P2ENDURE
PLUG & PLAY BUILDING RENOVATION

Software for energy monitoring, LCC and asset management

Deliverable Report D2.4

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P2ENDURE
Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 723391.

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Deliverable Report D2.4

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Colophon

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

Publishable executive summary

The P2ENDURE project aims at developing and validating Plug-and-Play (PnP) innovative technologies and renovation methods for energy-efficient building deep renovation, using a set of relevant IT technologies, and serving various business sectors. Especially for the technicians (i.e. architects and civil engineers), asset managers and local authorities, the P2ENDURE project develops desktop and mobile applications to equip these stakeholders with cost-effective instruments for building condition assessment, multi-year maintenance planning, life-cycle cost (LCC) analysis, asset management, and energy monitoring of building or building stock, as well as decision-support on deep renovation process.

This deliverable report is the documentation of two software tools:

- The tool for energy monitoring aiming at gathering and analysing energy data to help in choosing best renovation strategy
- The tool for LCC and asset management aiming at gathering and analysing information on building capital and operational costs to help in choosing best renovation scenario as well as to provide an overview of the total life-cycle costs of a building or building stock.

The tools described in this deliverable provide a useful overview of the building or building stock's technical condition, LCC and energy performance what is necessary to plan efficiently in long-term the maintenance and renovation activities in order to improve the overall condition of the asset with possibly best energy performance and fastest return on investment (ROI).

The preliminary results of the LCC analysis on the P2ENDURE demonstration cases are elaborated in the D3.3 validation report of reduced renovation cost and time. The mobile inspection tool for building condition assessment and other applications within the RE Suite software tool are described in the D2.3 deliverable report.
The methodology of performing BIM-based energy analyses of different renovation strategies with chosen innovative solutions is described in the D3.1 validation report of reduced use of net primary energy. The BIM Parametric Modeller, which allows visualising the results of the energy analyses and comparing the differences in energy performance of buildings depending on the chosen parameters/solutions, is described in the D2.2 deliverable report.

List of acronyms and abbreviations

AM:	Asset Management
DoA:	Description of Action
BEM:	Building Energy Model
BIM:	Building Information Model
Cap/OpEx:	Capital / Operational Expenditure
EE:	Energy Efficiency
EeB:	Energy-efficient Building
IEQ:	Indoor Environment Quality
IPR:	Intellectual Property Right
IT:	Information Technology
KPI:	Key Performance Indicator
LCA:	Life Cycle Analysis
LCC:	Life Cycle Costing
LCCA:	Life-Cycle Cost Analyses
MCA:	Multiple-criteria analysis
MYMP:	Multi-year maintenance plan
PnP:	Plug-and-Play
R&D:	Research and Development
ROI:	Return on Investment
TCP:	Technology Commercialisation Platform
TRL:	Technology Readiness Level
WP:	Work Package

Contents

1. Introduction

The building sector is one of the greatest energy consumers, accounting around 40% of the total energy use [1]. There are many reasons that energy use in buildings is expected to grow: the cities in developing countries continue to modernize and per capita income levels continue to increase. Given that the focus should be on retrofitting existing buildings in the cities, where building stock turnover is low, pursuing energy efficiency measures depends on local resources, on the basis of life-cycle cost (LCC) and benefit [2]. Therefore, in order to improve the energy efficiency of a European building stock, besides implementation of modern technologies, a proper asset management is necessary for a global overview of buildings 'technical condition, costs of building maintenance and renovation, and building energy performance.

In P2ENDURE, mobile and desktop software tool for LCC and asset management as well as a tool for energy monitoring are further developed and validated on example of real deep renovation projects.

1.1 Objective

The P2ENDURE project aims at developing and validating Plug-and-Play (PnP) innovative technologies and renovation methods for energy-efficient building deep renovation, using a set of relevant IT technologies, and serving various business sectors. Especially for the technicians (i.e. architects and civil engineers), asset managers and local authorities, the P2ENDURE project develops desktop and mobile applications to equip these stakeholders with cost-effective instruments for building condition assessment, multi-year maintenance planning, life-cycle cost analysis, asset management, and energy monitoring of building or building stock, as well as decision-support on deep renovation process.

This deliverable described two software tools:

- The tool for energy monitoring aiming at gathering and analysing energy data to help in choosing best renovation strategy
- The tool for LCC and asset management aiming at gathering and analysing information on building capital and operational costs to help in choosing best renovation scenario as well as to provide an overview of the total life-cycle costs of a building or building stock.

The tool for energy monitoring is developed within the BIM Parametric Modeller (D2.2 "BIM Parametric Modeller") by TU Berlin to visualise the results of the BIM-based energy analysis and compare them to the energy consumption of the demonstration cases before renovation in order to be able to choose the most energy efficient design strategy.

Nowadays, with the amount of available information, it would be difficult to keep track on all these data by relying completely on paper management of the as-builds, plans, or electrical assets [W1]. Moreover, the traditional methods are based often on last-minute maintenance of a building or reparation when damage occurs rather than on a preventative approach. Such reactive management is less cost-, time- and effort-effective in long-term than proactive building management when technical condition assessment and maintenance are scheduled on a regular basis. The asset management tool, based on the RE Suite software tool developed by DEMO Consultants, include not only data on building technical condition and life-cycle costs (LCC) but also information on building energy performance, information on indoor environmental quality (IEQ), and history of defects and maintenance.
Whether a building reaches a specific lifespan and how it performs in service depends on maintenance, repair, and modernization during that timeframe, or restoration and recapitalization near the end of that timeframe. Optimal asset management needs to consider minimizing the life-cycle costs related to these activities and ensure efficient building performance related to several aspects, like condition, serviceability, safety, and capacity [3].

The tools described in this deliverable provide an overview of building technical condition, life-cycle costing and energy performance necessary to identify operational, tactical, and strategic consequences and outcomes of certain decisions to maximize the benefit of an investment and to create long-term planning of efficient maintenance and renovation activities in order to improve the overall condition of the asset with possibly best energy performance and fastest return on investment (ROI).

Both tools are available online; the log-in credentials to the RE Suite tool and download instruction for the BIM Parametric Modeller can be provided by the project coordinator upon request,

The LCC and asset management tool is directly related to the mobile inspection tool (D2.3 “Mobile inspection tool demonstrator for building condition assessment”), which provides data on technical condition of the building and costs of maintenance. Below the Figure 1 shows the relation between the different deliverables in WP2 and WP4 related to the asset management tool (D2.4 “Software demonstrator for energy monitoring, LCC and asset management”), databases (D4.2 “Set-up of a database for asset management of deep renovation”) and BIM datasets (D4.8 “As-renovated BIM datasets for lifecycle management”).

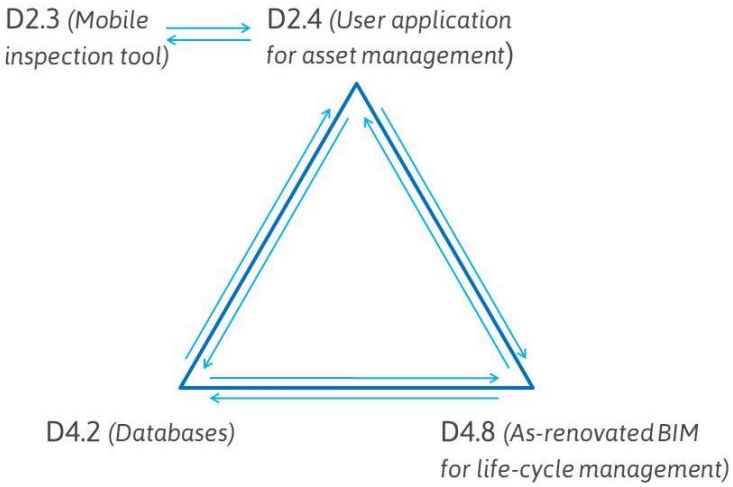


Figure 1: Relation between the D2.3 and D2.4 deliverables in WP2 and D4.2 and D4.8 deliverables WP4

1.2 Structure of this report

The type of this deliverable D4.2 is 'Demonstrator'; more precisely, this deliverable is prototype software tools and this report is a documentation of these tools.

The specific chapters describe the two tools for energy monitoring and LCC and asset management. An information movie on the BIM Parametric Modeller and e-Marketplace will be presented at the TCP (Technology Commercialisation Platform) Workshop on 5th October 2018 in Rome, Italy. Afterwards it will be also available on the P2ENDURE SharePoint and the website.

The following Chapter 2 describes the scope of energy monitoring, LCC and asset management in P2ENDURE. It explains the reason for performing these analyses within the project, how the relevant energy and cost data of the demonstration cases is gathered and at which stage of the project which activities are performed.

The subsequent Chapter 3 presents the IT tool for energy monitoring in P2ENDURE based on the BIM Parametric Modeller developed by the project partner TU Berlin. This chapter describes further development of the tool's functionalities and demonstration of the prototype.

Chapter 4 presents the tool for LCC and asset management based on the existing RE Suite software tool developed by DEMO Consultants. This chapter describes software development of the tool and demonstrates the usage of the LCC and asset management tool through a P2ENDURE renovation case, the Nursery in Genoa, Italy.

The final Chapter 5 summarises the outcomes and describes the status of the tools and their functionalities that can/will be developed for further improvements.

2. Scope

Within P2ENDURE two software tools are further developed;

- **RE Suite** developed by DEMO Consultants. The commercial RE Suite tool has been further developed within P2ENDURE as a mobile inspection tool for building condition assessment before renovation (D2.3) in the first year of the project. In the second year of P2ENDURE, RE Suite has been developed for life-cycle cost analyses (LCCA) and asset management. The preliminary LCC calculations have been performed for five P2ENDURE demonstration cases; the results are described in the D3.3 validation report of reduced renovation cost and time.
- **BIM Parametric Modeller** is an energy simulation tool within the P2ENDURE e-Marketplace. The Parametric Modeller has been developed by TU Berlin as a decision support tool to help planning a renovation project before the renovation works starts by adding or removing product solutions, which the user can find on the P2ENDURE e-Marketplace. Based on the selected renovation products, the Parametric Modeller adjust the parameters of the existing As-is BEM model (D2.2). The Parametric Modeller supports the user to find the most efficient renovation products on the P2ENDURE e-Marketplace. The aim is to display the building energy performance before renovation with an accurately simulated prediction of the performance and after renovation based on the chosen renovation design strategy (D3.1).

2.1 Energy monitoring

In P2ENDURE, energy monitoring is performed in the following stages / by the following means:

- Gathering energy data of the demonstration cases from energy audits and bills before renovation (Attachment 1 – example of an energy data sheet for the demonstration case in Ancona, Italy) and Installation of monitoring devices, like the Comfort Eye sensor, to monitor Indoor Environmental Quality (IEQ) before renovation.
- Performing BEM-based energy analyses of different renovation strategies with chosen innovative solutions (D3.1).
- Visualising the results in BIM Parametric Modeller; this allows comparing the differences in energy performance of the buildings depending on the chosen parameters/solutions (D2.2) and choosing the most energy efficient renovation design.

The tool for energy monitoring is an extended version of the BIM-based parametric modeller demonstrated in M12 – August 2017 with its functionalities described in the deliverable report D2.2.

In the following chapter 3 of this report D2.4, further functionalities to support energy data gathering and analysis are described.

The BIM parametric modeller has three main functionalities:

- Importing and displaying BEM models of buildings and building components
- Calculations of the provided energy data showing improvements of building performance of different renovation strategies
- Displaying the results of the calculations in form of graphs

In summary, the main goal, method and needed input for energy monitoring in P2ENDURE are as follows:

Goal
Visualising predicted / simulated energy consumption based on the chosen design strategies / solutions and comparing it with the delivered data on energy consumption before renovation in order to be able to choose most energy- and cost-efficient renovation strategy.
Method/how it will be achieved
By comparing the energy data of the energy bills and monitoring before renovation with the results of the energy analysis performed with BIM-to-BEM methodologies (D3.1) for different renovation strategies.
Frequency
Monthly energy bills before renovation are available for most of the demonstration cases. In the comparison, yearly or monthly average energy consumption could be displayed.
Input/based on what kind of data
Collecting available energy bills and results of energy audits in an Excel data sheet and updating the BIM models with the energy data to create BEM. These data is used in the BIM Parametric Modeller to show the building energy performance before renovation as well as of different renovation strategies.

The chapter 3 explains the additional functionalities of the BIM Parametric Modeller for energy monitoring.

2.2 LCC

In P2ENDURE a methodology and a tool for Life-Cycle Costs (LCC) analysis are further developed for deep renovation of buildings and tested on the real renovation projects.

Life-cycle cost analysis (LCCA) is a process of evaluating the economic performance of a building over its entire life [4]. It is also a good method to determine the most cost-effective design strategy among different competing alternatives. With a LCCA tool we can estimate the total resulting costs of a building, from initial construction / renovation through operation and maintenance. By comparing the life-cycle costs (LCC) of various design configurations, we can explore trade-offs between low initial costs and long-term cost savings, identifying the most efficient renovation and maintenance strategy for a given function, and estimate the Return on Investment (ROI) of implemented technologies and general costs of renovation [4].
LCC analysis is an integral part of the Asset Management tool resulting in more cost-effective management control of a building or building stock.

The information on building condition and costs of renovation and maintenance are gathered and analysed with the RE Suite tool to provide an overview of the costs of a building or a building stock as well as cost analysis of different renovation and/or maintenance strategies (Attachment 2 – example of a cost data sheet for the demonstration case in Genoa, Italy)

In summary, the main goal, method and needed input for LCCA in P2ENDURE are as follows:

Goal
Providing an absolute analysis to support the processes of planning, budgeting and contracting for investment in constructed assets and a comparative analysis to undertake robust financial option appraisals, for example in relation to potential acquisition of assets, design approaches or alternative technologies [5].
Method/how it will be achieved
By 1/ collecting actual costs data based on existing situation; 2/ performing cost simulation for different renovation strategies; and 3/ comparing cost calculations against real data after renovation
Frequency
The new cost data can be inserted whenever becomes available and it will be updated on a yearly basis

Input/based on what kind of data

Actual maintenance and operational costs before renovation and costs of renovation, maintenance and exploitation after renovation based on experience of the renovation, industrial and real estate companies participating in P2ENDURE, like Fasada, Mostostal Warszawa or Camelot Real Estate.

The preliminary results of the LCC analysis of three different renovation strategies (1/ maintenance only; 2/ traditional renovation; 3/ P2ENDURE renovation) and information on the methodology for LCCA in P2ENDURE are elaborated in the D3.3 validation report of reduced renovation cost and time (due in M24 – August 2018).

2.3 Asset management

Building asset management is a combined managerial and technological approach to maximize the value of assets by achieving the optimum mix of operational and maintenance cost, energy cost, capital cost (depreciation) and risk exposure. Building asset management is a value-generation activity making decisions to optimize the value of an asset based on the available data and results of the data analysis. The result is a lower asset total cost of ownership and risk related to, for example unexpected maintenance works of damaged building elements that create value [6].

There are two main management methods for building maintenance as referred to in this report [W1]:

- Proactive maintenance (also called scheduled maintenance or preventive maintenance) is a precautionary method in which maintenance and inspections are scheduled at regular intervals.
- Reactive maintenance (or corrective maintenance) is a strategy where repairs are performed when damage occurs. This is a far more time, cost and effort demanding approach, due to:
    - Unpredictability – higher costs of repairing already damaged elements instead of preventing the damage.
    - Shortened elements lifespans – higher costs of replacement of the damaged elements instead of prolonging their lifespan by regular maintenance
    - Indirect costs that may arise along the way due to a lack of proper maintenance.

The RE Suite tool for Asset Management allows to plan renovation activities, schedule regular condition assessment and create a multi-year maintenance plan (MYMP) in order to schedule maintenance on a regular basis and prevent the abovementioned costs of unexpected breakdowns of building elements.

The tool for Asset Management allows the stakeholders to monitor the operational management process efficiently with a real-time possibility. By sending digital data directly from the site without any paper work in-between, the inspection processes are streamlined. This method significantly saves effort and time as actions can be taken immediately by the person in charge without assistance. Long-term maintenance or LCCA is included in the tool to manage risks and costs of maintenance of buildings and sites. Inspection and surveys can be performed objectively using condition assessment norms.

The information on building technical condition is gathered by the mobile inspection tool (D2.3), which helps to gather the same kind of data for all the P2ENDURE demonstration cases, based on a coherent methodology for inspection and respective analysis of the existing condition before renovation. The condition scores of building elements are taken into consideration whether certain building parts should be maintained, repaired, refurbished or replaced depending on the selected renovation options. This information is directly used by the tool for LCC and asset management as described in the chapter 4.

Besides the cost data and information on condition of the building elements, it is also possible to insert data related to other P2ENDURE Key Performance Indicators (KPIs), like energy consumption, renovation time or level of comfort, in order to compare different renovation strategies or achieved results of deep renovation in different demonstration cases.

Based on the provided information, the results of different renovation strategies can be visualised and compared in the dashboard application within a multi-criteria analysis (MCA). RE Dashboard helps to display collected data and the chosen Key Performance Indicators (KPIs) for property control, asset management and performance based contracting in a clear way allowing analysing, comparing and showing the data effectively. The RE Dashboard is an independent application in RE Suite and can be applied for any kind of data.
MCA is a useful method in supporting comparison of different renovation strategies by assessing and scoring the different options against a set of decision criteria. The results support decision making by integrating and analysing complex / large amounts of data and diversity of criteria in a multidimensional guise, which can be adapted to a large variety of contexts [7]. The various criteria can be weighted to reflect their importance in decision making. The MCA allows the implementation of both quantitative and qualitative data in the ranking of options, which also allows consideration of qualitative characteristics such as urgency, aesthetics or co-benefits. The procedures and results obtained from MCA can be further improved with the available data and the interaction of stakeholders.

In short, the key strengths of MCA are a wide set of criteria and large amount of data that can be analysed and visualised, relatively simple and transparent method that can be done at low costs and limited time and possibility of adjusting the data at any time and combining expert judgment and stakeholder preference. On the other hand, the weaknesses of MCA may be possible high subjectivity in weighting importance of the criteria's and potential inconsistency in giving scores by different stakeholders [W2].

More information on the different applications within the RE Suite software tool are described in the D2.3 deliverable report.

In summary, the main goal, method and needed input for asset management in P2ENDURE are as follows:

Goal
Providing an overview of the technical building condition, building function and capital and operational costs to help the client (building owners/managers) in deciding of the most advantageous multi-year maintenance plan and/or deep renovation strategies, including possible transformation of a function of an individual building or a building stock.
Method/how it will be achieved
By analysing the building technical condition, costs and revenue (generation) of an individual building or portfolio of buildings.
Frequency
The new data can be inserted whenever becomes available and it will be updated on a yearly basis
Input/based on what kind of data
Building condition assessment (for more information on the mobile inspection tool, check the D2.3 report) and LCC (for more information on the LCC methodology and preliminary results of the LCCA of the chosen demonstration cases, check the D3.3 report).

The chapter 4 describes the RE Suite software tool for LCC and asset management.

3. Energy monitoring as part of the BIM Parametric Modeller

3.1 IT tool for energy monitoring

The tool for energy monitoring is developed within the BIM Parametric Modeller to visualise the results of the BEM-based energy analysis.

The Parametric Modeller consists of several components, which are combined into one system. In this chapter the main functions regarding energy monitoring are outlined and the new or changed functionalities of the Parametric Modeller are indicated. More detailed technical description of the BIM-based Parametric Modeller is included in the D2.2 deliverable report "BIM Parametric Modeller".

Visualising the results of BEM-based energy analysis in the Parametric Modeller is achieved in the following three steps:

- **Uploading the Building Energy Model (BEM)**

Before the user can run an energy simulation on the Parametric Modeller, a BEM must be uploaded. This model contains information about construction materials, HVAC/MEP system, water heating and also weather patterns for the local environment. The BEM is created with the help of EnergyPlus (D3.1). Compared to D2.2, the development has a strong progression: currently we are working with two comprehensive BEMs, based on which, a realistic development of the software can be driven.

- **Selecting products and simulating with new energetic values**

Because of the defined information structure of the BEM, new building elements can be added or removed from the model. Figure 2 shows the P2ENDURE e-Marketplace with different products that can be selected for the renovation design.

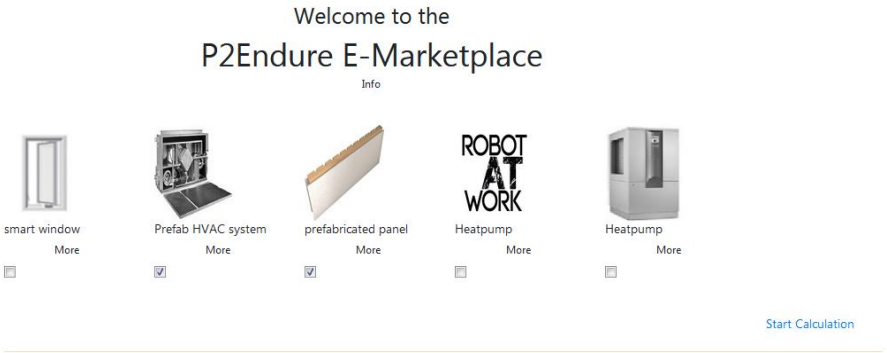


Figure 2: Selecting products and start simulation

The products can vary depending on a specific local district area. The user can select one or more of these products. After the selection is finished, the simulation can be started. The Parametric Modeller will change the "old" values of the BEM with the new values of the selected products (add drawing). Compared to the status at D2.2, text fields to support the uploading of new products for renovation have been integrated. These text fields are specifically adapted to the respective attributes of the products. For example, when adding windows, the product owner is queried for other attributes than for HVAC elements.

- **Presenting the energetic results**

Based on the values of the BEM, the results with the help of diagrams are presented. The diagrams are shown in the Figure 3. The diagrams on the left side of the figure display pre-renovation energy data and on the right side - the post-renovation energy data based on the selected products.

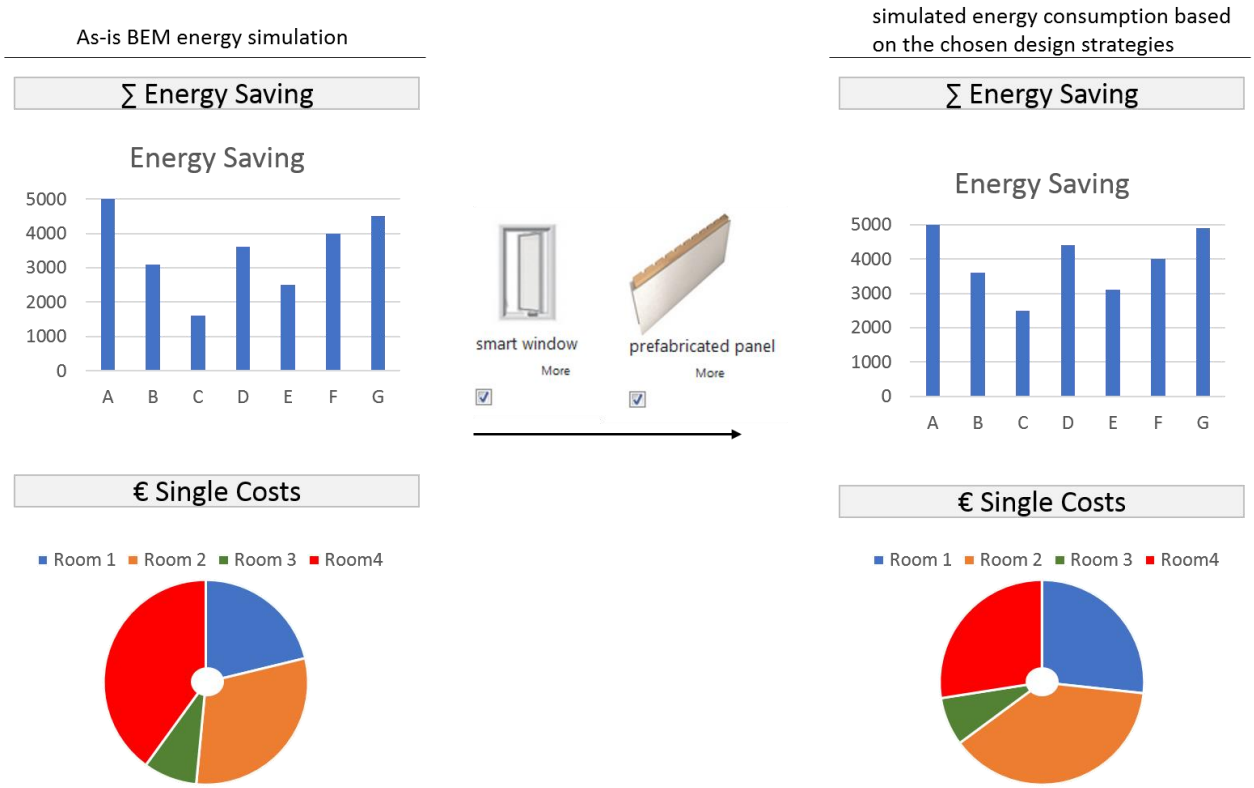


Figure 3: Diagrams presenting energetic results

The diagrams present the new energetic consumption of the building (or parts of it). During the next months, further development of the tool will be focused on the question how different parameters can be summarized to realise a graphical representation of energetic values based on changing data input.

3.2 Software development of the BIM Parametric Modeller

The following functionalities will be added / developed within the Parametric Modeller in the coming months:

- **Import function**

During the next weeks, a service to import the Excel and BEM files will be implemented.

- **Data exchange between BIM product data and energy Data**

TU Berlin will go on with developing of the data exchange between the Product Data and the related Energy Data. Product data structures, which describe for example a window, must

replace the same data in a BEM or Excel energy data sheet. The data exchange is necessary to run a simulation based on added Renovation Products.

- **Database**

In order to store and access the energy data, a database will be set up. For the test environment a Mongo Database (Mongo DB) will be implemented, which is open source and free to use. The database will be integrated in such a way, that the user can use it automatically after downloading the P2ENDURE e-Marketplace.
The MongoDB database and a method for collection of energy data is described in the D4.2 deliverable report based on an example derived from the H2020 MOBISTYLE project.

- **Algorithm for visualisation energetic values**

The development of an algorithm to visualize the energetic values out of the Excel or BEM sheet is the next important point. Therefore, a solution needs to be found on how the different values (construction materials, HVAC; water heating, weather patterns for the local environment) can be combined in order to show specific energy results out of the "As-is BEM" and after the selection of new products.

3.3 Prototype and demonstration of the tool for energy monitoring

This chapter gives an overview about the use of the P2ENDURE Parametric Modeller. A more detailed guidance is offered in the D2.2 deliverable report.

- **Overview**

The Figure 4 provides an overview of the P2ENDURE e-Marketplace with the integrated Parametric Modeller for a better understanding of its functionalities.

(1) The products that can be selected for the renovation project by the e-Marketplace user;
(2) The model of the "As-is BIM";
(3) In the text field user can add new products to the e-Marketplace;
(4) Visualisation of the energy values based on the chosen strategy.

The structure of the e-Marketplace was designed to allow the user editing the renovation project in a comprehensible and easy way.

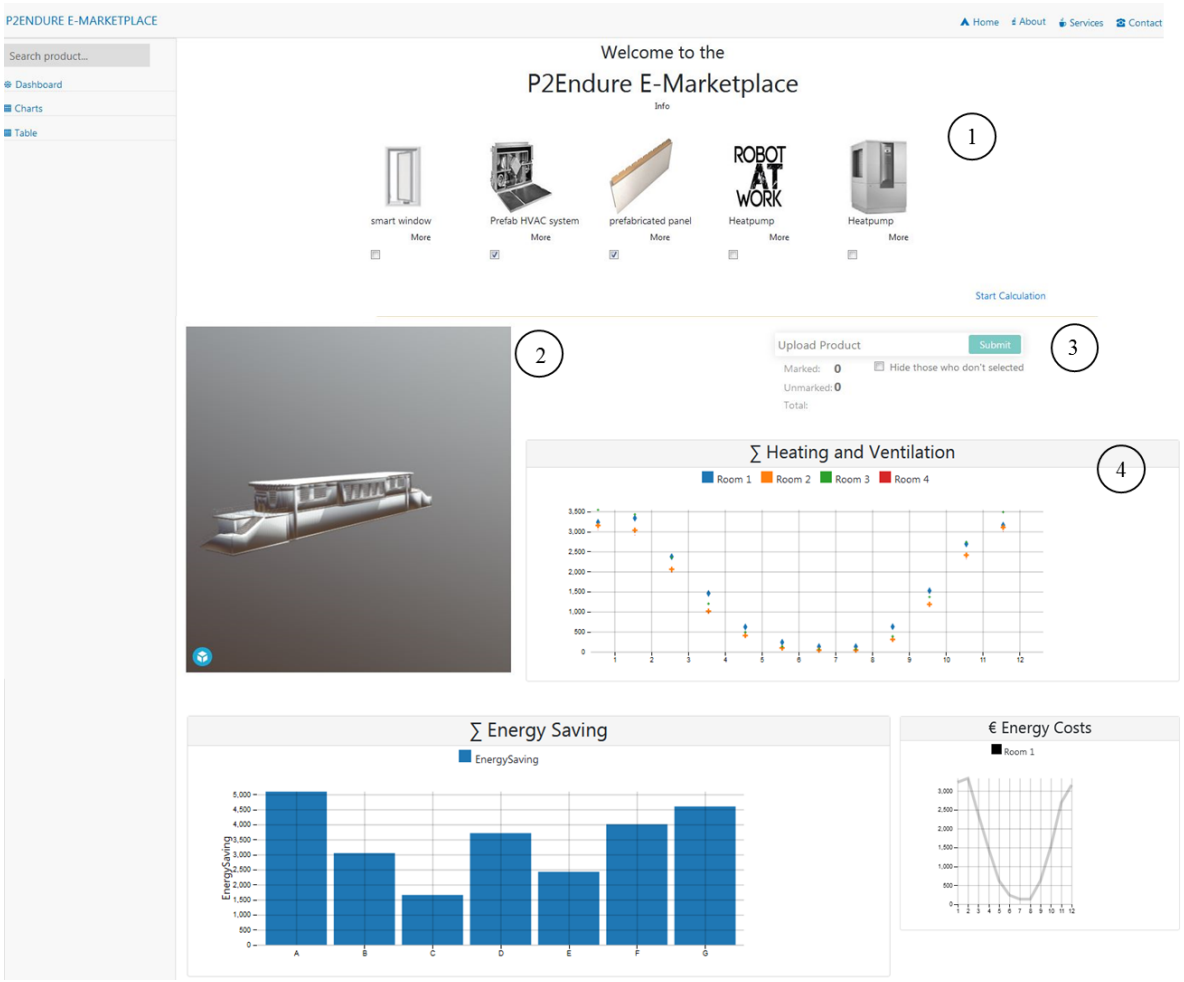


Figure 4: P2ENDURE e-Marketplace

- **Download the P2ENDURE e-Marketplace**

The P2ENDURE e-Marketplace is Open Source software. To share the software, GitHub[1] is used. The user can download the P2ENDURE software directly from GitHub (https://github.com/P2ENDURE/P2ENDURE_market). All components, which are important to run the software on the computer, are already integrated. Because of that, the e-Marketplace runs out of the box.

- **Uploading the "As is BEM"**

Uploading the "As-is BEM" is the initial step in the use of the e-Markeplace. The BEM model contains information about material, HVAC systems, water heating and also weather patterns. The uploaded energy information is structured in Excel or IDF data files.

[1] GitHub is an online service, which provides online resources (server) for a collaborative development of software. GitHub is free to use.

- **Uploading products**

Product owners have the possibility to upload their products to the local district market. The product information must be filled into the text field (3). At the moment, the e-Marketplace supports the uploading of window and material elements. Uploading options for other renovation components will be added next month.

- **Selecting products**

Selecting products is one of the main functions of the Parametric Modeller. The user can make a decision about the products for the upcoming renovation project. The products are characterized by unique parameters (for windows: transmittance, high, width, glazing etc.). The Parametric Modeller add these information to the "As-is BEM".

- **Starting energy simulation**

The energy simulation is based on the "As-is BEM" information and the information of the products, which are selected by the user. The new information of the products (for example, parameters of a new window) will replace the information of the "As-is BIM". Based on the new values, the Parametric Modeller will display diagrams which contain the energy information. The Parametric Modeller offers the user forecast information about the energy consumption of the building (or parts of the building). The modeller also delivers a comparison about the old and the new energy values. Figure 3 in the subchapter 3.1 shows the results of the analysed energy data. On the left side of the diagram, the pre-renovation energy data of the building are shown and on the right side of the figure - the energy data based on the election of renovation products.
The Parametric Modeller displays energy data of the pre-renovation energy consumption and visualised predicted / simulated energy consumption based on the chosen design strategies / solutions.

4. LCC and asset management as part of the RE Suite software tool

4.1 IT tool for LCC and asset management

This chapter will outline how the tool for LCC and asset management was conceptualized, how it was developed, and how it is integrated in the RE Suite. In order to do this, the following questions will subsequently be discussed:

- What are the main functionalities of the tool?
- What is(was) the concept and approach for developing this tool?
- Which existing tools were further developed in P2ENDURE?
- With regards to the IT Architecture; which components are located within this system, and what are their respective roles?
- What is the conceptual workflow in the LCC and asset management tool?

4.1.1 Main functionalities

In order to develop any software tool, it is first necessary to conceptually describe the functionality it should contain. On the highest level, the functionality of the LCC and asset management tool can be described as follows:

A software tool that provides the manager of a real estate stock with the functionality to capture and attain an overview of a real estate stock, provides the possibility to create multiple strategic renovation scenario's, and facilitates the process of substantiated decision making based on multiple, for example: financial, indicators.

From this short description more detailed functionalities were derived. The LCC and asset management tool should contain the following functionalities:

- **Capturing a real estate stock**
  Creating and interrelating real estate objects, and being able to add all relevant information and documents to these objects.

- **Creating renovation strategies for real estate objects**
  Based on the real estate stock, multiple renovation strategies should be able to be defined for each of these objects. These will form the foundation of the decision making process later on.

- **Performing LCC analysis**
  One of the main functionalities of the tool is to provide the user with the tools to able to perform financial, and more specifically, LCC, analysis for each renovation strategy.

- **Integrating other indicators**
  Aside from financial analysis, there are other aspects, such as the energy performance or predicted user comfort, for each renovation strategy that will contribute to making an informed policy decision. The LCC and asset management tool should provide the opportunity to integrate these indicators.

- **Provide an integral overview to support informed decision making**
  Once all necessary analysis has been performed, this resulting information should be brought together in an integral, holistic, overview to facilitate the asset manager in making an informed decision which renovation strategy, if any, to choose.

4.1.2 Approach

Within P2ENDURE there are a large number of interrelated products and thereby deliverables which all contribute to the end goal of making an informed decision about renovation scenario's. These include:

- Mobile inspection tool for building condition assessment (D2.3) for attaining an overview of the current maintenance state of real estate objects.
- Validation report of reduced renovation cost and time (D3.3), outlining the validated framework to calculate costs for renovation strategies.
- Set-up of a database for asset management of deep renovation (D4.2), concerning the database landscape used to store and disseminate information in P2ENDURE.

It is due to this interrelated nature that the LCC and asset management tool was conceptualized to not only provide functionality in itself, but also function as the glue binding several other P2ENDURE products together. This will be further elaborated upon in chapter 4.1.4.

4.1.3 Existing tool and architecture as the basis for development

The development of the P2ENDURE LCC and Asset Management tool was conducted in the framework of DEMO Consultants' primary software product: the Real Estate (RE) Suite. This software suite contains a plethora of different applications and modules which have all been developed for one shared purpose: the management of real estate information.

The RE Suite framework was as the environment and platform for the development of the functionalities as described under chapter 4.1.1.

IT Architecture

The IT architecture of the RE Suite is conceptually visualized below. The next paragraphs will describe the different components in this system with a brief description of their general role and functionality.

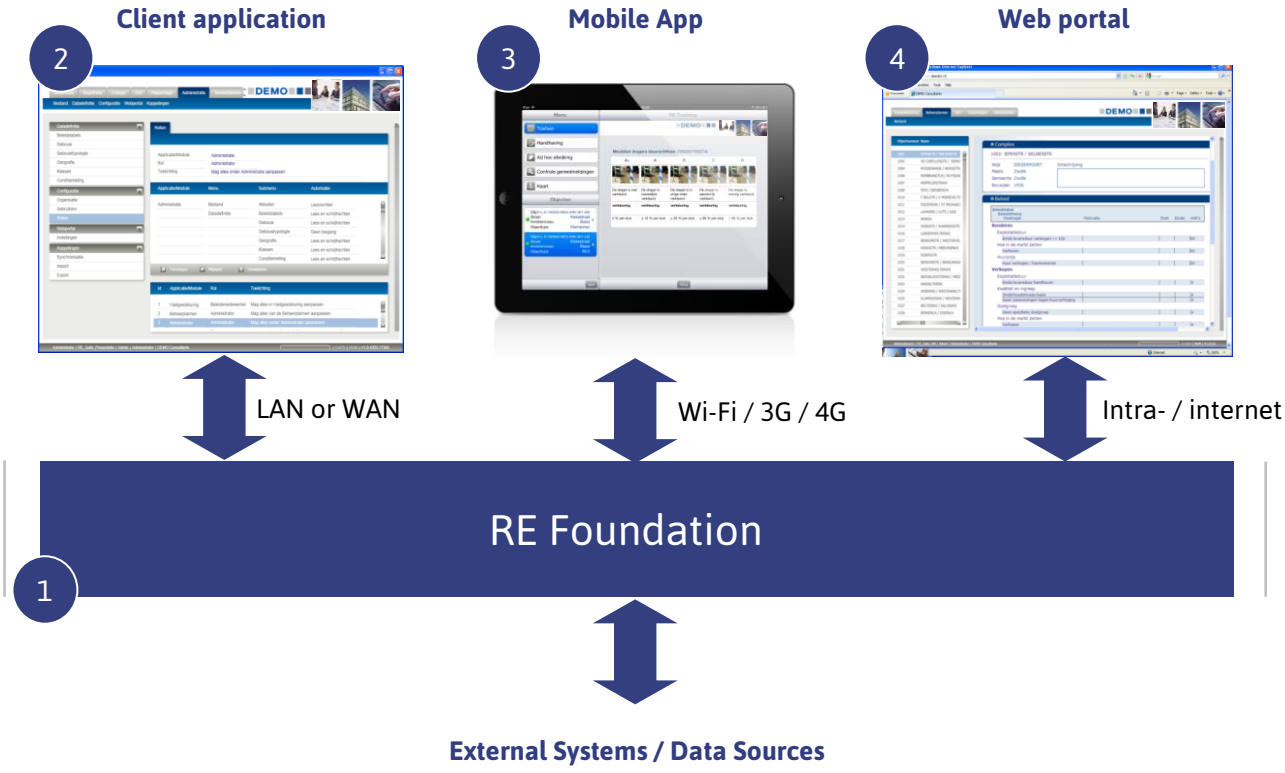


Figure 5: IT architecture of RE Suite

RE Foundation

The RE Foundation functions as the bedrock, the foundation, of all RE Suite applications. The key characteristic of this foundation layer is that it is platform-independent and can be used by all applications within the RE Suite system. The main functionalities of the RE Foundation are:

- Access and storage of data in the central RE Suite database;
- Providing and managing connections to external systems and data sources;
- Creating the possibility to use data described above on multiple platforms simultaneously;
- Providing generic functionality, for example user authentication, to applications built on top of it.

Client application

Built upon the RE Foundation, the RE Suite client application provides the end-user with software tools to attain, structure, analyse and disseminate information in the realm of real estate. This application is developed for the Microsoft Windows platform and is therefore a desktop application. As such, it meant for off-site usage.

Mobile App

Many processes in the real estate sector cannot be effectively managed only through off-site software tools. Therefore, mobile applications designed for on-site usage are also part of the RE Suite IT architecture. Examples of functionality offered in such apps are maintenance inspections or the inventorying of fire risks and safety of real estate objects. As the mobile applications are based on the same RE Foundation as the client application, there is extensive integration between both elements within the RE Suite IT Architecture.

Web portal

In the context of the trend of software products moving more and more towards being web-enabled or web-based, the RE Suite is also accessible through a web portal. This web portal can both provide access to a fully functional RE Suite client application as well as to dedicated web-based applications.

4.1.4 Conceptual workflow

In the light of the desired functionalities of the LCC and asset management tool (chapter 4.1.1), the outlined approach (chapter 4.1.2) and the available existing tools and architecture as the basis for development (chapter 4.1.3), the tool was subdivided into the following components, which have taken shape in the form of applications within the RE Suite:

- **RE Maintenance**
  Attaining an overview of the current maintenance state of real estate objects; primarily developed and described in D2.3, integrating databases as described in D4.2

- **RE Asset Management**
  Performing and integrating, among others, financial (LCC) analysis, integrating the outcomes of D3.3 and using database as described in D4.2

- **RE Dashboard**
  Providing the end-user with the tools to reach the end-goal of substantiated decision making for renovation scenarios

On the next page the conceptual workflow of the LCC and asset management tool is visualized in the form of a workflow diagram. The implementation of this workflow will be discussed further in chapter 4.3, including the demonstration through demonstration cases in the software tool.

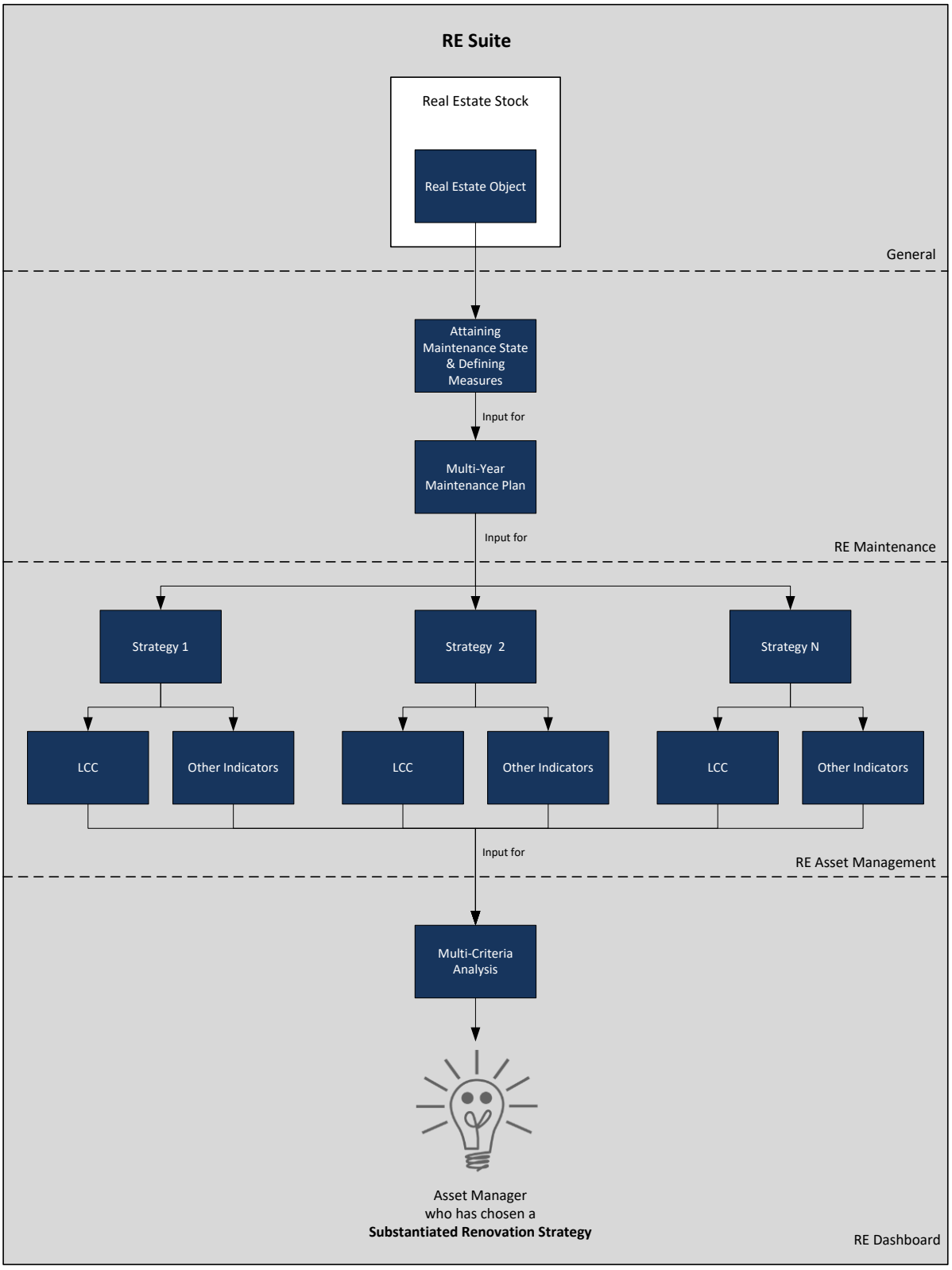


Figure 6: Conceptual workflow of the LCC and asset management tool

4.2 Software development of the RE Suite tool

The concept of the LCC and asset management tool has been implemented following the aforementioned approach, described in chapters 4.1: 4.1.4 and 4.1.2 respectively and resulting in a fully operational software tool that complies with the requirements as outlined in chapter 4.1.1. This tool is demonstrated through a P2ENDURE renovation case in chapter 4.3. Nevertheless, as with any software tool, there is always room for improvement. This chapter will outline areas briefly and point-by-point and functionalities that could be subject of improvements in the future.

- **Detailed additional indicators**
  Currently, aside from the detailed financial indicators, the indicators for energy, quality, and time are yet to be detailed and further subdivided. One can assume that during the course of the project these other aspects relating to renovation strategies will become clearer. From a software point of view, the indicator and MCA-framework are both highly configurable. Therefore, once more detailed indicators are available these can be integrated in the 'Performance' tab within RE Asset Management (see 4.3.4).

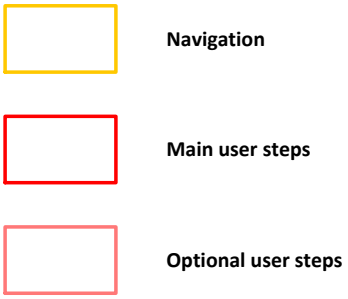
- **BIM-based general object content**
  One of the great strengths of BIM is that it can function as one, central, information store which can potentially feed many real estate processes. One of these aspects is quantity information, which could provide input for both general object content as well as the parameter used in the LCC calculations. This does mean that agreements should be reached on the structure and content of these models.

- **BIM-based inspection content**
  In RE Maintenance, there is functionality to derive maintenance inventories from BIM, and more specifically: IFC, models. Through the combination of building element classification, material properties and quantities an IFC-model can be decomposed into a building inventory. While this provides great opportunities, it also poses requirements on the structure and content of the IFC-models.

4.3 Prototype and demonstration of the LCC and asset management tool

This chapter will demonstrate the usage of the LCC and asset management tool through a P2ENDURE renovation case, the Nursery in Genoa. This will be done by following the conceptual workflow which is the basis for the tool, and was introduced in chapter 4.1.4.

This chapter will walk through this diagram step by step using the CH AM tool, and therefore functions as a description of the workflow, the implementation of the workflow in the software, as well as a preliminary user manual for using the tool. In this chapter screenshots of the software will be used to illustrate this process.



4.3.1 Prerequisite: Condition assessment using the inspection tool

As described in chapter 4.1.2, the approach for the development of the LCC and asset management tool was to create a holistic tool that also incorporates previous project results. One of these results is the development of the inspection tool, which has been submitted in M6 – February 2017 of the project and is described in D2.3. Since then, this tool has been used to inventory and inspect multiple P2ENDURE renovation cases, and therefore has provided the (content) foundation for the LCC and asset management tool to build upon.

The inspection tool is integrated as the application 'RE Maintenance' in the tool and workflow. For an overview of the step-by-step workflow to use this application we kindly redirect you to D2.3 itself. Below, a screenshot has been included of the end result of this process: a multi-year maintenance plan for the Genoa case.

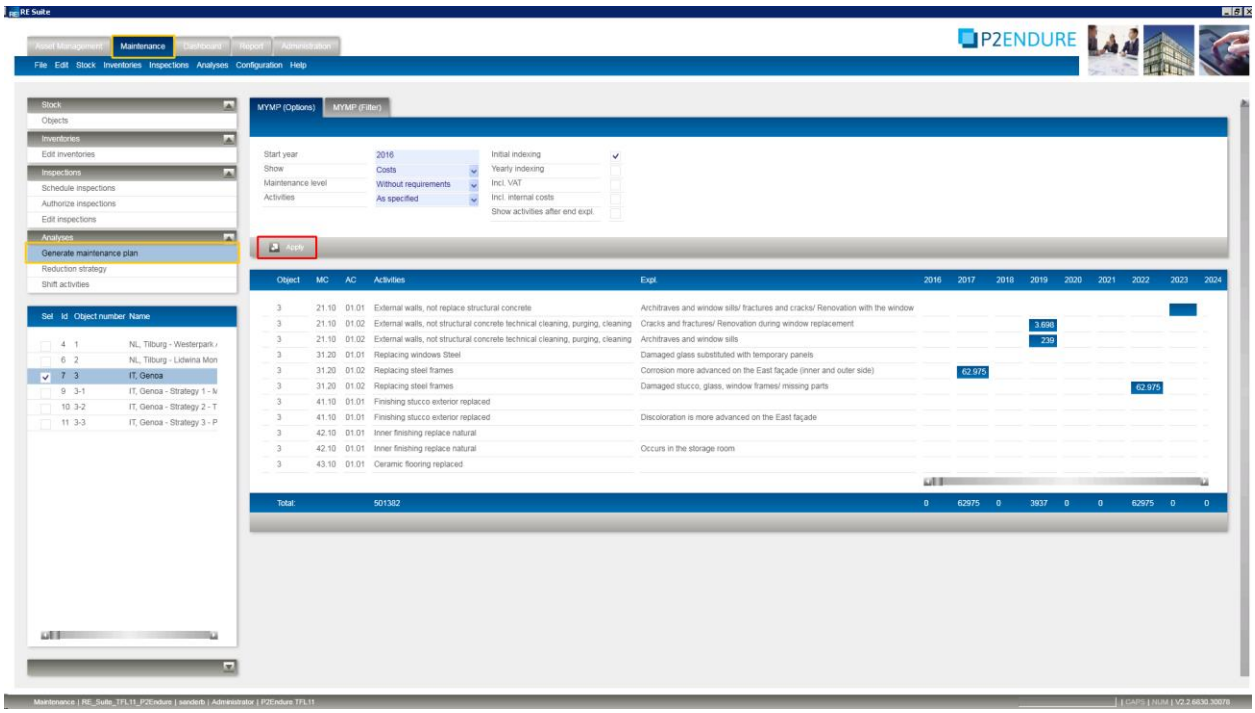


Figure 7: The multi-year maintenance plan for the Genoa case

4.3.2 Step 1 – RE Maintenance – Creating strategies

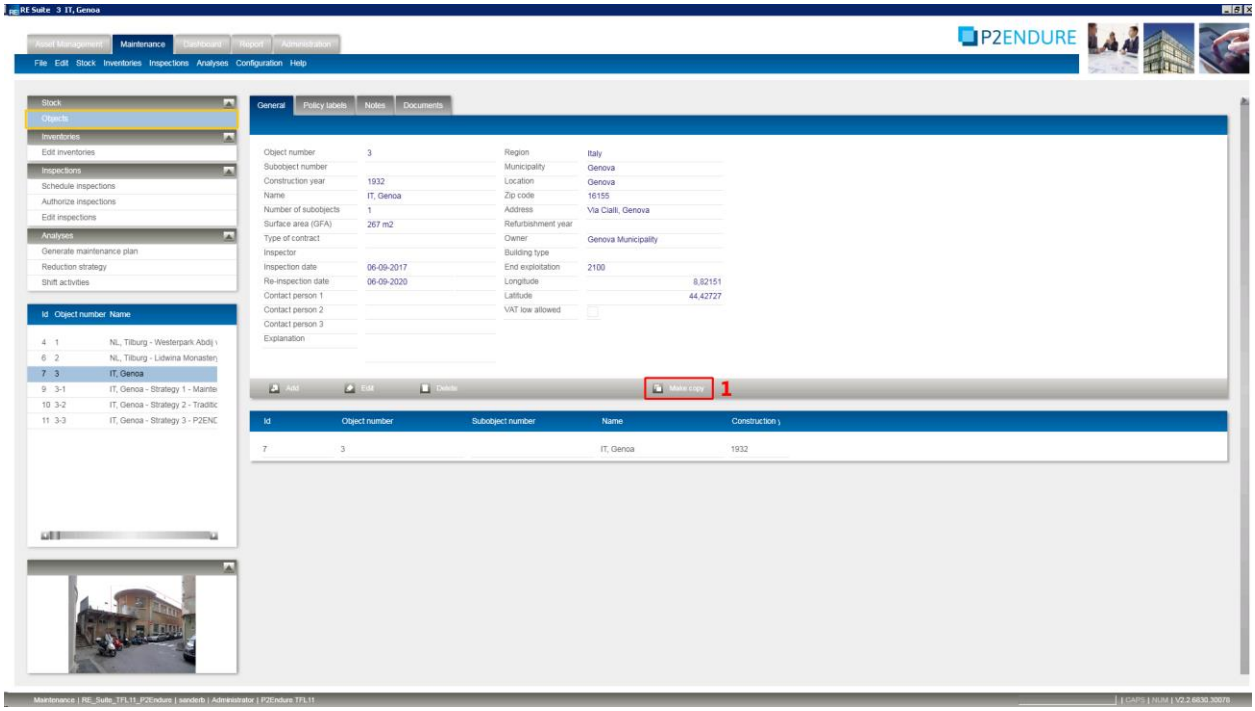


Figure 8: Creating strategies for a real estate object

After completing the inspection workflow and attaining a multi-year maintenance plan, the first step is to create multiple strategies. This is done in RE Maintenance by:

- Copying the renovation case three times, including all associated data (1)

4.3.3 Step 2 – RE Asset Management – Creating a LCC

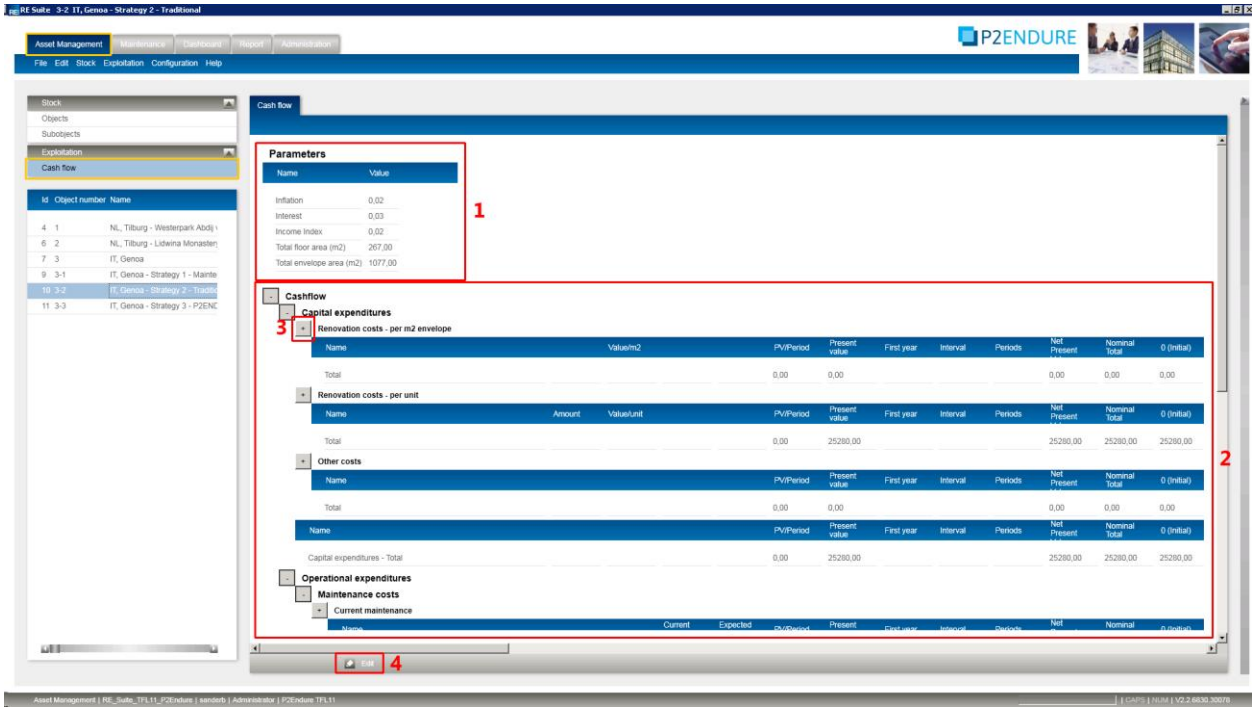


Figure 9: General overview of the LCC interface

After creating multiple strategies in the previous step, each strategy can now be (financially) defined through an LCC analysis. The methodology and structure of the LCC analysis has been described in the D3.3 deliverable report, and has been directly implemented in the software.

After switching to the application 'RE Asset Management' and selecting 'Cash flow' in the left menu the LCC interface is shown. This interface consists of the following elements:

- A number of user-configurable parameters used in the LCC, such as interest rates and areas. (1)
- A tree structure of LCC-entries shown below these parameters (2)

The user can show or collapse branches of this tree structure by clicking on the +/- icons in the lower portion of the LCC-interface (3). To edit the contents of the LCC, the user can click on the 'Edit' button (4).

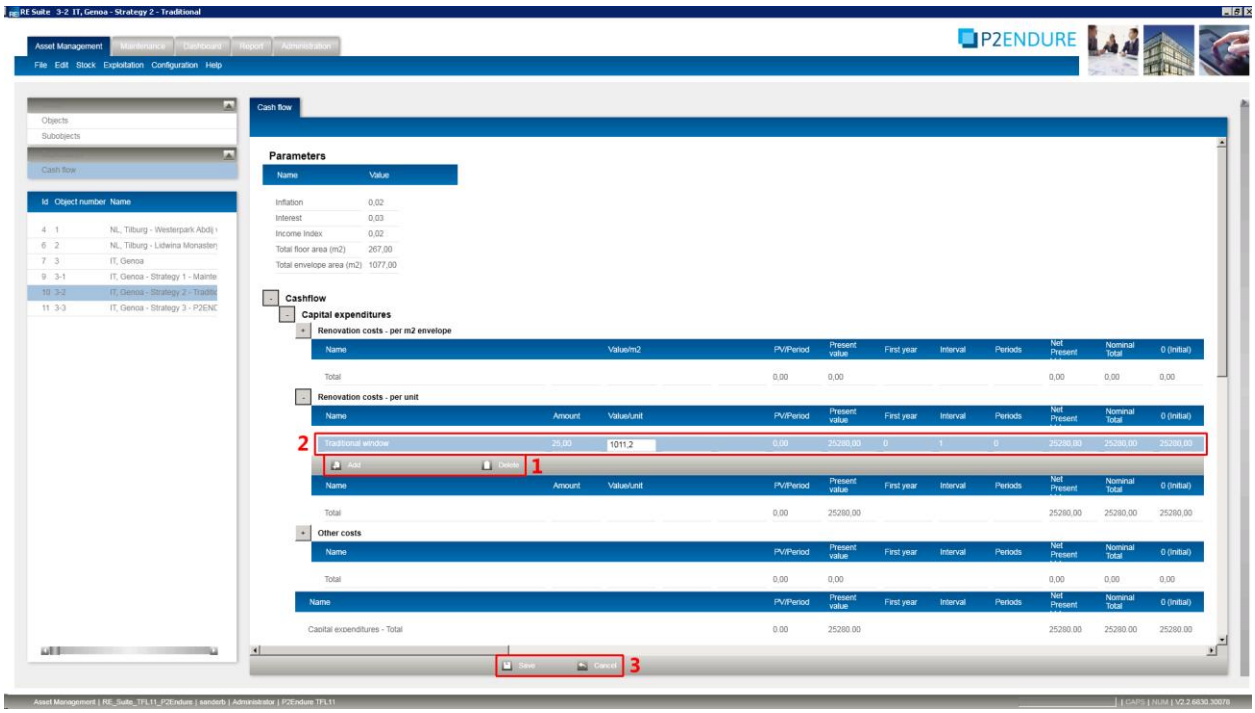


Figure 10: Editing the LCC

Once the user is in Edit-mode, he or she can:

- Add or delete entries from each branch-end of the LCC by clicking the 'Add' or 'Delete' buttons (1)
- Edit the contents of LCC-entries by modifying the field in horizontal rows. (2)
- Confirm or discard the changes made by clicking 'Save' or 'Cancel' (3)

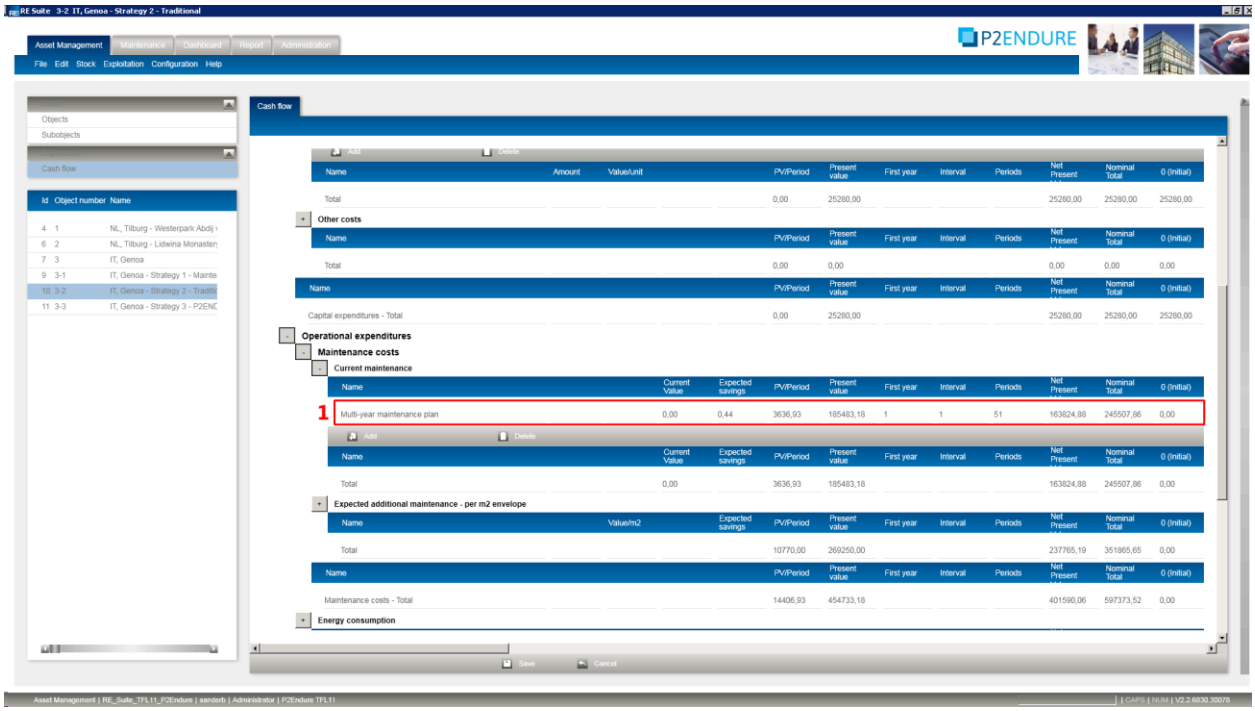


Figure 11: Maintenance costs in the LCC

In step 1 of this workflow the multi-year maintenance plan as attained in RE Maintenance was shown. The results of this MYMP serve as input for the LCC, and are automatically imported in the LCC-branch Operational Expenses > Maintenance Costs > Current Maintenance. (1) Expected savings on these costs, due to renovation measures to be undertaken in a renovation strategy can also be entered here.

4.3.4 Step 3 – RE Asset Management – Other Indicators

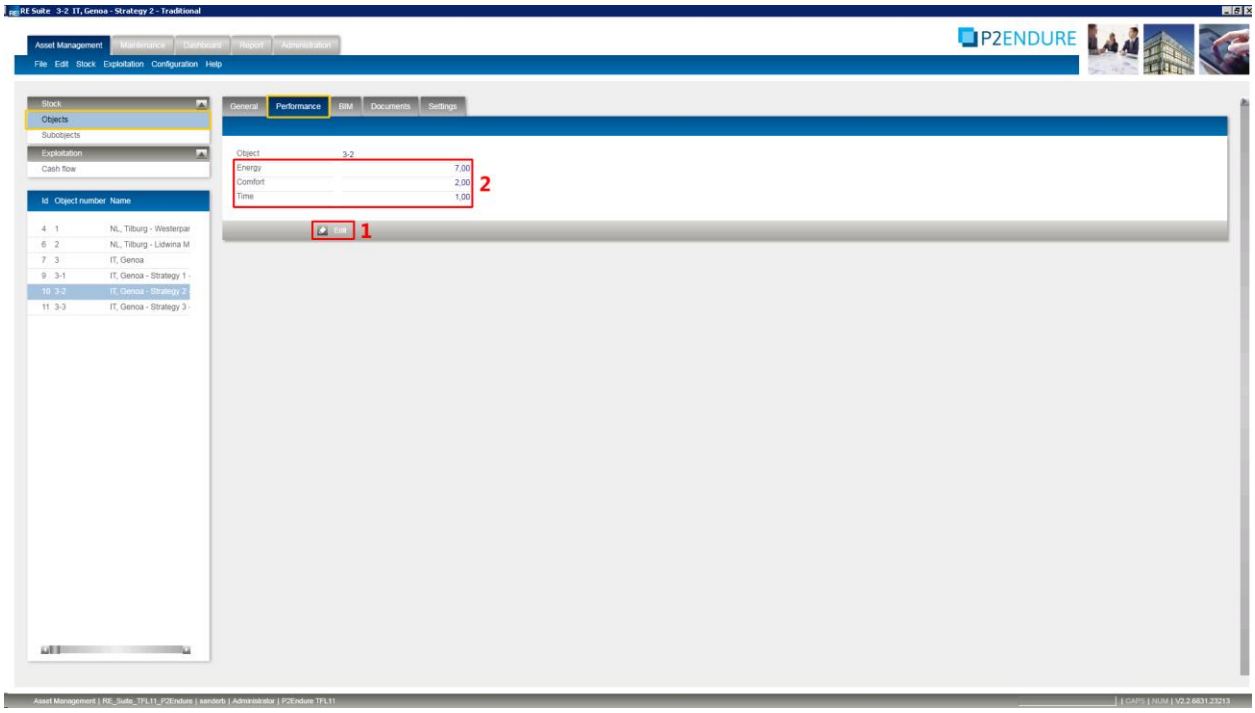


Figure 12: Other indicators in RE Asset Management

Aside from financial data and considerations, as captured in the LCC, one makes decisions on an asset management level based on multiple criteria. These other indicators, such as quality and energy performance, are not analysed by the LCC and asset management tool itself, but can instead be imported into the tool by the user.

This is done through a separate tab in RE Asset Management called 'Performance'. Once the user goes into edit-mode for an object (1), he or she can input scores for the other indicators (2).

4.3.5 Step 4 – RE Dashboard – Multi-criteria analysis

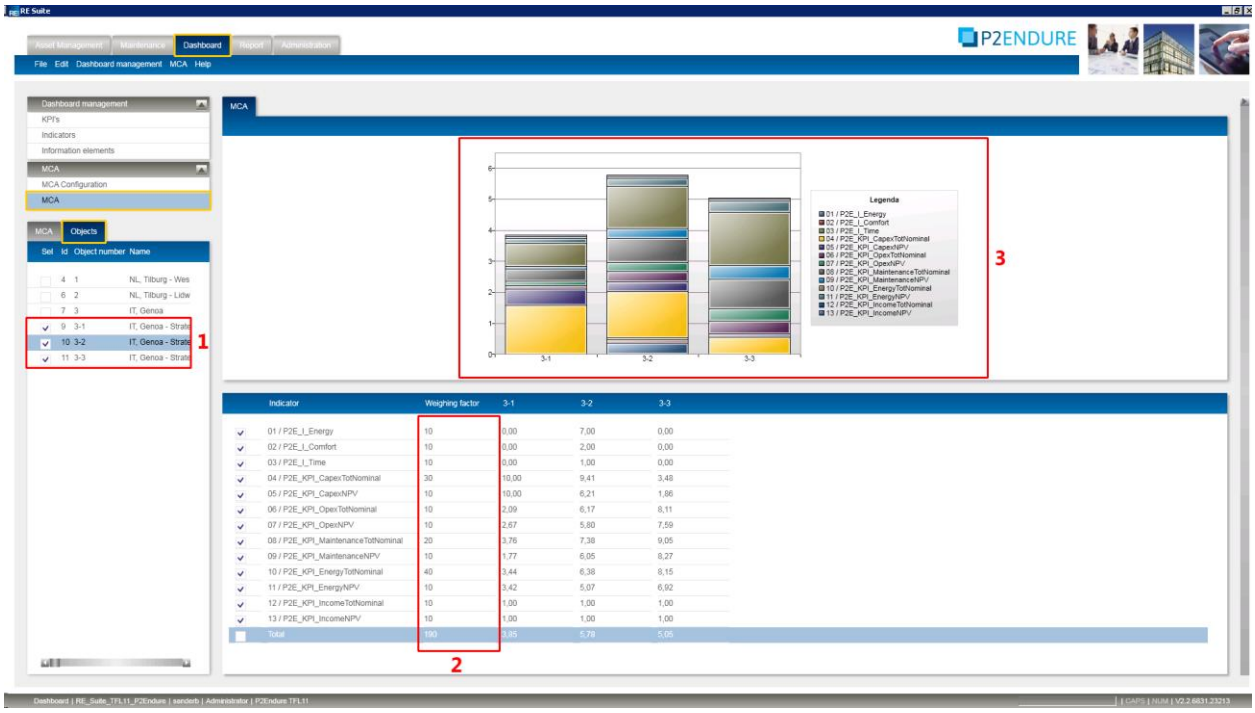


Figure 13: Multi-criteria analysis

The final step in the workflow is the LCC and asset management tool's vehicle for facilitating decision-making for the asset manager: multi-criteria analysis. This is a method of combining multiple indicators with each other to attain an overview of the best-performing strategy. For this MCA, both data from the LCC as well as scores for other indicators are incorporated.

The user can use and customize the MCA by performing the following steps:

- Selecting which strategies to incorporate in the MCA (1)
- Applying weighting factors to individual indicators. (2) For example, if energy performance is valued much more by the asset manager than financial aspects, he or she would apply a significantly higher factor to this indicator.
- Meanwhile, with every selection or change the user makes, the bar-chart (3) is updated. The strategy with the highest bar is the overall best performing alternative.

5. Conclusions

In the coming years the number of mayor retrofitting projects needs to be increased in order to meet the 20-20-20 EU energy efficiency targets in the building sector. A comprehensive overview of building or building asset's technical condition, life-cycle costs (LCC) and building energy performance is necessary for efficient planning of maintenance and renovation activities on a large-scale and in long-term in order to improve the overall condition of the asset, and therefore the building condition of the European cities, with possibly best energy performance and fastest return on investment.
Having a complete overview of the building asset, including energy monitoring and life-cycle costing helps building owners and asset managers to understand the financial benefits and opportunities that can be achieved with deep renovation and can make it possible to improve the energy performance of buildings considerably. Moreover, performing multi-criteria analysis (MCA), taking into consideration various decision criteria and chosen KPIs, is an easy way to assess, score and compare different renovation options based on the chosen solutions and different parameters.

The preceding chapters in this deliverable have shown the result of the empirical research approach adopted in the development of the P2ENDURE software tools for energy monitoring, LCC and asset management.
Both tools are available online to the consortium partners; the links and log-in details will be provided upon request. Please contact the project coordinator for more information on how to access the tools.

The functionality of the BIM Parametric Modeller to visualise potential energy performance after renovation with chosen solutions and indicating costs of the renovation strategy is operational and accessible by the consortium partners. In the coming weeks, TU Berlin will continue to develop the simulation of energy data; a process is being developed to exchange product data with the corresponding data within the BEM or CSV data sheets. Furthermore, functions for importing BEM and CSV energy data as well a database connection are also being developed.
The e-Marketplace based on the Parametric Modeller will be presented during the "Deep renovation joint workshop" organised by P2ENDURE in synergy with other H2020 projects in Rome on 5th October 2018.

By using an existing, state-of-the-art software solution by DEMO Consultants BV, which has been tested on the market, the P2ENDURE project can effectively meet the needs of the asset owners and real estate managers. Testing and demonstration based on a real pilot case have also contributed to improve the effectiveness of the newly developed prototype tool.

The possible follow up steps to improve the software's functionalities include adding additional indicators to the MCA or adding BIM-based general object content and inspection content.

The prototype tool for LCC and asset management is operational and tested on a real demonstration case. The preliminary results of the LCC analysis on the P2ENDURE demonstration cases are elaborated in the D3.3 validation report of reduced renovation cost and time. The mobile inspection tool for building condition assessment and other applications within the RE Suite software tool are described in the D2.3 deliverable report.
The methodology of performing BIM-based energy analyses of different renovation strategies with chosen innovative solutions is described in the D3.1 validation report of reduced use of net primary energy. The BIM Parametric Modeller, which allows visualising the results of the energy analyses and comparing the differences in energy performance of the buildings depending on the chosen parameters/solutions, is described in the D2.2 deliverable report.

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[4] Mendell, M. J., Eliseeva, E. A., Davies, M. M., Spears, M., Lobscheid, A., Fisk, W. J., and Apte, M. G., "Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools, Indoor Air", 2013

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P2ENDURE Deliverable report D2.3 "Mobile inspection tool for building condition assessment"; 2017

P2ENDURE Deliverable report D3.1 "Validation report of reduced use of net primary energy", 2018

P2ENDURE Deliverable report D3.3 "Validation report of reduced renovation cost and time", 2018

P2ENDURE Deliverable report D4.2 "Set-up of a database for asset management of deep renovation"; 2018

Websites:

[W1] SmartCSM, Proactive vs. Reactive Building Maintenance: https://smartcsm.com/blog/proactive-vs-reactive/

[W2] EC FP7 research project ECONADAPT (603906), "Multi-Criteria Analysis": https://econadapt-toolbox.eu/node/6/pdf

APPENDIX 1 – Example of energy data collection

An example of the collected energy data before renovation based on energy bills and audits of the demonstration case in Ancona, Italy:

	SUMMARY ANCONA DEMO CASE			COMMENTS
GENERAL INFORMATION	▪ CLIENT ORGANISATION		Erap (Ente Regionale per l'Abitazione Pubblica)	
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC		public	Social housing owned by the Municipality
	▪ RESPONSIBLE PARTNER		UNIVPM	
	▪ COUNTRY, GEOCLUSTER		Ancona, Italy	
	▪ BUILDING			
	TOTAL FLOOR AREA [M2]		6807	These values refer to the useful surface and to the heated volume
	TOTAL VOLUME [M3]		18671	
	▪ DEMO CASE			
	TOTAL FLOOR AREA [M2]		6807	
	TOTAL VOLUME [M3]		18671	
	▪ REFERENCE			
	NATIONAL ANNEX:			
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]	Due to privacy issues, it was not possible to collect real data from bills
	▪ HISTORIC ENERGY USE	N		
	ELECTRICITY			
	HEAT			
	HOT WATER			
	GAS			
	...			
	▪ ENERGY AUDIT	N		
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y		
	▪ BIM MODEL	completed		
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	N		It was possible to have a quick walkthrough only in one apartment. The features of the HVAC, lighting and power refer to that case. However, it should be quite representative of the status of the entire building.
	▪ TIME PATTERN	N		
	▪ HVAC	Y		
	▪ LIGHTING	Y		
	▪ POWER	Y		
	▪ ...			
ENERGY MODEL ASSESSMENT	SPECIFY METHODOLOGY/SOFTWARES			
	WITH BEM MODEL		WITH MANUAL TOOLS	
	The BIM model has been created using Revit 2018. The geometrical model has been exported using the Complement Open BIM for Revit (IFC standard). The BEM model has been developed using the CYPETHERM enenrgy simulation tool. Specifically, the adopted tools are: IFC Builder (geometrical check and definition of the thermal zones), CYPETHERM LOADS (definition of stratigraphy and loads), CYPETHERM HVAC (systems definition), CYPETHERM EPlus (energy simulation using EnergyPlus)		N	
ENERGY MODEL VALIDATION	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (BILLS/AUDIT) <5%	N		

Appendix 1, Figure 1/2: Example of energy data collection

ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [KWH/M2Y] — 85.8 (103.1 - 42.6)	The values written in bold refer to the whole building. The values within the brakets refer to the apartments which show the greatest and the lowest energy consumptions (n.b. the building is composed of 100 apartments with different geometry and orientations).
INTERVENTIONS	SUMMARY ANCONA DEMO CASE	COMMENTS
	DESCRIPTION — AMOUNT [nr./m2]	
	▪ 1st TECHNOLOGY	
	P2ENDURE TECHNOLOGY — Smart Windows BGTEC — 548 (windows)	The windows have been modelled with the same parameters of the SmartWIndows BGTEC (Uglass=1 W/m2K - Uframe=1.5 W/m2K - air permeability= class 4). The application refer only to the physical parameters but the BGTEC windows will not be applied in the reality.
	OTHER TECHNOLOGY	
	SAVING [%] — 30.20%	
	▪ 2nd TECHNOLOGY	
	P2ENDURE TECHNOLOGY	Five boiler supply 17 apartments while one supplies 15 apartments. The system is a condensing bioler with an efficiency of 0.97
	OTHER TECHNOLOGY — Condensing boiler serving an apartment block — 6 (boilers)	
	SAVING [%] — 32.40%	
	▪ 3rd TECHNOLOGY	
	P2ENDURE TECHNOLOGY	14 cm of exterior insulation (rookwool)
	OTHER TECHNOLOGY — Roof & exterior insulation system — ~6500 m2	
	SAVING [%] — 22.80%	
	▪ 4th TECHNOLOGY	
	P2ENDURE TECHNOLOGY	
	OTHER TECHNOLOGY	
	SAVING [%]	
FINAL COMBINATION	▪ P2ENDURE TECHNOLOGY	
	▪ OTHER TECHNOLOGY	
ENERGY CONSUMPTION POST-RENOVATION	▪ PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO — 85.8 (103.1 - 42.6)	The values written in bold refer to the whole building. The values within the brakets refer to the apartments which show the greatest and the lowest energy consumptions (n.b. the building is composed of 100 apartments with different geometry and orientations).
	▪ PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION — 27.4 (62.8 - 11)	
	▪ SAVING [%] — 68.10%	

Appendix 1, Figure 2/2: Example of energy data collection

APPENDIX 2 – Example of cost data collection

An example of the collected cost data for the existing situation and two renovation strategies: with traditional and P2ENDURE methods, of the demonstration case in genoa, Italy:

Input Data for LCC

General information

Name	Genoa demo case: Via Cialli nr 9	
Function	*Kindergarten*	
Country	*Italy*	
Year of construction	1932	
Surface/net area	*267*	*m2*
Envelope surface	*1077*	*m2 (including doors and windows)*

CAPEX

costs of the renovation

Renovation costs:	**Double glass windows (compliant with the national requirements) -**	**BGTech smart windows (25)**	**Product 2 - traditional**	**Product 2 - innovative (P2ENDURE)**	
New products	*17098*	60830	*25280*		
Materials					
Installation					
OTHER costs:	€	€	€	€	*Total amount*
Transport	€	€	€	€	*(break-down of other costs - optional)*
Disposal/removal	€	€	€	€	*(break-down of other costs - optional)*
Other (please name)	€	€	€	€	*(break-down of other costs - optional)*
Capex % (if payed in instalments	*% and no. of years*	*% and no. of years*	*% and no. of years*	*% and no. of y*	*(optional) (% of interest rate and number of years to pay back)*

OPEX

costs per X years

	Current situation	**P2E Deep renovation**	**Traditional renovation**	
Maintenance	*14 (€/m2y)*	*8 €/(m2 y)*	*10 €/(m2 y)*	*Total amount*
Windows	*€ and frequency*	*€ or % and frequency*	*€ or % and frequency*	*€/m2 or % of reduction per X years + frequency*
			energy reduction with traditional renovation is 15% based on benchmark	
Energy consumption	**€**	**€ or % of reduction**	**€ or % of reduction**	*Total amount*
Heating	*2,878 €*	*2,206.60 €*	*15%*	*€/m2 or % of reduction per year*
Electricity (exluded cooling)	*1,314 €*	*1,314 €*	*1,314 €*	*(break-down of total energy costs - optional)*
Cooling	*862 €*	*656 €*	*€ 832*	*(break-down of total energy costs - optional)*
OTHER operational costs	**€**	**€ or % of reduction**	**€ or % of reduction**	*Total amount*
Water	€	€ or %	€ or %	*€/m2 or % of reduction per year*
Rental costs	€	€ or %	€ or %	*(break-down of other operational costs - optional)*
Other (sewage)	€	€ or %	€ or %	*(break-down of other operational costs - optional)*

Revenue

costs per year

GENOA demo building is a public kinderkarten with no revenue

	Current situation
Room rent	€
Restaurant	€
Conference centre	€
Nursery/kinderkarten	€
Subsidy	€
Other (please specify)	€