be made available on the SPHERE ecosystem for external partners. Interfacing of this data to the RobMOS tool from the pilot site will be done directly. Due to a diverse source of data sources and limited access, data collection and combination will mainly be done manually for the Dutch pilots. The resulting total (raw) data will be shared with other partners through the SPHERE ecosystem.

3.5 Testing procedures and results for SPHERE

The RobMOS application has been tested through a series of individual tests of the components, followed by a full integration test of the entire system. Each of the components in the different layers of the RobMOS tool (see Section 3.2) has been individually tested. For most components these tests involve generation of a set of test inputs and comparison of results to an expected set of results.

3.5.1 Functionality tests

As mentioned, the individual parts of the RobMOS tool have been tested. Based on the Dutch pilot site, inputs for the models have been generated. Both for the RobMOS ventilation model and the RobMOS energy model. The parts have been run using these generated inputs, such as the different user profiles and a check was performed to see if the model yields plausible results. Further validation of the tools will be done once monitoring data from the pilot sites becomes available. With this data a comparison between the theoretical model and reality can be performed. Figure 12 below shows the total annual heating demand for the different combinations of households, windows and window usage. As expected, when the windows are opened more often, the heating demand increases.

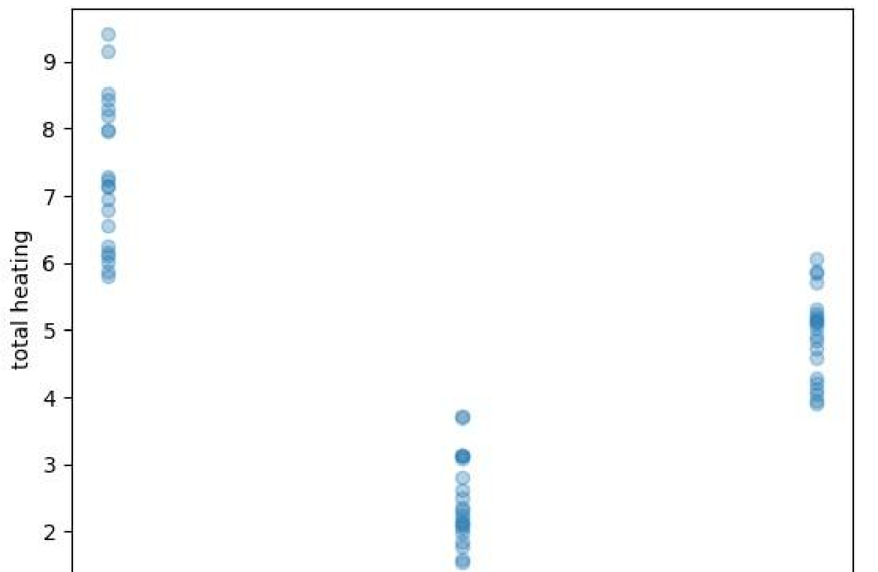


Figure 12. Annual heating demand versus window usage. Data points represent household types.

Figure 13 below shows the same results, with the annual heating demand plotted vs. the different types of households and the window usage shown in colour. As expected, the lower red dots, with no windows opening, are higher for small households and lower for households that consist of more occupants. The internal gain for these households will be higher, and therefore less heating is required.

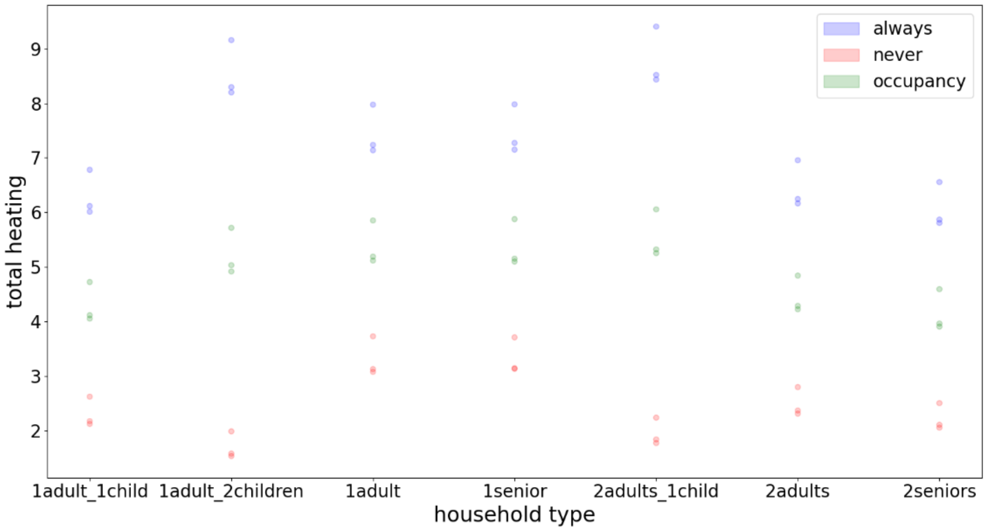


Figure 13. Annual heating demand of different households varying by ventilation regimes.

3.5.2 SPHERE Ecosystem Integration Tests Results

As described in Section 3.4, the main interface between the RobMOS tool and the SPHERE ecosystem is through the NEANEX portal. This interface is realized through an API accessible through https JSON requests. For testing purposes, the API has been made available to NEANEX using test data.

The data from the Dutch pilot will be manually processed due to the large number of different sources and limited accessibility. The combined data set will be shared with other partners through the SPHERE ecosystem. In addition to the link to the NEANEX portal, the sensor measurement will also be uploaded to the VTT sensor platform via a JSON API that will also be linked to the SPHERE ecosystem.

3.5.3 SPHERE PILOT TESTS

Once monitoring data of the heating season is available from the Dutch pilot tests, these datasets will be used for further validation of the RobMOS tool. Furthermore, this data can be used for calibration purposes of the models. For calibration purposes, data needs to be collected over a significant period of time (typically at least a few months) to account for statistical variances. Once data has been collected over the period of at least 2 months, the calibration process using this data can be started. The data will be split into a calibration set and a validation set. The validation set is used to verify the improvements of the model after calibration, also allowing for the detection of possible overfitting.

4 MicroService EcoSimpro SIMBOT (EAI)

4.1 Purpose, User Needs, Requirements

Description

EcosimPro is a tool for modelling a wide range of 0D and 1D multidisciplinary continuous and discrete systems based on differential-algebraic equations (DAE) and events. It provides an intuitive environment to create physical models based on schematic views, and a variety of visualisation modules to analyse and understand its results. In the context of SPHERE EcosimPro is used for the thermal simulation of a passive building, including the influences of a building structure and its thermal loads (including walls, doors, windows, and other building components), to a very high level of accuracy.

The results of the simulation are physical magnitudes like temperature or pressure, and KPIs such as energy savings in euros. These results can be exported in formats like ASCII, csv and hdf5; ready to be understood by people and machines alike, depending on the use case and user needs.

The key feature of the EcosimPro software is its ability to readily export mathematical models onto standalone, blackbox applications called decks or SIMBOTS. These blackboxes can be understood by third party programs and standards such as FMI, OPC UA or Matlab and Simulink, paving the path for co-simulation, SIL and HIL applications. This greatly improves the versatility of EcosimPro as it can then be used by field experts directly, such as MEP experts, who can understand the simulation models, yet do not need to have the skills to create the models themselves. They only need to tune them using visual and intuitive interfaces.

Purpose:

As mentioned, within the SPHERE Project, EcosimPro is adapted such that during the design phase HVAC engineers can analyse several different implementations that improve the energy and ventilation lifecycle of residential buildings. Also, during the operational phase, maintenance teams will be able to use the standalone, black box deck application to expand available information of the building by coupling sensor data with the simulation. Thus, the simulation will provide a more complete picture of every parameter of the building, enabling maintenance teams and inhabitants to make better decisions. This is possible because of the fine-grained representation in EcosimPro of every individual element of the HVAC system and its relation to the building, such that individual inefficiencies can be traced back, provided that the data is available.

User Needs:

The EcosimPro development team has been working in SPHERE towards a whole new set of components tailored to satisfy the engineering needs of HVAC engineers , based on a newly developed HVAC and building component library. This library will be the backbone of the simulation services provided to third parties.

Requirements:

In order to create a reliable model of an HVAC system EcosimPro requires:

- the geographical location of the building.
- the corresponding meteorological data of the location.
- the topology of the building (incl. spaces, characteristics of the walls, and thermal insulation properties).

- a description of the HVAC system, theAC ventilation network and the AC/heating system.

4.2 Tool Technical Description

EcosimPro is a desktop software tool including a result visualization module (EcosimPro monitor). The user can perform different simulation analyses, post process the results and export them into different formats.

To build a simulation in EcosimPro, one must start by creating components that describe the equations and events that govern the behavior of the object to be simulated. EcosimPro describes these using a language called EL that has been developed specifically for this simulation suite. The developed components, which have common fields, are grouped in libraries and can be joined together to generate components of greater complexity. In the case of SPHERE, EcosimPro engineers have built two libraries (HVAC and BUILDINGS) containing the main components needed to represent HVAC systems and building components for the simulations. These libraries are the basis for creating pilot case models, linking components and reproducing HVAC systems and building structures.

The BUILDINGS library most salient features are listed below:

- Heat transfer calculation between the walls and air by their thermo-hydraulic correlations.
- Thermal models of walls, windows, radiation and irradiation.
- Components to set the local weather and solar data.

The BUILDINGS library provides the following components to model and simulate buildings:

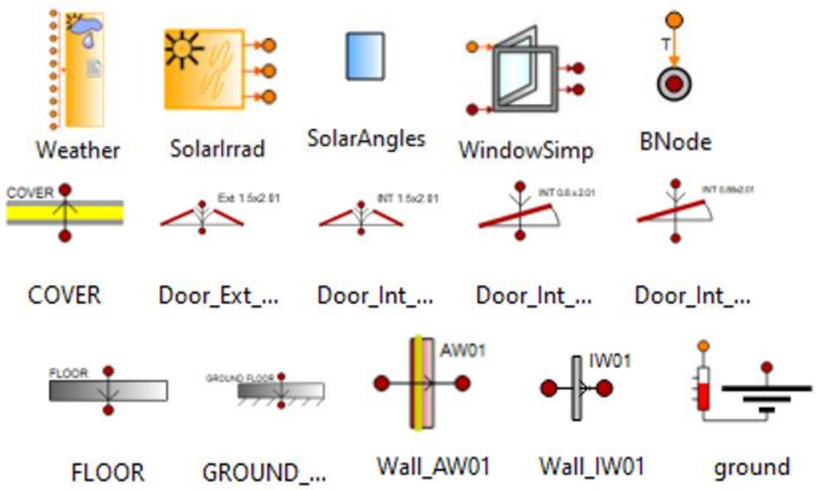


Figure 14. Graphic symbols of the Buildings library in EcosimPro.

The HVAC library provides a palette of components to be inserted in a model as they are integrated in a real system. Figure 15 shows the generic HVAC components:

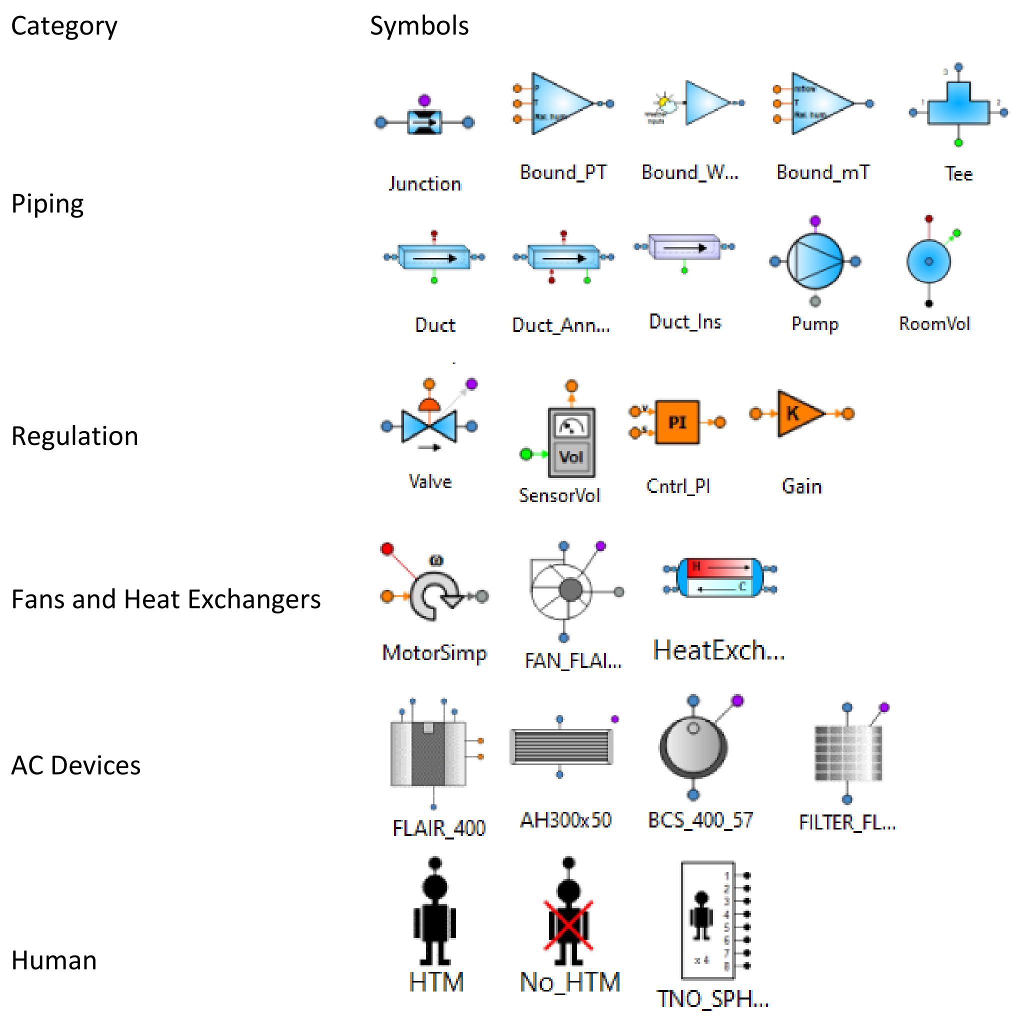


Figure 15. Graphic symbols of the HVAC library in EcosimPro.

The HVAC library most salient features are listed below:

- Pumps, fans and compressors components are provided with user-defined or generic performance maps.
- The working fluid(s) circulating in a loop (refrigerant, water, air constituents including CO2, etc.), can be easily selected from a large collection of fluids. The mixture composition and the phase of the main fluid will be automatically calculated in any component.
- Direct or reverse flow, inertia, pressure losses including two-phase wall friction correlations and gravity forces are considered in ducts, volumes, junctions, heat exchangers and turbomachinery, so the HVAC library allows a physical simulation of such elements.

To generate a system diagram, the libraries' components once built can be easily inserted (click and drag) into a model. Components can be linked to build a schematic as they are integrated in a real system. The tool is open to complex topologies and systems that can be easily replicated to larger models. In Figure 16 we can see the model of the HVAC system and the passive thermal design of a pilot building.

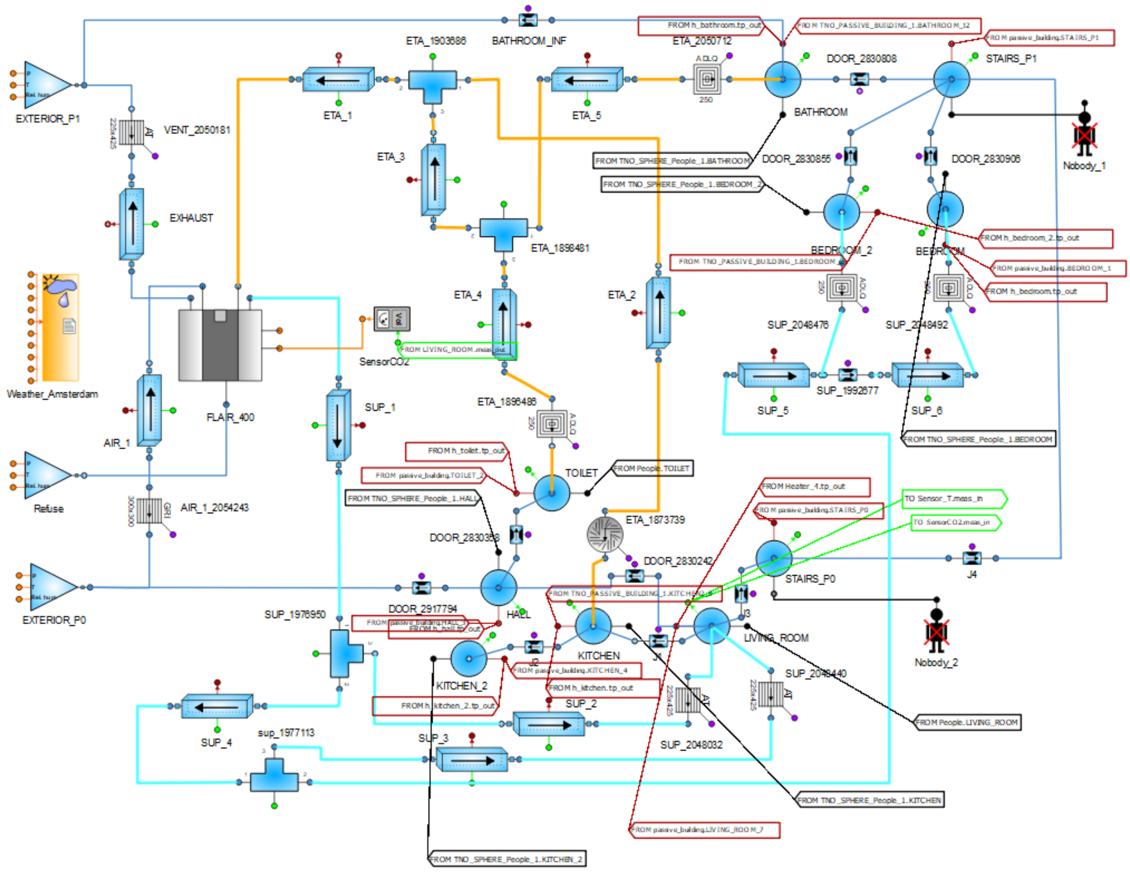


Figure 16. Graphic diagram of an HVAC system using components from libraries.

Once the modelling stage is completed, an HVAC engineer can create the simulation of that model and validate the results within EcosimPro (using the EcosimPro Monitor application), shown in Figure 17.

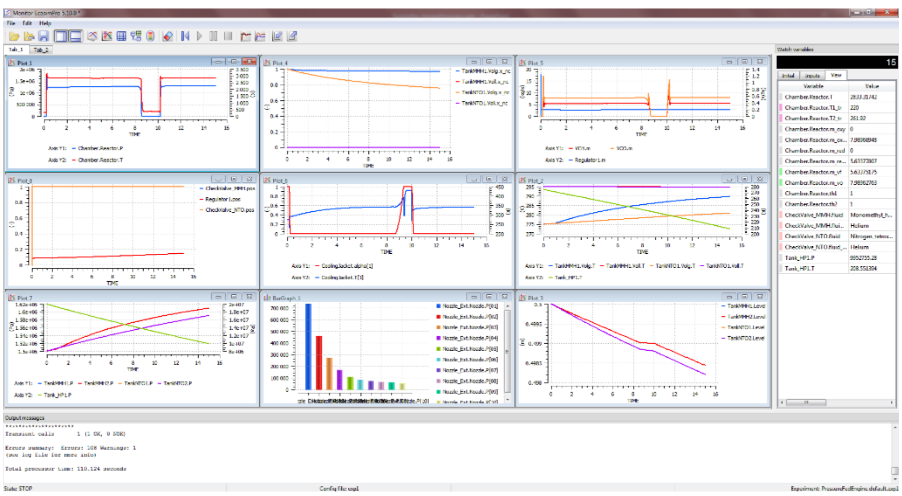


Figure 17. EcosimPro Monitor showing the results of the simulations

The advantage of using EcosimPro with its HVAC library is that the HVAC engineer could create a final simulation product called SIMBOT to be used outside of EcosimPro. A SIMBOT can combine both technical equipment and cost analysis modelling to generate more complex analyses.

These SIMBOTs open a whole new path towards new products, applications and services. As part of the SPHERE project a laboratory validation has been made with manufacturers of home ventilation machines. These were found to be open to provide information to build a SIMBOT of their products, so that their clients can use the SIMBOTs in their building design phase. This route is highly promising because of the accuracy of the SIMBOTs when built directly with manufacturers information about the appliance. Especially when during the exploitation phase the SIMBOT model can be coupled with sensor signals and building digital information. SIMBOTs of appliances will be a way to introduce appliances in a virtual house design. It can also provide information for commissioning of the building, and the detection of potential faults of the control system. This is possible because of the fine-grained nature of EcosimPro models that enable the rapid identification of which component is not functioning according to expectations. Finally, we can take advantage of their validation process to support a more thorough certification process.

The first SIMBOT prototype developed with the TNO pilot project illustrates the potential in terms of the level of detail that can be presented. In the HVAC context for the Dutch Pilot, the ventilation solution includes a home ventilation machine from the fabricator BRINK (see https://www.brinkhrv.com/). Following the validation steps already described, we have developed a simulation schematic—a prototype of sorts—that includes all the components within the machine: fans, heat recovery unit, filters, preheater, post heater, bypass, and control options.

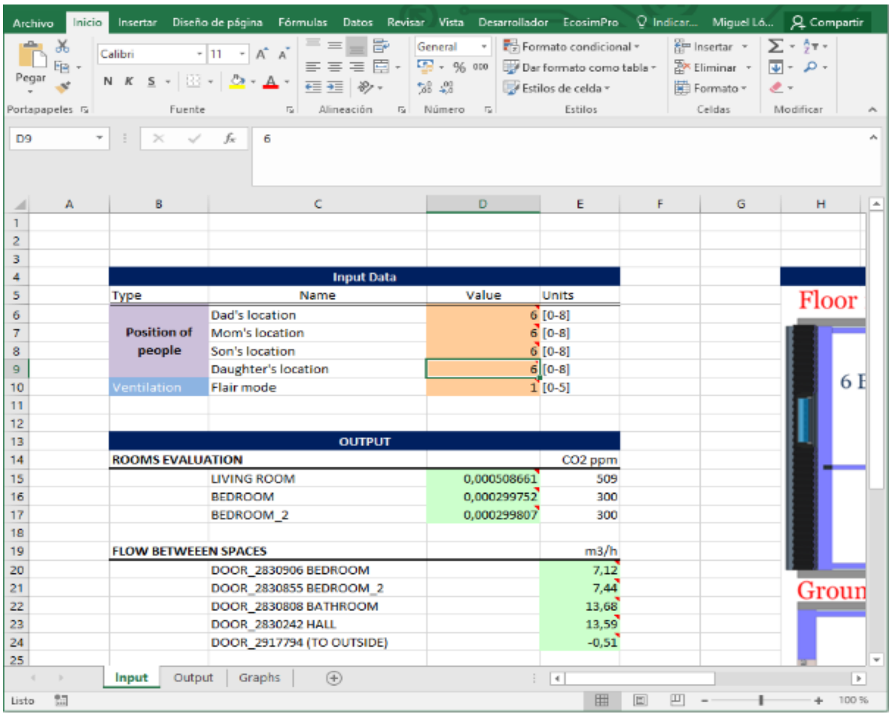


Figure 18. Excel SIMBOT based on a model export from EcosimPro

4.3 User Stories and Use Examples

A SIMBOT produced in EcosimPro with the OPEN SIL libraries is a simulation of a building's HVAC system.

This simulation allows different use cases ranging from the design phases of the building, when decisions are being made about the HVAC systems to be included in the building, to the operation and maintenance stages of the building, when the simulation can act as a software element able to anticipate situations or see deviations from ideal use cases.

The following user stories were developed for SIMBOT to guide the development works:

- Phase of concept/technical design - Creating of SIMBOT for HVAC design
- Phase of use - Using SIMBOT for predictive analysis of HVAC
- Phase of use - Using SIMBOT for case studies of HVAC

The main actors are:

- The end user (pilot): user who raises the need to create a digital twin of a building's HVAC system. This is the user of the final product built with EcosimPro (the SIMBOT) that will allow him/her to understand the real HVAC system and to make decisions regarding the design of the system, its operation and performance, costs, etc.
- The simulation engineer: expert capable of creating in EcosimPro the digital simulation of the actual HVAC system that the end user has requested.

Creation of SIMBOT for HVAC design:
A digital twin of an HVAC system needs all relevant information about the real system to be simulated. This so that the digital results are accurate and correspond to what would be obtained in reality. The relevant information needed for EcosimPRO to represent an HVAC SIMBOT can be classified into three categories:

- Location: geographic position of the building to obtain meteorological data.
- Topology: distribution of the building, existing spaces and technical characteristics of the walls (including thermal insulation properties).
- HVAC system including information about the AC ventilation network, information of the AC/heating system, and datasheets of HVAC machinery.

This starting information is provided by the user who works on or builds the HVAC system. In the context of SPHERE the Pilot owner, exchanging this information with the Simulation Engineer who has to create the Digital Twin in EcosimPro.

The entire process can be iterative until a final SIMBOT is realised. The goal is to arrive at a design solution validated by the pilot. At each step of the iteration, different HVAC systems can be designed with different technical characteristics to find the best solution. The process is graphically illustrated in Figure 19.

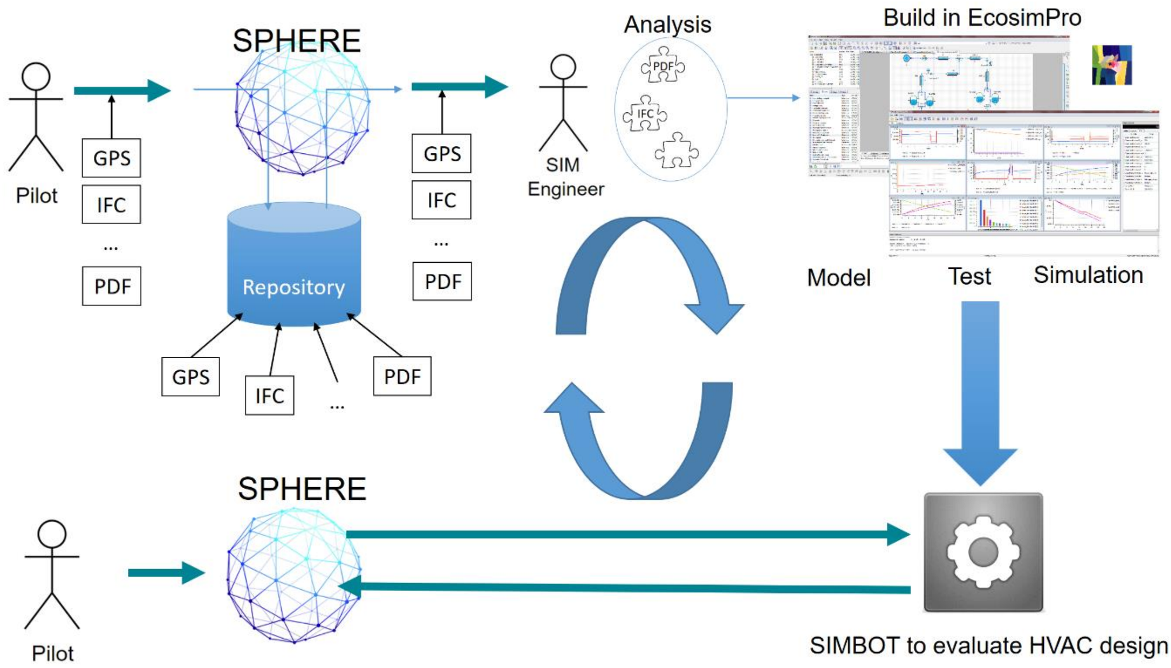


Figure 19. Design of HVAC system based on SIMBOT

Once a final SIMBOT is realised that faithfully represents the real system to be created in the building, this SIMBOT can be used in the following user stories described in more detail below.

Using SIMBOT for predictive analysis of HVAC:

In this case, the starting point is the final SIMBOT of the building that faithfully represents the digital twin of the building's HVAC system.

The interest of this example of use is to obtain predictions that favour the operation and general maintenance of the building's HVAC system. To do this, the first step is to collect real data from the pilot building that can be obtained by software or sensors. Such data can include measurements of parameters such as outdoor temperature and equipment operating mode.that are saved into an IoT time-series database.

The responsibility for capturing the data is outside the SIMBOT service capabilities. Linkage to another MicroService that measures and captures data is therefore needed. Data contained in an IoT database from another MicroService can be used by a SIMBOT to simulate different scenarios so that the end user (pilot) can perform predictive analysis. This is illustrated in Figure 17.

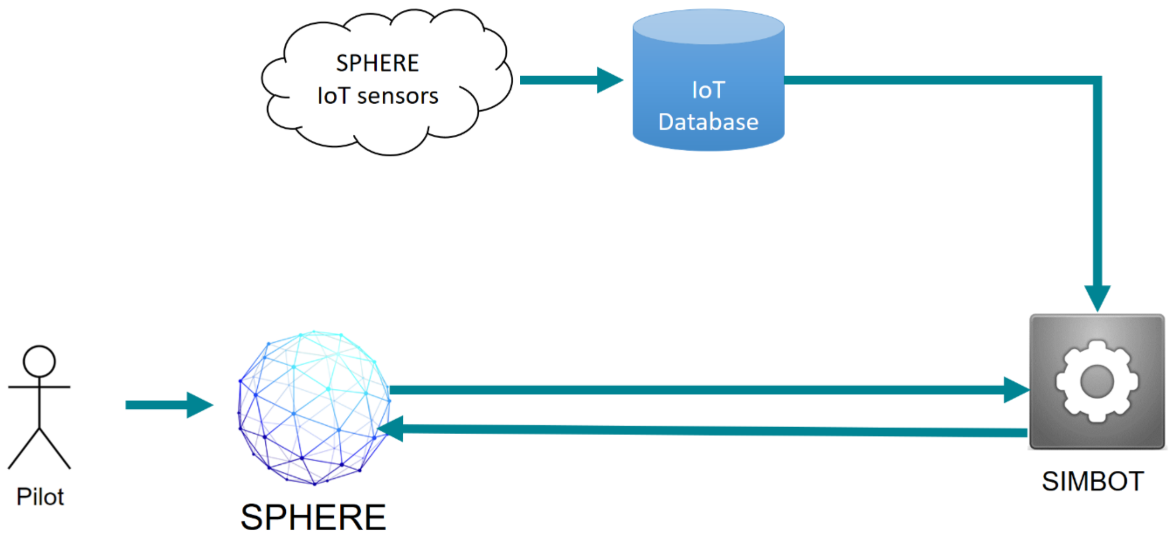


Figure 20. Predictive analysis of HVAC system based on SIMBOT

Using SIMBOTs for evaluating the malfunctioning of HVAC systems:

As in the previous case, the starting point is the final SIMBOT of the building. The analysis and case study needs of end users can be supported with EcosimPro SIMBOTS also for comparing unexpected/inconsistent values and trends measured in reality against simulated standard scenarios, comparing measurements and results, as illustrated in Figure 21. This would enable the detection and pinpointing of the origin of failure of components.

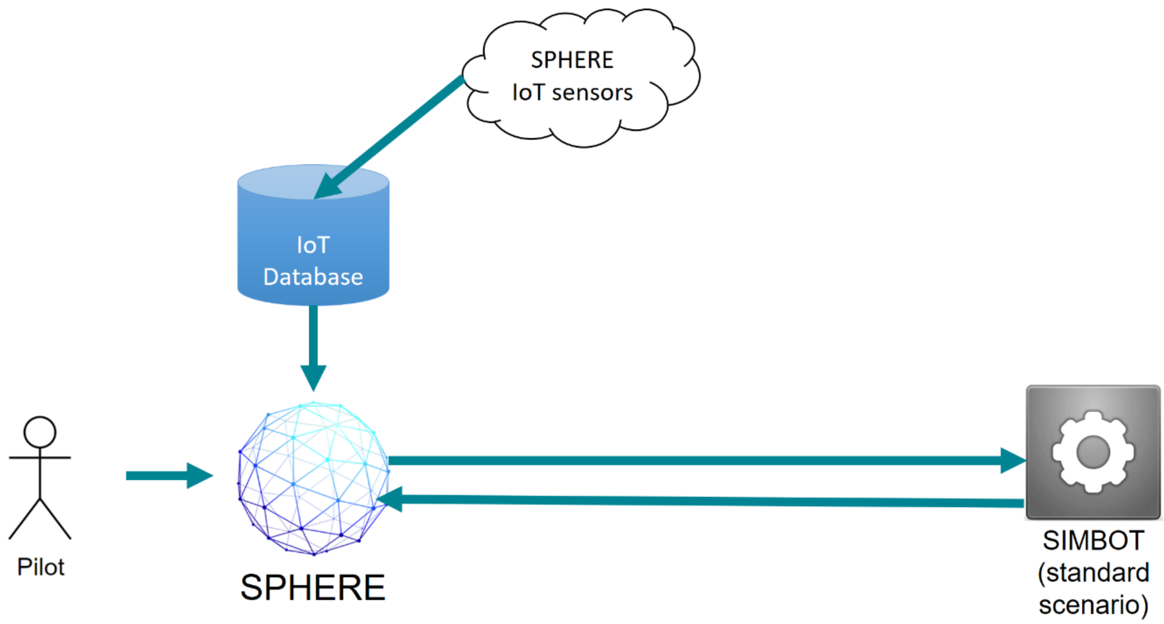


Figure 21. Using SIMBOT for study cases of HVAC

4.4 Integration in the SPHERE platform

The process of creating a model in EcosimPro is similar to the developed process from several decades of EcoSimPro's existence. Based on getting initial data, using EcosimPro libraries and modules, and finally building an executable simulation.

In SPHERE the target is to improve two aspects of this workflow:

- The data exchanges between the end user and the simulation engineer, so it would be appropriate to use SPHERE to improve this exchange and also the packaging and the organisation of the initial data, for example using repositories or databases.
- The final simulation must be able to be used remotely from the internet, without having dependencies of local applications (as in the case with a SIMBOT based on Microsoft Excel).

4.4.1 Schematic description of operational workflow

The first step is to build the simulation for which the EcosimPro engineer must obtain from SPHERE the descriptions of the HVAC system to be simulated. In other words, the description of the system, the building containing the system, and the HVAC system itself. This information can be contained in the platform's repositories or sent through the necessary interfaces.

From this data, the simulation is built in online mode, which is a web application that interacts with SPHERE through a software API.

Regarding simulations, the first and simplest way is to use the data generated by EcosimPro exported Excel SIMBOT simulations, and to generate result files that can be consulted or processed. EcosimPro can export its models to excel to enable them to run as standalone applications, which provides greater versatility and interoperability.

A second route is the use of web services altogether, removing the need for an Excel SIMBOT simulation step. In this case the model packaged as a SIMBOT needs to exchange the information using JSON files as input-output between the end user and the simulation. If deemed necessary, EcosimPro simulations can also be used also in conjunction with IoT platforms (e.g., the OPC Unified Architecture makes it possible to feed a system with inputs and outputs from hardware).

4.4.2 Links to other tools, work to date on linkages

First, the EcosimPro HVAC engineer needs to obtain data in order to create the pilot case simulation. This data exchange is simple and will be done through SPHERE to allow basic information to be obtained to create the HVAC model of the building.

Once the information is received and the simulation is created, the HVAC engineer will create a final web server SIMBOT that will act as a backend capable of receiving and delivering data on request.

The connection of the web SIMBOT with SPHERE will be through the IDP portal which will be the end user interface in charge of sending and receiving the data through API calls (JSON format) from the web SIMBOT of each implemented pilot.

Through the IDP portal, the SIMBOT will be able to receive as JSON data the values of the input variables that are considered relevant in the model to be simulated (pilot). Subsequently, produced results will be sent from the SIMBOT in JSON format to the IDP portal. Ths process is illustrated in Figure 22.

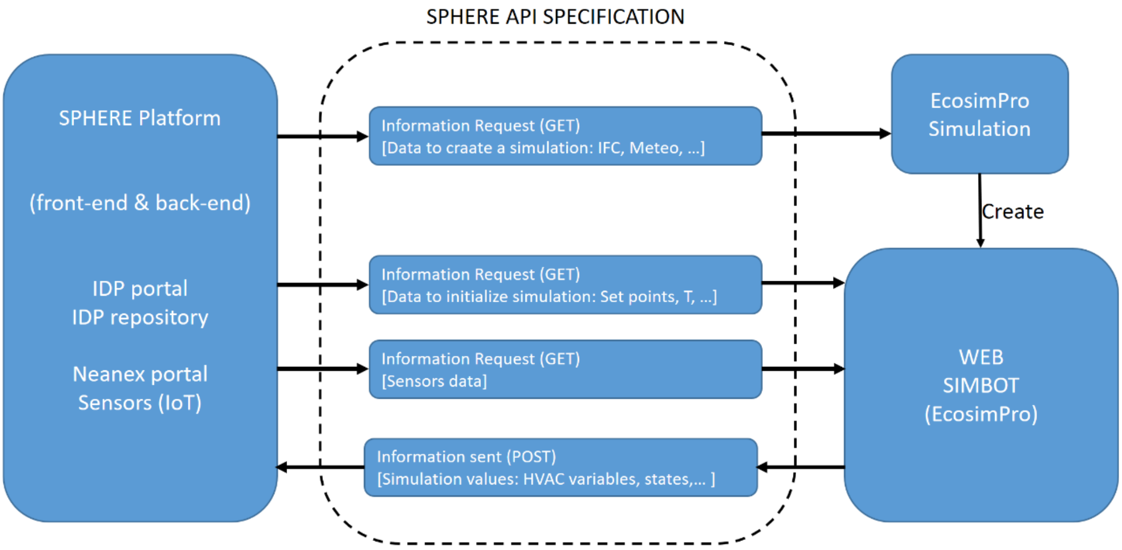


Figure 22. Interaction between the SPHERE platform and the MicroService SIMBots in EcosimPro

4.5 Testing procedures and results for SPHERE

Validation processes for EcosimPro are carried out in a bottom-up basis: considering first the most basic components—such as appliances—to then step-up to aggregates—like heating or ventilation—and, finally, the complete building model.

The first step, the validation of appliances, is based on the manufacturer specifications and official test results. The final SIMBOTs are based on both passive building and HVAC system models. Each of them is modelled based on different physical phenomena.

The passive building mainly considers heat transfer through the walls, floor, ceiling, roof and windows. It is related to thermal conductivity and capacitance (thermal inertia). Therefore, several tests were carried out to address the proper behaviour of the above-mentioned components throughout several days with various meteorological conditions. There have been analysed different temperature distributions in both the outer and inner layers of the wall, heat flows, energy stored and thermal inertia of the building.

In contrast, whereas the passive building model only takes into consideration heat transfer phenomena, the HVAC system model also accounts for fluid transportation, control system functioning and human occupancy.

The validation of such a model is more complicated as several case studies must be run to analyse the proper functioning of the HVAC system.

4.5.1 Functionality tests

The validation of the components of the HVAC library involves necessary steps to assure that what is inside our computers accurately represents the real world. The initial laboratory validation followed the next steps:

- Selection of the phenomena to be simulated.
- Detection of relevant simulation parameters to be validated.
- Collection of information about these parameters from the real world.
- Comparison of the real world (experimental) behaviour with the behaviour predicted through the simulations.

After validation, EcosimPro allows the creation of a SIMBOT to externally simulate the whole system, obtaining different results based on various inputs. This SIMBOT allows end users to obtain analysis results, and access the values of the different parts of the simulation, by isolating them from the mathematical complexities of the components or the relationships that exist between them.

SIMBOTs have to this end been developed for both the TNO and DE5 pilots including:

- Standalone application based on an EXCEL sheet.
- A web service that is integrated in the IDP SPHERE portal

4.5.2 SPHERE Platform Integration Tests

The first version of the pilot SIMBOTs has been developed to be run in a local environment with an integrated Excel user interface. However, the next version of the SIMBOT will be run through a web server based on an API whose graphical interface will be provided by SPHERE (e.g. the IDP portal).

The user interface or the API has been divided into 3 parts:

- Input data: where the main parameters of the building are defined for the simulation.
- Results: where the most relevant output parameters are returned.
- Output report: where the output data is given for the desired time step.

Moreover, in the Excel case, different charts and graphs can be inserted to improve the overall aspect of the SIMBOT and provide an interactive environment for the user, as shown in Figure 23.

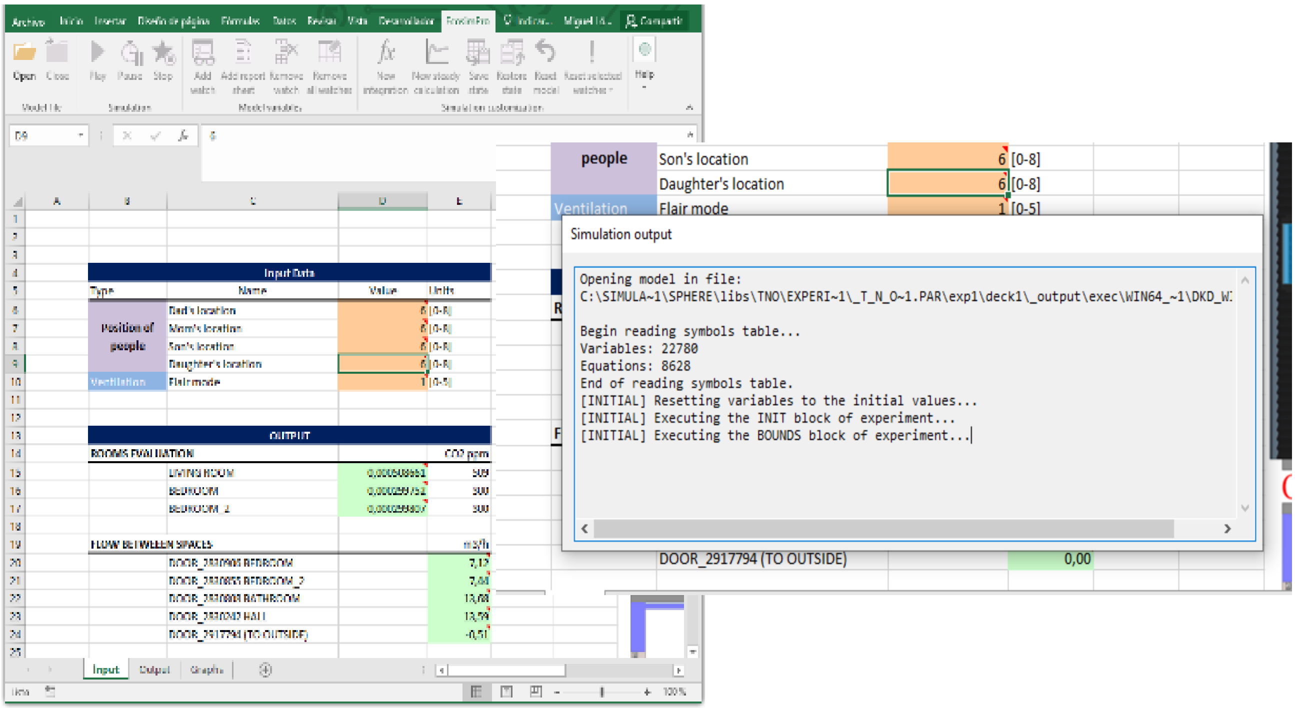


Figure 23. SIMBot Excel interface

The ultimate goal of this integration is to get a web server that accepts simulation requests from external clients (for example a IDP web portal). Currently this integration with SPHERE is under development. A first version of the web server is being built to be used with a POST based API with exchanges in a JSON format. The next integration steps should go in the direction of using the web service from SPHERE (the IDP portal) and feeding the service with input data that can come from a form-like user interface and from an IoT database.

4.5.3 SPHERE pilot tests

Many of the descriptions of buildings have currently been done through the IFC format. This format defines a kind of standard rules that allows one to create 3D models of buildings as well as to define the properties of some of their parts, illustrated in Figure 24.

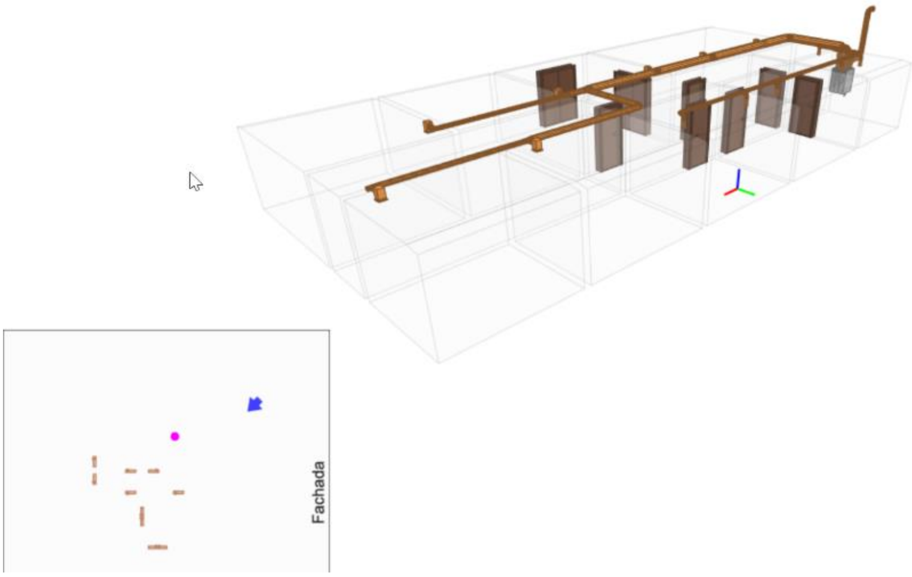


Figure 24. IFC model of a building with a HVAC system definition

There are a large number of programs capable of representing and creating IFC model files. The problem is that these IFC files can be very different (imagine the XML standard, it defines creation rules but two XML files that talk about the same thing do not have to be represented with the same internal structure).

To solve the IFC problem we carried out the following tasks:

- **IFC reception:** We have developed internal documents with rules of acceptance for pilots. There is a first stage of acceptance with very general requirements, with specific notes about critical problems which imply that an IFC model is not acceptable. In a second step (and once the model is accepted), we analyse each discipline/aspect of the IFC file, beginning with ventilation and passive building.
- **IFC pre-processing**: To be able to translate the IFC entities into simulation components we have developed a methodology which begins with pre-processing the IFC file grouping all entities. We get a final schematic in the simulation environment ready to work with it, saving time and mistakes.
- **Creation of EcosimPro simulations:** Using the Open SIL libraries, simulations for TNO and DE5 pilots have been created within EcosimPro. Two types of SIMBOTS have been built from these simulations:
  - one integrated in Excel spreadsheets to be tested by the pilots and by the SPHERE project managers in tests and improvements.
  - others as web services that are integrated in the IDP portal and can be remotely invoked from the web portal.

The process is illustrated in Figure 25.

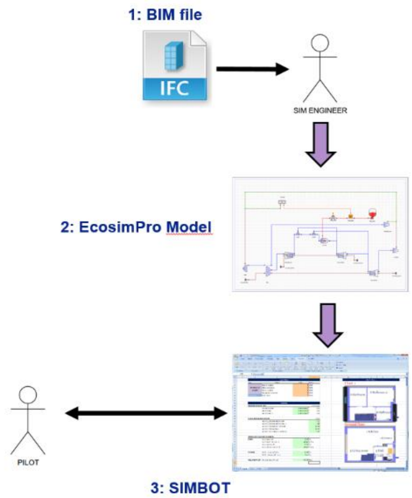


Figure 25. Transformation from IFC to EcosimPro to Excel SIMBOT

Regarding the demo pilots, we have received information from TNO and DE5 pilots that includes ventilation, passive building and basic heating. Both demo pilots were presented to the consortium.

The final result of these developments has been two Excel SIMBOTs, one for TNO (shown in Figure 26) and one for DE5, which simulate the pilot buildings and their HVAC systems. With these SIMBOTs the user can determine various KPIs (incl. cost analysis, energy performance.) both for the design phase of the building and for the operation of the building.

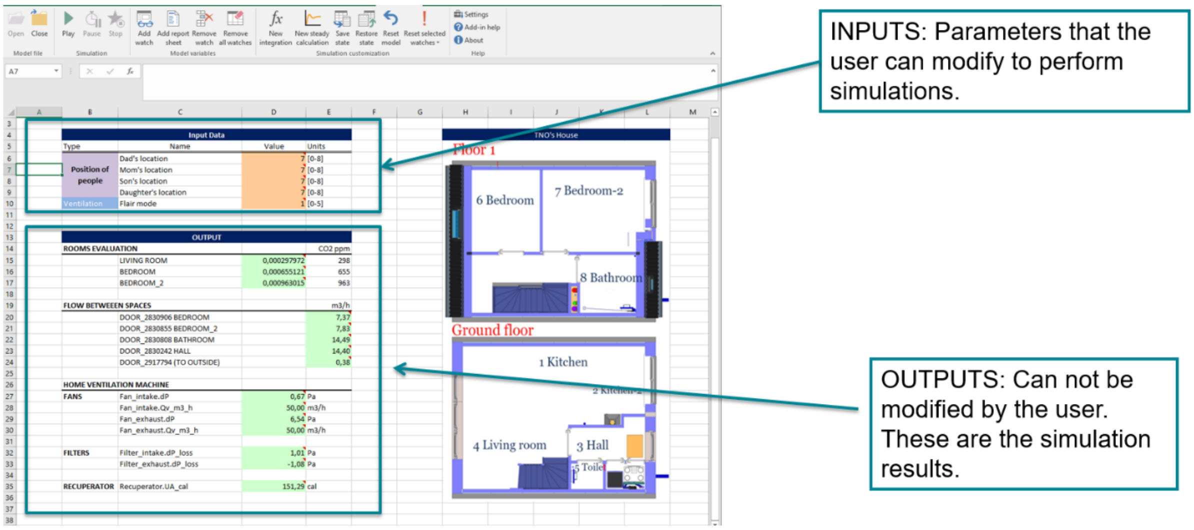


Figure 26. TNO Excel interface

Similarly, a web server for running EcosimPro SIMBOTs is being developed that through input and output JSON files will be integrated into the IDP portal. Currently, the web server for the DE5 pilot is under development. This server is under internal testing, but first simulation results are the same as for the Excel case.

The internal testing includes two test cases, one for summer and other for winter. For each test case different working modes for the HVAC system are defined as well as various set point temperatures for the rooms. Figure 27 shows first results of the cumulative energy consumption (top) and room temperature (bottom).

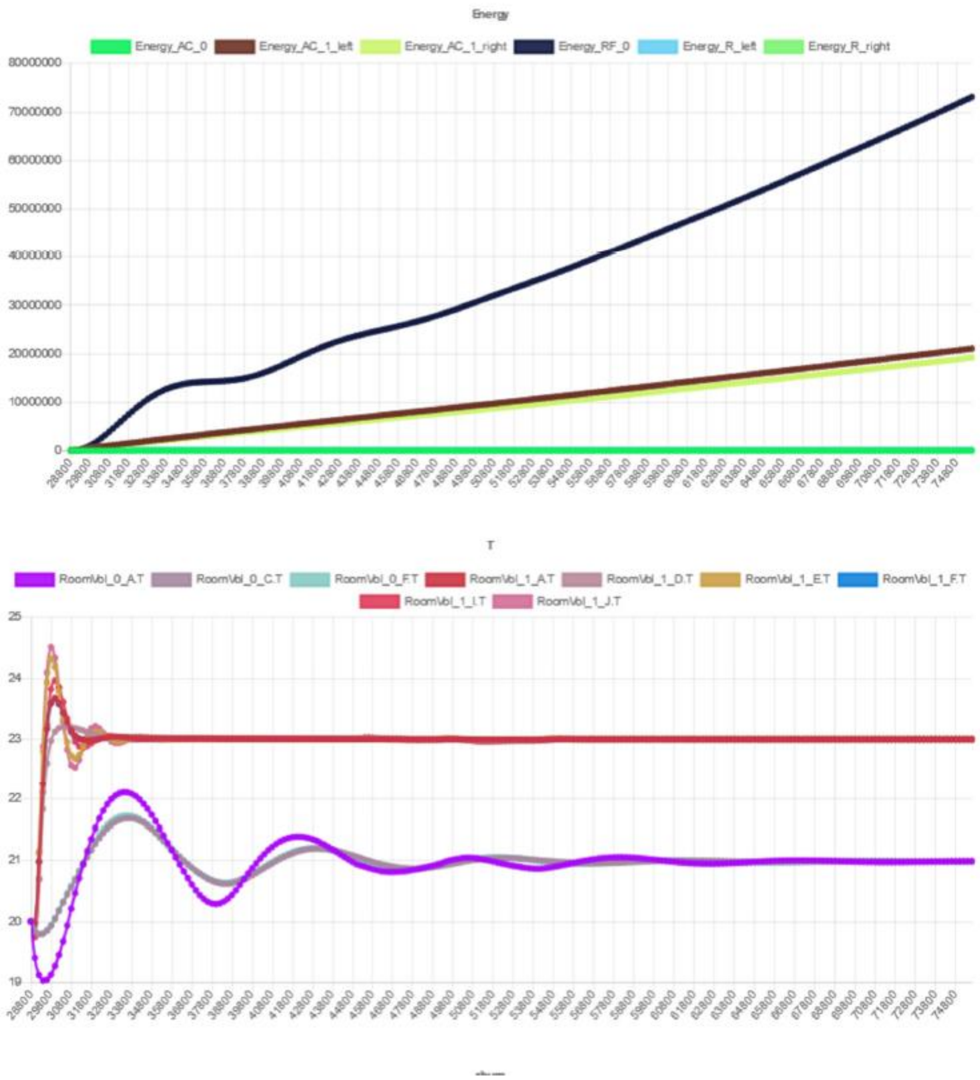


Figure 27. DE5 results: cumulative energy consumption (top) and room temperature (bottom)

5 MicroService Indoor Environment Quality (temperature) RobMOS (TNO)

5.1 Purpose, User Needs, Requirements

User needs:
Designers of a building want to assess the Indoor Environment Quality (IEQ) of a building so as to achieve early insights in improving their designs for various weather conditions.

Purpose:
The IEQM MicroService that is part of the RobMOS suite, can be used by designers and consultants to estimate the IEQ performance of a building. Both during the design and operational phase or to use model predictive control in a building during the operational phase. The goal is a better prediction of the thermal comfort and to identify ways to improve the thermal comfort and reduce excess heat and excess cold, so as to increase the overall wellbeing of building occupants.

Requirements:
Similar to the EM MicroService (Chapter 3), the IEQM requires information about the building and heating, cooling and ventilation installations. This MicroService can combine data from different sources available in the SPHERE ecosystem.

5.2 Tool Technical Description

The MicroService Indoor Environment Quality (IEQ) uses the same architecture as the energy part of the RobMOS suite (chapter 3) to predict the temperatures (thermal comfort) in the dwelling during the design and operational phase. It is comparable with the MicroService as described in Chapter 3, however, in this case for the prediction of temperatures instead of energy. This MicroService uses an Indoor Environment Quality model (IEQM). The IEQM can be similar to the Energy Model (EM) as described in chapter 3 in terms of the zonal layout of the building and construction. It is noted however that both models, EM and IEQM, may differ on certain aspects because of the different goals to predict either energy or temperature. Consequently, the MicroServices differ specific in terms of rules, thus requiring a different set of equations, variables, and parameters.

5.3 User Stories and Use Examples

Because of the large similarities between the IEQ and energy parts of the RobMOS tool, the user stories developed for the IEQ part are roughly the same as the ones described in Section 3.3. They are only updated to reflect IEQ instead of energy.

The following user stories were developed for RobMOS to guide the development works:

- 1 - Concept Design – As an architect or real estate developer, I want to estimate the expected IEQ based on the design of a building using IEQM so as to achieve early insights in feasible/good designs.
- 2 - In Use – As an owner or real estate developer, I want to know how the actual performance w.r.t. the IEQ is of the building
- 3 - In Use – As an owner or real estate developer, I need to calibrate the model to be able to have a good result for the actual performance.

The user stories guide the implementation of the testing approach for the tool, as for each user story the steps to utilise the tool have been defined in a flow-schematic as per the steps that need to be taken to implement it. The flow-schematics for the user stories can be found in Figure 28, Figure 29 and Figure 30.

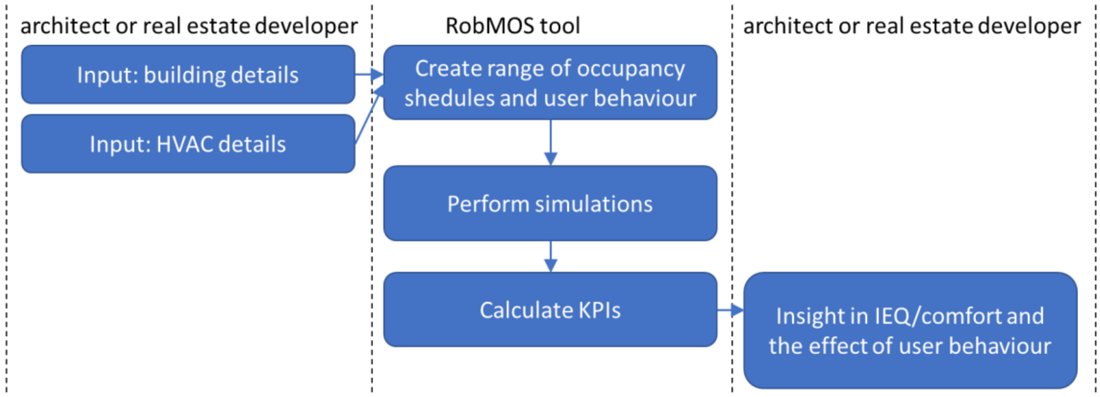


Figure 28: User Story 1 flow of user steps in carrying out the user story tasks

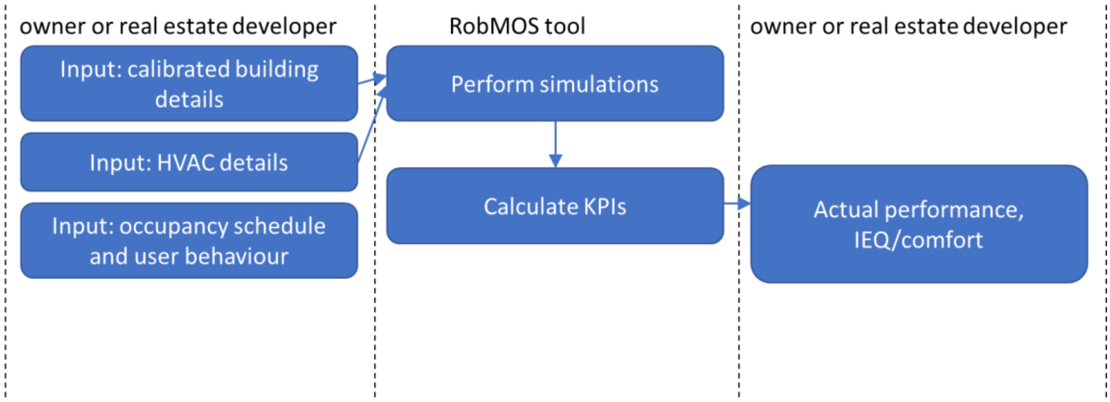


Figure 29: User Story 2 flow of user steps in carrying out the user story tasks

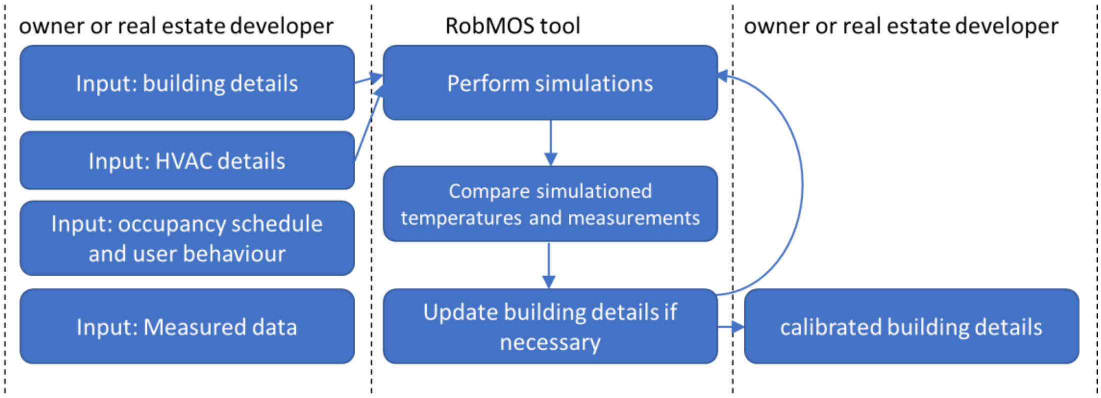


Figure 30. User Story 3 flow of user steps in carrying out the user story tasks

5.4 Integration in the SPHERE ecosystem

Because of the similarities between the IEQM and energy part of RobMOS, a large part of the interface is already described in Section 3.4. The KPIs that can be accessed w.r.t. IEQ are air and operative temperatures and thermal comfort as specified in either NEN16789-1:2019 or ISSO74:2014. It is important to note that these KPIs are calculated per zone that is present in the model rather than at a whole building level.

5.5 Testing procedures and results for SPHERE

5.5.1 Calibration of model parameters

An important difference between the energy and IEQ part of RobMOS is that detailed data on IEQ from the pilots allows for calibration of a more detailed level of the models. To validate this calibration on a more detailed level, an experiment based on data available from a single office space in an office building has been used. A simplified model was used, shown in Figure 31.

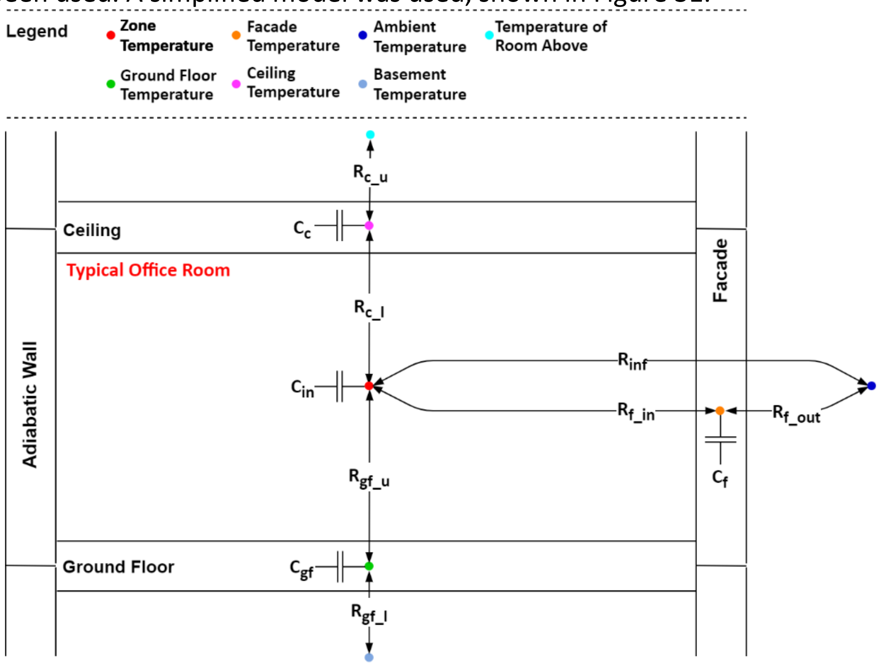


Figure 31. Model structure used in the activity pilot.

The model has a temperature node in the façade, ceiling and floor of the room. Temperature exchanges with adjacent rooms and the hallway were not modelled in the validation as these were generally at the same temperature as the modelled rooms. The room modelled is located on the ground floor and below it is an unheated and well-ventilated basement. The nodes in the basement, floor above and outside are assumed to be nodes of infinite thermal capacity, for simplification purposes, and their temperature is obtained from monitoring data.

The model was made without modelling the HVAC system of the building or the occupant behaviour. Thus, the parameters to be calibrated were only the capacities of each of the nodes and the resistances between nodes in the model, related to the building zonal representation. The allowed ranges for each parameter were set by an energy modelling expert of TNO.

The calibration was executed using a sum of least squares of indoor air temperatures as the comparison function. A black-box hillclimber method was implemented which attempts to improve parameter values by searching in different directions and checking if improvements occur.

Because the model did not include user behaviour or the HVAC installation, the calibration process was carried out using only time periods within the monitoring set for which the installations were off and no users were assumed to be present. These periods are between 20:00 p.m. and 4:00 a.m.

Because the calibration period is relatively short, the initial values for the temperature of the thermal masses should be well chosen. The best results were obtained in case predicted temperatures were used as initial values of the temperature of the walls, floors and ceiling. The summed squared differences for the predicted and measured temperature overnight, when averaged over the period of January 1st 2019 to June 1th of 2019, was roughly 1.5˚C. For a typical night the fit is illustrated in Figure 32, with purple line representing the measured temperature and the blue line the predicted temperature. The graph shows that the night-time cooling down of the office space is well reproduced, with the parameter values found as insights in the thermal behaviour of different building parts including the floors, ceilings , and walls.

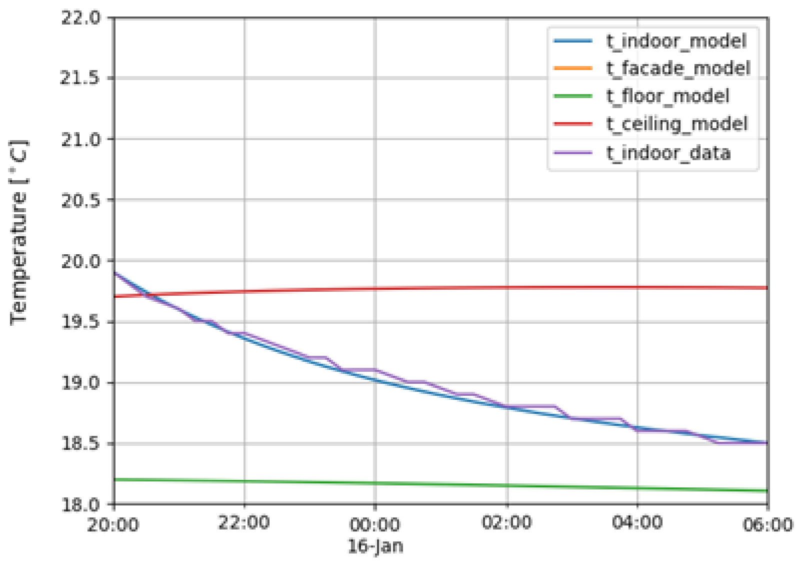


Figure 32. Temperature fit for a typical night

The testing of the RobMOS IEQ MicroService has a lot in common with the testing of the energy part of RobMOS. Therefore, we refer to Section 3.5 for details on the testing procedure. For the IEQ the parts have been individually tested. However, for more detailed test measurement data is required. Further tests will be performed when enough measurement data is available. For the IEQ RobMOS the most interesting period is the summer period and the transition period between the summer and winter. In those periods the indoor temperature is “free floating” and the comfort temperature is different from day to day due to the adaptive comfort. During the test it is key to validate that the predicted indoor air temperature and operative temperature are in line with the measured data.

6 MicroService iESD-W Water Recycling Management (EUT)

6.1 Purpose, User Needs, Requirements

Purpose:
The purpose of this tool is to recommend the most suitable water treatment technology for a particular building and its sizing based on technical operations and cost perspectives. It evaluates from initial water situations which technologies are best suited to achieve a legally required water quality to enable water reuse.

User needs:
The potential users that have been identified will be mainly interested in two scenarios to understand the best suitable water treatment technologies, either for constructing a new building or adapting an existing one. In both cases they need to meet local legislation requirements for water qualities to enable water reuse, and also ensure feasibility of installing a water treatment technology that also fits into the available space of the building and/or its surroundings.

Requirements:
To operate iESD-Wdata is required of the annual water demand and its quality requirements, the available greywater and rainwater per year from the environment, and the characteristics of the building. iESD-W canl be used by engineering firms, service and maintenance companies, local administration, and environmental associations.

At this point of the project all the information regarding water demand and its quality requirements as well as the greywater and rainwater availability have been collected. The collection has been carried out for all the different SPHERE pilot sites and as a function of their location and the building characteristics.. This set of data will be implemented in the SPHERE Digital Twin ecosystem to enable the creation of scenarios for various country situations. All the potential treatment technologies have been chosen and the design equations for each have been established to understand their water management potentials. Currently these equations are being refined in the tool as part of laboratory validation procedures.

6.2 Tool Technical Description

The iESD-W tool has been designed and written in Python. This tool consists of three main blocks including the input data, a calculation core, and the output information (see Figure 33). In this section, each part of the iESD-W tool is described in sequence.

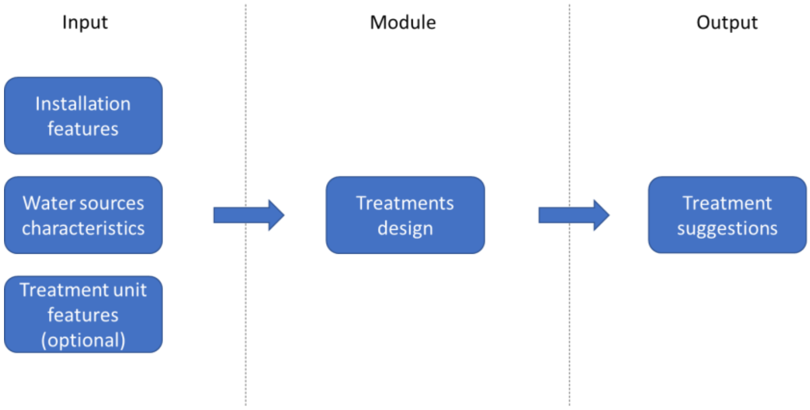


Figure 33. Scheme of the iESD-W architecture.

User input:

The tool requires information introduced by the user. The required data includes the installation features, i.e. the characteristics of the space available to install the water treatment unit, and water source characteristics such as the specifications of the rainwater catchment. Also required are building features and occupancy to understand water demands. This information has to be filled in two different interfaces as is shown in Figure 34: (i) on the left hand, the “General” window for the global characteristics of the project, and (ii) on the right hand, the “Water sources” window intended for water sources characteristics.

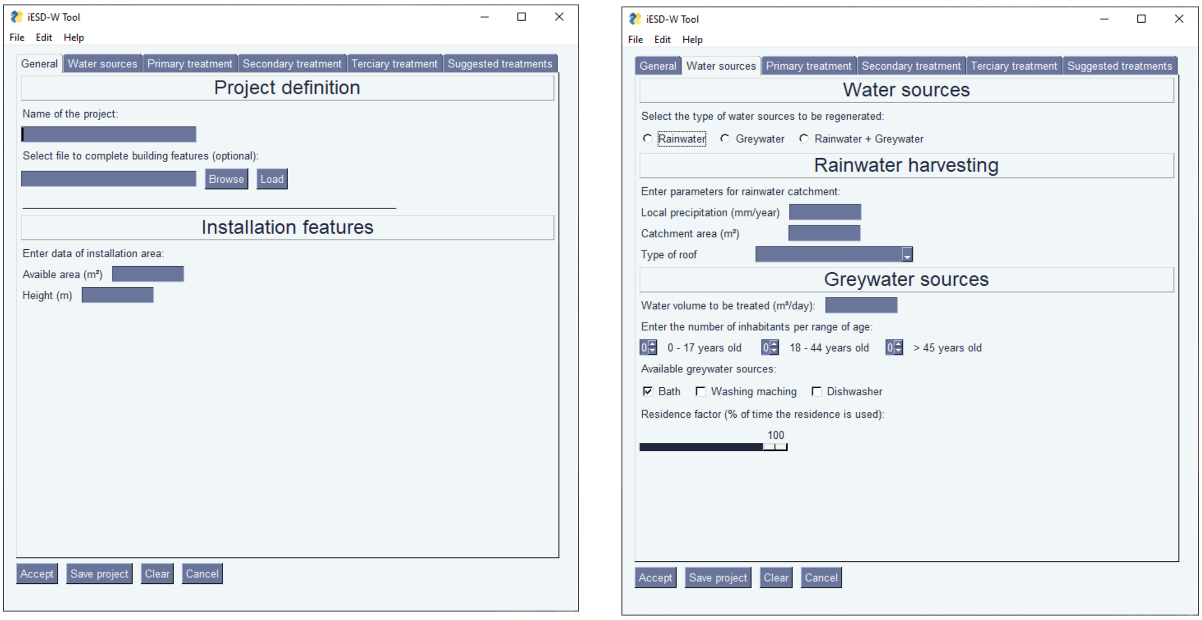


Figure 34. User interface screenshots of the required input data from the user. On the left, the “General” window and on the right, the “Water sources” window.

Optional user input:

The tool includes three windows relating to primary, secondary and tertiary water treatment technology features (See Figure 35). In these windows, additional specificities about different treatment processes can be detailed by the user if they are known. If this information is unavailable or not known by the user, the platform uses default values taken from literature..

Figure 35. User interface screenshots of the additional information about units treatments.

At the top left, the "Primary treatment" window, at the top right, the "Secondary treatment" window, and at the bottom "Tertiary treatment" window scrolled up and down.

Calculation core:

Beyond the graphical user interface, the tool integrates a module containing the design equations of the selected treatment technologies to achieve a particular water quality. Based on the input information this module allows to determine which are the optimal treatment chains for water reuse on private gardens and/or toilet discharge.

Output:

The output of the tool includes two lists of suggested treatment chains (See Figure 36). The first presents the recommended treatment chains that meet legislation requirements and the second the treatment chains that can be installed given the available spatial area. In case no treatment chains have been identified, for example due to a lack of available space, the user will be informed. In addition, the recommended technology treatments can also be exported in a text file.

Figure 36. User interface sreenshot of the outcome of the tool

6.3 User Stories and Use Examples

The iESD-W tool has been developed with the user needs in mind as described in section 6.1. To this end specific user stories have been developed based on the standard approach used in software product development.[3] User stories are expressed in a simple sentence.

The user stories were developed for different actors based on the life cycle of the construction/renovation works as defined in SPHERE task 2.1 based on the seven different life cycle phases : 1) Strategic definition, 2) Preparation and Brief, 3) Concept Design, 4) Technical Design, 5) Construction, 6) Handover and closeout, 7) In Use.

The following user stories were developed for iESD-W to guide the development works:

[3] https://www.atlassian.com/agile/project-management/user-stories

- Phase of building design [user story 1 – architect] : As an architect, I want to know the sizing of a water treatment technology using the iESD-W so there is enough space left in the building for its installation.
- Phase of renovation - [user story 2 – consultant] : As a consultant, I want to choose a water treatment technology using the iESD-W so as to reuse water in the building meeting the requirements set by local authorities.

The user stories guide the implementation of the testing approach for the tool, as for each user story the steps to utilise the tool have been defined in a flow-schematic as per the steps that need to be taken to implement it. The flow-schematics for the user stories can be found below.

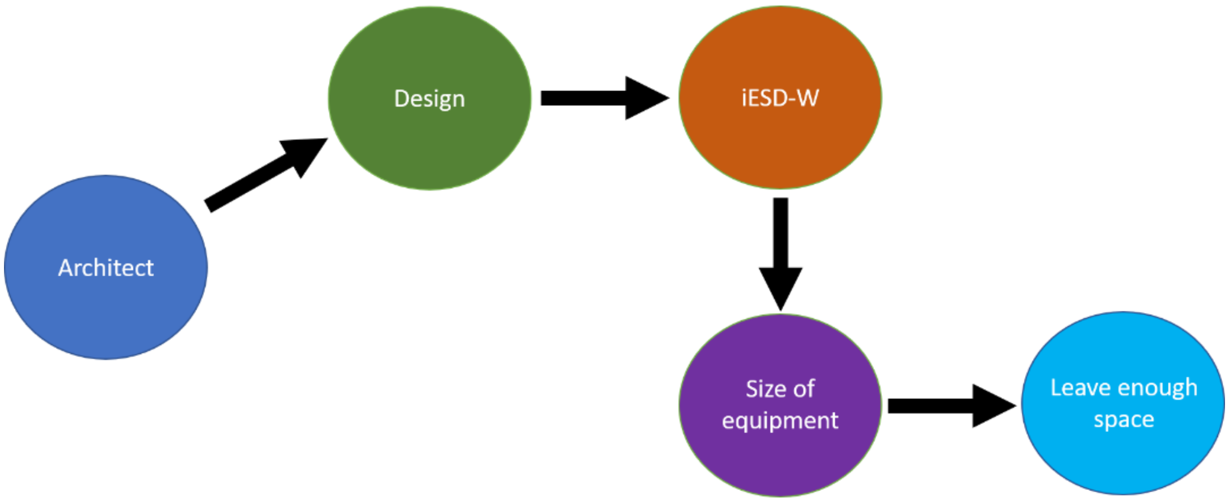


Figure 37. User Story 1 flow of user steps in carrying out the user story tasks.

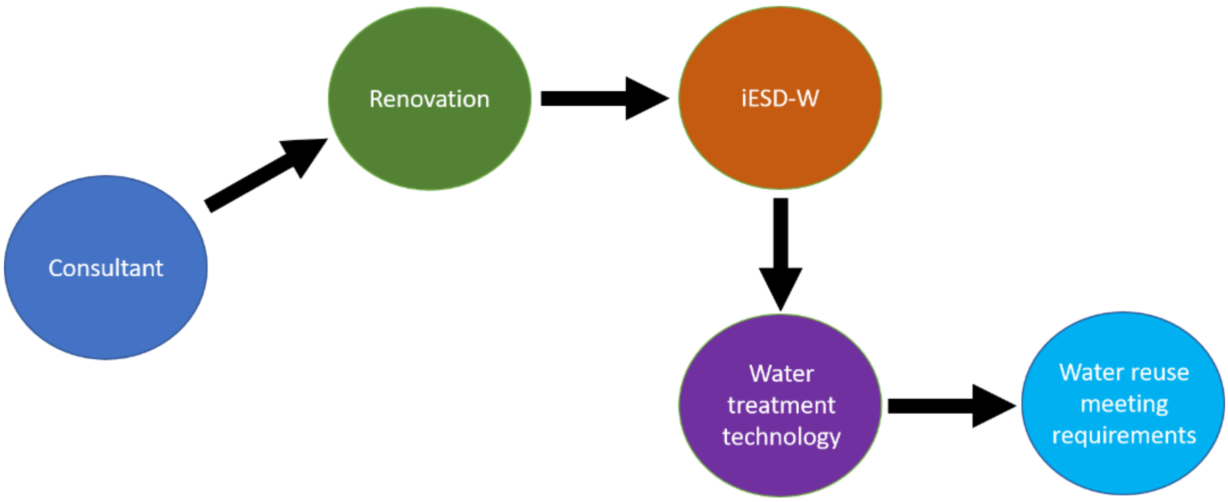


Figure 38. User Story 2 flow of user steps in carrying out the user story tasks.

6.4 Integration in the SPHERE ecosystem

The user story steps as defined in the previous chapter, combined with the technical development of the tool, led to complete definitions of the required inputs and outputs of the iESDW tool. It also led to an identification of when what inputs are required and what outputs are provided at which steps in using the tool from a usage perspective.

The iESD-W tool needs historical meteorological data and specific local legislation on the required water quality for water reuse at the site where the building is located. Regarding the building itself, information about the building characteristics, location and the desired degree and quality of water reuse are needed as inputs. Specific required data characteristics of the building include the following :

- Roof surface
- Type of collector for rainwater harvesting
- Number of inhabitants and their ages
- Available greywater sources
- Available space for water treatment technology installation

The format of these inputs is still pending definition, but it would need to be a file format that can be used by the Python code, such as an CSV file format, or an exchange format in case of a web-service such as XML or JSON.

The outputs obtained from the iESD-W tool include the following :

- Type of water treatment technology
- Sizing of the water treatment equipment
- Quality achieved for the water reuse

This output information will be shown in the graphical user interface and also saved in a data file, whose format still need to be defined.

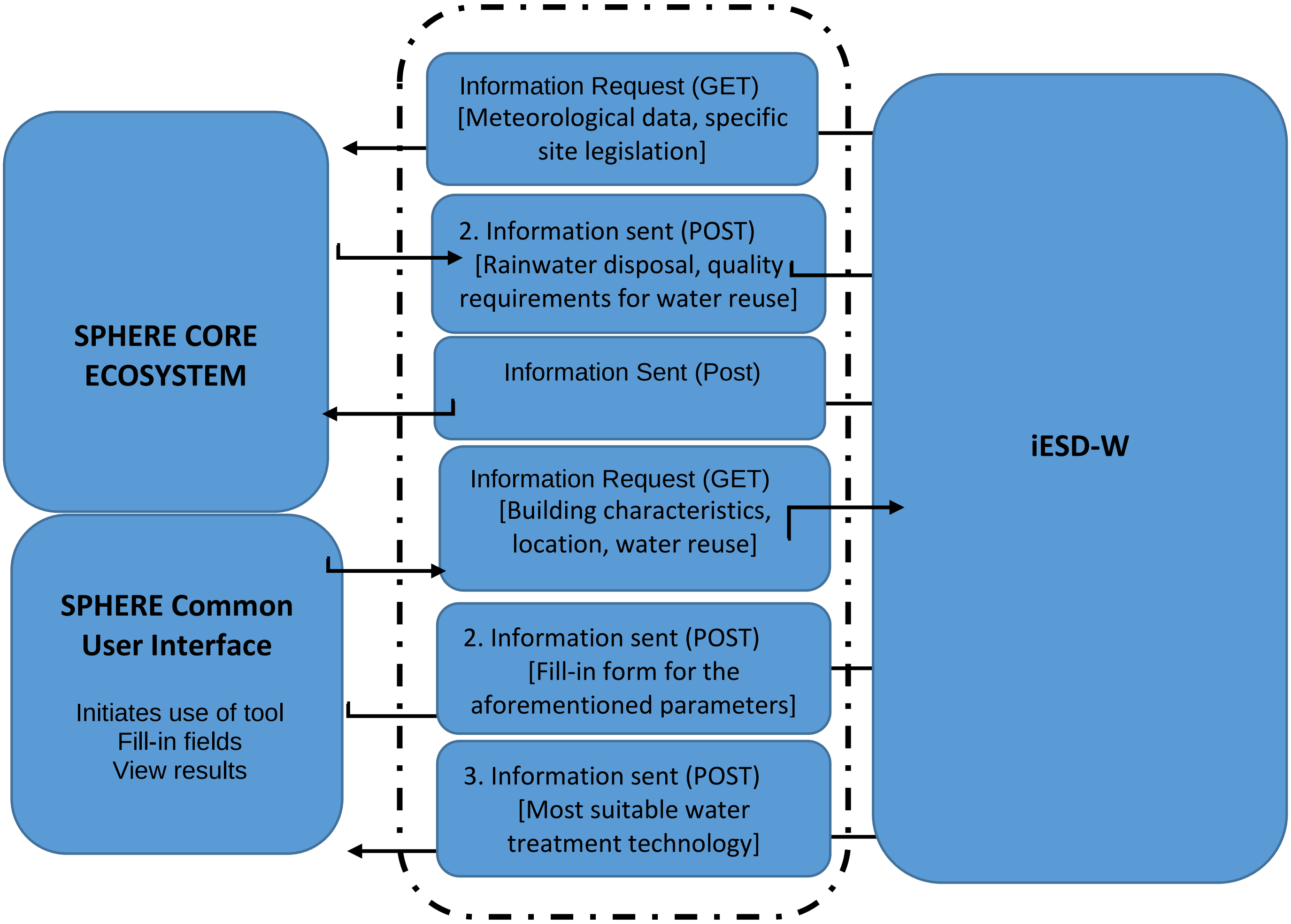


Figure 39. Interaction with SPHERE Ecosystem and MicroService iESD-W

6.5 Testing procedures and results for SPHERE

A first working version of the iESDW tool is being evaluated by other partners as well as internally by the iESDW team. Once feedback from these early users is received some improvements may be implemented.

6.5.1 functionality tests

The laboratory validation has just started for the tool. Feedback from first users during this validation period will be used to implement additional features in the iESDW tool if needed.

6.5.2 SPHERE Ecosystem Integration Tests

SPHERE ecosystem integration test results are not yet available given the delay in the development of the tool.

6.5.3 SPHERE Pilot tests

SPHERE pilot tests results are not yet available given the delay in the development of the tool.

7 MicroService ModSCO tool for energy savings (NUIG)

7.1 Purpose, User Needs, Requirements

Purpose

Within the last decade, the European Union (EU) has developed policies aimed at accelerating the cost-effective renovation of existing buildings, with the vision of a decarbonised building stock by 2050. One of the potential measures to target this objective and enhance the energy efficiency (EE) of buildings is Energy Performance Contracting (EPC). However, there are different risks and barriers opposing the uptake of EPC such as process complexity, lack of information, uncertainty about post-renovation energy performance, access to finance, lack of trust in Energy Service Companies (ESCO), and lack of skilled professional, fragmentation of value chain and unclear financial mechanisms.

One way to tackle the barriers posed by the aforementioned uncertainties is the utilisation of the international Measurement and Verification (M&V) or IPMVP protocol developed by the EVO organisation. M&V is a procedure which measures, and analyses data needed to verify and report energy savings within a system or a whole facility. M&V underpins and enhances a standards-based approach to the implementation of energy conservation measures (ECM's). For example, the placement of LED lights or improvement of an HVAC system that improves the energy efficiency and energy usage of a building.

Guidelines regarding the M&V protocol are provided by the International Performance Measurement and Verification Protocol (IPMVP®). This protocol defines a standards-based approach to estimate the potential and actual savings and can be used to quantify the payments to all stakeholders throughout the EPC process. In verifying the results of energy efficiency and renewable energy projects, the IPMVP® provides four options referenced from A–D. One of the main recommendations of the IPMVP® guidelines is that the costs of carrying out M&V of building improvements does not exceed 10% of the average annual savings achieved through its application. Additional cost limits are provided by M&V guidelines, such as the M&V handbook, where the cost limits range from a minimum of 1% of the annual measured savings for the IPMVP® Option A to a maximum of 10% for the IPMVP® Option D.

Option D is the development of a calibrated computer simulation model that supports detailed analysis of various ECM's. This option also provides a big opportunity to evaluate the savings of each ECM or multiple ECMs. Thereby it allows for testing the best renovation scenario to apply to a building.

Option D, the simulation of the building, relative to options A to C that cover building real-life measurements, can require high computational time, complexity, high cost of implementation, and comes with uncertainty of model parameters. As a consequence this procedure is not a popular method and is rarely used by IPMVP® practitioners, and in general for thermal prediction of existing buildings in the deep-renovation process. All issues aforementioned also carry the increasing cost burdens of this option that usually exceed cost limit recommendations. Two alternatives from this purely physics modelling approach (white-box) can be found in a purely empirical approach (black-box) and in a synthesis of White and Black box modelling approaches into a grey-box modelling approach.

The ModSCO tool is the acronym for Model-Supported Control. ModSCO uses Reduced Order Grey Box Models (ROM) developed with the MODELICA ® language. ModSCO is a web-based tool, which is able to generate the IPMVP Baseline Period Energy (BPE) consumptions. The BPE generated by the ModSCO application can be used for two main applications:

(i) Systematically quantify the monthly energy savings achieved through a standards-based ECM (Method 1).
(ii) Estimate directly the monthly energy savings through the investigation of different building retrofit scenarios (Method 2).

The parameters needed to set up the ModSCO building simulation are calculated using MS Excel supporting tools, downloadable from the web ModSCO GUI and a series of manual parameters. The tools use information obtained through data collection and on-site surveys. Once the parameters are calculated they are inserted into the ModSCO GUI to run the initial simulation.

The ModSCO model needs to be calibrated under the IPMVP Calibration Criteria (NMBE, CV(RMSE), R^2 and Monthly Deviation) in order to generate the adjusted baseline energy performance (i.e the energy consumption of the building as if the ECMs were not installed). A simplified and knowledge-based calibration procedure has been developed to facilitate the process. The calibration consists of systematically changing a restricted number of uncertain parameters within a specified range within a pre-chosen step.

Once the ModSCO model is considered calibrated it can be used to calculate the energy savings or avoided energy consumption by comparing the adjusted baseline energy performance generated by ModSCO with the actual building energy consumption called by the IPMVP Reporting Period Energy Consumption (RPE). The RPE is generated from the utility bills or the building meters. The comparison of the adjusted baseline energy performance and the reporting period energy consumption, or the before and after the measures were installed that saved energy, is supported by MS Excel tools.

User need:
In the design phase of a building retrofit there is a user need by project managers, design teams, DT configuration managers, and architects to predict the energy use of a building in relation to different retrofit packages(i.e. building envelope and/or heating/cooling system). The ModSCO tool can be used to predict this consumption in an accurate way before the actual implementation. In particular, the presence of a GUI and a dedicated user guide allows a user to run energy simulations for buildings using a limited amount of information of the building. This is allowed even from users that are not experts in energy simulations.

In the operational phase there is a user need by consultancy companies, architects, real estate developers, housing corporations and home owners to validate the real impact due to the adoption of certain retrofit measures for the building in terms of energy KPIs.

For a good evaluation of the above aspects the use of calibrated building energy models is required. The ModSCO calibration is carried out based on monitoring data from the building, for example monthly energy bills. This phase needs to be carried out by the users.

Requirements:
The microservice requires information regarding the building, heating/cooling system, internal gains and occupancy schedules. In case of lack of information for a certain building, the tool would allow the adoption of assumptions based on standards in order to maintain the accuracy of the energy calculation. This MicroService can combine data from different sources available in the SPHERE ecosystem, including importing BIM data, using a dedicated API.

Status development:
At this point of the project the back engine of the tool developed in Modelica language is ready and fully validated. During the project a GUI has been developed and has been successfully tested. A first version of a simulation model for the TNO pilot has been generated and run successfully. The integration between the simulation engine and the GUI is still under development and testing with the intention to complete this step by the end of November 2021.

7.2 Tool Technical Description

The ModSCO Web Application framework, shown in Figure 40, consist of three phases:

1. Parameters calculation (top part of Figure 40). This phase is accomplished by utilising three MS Excel based tools (ROMPar, Schedules Generator and internal gain estimator) downloadable from the ModSCO GUI and by retrieving a list of manual parameters. The tools receive building specific data as input.
2. Simulation and calibration (middle part of Figure 40). This phase is done by an iterative process in which the uncertain parameters are changed in the ModSCO GUI. The core of ModSCO is based on a Python script (ModSCO script) that runs a Modelica Reduced Order grey box Model (ROM) compiled as FMU file. The result of this phase is the calibrated BPE consumption of the building.
3. Utilisation (bottom part of Figure 40). This phase consists in utilising the calibrated BPE generated by the ModSCO GUI for the creation of the Adjusted BPEs. Utilizing an MS Excel Tool, the BPEs are compared with the Reporting Period Energy consumption (RPEs) to estimate the energy saving (or avoided energy consumption) due to building retrofits using two different methodologies.

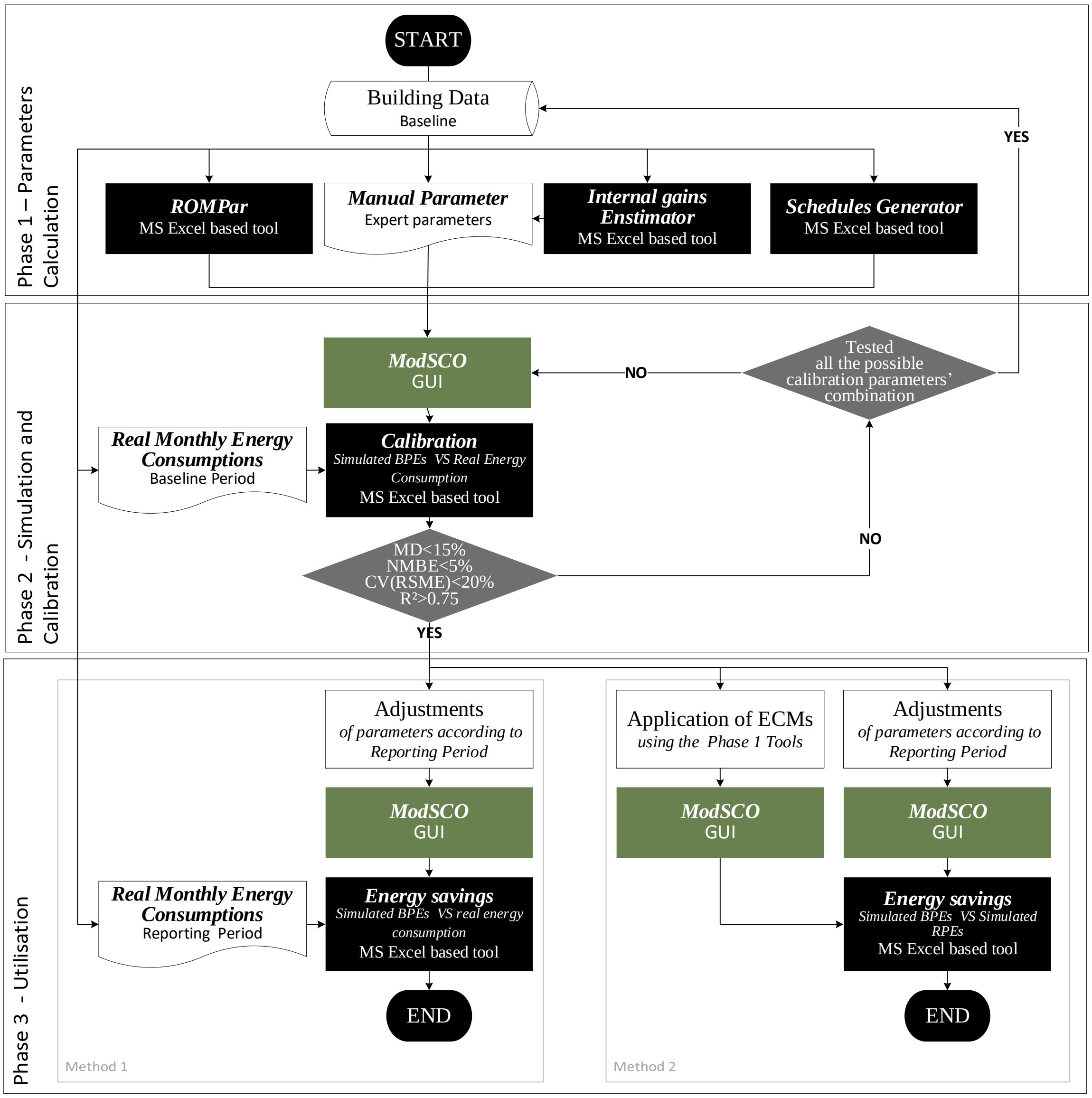


Figure 40. ModSCO Web tool Workflow

7.2.1 The Reduced Order Model

The core of the ModSCO is a Reduced Order gray box Model (ROM). The electrical equivalent of the ModSCO ROM is a socalled RC-network using resistors (R) and capacitors (C), shown in the top part of Figure 41. The RC network is composed of 13 resistances and 4 capacitances that divide the building's mass into four groups.

The first group is used to combine the building internal partition and slabs (R_M, R_{M_IS}, C_M). The second group captures the whole building external envelope (R_{WALL_ES}, R_{WALL}, R_{WALL_IS}, C_{WALL}), the third represents the building external windows (R_{WIN_ES}, R_{WIN}, R_{WIN_IS}) and, finally, and the fourth group considers the building ground floor (R_{GF_ES}, R_{GF}, R_{GF_IS}, C_{GF}). Finally, the components "L_{RATE}" and "NV_{RATE}" are developed in Modelica with the scope of simulating air infiltration and natural ventilation.

The bottom part of Figure 41 shows the ModSCO ROM developed in Modelica model that is based on the RC -network in the top part of Figure 41. The Modelica ROM is developed in the Dymola Environment and consists of four main components: 1) Internal Gains 2) Heating and Cooling. 3) Building and 4) Weather.

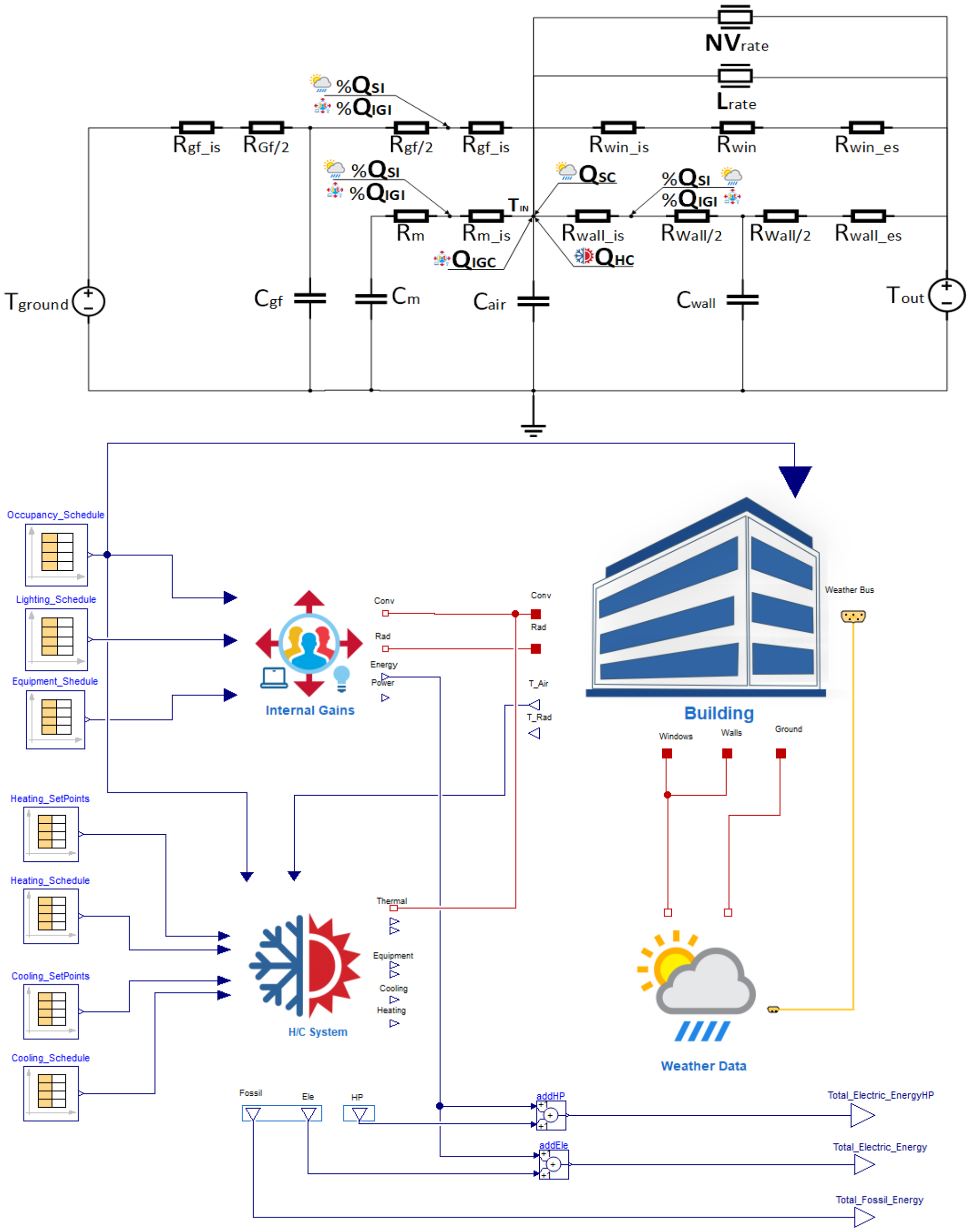


Figure 41. ModSCO RC-network (top)and Modelica model (bottom)

The ROM represented in Figure 41 was compiled on an Functional Mock-up Unit (FMU) file in order to make it opensource and usable for the creation of the ModSCO web application.
Using the language programming Python a script (i.e. ModSCO Script) was created in order to : utilise the FMU file of the ROM. The script was developed using the standalone package PyFMI and its dependencies (i.e. Assimulo, FMI Library, Cython).
The ModSCO Script, run a simulation with the parameters set in the interface (Section 8.2.2) and generates three csv files representing the BPEs and containing annual time series with hourly steps regarding:

- ElectricityConsumption.csv [kWh]
- FossilConsumption.csv [kWh]
- HeatPumpConsumption.csv [kWh]

The first two are used in case of different sources for heating (i.e. fossil fuel) and cooling (i.e. electricity). The third is used in case of a heat pump installed in the building where the same source is used for heating and cooling (i.e. electricity).
The ModSCO Script was then integrated in a Microsoft server to allow the usage through the ModSCO Web GUI.

7.2.2 The ModSCO GUI

The ModSCO GUI is developed using Bubble.io and makes use of the API to send and receive information between the GUI and the ModSCO Server where the python script is stored.
The ModSCO framework starts from the parameters calculation (top part of Figure 40). Table 5 shows the full list of parameters with the unit, the data type and the uncertainty that has to be input in the ModSCO GUI (Figure 42) in order to run the simulation and create the BPEs.

Table 5. ModSCO Parameters

Input	Description	Unit	Data Type	Uncertainty
BUILDING PARAMETERS				
BuilType	Building type residential or not residential	-	Boolean	Low
Latitude	Building/room latitude	-	Real	Low
Volume	Building/room volume	m3	Real	Low
ROMPar .txt	Building Parameters file	-	list	Low
WeaFile	Weather data file .mos	-	time series	Low/ Medium
GroundT	Ground Temperature	°C	Real	Medium
MLoadPeo	Maximum heat gain per people	W	Real	Medium
MLoadLig	Maximum electrical power per lighting	W	Real	Medium/ High
MLoadEqu	Maximum electrical power per equipment	W	Real	Medium/ High
SBLoad	StandBy electrical power per lighting/equipment	W	Real	Medium
MCoolP	Maximum system cooling Power	W	Real	Medium/ High
MHeatP	Maximum system heating power	W	Real	Medium/ High
HCEquP	System equipment electrical power (pumps, fans)	W	Real	Medium
SBHeat	StandBy heating power	W	Real	Medium/ High
SBCool	StandBy cooling power	W	Real	Medium/ High
L_Rate	Air infiltration rate		Real	High
PeoSch .txt	Schedule People	-	time series	Low
LigSch .txt	Schedule Lighting	-	time series	Low
EquSch .txt	Schedule Equipment	-	time series	Low
HeatSch .txt	Schedule Heating System	-	time series	Low
CoolSch .txt	Schedule Cooling System	-	time series	Low
HeatSet	Heating Setpoint	°C	Real	Low/ Medium
CoolSet	Heating Setpoint	°C	Real	Low/ Medium
CALIBRATION PARAMETERS				
AlphaLig	Lighting efficiency/utilization	-	Real	-
AlphaEqu	Equipment efficiency/utilization	-	Real	-
AlphaPeo	People system influence (for residential buildings)	-	Real	-
AlphaHeat	Heating system efficiency/utilization	-	Real	-
AlphaCool	Cooling system efficiency/utilization	-	Real	-

Supporting MS Excel Based Tools:

Figure 42 shows the three MS Excel Based Tools discussed previously that are needed to calculate the parameters can be downloaded directly from the GUI. These tools are:

- ROMPAR: it generates the ROMPar.txt file, which contains all the building construction characteristics. A user guide on how to use the tool is included and it involves eight simplified steps to be followed by the user.

- Schedule Creator: it generates five schedules, three regarding the internal gains (PeoSch .txt, LigSch .txt,, EquSch .txt) and two regarding the operation of the heating and cooling system (HeatSch .txt CoolSch .txt). These schedules refer to a full year with a time step of one hour.
- Internal Gain Estimator: it is a suggestion tool, which can be used in case data such as maximum internal gain per occupant, maximum electrical power for lighting, maximum electrical power for equipment (MLoadPeo, MLoadLig, MLoadEqu) are missing. The tool is based on the ASHRAE 55:2013 standard and it depends also on an evaluation of building occupancy.

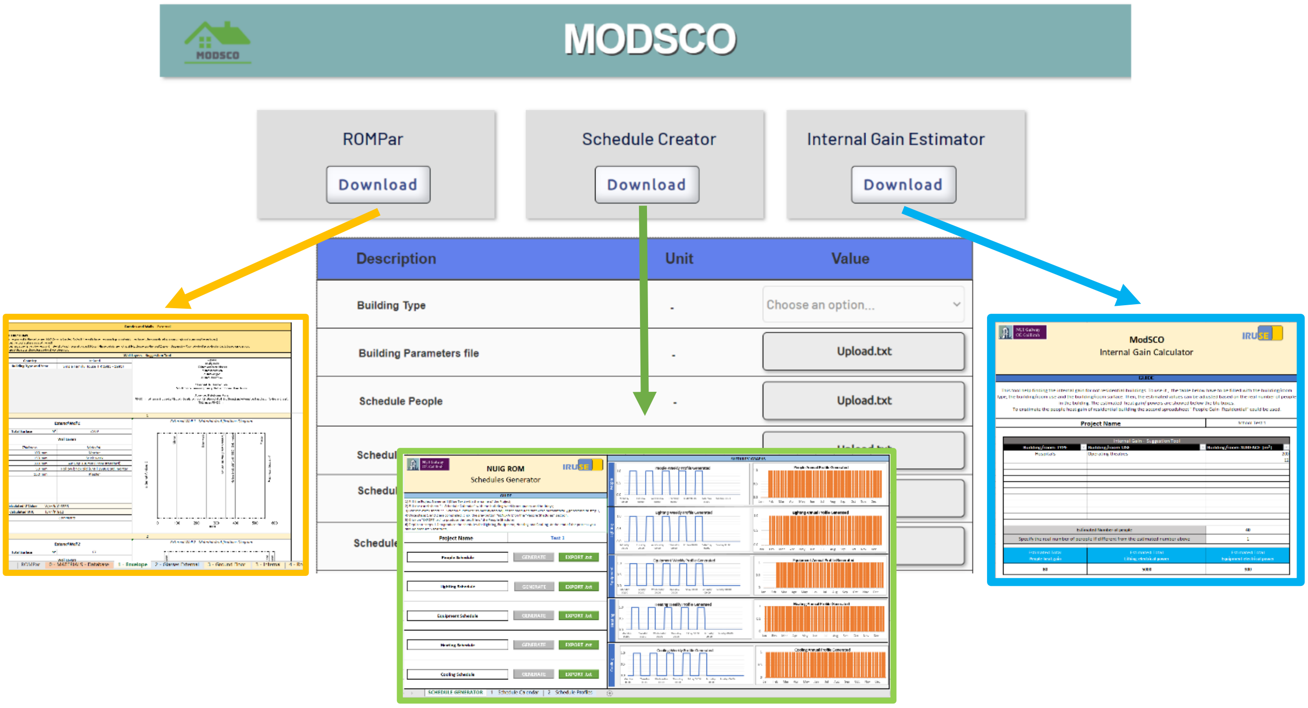


Figure 42. Supporting MS Excel Based Tools in the ModSCO GUI

The MS Excel based tools generate a series of text files which need to be manually uploaded on the ModSCO GUI, together with the series of parameters described in Table 5.

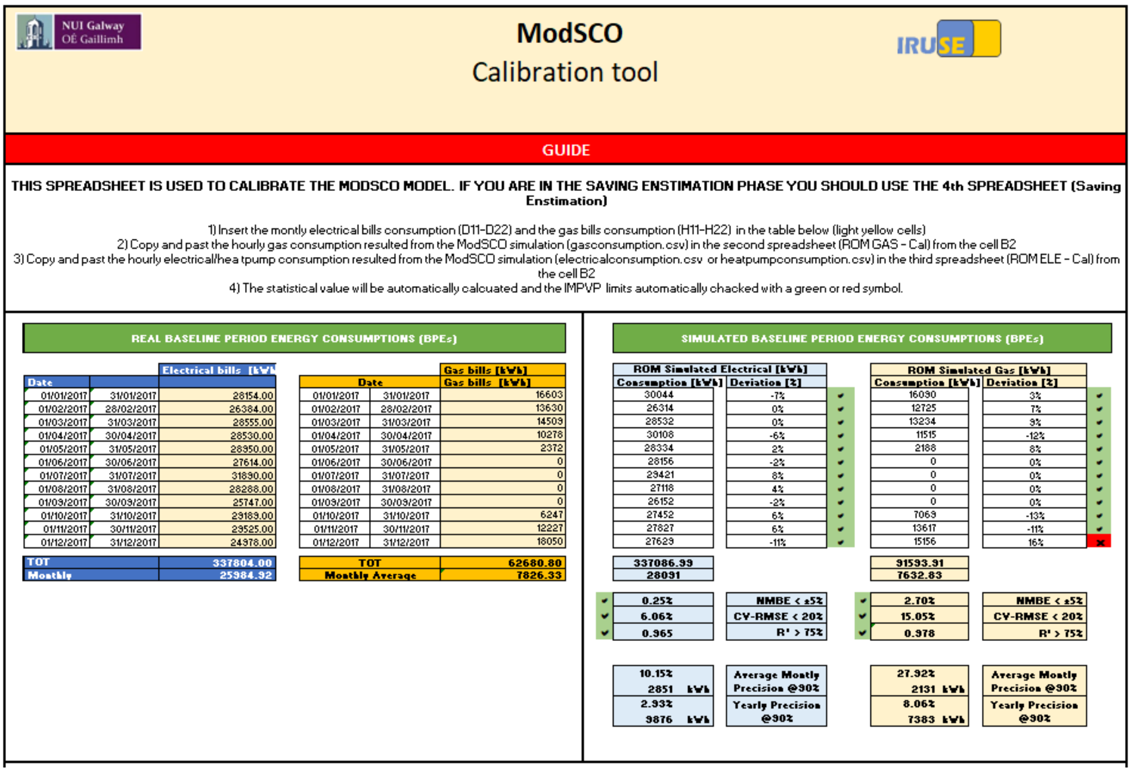
Calibration of parameters:

Table 5 divides the parameters into two groups, the first group (building parameters) are estimated starting from the building data and then corrected during the calibration phase by the second group of parameters (calibration parameters) based on and their uncertainty during the data collection. The parameters with the higher degree of uncertainty are usually used in the calibration procedure. Thus, following the Giretti et al. (2018) assumptions, these parameters are adjusted during the calibration process.

The calibration is supported by the Calibration and Saving estimation MS Excel tool (Figure 43). ModSCO calculates the BPEs monthly consumptions and compares them with the actual energy consumptions (gas and electricity) of the building. From this comparison, the following IPMVP statistical values (EVO, 2016) are calculated and verified with their limits:

- Normalised Mean Biased Error NMBE < 5%
- Coefficient of Variation of Root Mean Square Error CV(RMSE) < 20%

- Coefficient of Determination $R^2 > 0.75$
- Monthly Deviation < 15%



NUI Galway
OÉ Gaillimh

ModSCO
Calibration tool

IRUSE

GUIDE

THIS SPREADSHEET IS USED TO CALIBRATE THE MODSCO MODEL. IF YOU ARE IN THE SAVING ENSTIMATION PHASE YOU SHOULD USE THE 4th SPREADSHEET (Saving Enstimation)

1) Insert the montly electrical bills consumption (D11-D22) and the gas bills consumption (H11-H22) in the table below (light yellow cells)
2) Copy and past the hourly gas consumption resulted from the ModSCO simulation (gasconsumption.csv) in the second spreadsheet (ROM GAS - Cal) from the cell B2
3) Copy and past the hourly electrical/hea tpump consumption resulted from the ModSCO simulation (electricalconsumption.csv or heatpumpconsumption.csv) in the third spreadsheet (ROM ELE - Cal) from the cell B2
4) The statistical value will be automatically calcuated and the IMPVP limits automatically chacked with a green or red symbol.

REAL BASELINE PERIOD ENERGY CONSUMPTIONS (BPEs)

Date		Electrical bills [kWh]
01/01/2017	31/01/2017	28154.00
01/02/2017	28/02/2017	26384.00
01/03/2017	31/03/2017	28555.00
01/04/2017	30/04/2017	28530.00
01/05/2017	31/05/2017	28950.00
01/06/2017	30/06/2017	27614.00
01/07/2017	31/07/2017	31890.00
01/08/2017	31/08/2017	28288.00
01/09/2017	30/09/2017	25747.00
01/10/2017	31/10/2017	29189.00
01/11/2017	30/11/2017	29525.00
01/12/2017	31/12/2017	24978.00
TOT		337804.00
Monthly		25984.92

Date		Gas bills [kWh]
01/01/2017	31/01/2017	16603
01/02/2017	28/02/2017	13630
01/03/2017	31/03/2017	14509
01/04/2017	30/04/2017	10278
01/05/2017	31/05/2017	2372
01/06/2017	30/06/2017	0
01/07/2017	31/07/2017	0
01/08/2017	31/08/2017	0
01/09/2017	30/09/2017	0
01/10/2017	31/10/2017	6247
01/11/2017	30/11/2017	12227
01/12/2017	31/12/2017	18050
TOT		62680.80
Monthly Average		7826.33

SIMULATED BASELINE PERIOD ENERGY CONSUMPTIONS (BPEs)

ROM Simulated Electrical [kWh] Consumption [kWh]	Deviation [%]	ROM Simulated Gas [kWh] Consumption [kWh]	Deviation [%]
30044	-7%	16090	3%
26314	0%	12725	7%
28532	0%	13234	9%
30108	-6%	11515	-12%
28334	2%	2188	8%
28156	-2%	0	0%
29421	8%	0	0%
27118	4%	0	0%
26152	-2%	0	0%
27452	6%	7069	-13%
27827	6%	13617	-11%
27629	-11%	15156	16%
337086.99		91593.91	
28091		7632.83	

Electrical		Gas	
0.25%	NMBE < ±5%	2.70%	NMBE < ±5%
6.06%	CV-RMSE < 20%	15.05%	CV-RMSE < 20%
0.965	R² > 75%	0.978	R² > 75%
10.15% 2851 kWh	Average Montly Precision @90%	27.92% 2131 kWh	Average Montly Precision @90%
2.93% 9876 kWh	Yearly Precision @90%	8.06% 7383 kWh	Yearly Precision @90%

Figure 43. ModSCO Calibration tool

If the statistical values are not within the IPMVP limits, the user needs to repeat the calibration process, consisting of three steps.

The calibration start with a data analysis task, where all the parameters are classified based on their uncertainty, which is described in Table 5. The parameters with the lower reliable information are considered uncertain and thus changed during the calibration process, the remaining parameters are considered trustable, so they are assumed fixed.

The second phase is the *Alpha Parameters calibration.* These parameters allow adjusting the building parameters affected with the higher uncertainty without changing the original values estimated. In particular: the Alpha equipment and lighting (AlphaLig, AlphaEqu) are used in the calibration to consider the uncertainty due to the internal gain values of lighting and equipment, and to take into account the average efficiency/utilisation of the equipment and lighting. The Alpha Heating and Cooling (AlphaHeat, AlphaCool) are used to represent the average efficiency/utilisation of the system installed in the building. In reality, the efficiency/utilisation of lighting, equipment, heating and cooling varied depending on the zone within the building, but the ROM considered a single volume with a single schedule for each of the heat gains.

The Alpha People (AlphaPeo) is just used in residential buildings. This parameter correlates the heating and cooling consumption at the number of people in the building. In fact, in reality the heating and cooling consumption in s residential buildings varies depending on the zone heated and cooled and based on the interaction of the people with the thermostat.

Finally, the last parameter usually needed by the model is the air leakage rate of the building (L_RATE), this value is approximated and then used in the calibration process because generally, it cannot be easily measured or quantified without appropriate equipment (e.g. by means of a blower door test).

The third phase is the *Building Parameters calibration,* after the adjustment of the alpha parameters, eventually all the other uncertain parameters could be changing according to the comparison between the simulation results (BPEs) and the actual energy consumptions made with the Calibration and Saving estimation MS Excel. One of the parameters that usually is adjusted during this phase is the air leakage rate (L_rate) since this parameters cannot be easily measured.

The second parameter usually affected by uncertainty is the Ground Temperature (GroundT) since usually it is taken from an online database.

If after following these three steps using the Calibration and saving estimation tool the BPEs generated do not comply with the statistical values limit, an error in the operation schedules or in the building data can occur. In the first case since the schedules are usually purely knowledge based, a new stage of interview and observation can be carried out to retrieve some fault in the profiles generated. In case of any error in the schedules generated, the building data must be manually checked and eventually adjusted, and the simulation and calibration process needs to be repeated.
On the other hand, if the model complies with the statistical value limits, the baseline period energy consumption generated by ModSCO can be considered calibrated and the list of parameters can be utilised in the Reporting Period for the generation of the Adjusted BPEs and to calculate the energy savings (or avoided energy consumption).

The last part of the ModSCO Flowchart, described in Figure 40, is the utilization of the model generated by the tool. As explained in the introduction, the model could be used for a systematic quantification of the monthly energy savings achieved through standards-based Energy Conservation Measures (ECM's).

Method 1. In this case the savings are calculated as:

Savings =		(Adjusted Baseline Period Energy (i.e. ModSCO output)
	–	Actual Reporting Period Energy [e.g. energy bills])
	±	Calibration Error in the Corresponding Calibration Readings

The ”Adjusted Baseline Period Energy” is obtained starting from the calibrated ModSCO Set of parameters generated after the calibration of the ModSCO Model. The ModSCO calibrated set of parameters is updated with the data referred to the reporting period. This data includes all the independent variables as the weather file, internal gain schedules, system, HVAC set points (routine adjustment). Furthermore, in some cases other input could be adjusted when the static factors were modified in the reporting period (non-routine adjustments). These could include the heat gains from building occupants (occupancy type, density), significant equipment problems, lighting levels, etc. Figure 44 displays the concept of IPMVP® savings referred to ModSCO. After the implementation of the Energy conservation measure (ECMs) the blue line represent the ModSCO Adjusted BPEs (i,e. forecasting of energy consumption as if the ECMs were not installed in the building) while the green line represents the Reporting Period Energy consumptions (RPEs) related to the measured data (e.g. energy bills).

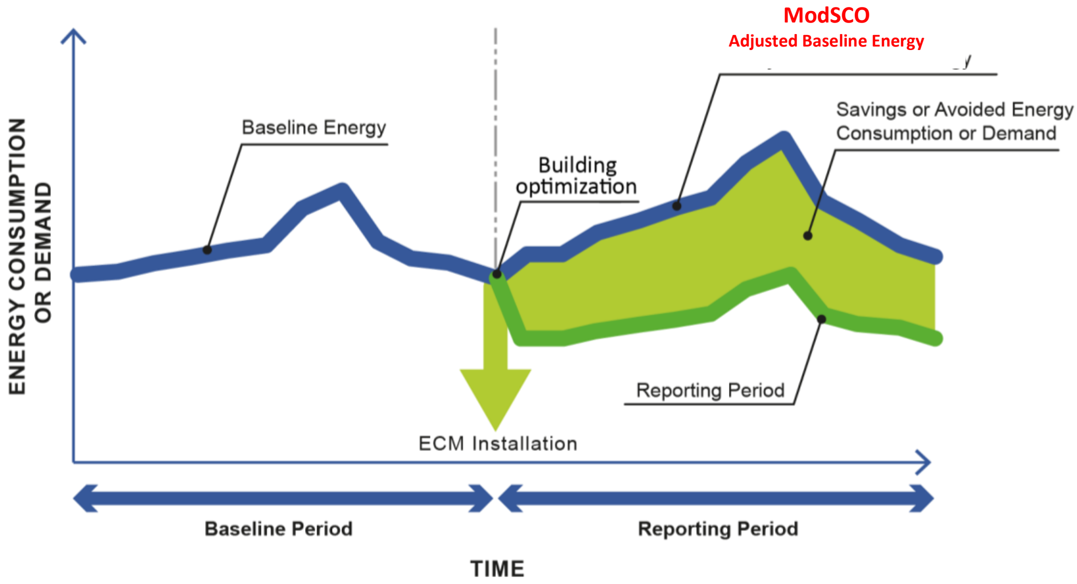


Figure 44. Savings calculated using the ModSCO Web App for the baseline energy consumption.

Adapted from (EVO, 2016). (single column)

The comparison between the two BPEs and RPEs is simplified by utilising the Calibration and Saving Estimation tool discussed previously. Once all the data has been uploaded in the ModSCO GUI according to the reporting period, the.csv files resulting from the simulation are the Adjusted Baseline Period Energy Consumptions of the building. These files have to be uploaded in the Saving Estimation tool spreadsheet together with the monthly Consumption of the reporting Period (i.e., electricity and/or fossil fuel bills). Automatically the spreadsheet will calculate with a level of confidence of 90%, the annual saving with the annual precision according to the accuracy of the calibration.

Method 2- Using the calibrated ModSCO model to calculate energy savings. This involves a direct estimation of the monthly energy savings through the investigation of different building envelope retrofit scenarios. In this case the savings are calculated as:

Savings = (Adjusted Baseline Period Energy [i.e. ModSCO output - without ECM]
– Reporting Period Energy [i.e. ModSCO output - with ECM]

In this case, the “Adjusted Baseline Period Energy” is calculated as done previously, while the “Reporting Period Energy” is calculated by applying the Energy Conservation Measures (ECM) and thus by modifying the calibrated model set of parameters using the tools of the 1st phase (e.g. adding the insulation with ROMPar at the external wall). In this case, the ROM and thus the ModSCO GUI was used only for the application of envelope retrofits, e.g. additional external wall insulation (Piccinini et al., 2019a); and HVAC simple controls, e.g. changing temperature set points (Piccinini et al., 2019b). Figure 44 shows the application of retrofitting scenarios using a ROM where in this case, the Reporting Period (green line) is related to the ModSCO simulation.

7.3 User Stories and Use Examples

The ModSCO has been developed with the user needs in mind as described in section 8.1. To this end specific user stories have been developed based on the standard approach used in software product development.[4] User stories are expressed in a simple sentences as follows :

As an [actor], I want to [carry out a task] using the [tool name] so as to achieve [an insight/result decision]

The user stories were developed for different actors based on the life cycle of the construction/renovation works as defined in SPHERE task 2.1 based on the seven different life cycle phases : 1) Strategic definition, 2) Preparation and Brief, 3) Concept Design, 4) Technical Design, 5) Construction, 6) Handover and closeout, 7) In Use.

The following user stories were developed for ModSCO to guide the development works:

- Concept Design/renovation - As an energy engineer, an architect, real estate developer, or building owner, I want to generate a BPE for a certain building. The objective is to have an accurate baseline of energy consumption of a building to be used in the future for comparison with potential implementation of ECMs or detect unexpected energy behavioural changing of the building (Figure 45)

- Concept Design/renovation - As an energy engineer, an architect or real estate developer, I want to estimate the energy impact of a certain renovation solution for a building using ModSCO. The objective is to define the best retrofit solution for the building within the available ones (i.e. envelope upgrade, heating/cooling control scenarios), before the implementation, using limited building data and in a fast and accurate way (Figure 46).

- In use/renovation - As an energy engineer, an owner or real estate developer, I want to have a reliable estimation of the energy savings resulting from a renovation with a certain set of ECMs (Figure 47).

The user stories guide the implementation of the testing approach for the tool, as for each user story the steps to utilise the tool have been defined in a flow-schematic as per the steps that need to be taken to implement it. The flow-schematics for the user stories can be found below.

[4] https://www.atlassian.com/agile/project-management/user-stories

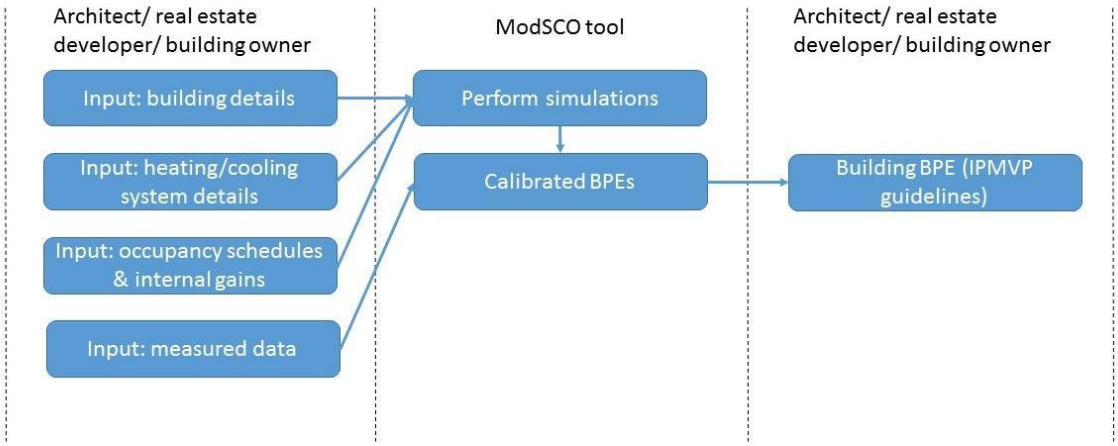


Figure 45. User Story 1 flow of user steps in carrying out the user story tasks

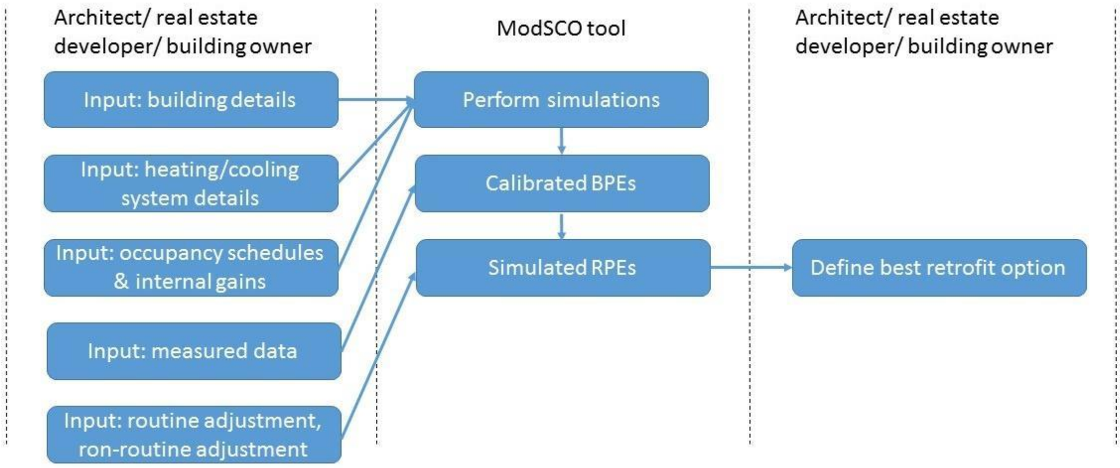


Figure 46. User story 2 flow of user steps in carrying out the user story tasks

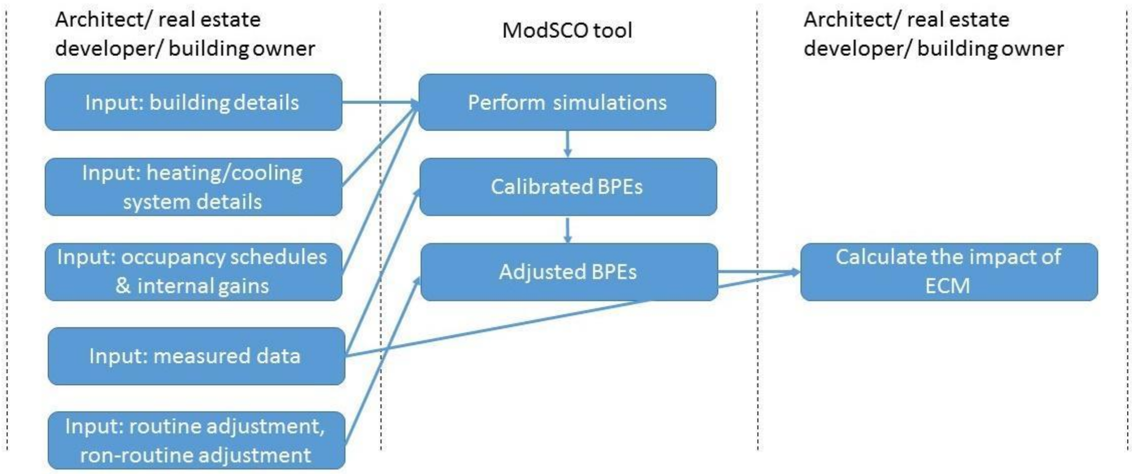


Figure 47. User story 3 flow of user steps in carrying out the user story tasks

7.4 Integration in the SPHERE ecosystem

The work on the integration of the tools within the SPHERE ecosystem was carried out in the pilot testing phase of the project (M24-M36 period). ModSCO has its own user interface that will be linked to the SPHERE platform ecosystem using a web link. As depicted in Figure 3.3 below, ModSCO will receive just some predefined data from the BIM (as test data set using the NEANEX API connector), other information need to be gathered by the user using SPHERE building information repository. The user would be able to play with the web ModSCO application, perform simulations, and results will be delivered automatically by the web service to the user by e-mail.

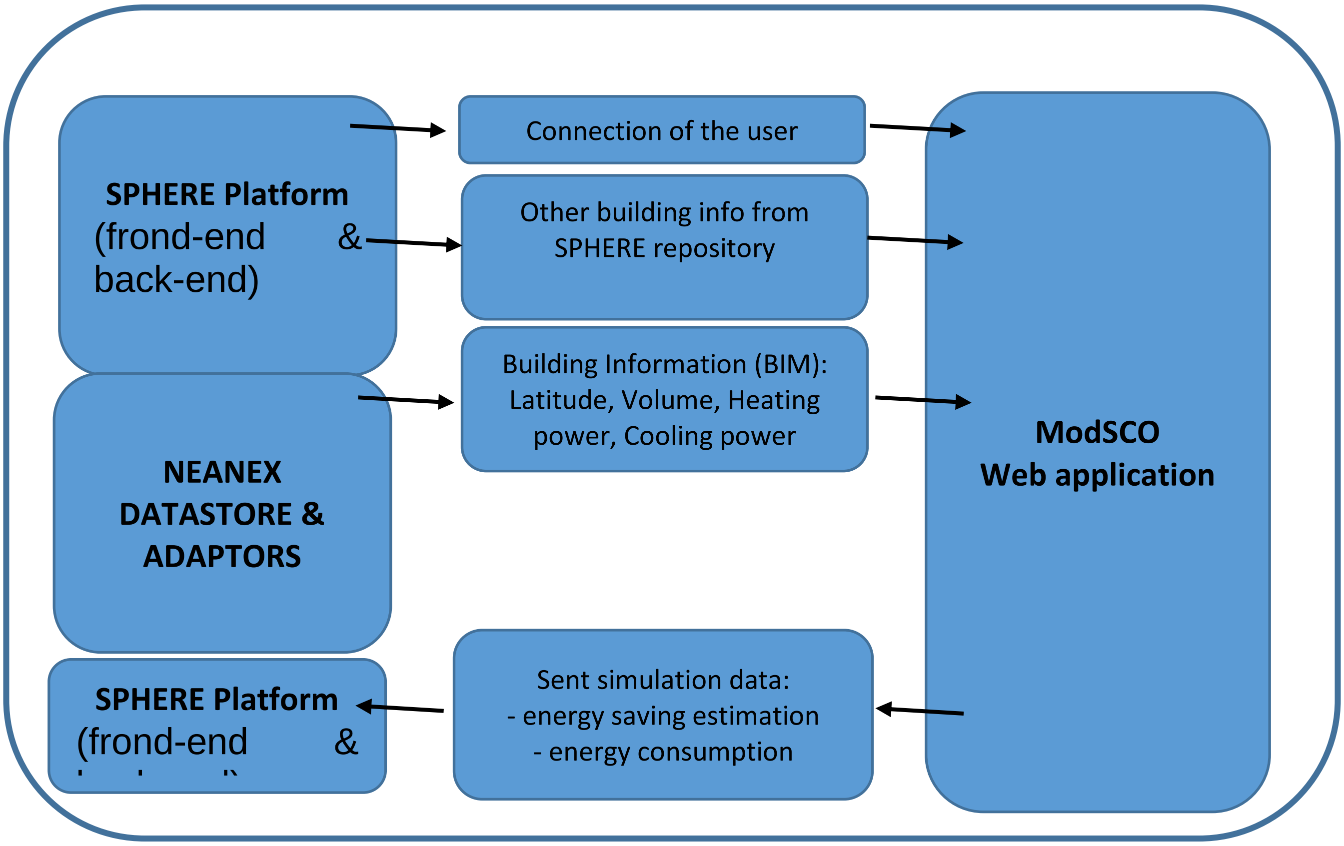


Figure 48. Interaction between SPHERE Ecosystem and MicroService ModSCO

7.5 Testing procedures and results for SPHERE

The ModSCO application has already been validated through a series of individual tests on the web GUI, simulation engine and the core model. The full integration of the tool is expected to be ready by the end of November 2021. The BIM import data functionality will be tested using a small group of data as a test data set. These tests will be necessary to reach the full capability of BIM data import.

7.5.1 functionality tests

The functionality tests have been performed using a residential dwelling in the Dutch pilot. Inputs for the models have been generated using the Phase 1 of the workflow described in Section 8.2.
The functionality test has been performed by manually inserting the parameter dataset using the ModSCO web GUI into the ModSCO Script discussed in Section 8.2.1.
The simulation has been run using the calculated inputs and the BPE has been generated as preliminary. Further validation and calibration of the generated BPE will be done once measured data (i.e. monthly energy bills) from the pilot sites becomes available.

7.5.2 SPHERE Ecosystem Integration Tests

The main interface between the ModSCO tool and the SPHERE platform ecosystem is through the NEANEX portal. This interface is realized through a dedicated API. For testing purposes, the API has been made available to NEANEX using test data.

The data from the Dutch pilot will largely be manually processed due to the large amount of different data sources and limited accessibility. Once the data will be available on the SPHERE ecosystem, the BIM data importing functionality will be tested.

7.5.3 SPHERE Pilot tests

The preliminary ModSCO test has been performed using a dataset provided by TNO, from one residential building from the pilot in Heerhugowaard, Netherlands. The building under analysis is a two floor apartment: ground-level (living room, kitchen, toilet, corridor), top-level (bedroom1, bedroom2, bathroom, landing).

The building data has been divided into three groups depending on the source: IFC data (data from SPHERE ecosystem, Table 6), TNO data (data from the survey and interview, Table 7), and data assumptions (estimated data based on international standards and online database, Table 8). This is schematically shown in Figure 49.

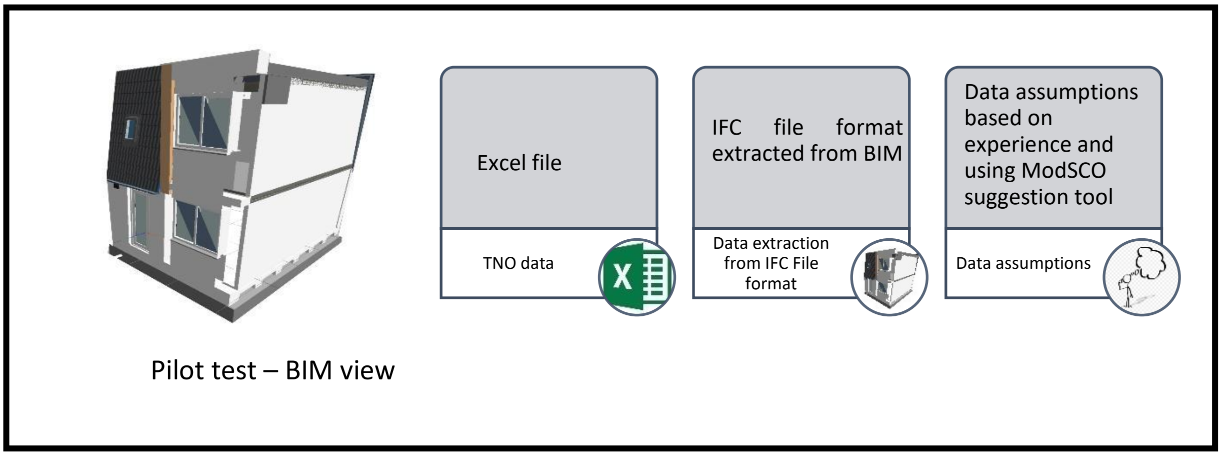


Figure 49: Dwelling in the Dutch pilot and 3 sets of input data

Table 6. Input data extracted from IFC file

IFC Data	Value
Building's latitude	Degree: 42.0, Minute: 21.0, Second:31.0, Milliseconds: 181945.0
Building's Longitude	-71.0, Minute: -3.0, Second: -24.0, Milliseconds: -263305.0
Building total volume	184.2 m3
Maximum electrical power of the system equipment	2500 W

Table 7. Building characteristics provided by TNO

TNO Data	Value
Building Type	Residential
Room usage	Two floors : Ground-level (living room, kitchen, toilet, corridor), top-level (bedroom1, bedroom2, bathroom, corridor)
Ceiling hight	3m
Location	Heerhugowaard, Netherlands
External walls	Neighbour Wall (150mm Concrete, sand/cement screed (beton2400), 40mm Air gap, 150mm Concrete, sand/cement screed (beton2400)), Facade (120mm Concrete, sand/cement screed (beton2400), 140 mm polyisocyanurate, 40mm Air gap, 100mm Brickwork)
External windows	Triple glazing windows – total surface of 14.89 m^2
Ground floor	64mm Concrete, Broom finish, 200mm prefab concrete floor
Roof	200mm prefab concrete floor, 50mm rigid insulation, 190mm Polyisocyanurate
Slob roof	235mm Kanaalplaat 200, 30mm roof tiles
Ventilation system	Type D (heat recovery) Brink Flair 400
Type of heating/cooling system	Ground source (water) heat pump for space heating, cooling and DHW, Itho Daalderop WPU 25 5G in combination with a boiler vessel type WPV150, there is also and shower heat recovery installed which is connected to both the input of the boiler as well as the cold-water connection of the shower. Technea Q-blue Showersave-QB1-21

Table 8. Input based on ModSCO user expertise

Assumptions	Value
Ground temperature	16°C
Occupancy Schedule	6pm to 7am from Monday to Friday – Entire day from Sunday and Saturday
Number of people leaving in the house	4 people
Heat gain per people	100W
Lightbulbs	9 LED light bulbs – single power equal to 20 W
Maximum electrical power per Equipment	Oven (2300W), 2laptops (120W), fridge (1200W), washing machine (650W), dishwasher (1800W). Total maximum electrical power of 6070W
The maximum heating/cooling power of the system from datasheet	2500W

Figure 50 shows the monthly Electric Energy Consumption generated by the ModSCO web application for the Dutch Pilot. The result has been generated following the workflow described in Section 7.2 and by using the data reported in the previous tables (i.e.,Table 6,Table 7,Table 8).
The result of Figure 50 represents the IPMVP not calibrated Baseline Period Energy consumption. The BPE generated by the model does not include the yield of the PV panels installed on the building.

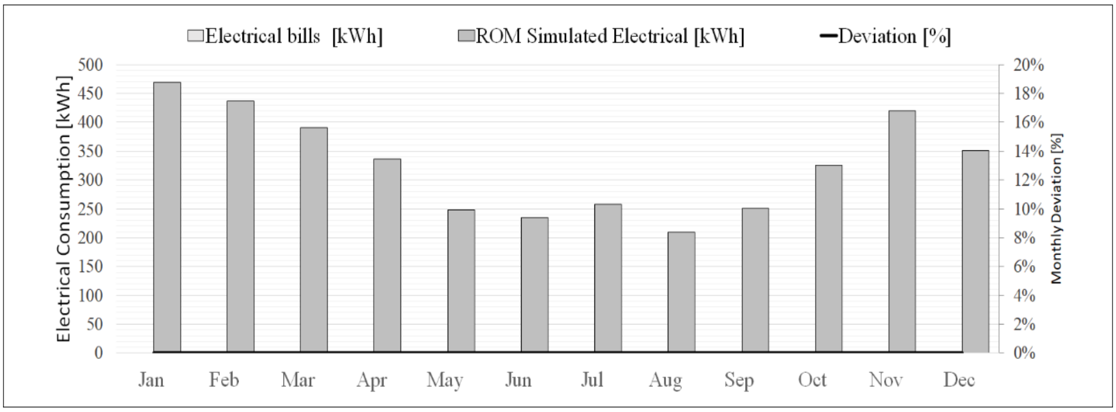


Figure 50: Monthly electric energy consumption of the Dutch pilot generated using the ModSCO web application (non calibrated result)

This BPE shown in Figure 50 will be the starting point to create the Adjusted BPE (calibrated BPE) necessary to estimate the Energy savings due to ECMs potentially installed in the building. The Adjusted BPE will be generated once the actual energy consumption (electrical monthly bills) necessary to calibrate the model will be available for the building.

8 Digital Asset Register (NEXT)

8.1 Purpose, User Needs, Requirements

Purpose

The Neanex Portal serves as a Digital Asset Register or Digital Twin Repository. All static asset data of a Building Digital Twin (alpha numeric and geometric data) can be managed inside of the Neanex Portal application. The Neanex portal is based on semantically managed data instead of documents and files, in order to improve project information and workflow management across the entire lifecycle of building or infrastructure assets.

The main goal of Neanex Portal is to ***combine, enrich and handover*** relevant asset related data.

1. combine information from different sources like BIM models (design), requirements,
2. enrich the asset data within Neanex Portal directly or from other external sources like libraries, product catalogs represented in linked data.
3. handover any information to the ecosystem in a lean and efficient manner, following OPEN standards.

Users and their needs

The Neanex Portal has a very wide range of users across the entire building life cycle. As the name already specifies "Portal", it's a place where project (asset) data can easily be accessed within the context of the user (less effort to find and understand the data). After all, different users have a different perspective on Asset Data. Below a number of these perspectives are summarised to showcase the diversity of Neanex Portal users.

Perspectives for users based on Functional vs. Geographical vs. System (project breakdowns):

- An *Electrical engineer* thinks in terms of his Electrical system and the decomposition of that system.
- An *Architect* is more interested in the functionality of a building and how functions are grouped together.
- A *work preparation manager* works very geographically based on floors, zones,...
- A *Digital Twin Manager* on the other hand wants to manage the more holistic view and how the systems, geography and functionality are interrelated.

Perspectives for users based on *As Required* vs. *As-designed* vs. *As-built* vs. *As Maintained*. different users have a particular interest in different Life Cycles as they operate in other Life cycles.

Perspectives for users based on Data quality and consistency. A *Digital Twin Configuration Manager* is more interested in whether all Asset data is complete, where the data comes from, and if a proper handover can be made.

A distinction can also be made between *direct users* and *indirect users*:

- A *direct user* logs in directly in Neanex Portal and uses its UI (User Interface) to interact with the Asset Data to view and enrich that data within his context.
- An *indirect user* accesses the Asset Data via another *consumer* like a site inspection tool, simulation software (for example a Life Cycle Assessment tool - LCA) or CAD-application (for example AutoCAD, Revit, Civil 3D, Navisworks). They act in their tool of choice, but via the

Open API (see section 2.4) of Neanex they easily have access to the data of their interest and context.

Requirements
In order to implement the Neanex Portal as part of the SPHERE ecosystem in the role of the Configuration Management Database or Digital Asset Register, several components are in the process of being improved and implemented.

As the integration with the IoT platform (dynamic data) is a crucial part of the Digital Twin solution, many end users will work in both applications. Hence, an agreement was made early on with VRM (which later left the consortium due to liquidation) to implement a Material User Interface (UI) to create a more consistent environment for the end user, who would be using both applications. Material UI is gradually implemented within Neanex Portal throughout the span of the SPHERE project.

To create a sustainable and robust interface between Neanex Portal and Clarity (VRM's IOT platform) and other applications of the ecosystem, a SPHERE API (section 2.4 SPHERE OPEN API) was developed on top of the Digital Twin Ontology Network in WP3 (described in more detail in SPHERE deliverable 3.1 Digital_Twin_requirements chapter 5). The advantage of such an Open API is to create more independence of the specific tooling chosen by a project/client.

In order to comply with this newly developed standard, Neanex is implementing this API in both REST and GRAPHQL and will extend this API layer during the course of the SPHERE project as more integrations need to be set up. A next step is currently being investigated how to apply automatic validation of the data being exchanged between two applications when applying the SPHERE API to reduce errors in exchanging and using datasets. Possibly this will be integrated as a Proof of Concept within the Neanex Portal during one of the pilots.

In order to make the static Asset Data of a building more transparent and insightful, a 3D viewer is an important aspect. To comply with the proposal of SPHERE the functionality of the 3D viewer implementation within Neanex Portal was extended to support IFC-files and offer some improvements concerning usability.

One of those extra improvements is related to communication in an open and transparent method based on the international standard BCF (BIM Collaboration Format).

More requirements to implement Neanex Portal within the SPHERE Digital Twin will be discussed in the Tool Technical Description.

8.2 Tool Technical Description

8.2.1 Service Architecture and Accessibility

Neanex Portal is a web application built on top of a Graph Database and combines information from with different tools used in the construction process (CAD, QA/QC, Project management, Asset management, Sensor platforms etc.). All project members can easily share and access asset related information using the web interface, dedicated plugins (developed by Neanex Technologies) or the Open API (both REST and GraphQL).

Architectural basics

As the Neanex Portal is a cloud based SaaS (Software as a Service) no specific hardware is needed. It runs on all computers, laptops and tablets connected to the internet, applying all common browsers such as Chrome.

Next to the Cloud application Neanex developed several Add-ons to connect desktop applications to the Neanex Portal. These Add-ons (mainly CAD-related) are integrated in the specific application such as REVIT and NavisWorks. Those CAD add-ons have a generic architecture, enabling easy and fast development of new Add-ons in other CAD applications available on the market. Only the interaction with the API of the specific CAD application is different for every Add-on. This allows for interoperability to integrate designed assets into a building project registered in the Neanex portal.

Available open services, APIs

External applications can exchange data through the Open API, using GET to read data, POST to create new entries, PUT for updates and DELETE for deleting data. Not all endpoints have all 4 of these defined.

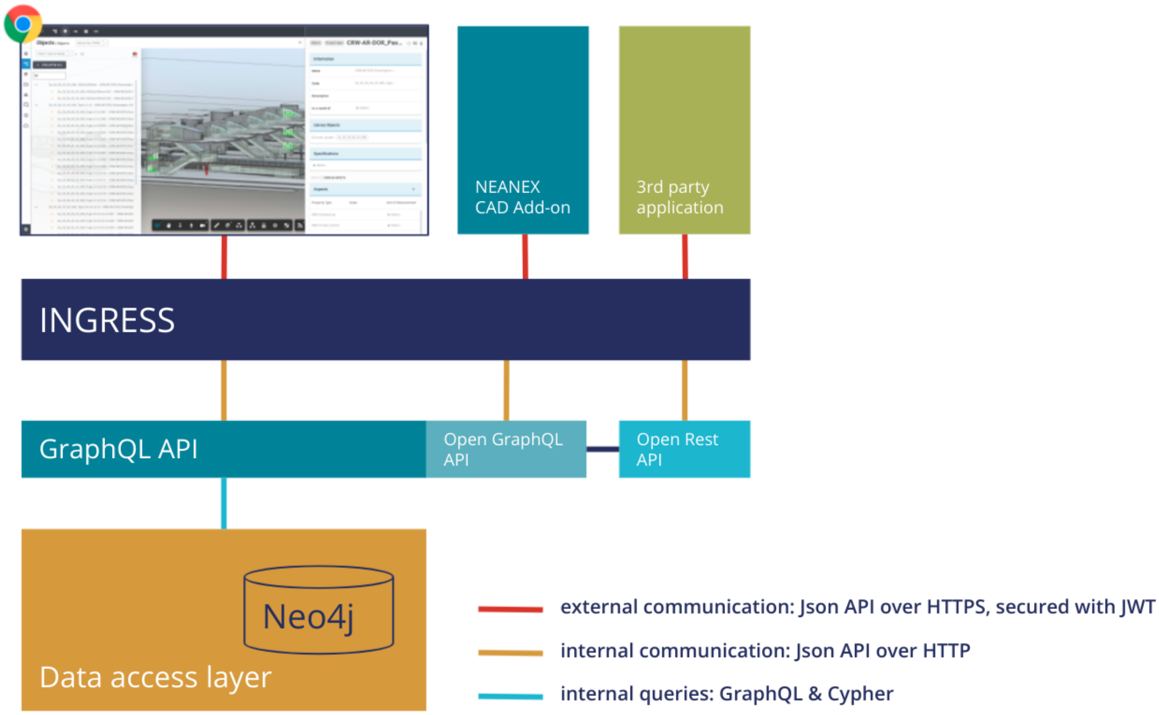


Figure 51. Basic Architecture Neanex Portal

8.2.2 Core modules / functionality

As mentioned earlier, the main goal of the Neanex Portal is to combine, enrich and handover relevant asset related data.

1. combine information from different sources like BIM models (design), requirements,...,
2. enrich the asset data within Neanex Portal directly or from other external sources like libraries, product catalogs represented in linked data.
3. handover any information to the ecosystem in a lean and efficient manner, following OPEN standards

Below three high-level functions are described that provide the rationale of the Neanex portal for combining BIM with Requirement Management, linked to four specific use cases.

Function 1: Combine information from different sources

The Neanex Portal collects and relates all relevant asset-data from different sources like CAD, Requirement Management in a central data repository or Configuration Management Database (CMDB).

Collecting all relevant Asset data within a construction process is a challenging task, definitely within a scattered IT-landscape.

Each tool in the SPHERE ecosystem can choose for themselves how they structure, store and process data internally. The only prerequisite is that data can flow between applications, e.g. by relying on the SPHERE open API which is based on the SPHERE Ontology Network. The Neanex Portal stores data internally in a graph database (neo4j) and applies the SEm™ framework from Semmtech to build an internal information model. The SEm™ framework offers an information modelling rule-set based on the ISO 15926. The internal Neanex information model, thanks to its flexible basis of the SEm framework, can easily be applied to structure data conform the SPHERE ontology network, to offer data through its SPHERE API to other parties. Semantic Web Technologies are thus mainly used at the edges of the tool. Hence, the Neanex Portal can easily import/link this project information (from various sources) and map them to the internal open data Information Model. Exporting all available data within Neanex Portal into an industry standard like CObie or COINS or as Linked Data, becomes a technicality, rather than a challenge.

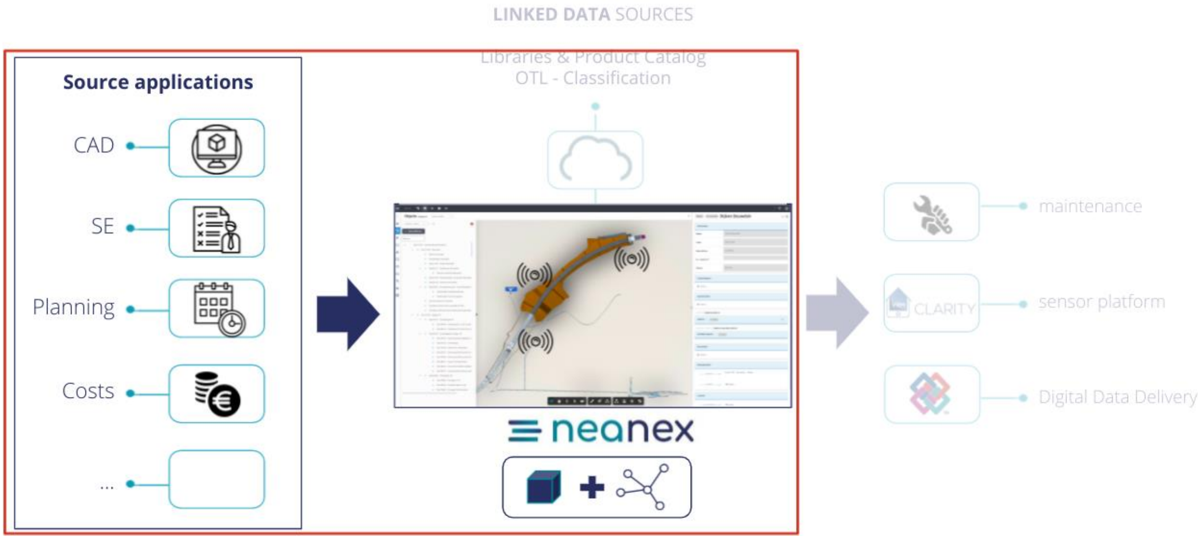


Figure 52. Combination principle of data coming from different sources

The functionality is illustrated in a number of Use Cases (UC)

Use Case 1 - BIM versus Systems Engineering Integration (Requirement Management)

BIM and Requirement Management are often two separate worlds barely communicating with each other. The 3D BIM models are used outside of their intended purpose to store all sorts of non-geometrical information such as requirements, activities (planning), and cost data. Moreover, different building development project partners typically use their own modelling software, and all store the same data in their own tool according to their own company standard. This results in a highly scattered landscape of information, with lots of duplicate and / or contradictory data.

Neanex centralizes the non-geometrical data in the Neanex Portal, and created a set of Add-ons for various CAD programs (AutoCAD, Revit, Civil 3D, Navisworks) to allow the user to access data from Neanex Portal from their own CAD environment and vice versa. This methodology enables various possibilities ranging from requirement driven design, automated design verification and centralised data management.

Figure 53 shows the high-level workflow where the Neanex Portal acts as the bridge between the world of 3D design/modelling and Requirement Management. It allows users to access combined information from the Requirement Management process in relation to the Design/Modeling Process.

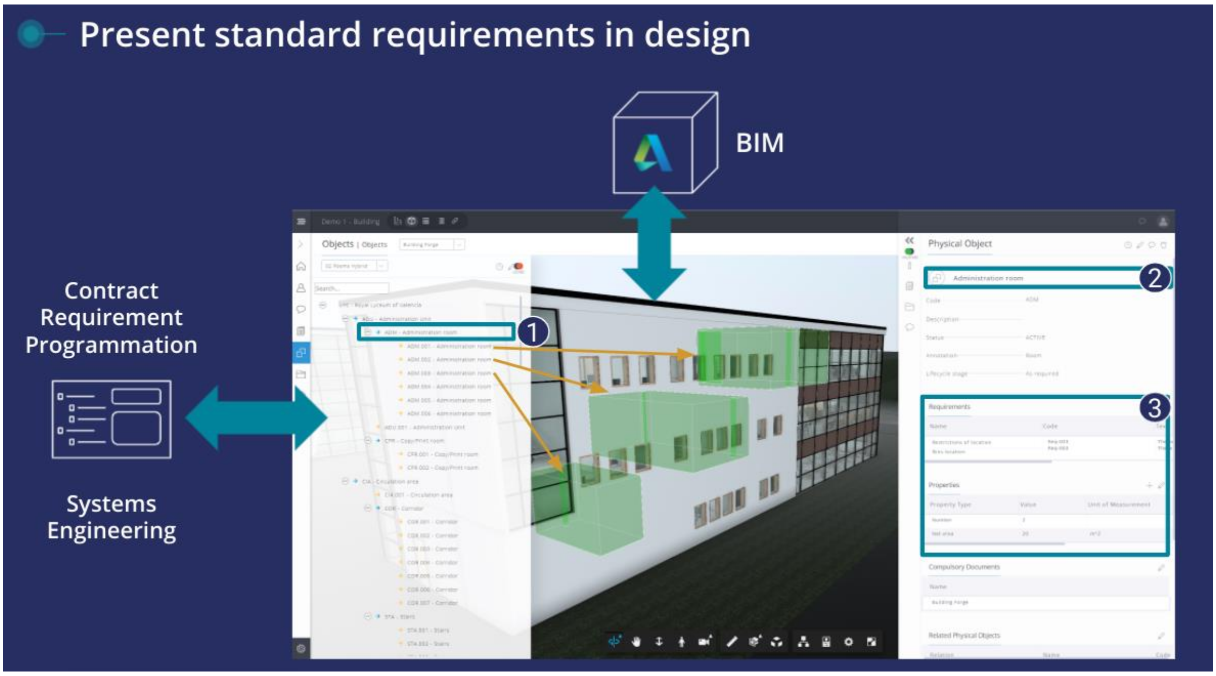


Figure 53. Use Case - Integration of Requirement Mgt & BIM via Neanex ortal

Workflow for Use Case 1

1. Synchronise the Building program to Neanex Portal. The Building program typically contains as-Required (life cycle that represents the requested state of an asset) data in the form of Breakdown Structures (e.g. object types and space types) and their requirements.

2. Create as-designed (life cycle that represents the designed assets) objects the Neanex Portal applying the Neanex CAD Add-on and connect the objects to a geometrical representation in the 3D model. During the design process the Modeler can access all relevant information to make their design choices and check whether the design is compliant to the available

requirements (step 4). The figure below displays the Neanex CAD Add-on within REVIT. The Modeler sees all the available Breakdown Structures and all related information about an Object of Choice.

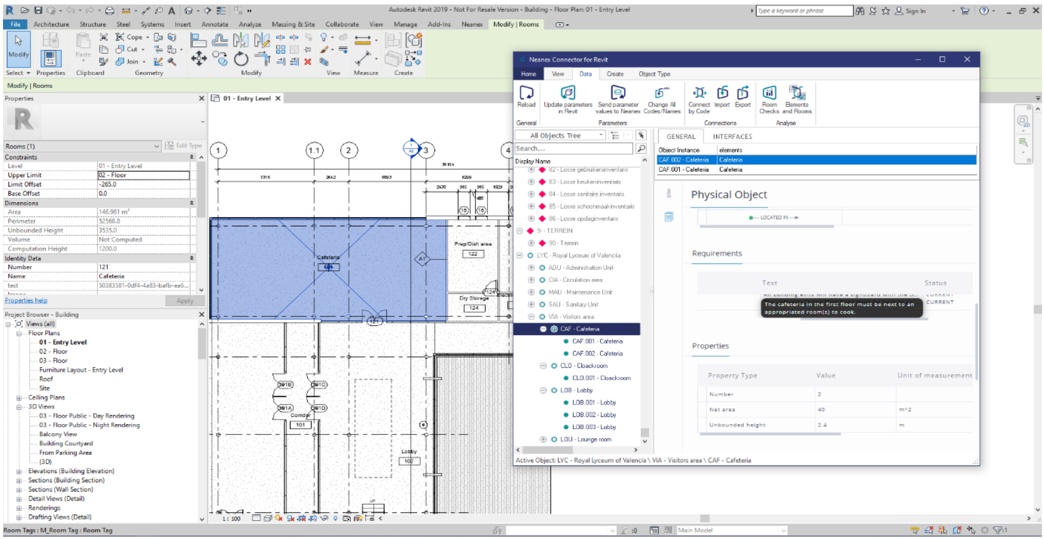


Figure 54. Neanex CAD Add-on in REVIT to create & Connect Asset Instances

3. Parameter exchanges between the CAD environment and the BIM Portal database. Once the design is connected to the Neanex Portal, the CAD modeler is able to exchange information bi-directionally between the CAD application and Neanex Portal at an object level. The figure below shows the dialog to select the information you want to exchange for a certain selection of objects.

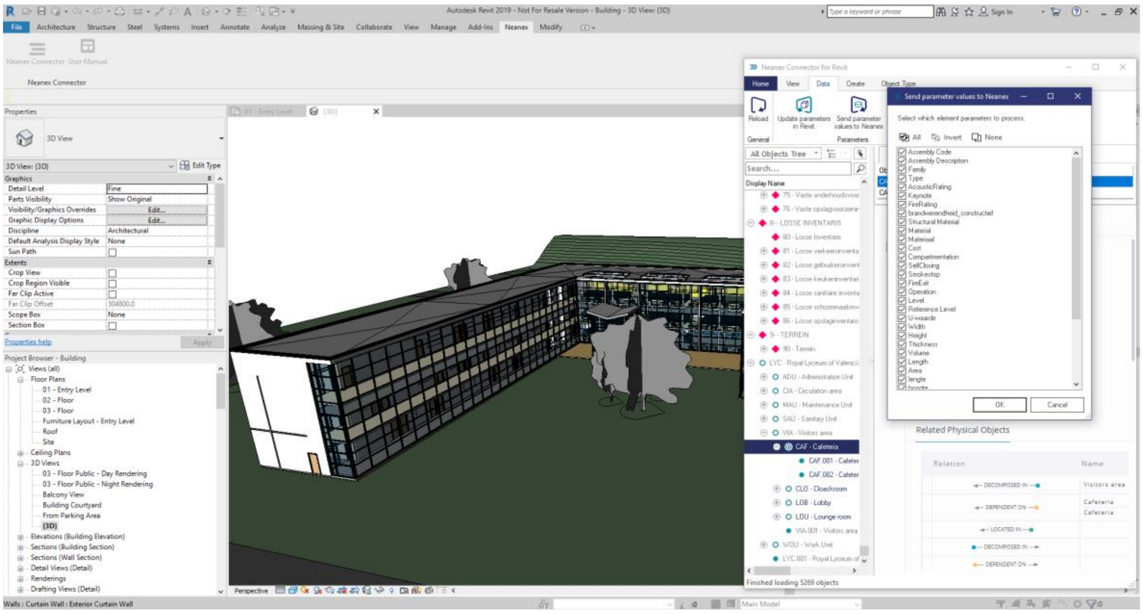


Figure 55. Neanex CAD Add-on to exchange metadata

4. Test and verify requirements while designing in CAD to ensure a compliant building project. A designer can easily perform an automated check to verify certain geometrical requirements.

The following figure displays the result of an area check of the designed spaces versus the space types and their required area.

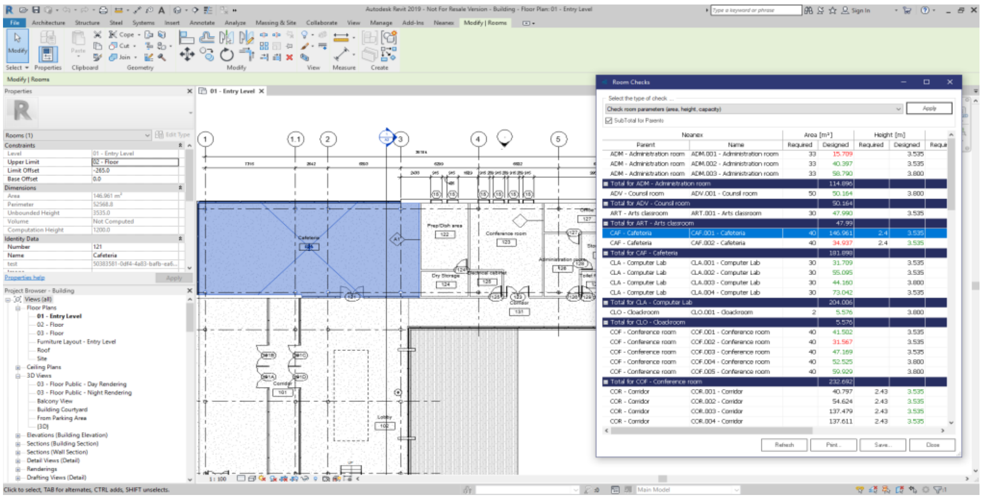


Figure 56. Neanex CAD Add-on Dashboard for testing and verification

5. Send back relevant data to the requirement Mgt tool (if applicable).

Use Case 2 - Manage baselines of the assets (Design, As-built, …)

True Collaboration concerning every baseline within the entire Project Organisation about any type of Information Object (objects, requirements, activities, aspects,…) without sending one single email.

Figure 57. Schematic representation of a workflow between an Owner and Contractor to exchange information and communication without applying email.

Communication is typically driven by email, although an email is by default not structured, not related to the asset (or other project information) and not traceable. The Neanex Portal allows easy collaboration by making sure the entire project team is working on the correct baseline of the asset, and by providing easy-to-use and fully integrated issue tracking capabilities. Lean Kanban principles are implemented so that project teams can limit their work in progress and can be as agile as possible to cope with last-minute changes in (design) requirements.

Workflow for Use Case 2

1. Upload a baseline 3D-model (linked to the assets - both individuals and conceptuals) via the Documents section of Neanex Portal (see figure below). Supported file formats are: .rvt, .nwd, .ifc.

   The CAD objects of the 3D-model are related to the assets in the database, based on matching GUID's (Global Unique Identifier) between the database and CAD objects.

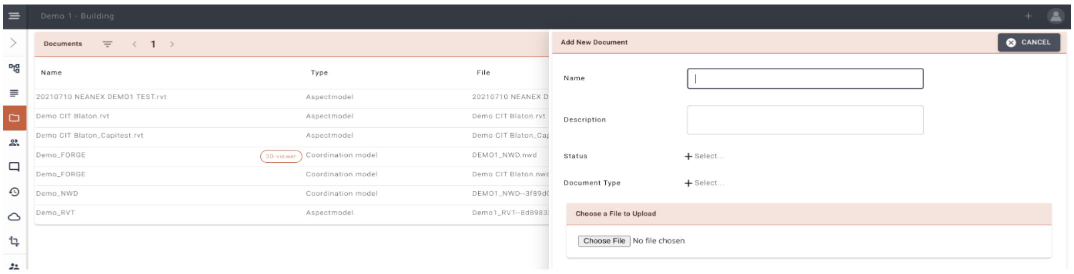


Figure 58. Dashboard with the upload options for the 3D-model

2. Communicate within Neanex Portal in context about any information object (asset, requirement,...) using Topics/issues. The figure below shows the creation of a topic with all relevant information about such a topic .

   Topics are stored within the Neanex Portal and can be exchanged according to the BCF-standard (BIM Collaboration Format). http://www.buildingsmart-tech.org/specifications/bcf-releases

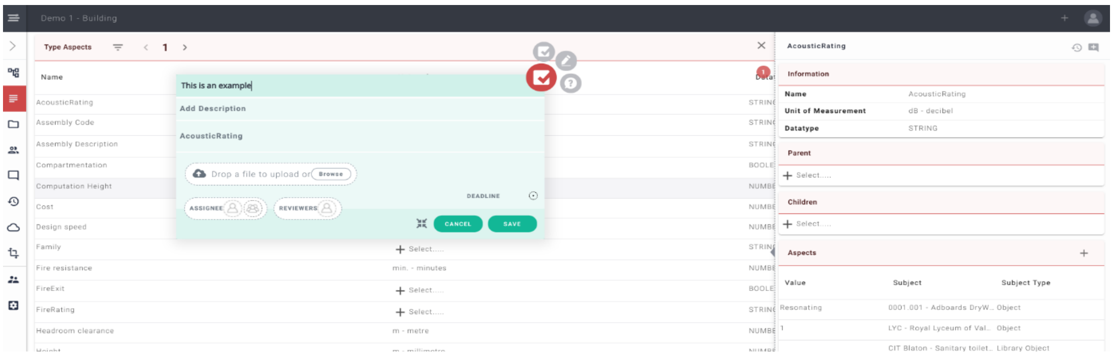


Figure 59. Dashboard with the communication options about the assets

3. Manage all communication (issues) in a Kanban board (Personal boards & Team boards), as shown in the screenshot below, to have a clear overview of all topics and their progress.

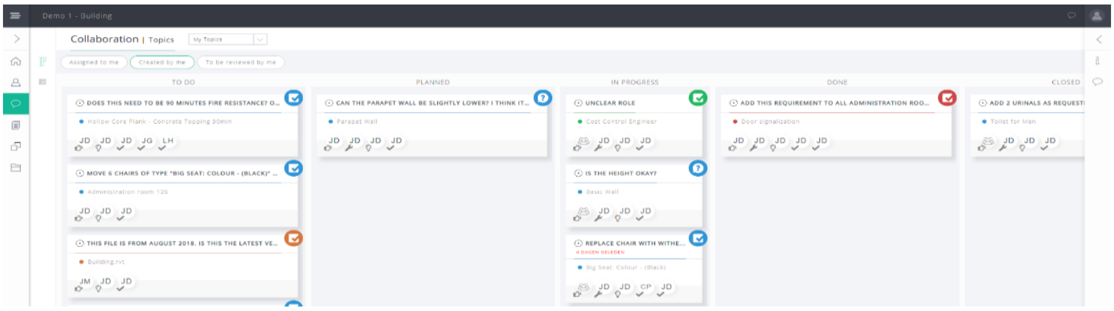


Figure 60. Dashboard with a Kanban to-do-list

4. Easy accessibility via a 3D viewer. Navigate through the model via the asset information available in the BIM portal presented in a configurable tree or list (e.g. via the System Breakdown Structure SBS).

Figure 61. Dashboard with a 3D Viewer

Function 2: Enrich your Asset Data applying Linked data (Master data)

Next to combining information from different project sources, the Neanex Portal allows easy enrichment of the asset data. Asset data can be enriched within the Neanex Portal directly.
Typically you want to enrich your asset data with external data that is not project specific but standardised or generalised, so called Master Data. Master Data is usually described in libraries, or catalogues and made available on Linked Data principles. The most known application of data enrichment based on Master Data is the classification of project assets to generic assets containing the information we want to apply within the project context.

Use case 3 – Classification of design against the reference data libraries

Enhance the collaboration beyond the boundaries of one Project Organisation by classifying assets towards a standardized OTL (Object Type Library) and exchanging information in an open data structure (RDF - Resource Description Framework).

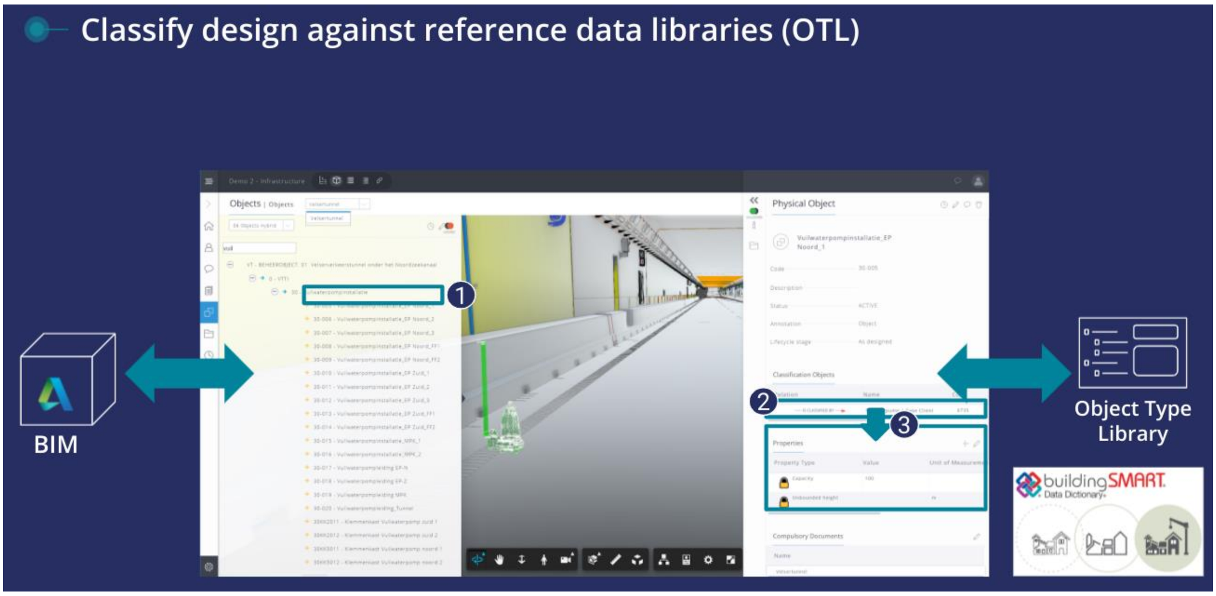
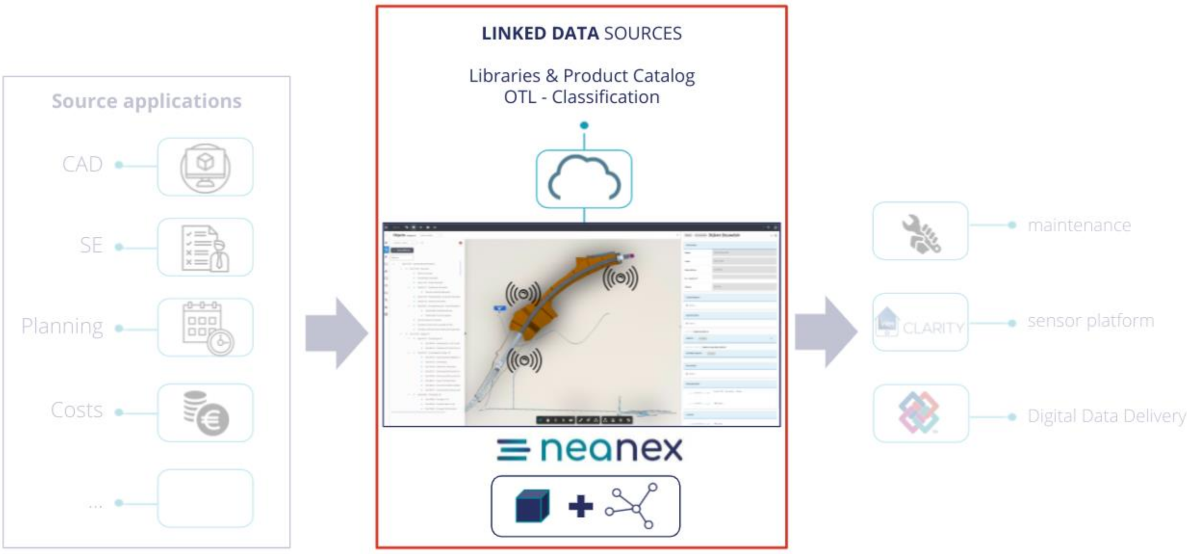


Figure 62. UC3 - Enrich Asset data from an external source based on Linked Data

More and more authorities define a dedicated OTL, and demand that project teams deliver their asset information according to their OTL definitions and structure. This tendency towards standardization allows a proper management of assets across different projects, which fits in a more lifecycle oriented approach within the Architecture Engineering and Construction (AEC) industry. The Neanex Portal classifies the project assets to OTL objects, available as Linked Data, and exchanges the necessary information between the project database and the Linked Data repository like Laces hub. Instead of exchanging files, project data is structured according terminology of the SPHERE Ontology Network and can therefore be easily shared with other applications in an automated way using the SPHERE REST API based on the exchange of JSON-LD payloads, where JSON-LD is a Linked Data format conform the W3C standardized RDF data model[5] (see D3.3 for more information).



[5] https://www.w3.org/TR/rdf11-concepts/

Figure 63. UC3 - Global overview of the IT-landscape setup to enrich Asset data in Neanex Portal

Workflow for Use Case 3

1. Classify assets towards an external OTL object available through Linked Data.
2. Instantiate all the properties of the OTL object on the level of the Project Asset.
3. Enrich the assets with meta-data coming from the CAD and BIM applications using the Neanex CAD Add-ons.
4. Data validation towards the OTL. Check if all required properties specified in the OTL are present and if the values meet the data requirements of the OTL
5. Easy Digital Delivery. Typically the asset information is enriched as the project evolves, and data delivery needs to happen multiple times on baseline versions of the project data and of the corresponding BIM models. It is therefore indispensable that data delivery can happen fast and in an automated way. The Neanex Portal eases the pain of collecting all data over and over again by automating these data transfers.

Function 3: Integration with other Tools - DATA handover

Allow easy data exchange between Neanex Portal and various Engineering tools (such as planning software, design analysis tools …) and / or other 3rd party applications. For example,site inspection tools and DMS (Document Management) systems. These integrations allow different software solutions to interact with each other directly or via the Neanex Portal.

Use Case 4 – Data exchanges from the NEANEX portal to 3rd party tools

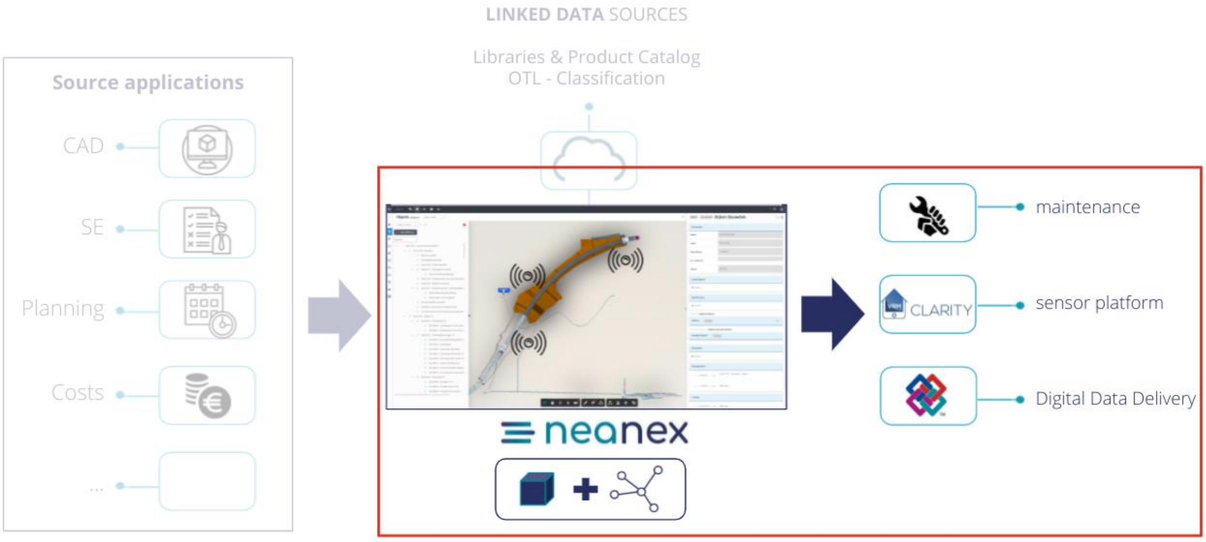


Figure 64. UC4 - Global overview of the IT-landscape setup to Handover Asset data

The data that needs to be exchanged varies per use case and is recorded in an Interface Agreement document. Depending on the use case, dedicated plug-ins are developed to use directly in the software tool that needs to be linked with the Neanex Portal, or a simple integration is set up using the Open API of both the Neanex Portal and the external software tool.

Practical examples of Use case 4 (integrations with 3rd party applications)

Below a couple of possible integrations between the Neanex Portal and a 3rd party application are listed.

Link planning activities to project assets to achieve insights related to the location of planned activities, also known as Location Based Planning.

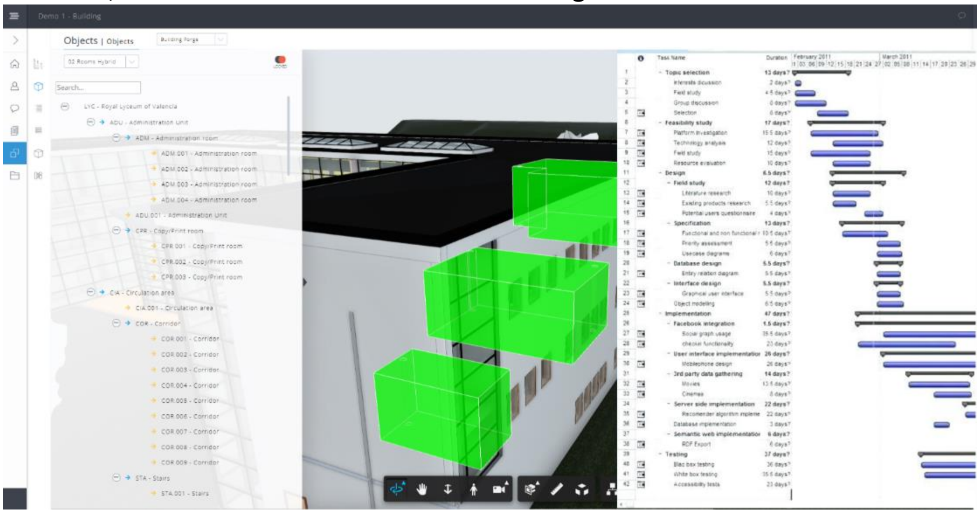


Figure 65. Dashboard with the planning of activities related to the building location

Exchange the results of a finite element analysis (FEA) with the Neanex Portal so that the CAD modeler can adjust his design where necessary.

Figure 66. Dashboard with finite element results displayed in the NEANEX portal

Visualize live dynamic data from an IoT platform (like Clarity from VRM) in Neanex Portal.

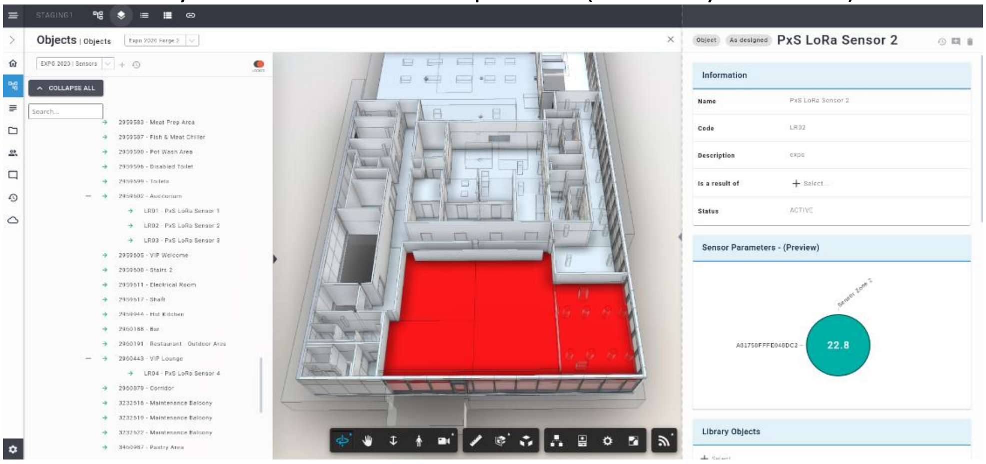


Figure 67. Dashboard with live IoT data display

Enrich Assets with on-site inspection data registered on a digital inspection app like flink2go from Ascora.

Perform a Life Cycle Assessment like CEAT from Ekodenge, based on the actual asset data from Neanex Portal and report the results of the analysis back to the user with Neanex Portal.

8.3 User Stories and Use Examples

The Neanex Portal has been developed with the user needs in mind as described in section 3. To this end specific user stories have been developed based on the standard approach used in software product development.[6] User stories are expressed in a simple sentences as follows :

As an [actor], I want to [carry out a task] using the [tool name] so as to achieve [an insight/result decision]

The user stories were developed for different actors based on the life cycle of the construction/renovation works as defined in SPHERE task 2.1 based on the seven different life cycle phases : 1) Strategic definition, 2) Preparation and Brief, 3) Concept Design, 4) Technical Design, 5) Construction, 6) Handover and closeout, 7) In Use.

The following user stories were developed for Neanex Portal to guide the development works:

- Preparation and Brief - As a Digital Twin Manager (DTM) I want to register the building program in relation to an OTL/library to obtain a well defined project base structure before starting the (detailed) design and speed up the design process.

- Concept Design/technical Design - As an Architect/Engineer I want to relate the Design to the Program to allow better project Management and enable the verification of the design.

- Technical Design - As a Digital Twin Configuration Manager (DTCM) I want to manage all the Configuration Items from the design to have a better grip on planning and costs and keep track of the original design during the operation stage.

- Construction - As a DTCM/contractor/Engineer I want to manage all the Configuration Items from the as-built to keep track of progress (quantities & quality).

- Handover - As a DTCM I want to manage all the Configuration Items from the as-built, and their according metadata, to deliver the relevant data to the owner/operator.

The user stories guide the implementation of the testing approach for the tool, as for each user story the steps to utilise the tool have been defined in a flow-schematic as per the steps that need to be taken to implement it. The flow-schematics for the user stories can be found in Figure 68, Figure 69, Figure 70, Figure 71 and Figure 72.

[6] https://www.atlassian.com/agile/project-management/user-stories

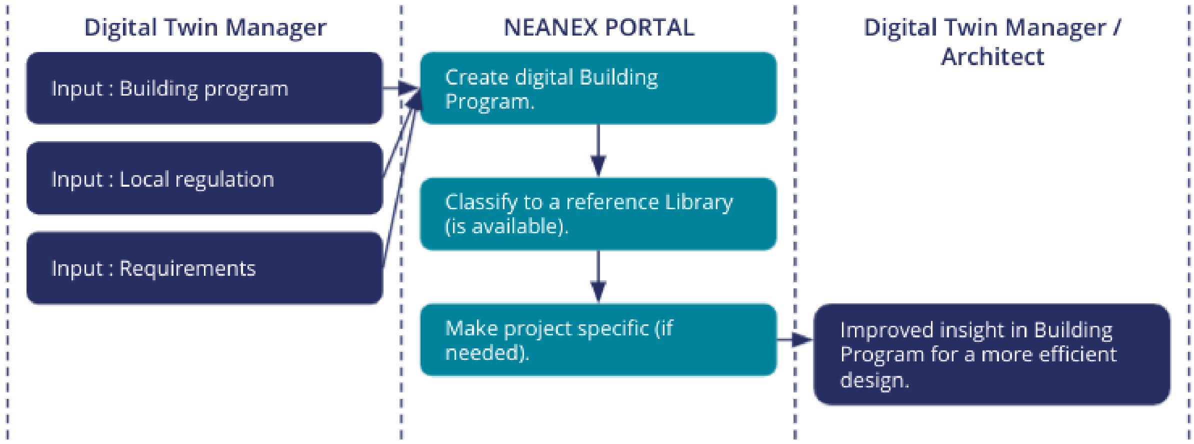


Figure 68: User Story 1 flow of user steps in carrying out the user story tasks

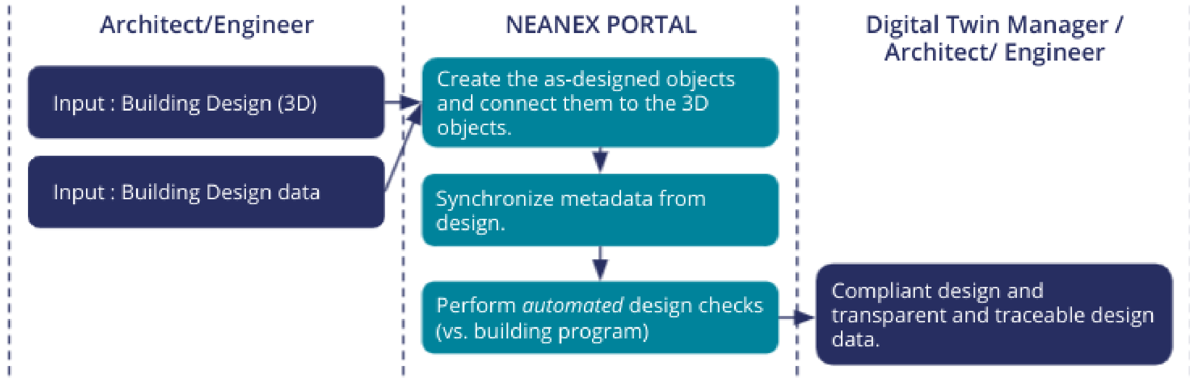


Figure 69. User Story 2 flow of user steps in carrying out the user story tasks

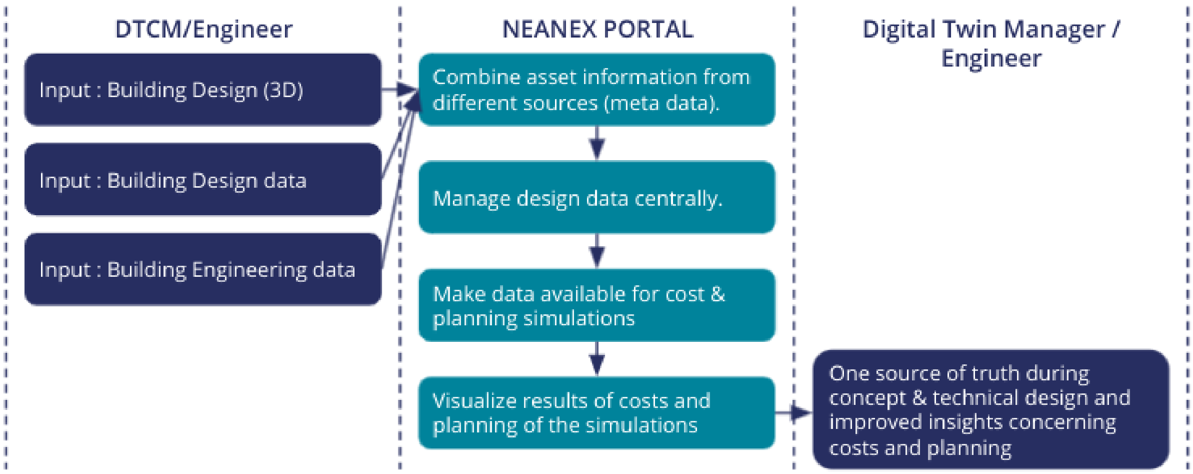


Figure 70. User Story 3 flow of user steps in carrying out the user story tasks

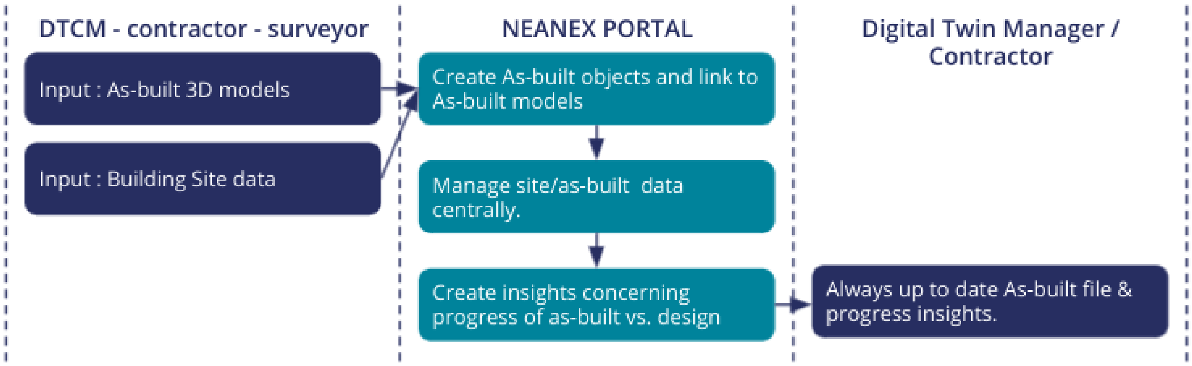


Figure 71. User Story 4 flow of user steps in carrying out the user story tasks

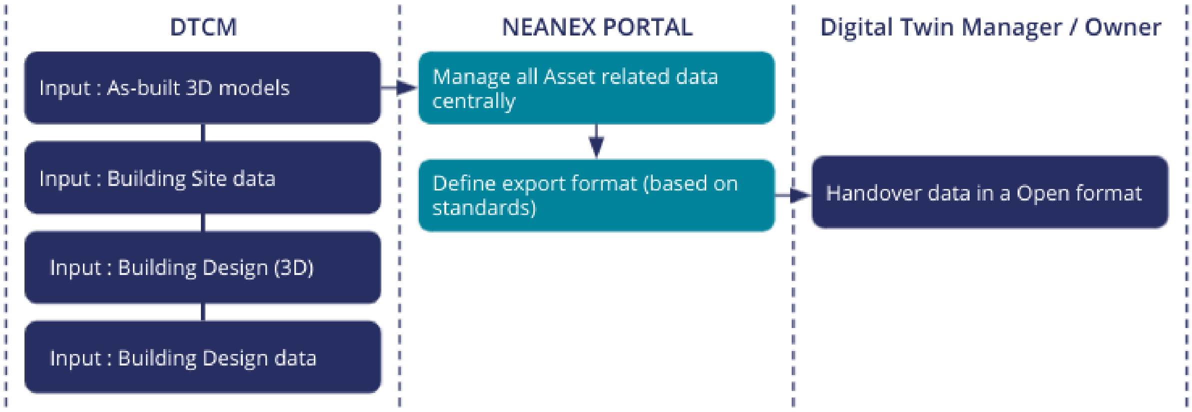


Figure 72. User Story 5 flow of user steps in carrying out the user story tasks

8.4 Integration in the SPHERE platform

The user story steps as defined in the previous chapter, combined with the technical development of the tool, led to complete definitions of the required inputs and outputs of Neanex Portal tool and when they would be required at which steps.

As the Neanex Portal OPEN API is conceived on top of the SPHERE Ontology Network as defined in WP 3 (D3.1 Digital_Twin_requirements chapter 5), the integration of Neanex Portal within the SPHERE ecosystem is rather a technicality, than a challenge.

The general approach to integrate within the SPHERE ecosystem is being described in chapter 2.

8.5 Testing procedures and results for SPHERE

The testing procedures and results for SPHERE are covered in the sections on the MicroSevices that utilise the asset data from the Neanex portal (chapters 3.5, 4.5, 5.5, 6.5, and 7.5).

9 Conclusions and next developments

9.1 MicroService Energy Prediction RobMOS (TNO)

The MicroService Energy Prediction RobMOS has been developed for several use cases. One of these is to predict the energy use for heating and cooling in the design phase of the project, based on combinations of different types of households, window usage and the usage of mechanical ventilation. The other use case is to assess the actual performance of the building during the operation phase. For the actual performance the model should be calibrated with measurement data.

In these use cases, there is a strong relation between energy use and ventilation. Therefore the RobMOS tool has a combined solver both for building energy use and for building ventilation. The two solvers are working together to give a more realistic prediction of the amount of energy needed for heating and cooling of the building. It takes about 1.5 minute to perform a calculation with the combined solver for an entire year in timesteps of one hour.

At this moment the functional tests of each module have been carried out. Tests with the complete tool have also been done. The functional tests show that the model yields plausible results. It is expected to have enough measurement data available from the SPHERE Dutch pilot by December 2021 to be able to compare the simulation results with measured data. The data also allow the model to be calibrated.

9.2 MicroService EcoSimpro SIMBOT (EAI)

At present SIMBOT models have been completed for the Italian (DE5) and the Dutch (TNO) pilot. Based on the validation step as a proof of concept, more SIMBOT models can be made available in, for instance, the SPHERE repository and the manufacturer's website.

For a real-life validation in the SPHERE pilots in a residential home, the following next steps will be undertaken:

- Introduction of the geometry of the house and HVAC appliances and networks.
- Selection of relevant parameters to see: energy savings through ventilation and air quality.
- Comparison of the results with information available: CO_2 and Tº sensor data and energy bills.

A higher-order SIMBOT of a whole house can be packed in a black-box and inserted in real time supervision or a SCADA system, which will be a future development that will be tried out in the SPHERE project.

SIMBOTs will be a good way to integrate functional components inside a virtual building, where we can check their dimensions and their compatibility with control systems. Significant further efforts are needed before they are widespread in the market within the Digital Twin Simulations context.

Potential challenges include lack of investment in good sensors and installations (and hence simulation and control), cost limitations regarding quality projects and detailing of the new buildings, implication of the industry and manufacturers, market-players inertia to accept a new methodology, certification of the models and correspondence with real laboratory results and, finally, exchange of SIMbots between commercial simulation environments.

On the other hand, SIMBOTs could be very useful for evaluating MEP systems in new and existing buildings when considering the control setup. Not only for the individual equipment, but also for analysing the networks in real conditions instead of stationary responses, and for using the same SIMBot for project design and for real time implementation (commissioning and maintenance).

After contacting some manufacturers, it is not yet clear how much they are willing to collaborate for SIMBOT development if they are not incentivised or required to do so by a certification or legal code. This is likely needed to assure the functional description of their appliances is accurate at the required level of detail for simulation purposes.

The first implementations in SPHERE and live demonstrations for TNO and DE5 pilots provides initial evidence of potential benefits that forms the basis for manufacturer collaboration. Especially with manufacturer's that provide high performance equipment, as the SIMBOT approach will provide the means to give more certainty to customers of their performance, when using in conjunction with real-life IoT based building measurements which can be linked to new building designs.

The intention is to keep on working in the same direction, using the SPHERE spin-off Building Digital Twin Association (BDTA) web space as a potential route to generate market interests in this new product (first totally free in a benefits demonstration mode).

9.3 MicroService Indoor Environment Quality (temperature) RobMOS (TNO)

The calculation core of the MicroService Indoor Environment Quality (IEQ) RobMOS is similar to the MicroService Energy Prediction RobMOS (chapter 9.1). Like the Energy Prediction tool, it can be used for several use cases. The first is to predict indoor temperatures (in particular related to thermal comfort) during the design and operational phase. Indoor air temperature, operation temperature and thermal comfort can be assessed either according to NEN16789-1:2019 or the ISSO74:2014 standards.

The second is to assess the actual performance of the building during the operation phase, comparing the actual performance with expected performance. The calculation core has been tested using a simplified model. When enough measurement data from the Dutch demo become available the tool can be further tested and calibrated. It is expected that sufficient measurement data will be available in December 2021.

9.4 MicroService iESD-W Water Recycling Management (EUT)

The iESD-W tool is able to contribute both in the design phase of a new building as well as in rehabilitation processes. Data from the building and the geographical location is needed. In the case of a new building, the required information should be available in the SPHERE platform or, if that is not the case, the user can introduce the required information via a graphical user interface (GUI). As for the location, the user needs to enter some data via a GUI, such as the annual precipitation. With that information the tool can recommend different water treatment technologies that fit both the local legislation for water reuse and the space availability within the building.

At its current stage of development, it is a standalone tool. Its integration within the SPHERE platform will be performed during the next months. Once that is achieved, some of the inputs currently entered by the user through the GUI will be able to be retrieved directly from the platform.

9.5 MicroService ModSCO support tool for quantification of energy savings (NUIG)

All the tool components for ModSCO have been developed and tested successfully. The next steps would consist of the final integration of the tool within the SPHERE Ecosystem. In particular, further tests to enable IFC data import from NEANEX portal, integration of the tool in the main SPHERE platform and automatic results delivery to the user.

The tool has been preliminary tested in a non-integrated manner using SPHERE pilots data. The availability of future energy consumption for the building will allow the simulation model calibration and finalisation of the tool application on a real test case.

9.6 Digital Asset Register (NEANEX)

The development of the Neanex Portal and the corresponding API will continue as long as new Use cases and/or integrations are being set-up with 3rd party applications, since we opted for a Use Case driven approach to define and develop the SPHERE OPEN API.

As far as the Neanex Portal specific functionality, all developments were based on the existing core from before the SPHERE project started (background IP). The SPHERE specific developments like aligning the API with the SPHERE OPEN API in both REST and GraphQL are ongoing, the development of SSO has a slight delay and would be operational in the first quarter of 2022. The improved viewer functionality is currently being tested and will be rolled out shortly. Finally, the adoption of the Material UI is an ongoing process that is tackled part by part.

The Neanex Portal has been implemented in different pilots to test the performance of Neanex Portal itself. The data exchange and integration with other applications, based on the SPHERE OPEN API has been tested with tools like Clarity from VRM and CEAT from Ekodenge. But most of the integrations are still ongoing and will be tested when possible.