Life-Cycle Cost and asset management tool

Deliverable Report D7.4

Deliverable Report: D7.4 issue date on 23 April 2023

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

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

Life-Cycle Cost and asset management tool

Deliverable Report D7.4

Issue Date	23 April 2023
Produced by	DEMO Consultants BV (DMO)
Main author	Samaneh Rezvani (DMO), Maurijn Neumann (DMO), Mija Sušnik (DMO), Maria Chiara Caruso (STRESS)
Version	Final
Reviewed by	Timo Hartmann (TUB)
Approved by	Timo Hartmann (TUB)
Type	Other

Colophon

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

Change log

Description	Author	Date
Initial version for internal review	Samaneh Rezvani	26.08.2022
Internal review	Timo Hartmann	30.08.2022
Addressing internal review comments	Samaneh Rezvani Maurijn Neumann Mija Sušnik	06.09.2022
Finale editorial review	Samaneh Rezvani	09.13.2022
Final draft	Samaneh Rezvani	09.13.2022
Addressing the comments of the reviewer	Samaneh Rezvani	23.04.2023

Publishable executive summary

Overview

It is common that for a renovation project, several renovation strategies are proposed. Before any detailed deep renovation installation and engineering work can commence, a renovation scenario needs to be selected that is convincing and acceptable for all stakeholders involved in the project. The BIM-SPEED multi-criteria decision-making tool allows different stakeholders to make a satisfactory decision based on the chosen criteria among different renovation strategies. The decision-making tool (explained in D7.1) includes a criteria framework, suggested methods to quantify the criteria, a weighting method to capture the preferences of the decision-makers over the criteria, and a raking method that enables a transparent and inclusive process to support different stakeholders to rank the different alternatives. For different renovation strategies, different KPIs will be measured. One of these KPIs that needs to be assessed is the total cost of the renovated asset over its life cycle including initial capital costs, maintenance costs, and operating costs. As such, the development of a Life Cycle Costing (LCC) tool is the focus of this report. More specifically, this report summarizes the results developed within task 7.3, i.e. a "BIM-based Lifecycle Cost and Asset Management". It is important to highlight that this report is only a supporting document to facilitate the use of RE LCC tool, which is the final deliverable of task 7.3, and as such, this report is to act as a manual for the tool. The proposed cost classification, as well as the calculation methodology used in the proposed LCC tool, is in accordance with ('NEN-ISO 15686-5:2017 En' n.d.), the Code of Practice suggested by SETAC ('Environmental Life Cycle Costing: A Code of Practice - Society of Environmental Toxicology and Chemistry' n.d.), and the LCC ontology developed in task 2.2. The proposed LCC tool is capable of extracting the relevant cost data of components and elements from the BIM-SPEED library.

This software application can be found at https://demo.demobv.nl or through the BIM-SPEED platform. The username and password can be provided upon request.

List of acronyms and abbreviations

API: Application Programming Interface
BEM: Building Energy Model
BIM: Building Information Modelling
DoA: Description of Action
EC: European Commission
EE: Energy Efficiency
EEB: Energy Efficient Buildings
GUID: Global Unique Identifier
IEQ: Indoor Environment Quality
KPI: Key Performance Indicator
LCC: Life-Cycle Costing
MET: Metabolic Equivalent of Task
UC: Use case
WP: Work Package

Definitions

LCC: Life Cycle Costing
EE: Energy Efficiency
MVVM: Model-View-ViewModel architecture for separation between presentation and business layer logic
.NET Framework: is a software framework developed by Microsoft that runs primarily on Microsoft Windows
REST API: Representational state transfer is a software architectural style that defines a set of constraints to be used for creating Web services
SQL: Structured Query Language is a domain-specific language used in programming
WPF: Windows Presentation Framework, a toolkit for producing graphical interfaces

Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Across Europe, there is a real and urgent demand for deep renovation of the existing building stock and transformation of vacant, obsolete, or vacant buildings into dwellings. Due to the enormous scale of such operations (e.g., in the case of corporate-owned housing stock) and the need for the attainment of energy efficiency goals, a systematic approach is required to inform any decision making in the process of renovation with respect to monetary and environmental consequences of the choices. However, several challenges must be overcome prior to scaling up the renovation process resulting in energy-efficient buildings. One of the challenges is the lack of tools and methods for quickly estimating the costs, benefits, and expected return on investments for each proposed renovation strategy at an early stage of decision-making. As detailed in (*Directive 2014/24/EU of The* 2014) to identify the most advantageous tender, the decision should not be only based on non-cost criteria. Qualitative criteria should therefore be accompanied by a cost-effectiveness approach such as life-cycle costing. Simple "payback time" is a quick way of evaluating the financial attractiveness of EE measures and sufficient evidence-based information on the costs and benefits (Liu, Meyer, and Hogan 2010). Moreover, one of the recent trends is the integration of building information modelling (BIM) with life cycle costing (LCC) which allows for quick and accurate automatic quantity take-off (Zuo et al. 2017) .

1.2 Developed framework

1.2.1 Life-Cycle Costing method

Life-cycle costing (LCC) is a methodology for the economic evaluation of a cost of an asset over a period of analysis. Such analysis is used for decision-making and evaluation processes through a comparison between alternatives and evaluation of different investment scenarios or through estimation of future costs for budgetary purposes and evaluation of the acceptability of an investment. Such a definition can be found in the ('NEN-ISO 15686-5:2017 En' n.d.) Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing, which is an international standard that provides requirements and guidelines for performing Life-cycle cost analysis of buildings and constructed assets. LCC can be used for new assets or major refurbishments and for planning the future use of existing assets. The LCC analysis normally gives insight into the following questions:

- Will the future expenses for maintenance and management considering the capital cost related to a renovation investment be in balance with the rental benefits?
- If there is not a good cost/benefit balance will that then be compensated by an increased market value?
- Is a renovation investment needed and what will the effect be on the future market value by the end of the life cycle taken into account?

- Will the quality of the real estate stay on a level, during the life cycle, which can facilitate refinance of the outstanding loans?
- Is it worthwhile to invest or better to just maintain? Is it better to sell now or to wait and do that later?

Costs that should be included in the LCC are construction, operation, maintenance, and end-of-life costs. The typical scope of costs for each category is shown in Figure 1.

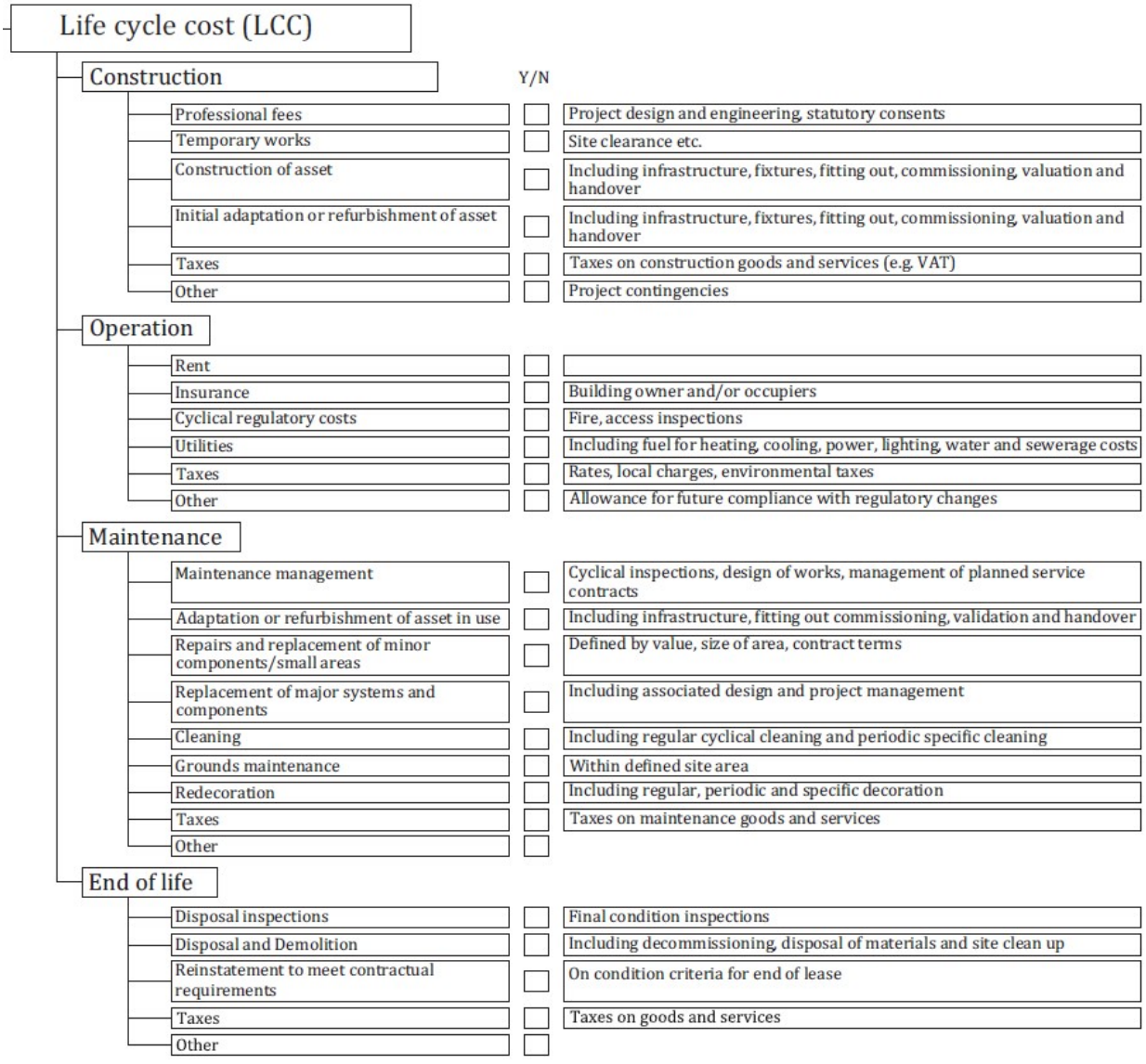


Figure 1 Typical scope of LCC costs

Due to the uncertainty of the future, the cost should be expressed in real values (the value of something after accounting for inflation) and not in the value in the current situation (nominal cost). The design life of the constructed asset and the time profile of when the cost occurs or reoccurs should be determined as well. Cost values can be derived from a direct estimation of known costs, historical data analysis of typical

applications (e.g., bills of quantities), models based on expected performance, or best guesses of future trends in technology, market, and application.
LCC analysis can be performed during different stages of the life cycle of the construction asset, namely in the project investment and planning phase, the design and construction phase, the occupation phase, or the disposal phase. Based on the level of available information, the LCC analysis can be performed at a coarse level, using benchmarking figures, or at a detailed level, using specific estimates or predictions. The benchmark analysis can be based on the functional unit or total area of the asset, while detailed analysis shall be based on the proposed design detailing and a quantum of individual elements. The LCC calculation requires some assumptions about the future, such as discount rates, the period of analysis, and information about the service life or maintenance, repair and replacement cycles, or costs. The range of uncertainty and risks regarding the LCC analysis can be assessed using the Monte Carlo method or the sensitivity analysis.

To compare different alternatives over a defined period of time, the present value should be used, which represents the present monetary sum that should be allocated for future expenditures on an asset. It is calculated by discounting future cash flows to the base date.
The net present value (NPV) is a single figure that can be used to compare different alternatives for informed decision-making.

$$NPV = \sum (C_n \times q) = \sum_{n=1}^{p} \frac{C_n}{(1+d)^n}$$

Where:

Cn is the cost in year n

q is the discount factor

d is the expected real discount rate per annum

n is the number of years between the base date and the occurrence of the cost

p is the period of analysis

1.2.2 LCC purpose

The main purpose of using LCC in the BIM-SPEED project is to assess the cost performance of a renovation strategy and eventually compare alternatives. In principle, the LCC analysis can be applied to different stages of the life cycle of an asset, however, as shown in Figure 2, the potential for value improvement is much greater in the planning stage compared to other stages. Up to 80 % of the operation, maintenance, and replacement costs of a building can be influenced by the first 20 % of the design and planning process. ('NEN-ISO 15686-5:2017 En' n.d.)

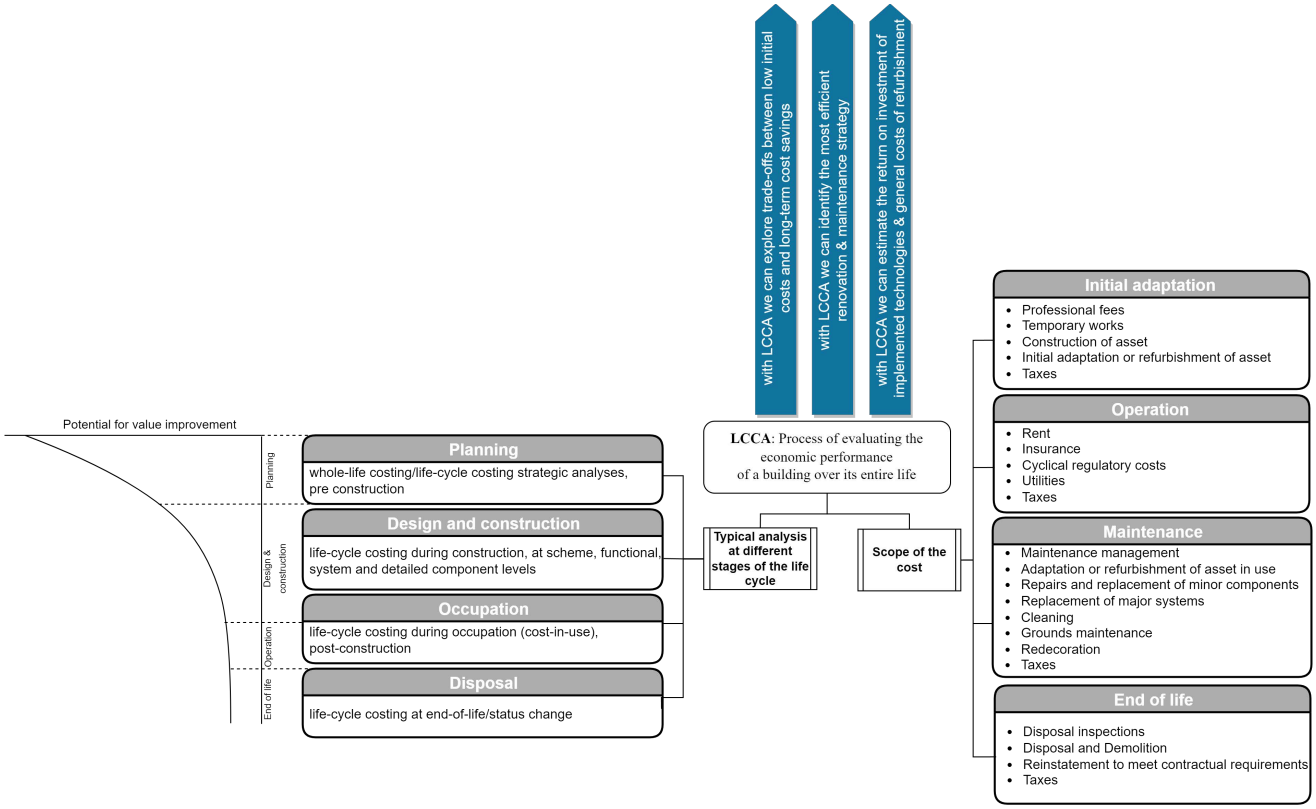


Figure 2: Different scopes and the extent to which they influence LCC savings over time based on NEN-ISO 15686-5

1.3 LCC Components & Categories

Figure 3 describes a generic cost classification that may be used to define the specific scope of the analysis, providing a structured base. The proposed structure has been used as a template in the proposed LCC tool, however, the system allows the user to delete or add categories or sub-categories as some additional or different costs can be required for certain projects. The costs are mainly divided into two categories:

- Capital expenses (CAPEX), consist of:
  _ Construction costs per m2 envelope (e.g. façade panels) or costs per unit (e.g. number of windows)
  _ Other costs (e.g. costs of transportation, disposal, and removal)
- Operational expenses (OPEX), consist of:
  _ Current maintenance (building-related running costs)
  _ Operation costs (e.g. costs of heating, electricity)

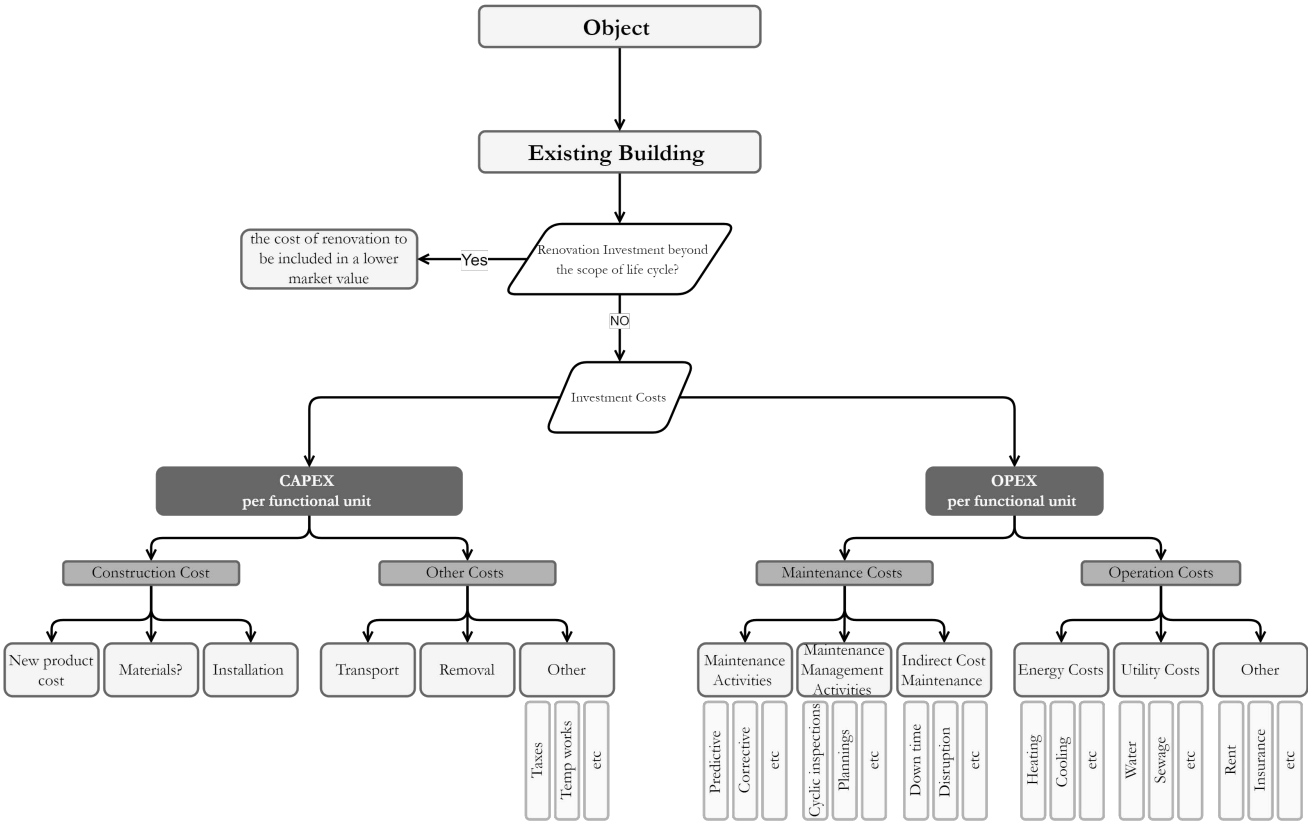


Figure 3: Typical cost classification based on NEN-ISO 15686-5

The other two important cost variables are the following that need to be considered for the calculation:

- The inflation rate, price increase rate, and discount rate
- The discount rate is often related to the Euribor rate plus a risk commission

1.4 Interaction with other BIM-SPEED tasks

The development of the LCC was linked to a few other tasks and activities, namely the multi-criteria decision-making, the LCC ontology, and the BIM_SPEED product database as shown in Figure 4. The required cost parameters both in the LCC tool and product database were informed by the developed ontology in deliverable 2.2 "BIM Family ontologies for materials, components, HVAC equipment in renovation". The products in the database contain Life Cycle Costing data which can be then used by the LCC tool for net present value calculations. The result from the tool can be regarded as a cost KPI which can be used as one criterion in the decision-making tool for choosing the optimum solution.

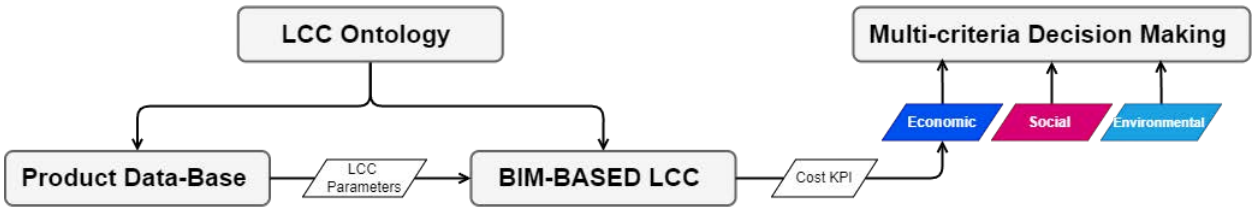


Figure 4: The link between the LCC and other tasks in the BIM_SPEED project

1.4.1 BIM_SPEED decision-making tool

The multicriteria decision-making tool developed in the BIM-SPEED project takes different qualitative and quantitative key performance indicators into account to identify the optimum renovation strategy. The decision-making framework proposed in BIM-SPEED follows the following steps:

- Chose the most important objectives (sub-criteria) from the economic, environmental, and social criteria to assess the performance
- Assign weights to the selected sub-criteria
- Quantify the performance of each renovation strategy according to the selected criteria
- Rank the alternatives according to the criteria and weights

As seen in the criteria tree (Figure 5), the economic aspect is one of the decision factors. To quantify the performance of different renovation strategies, a BIM-based LCC is used.

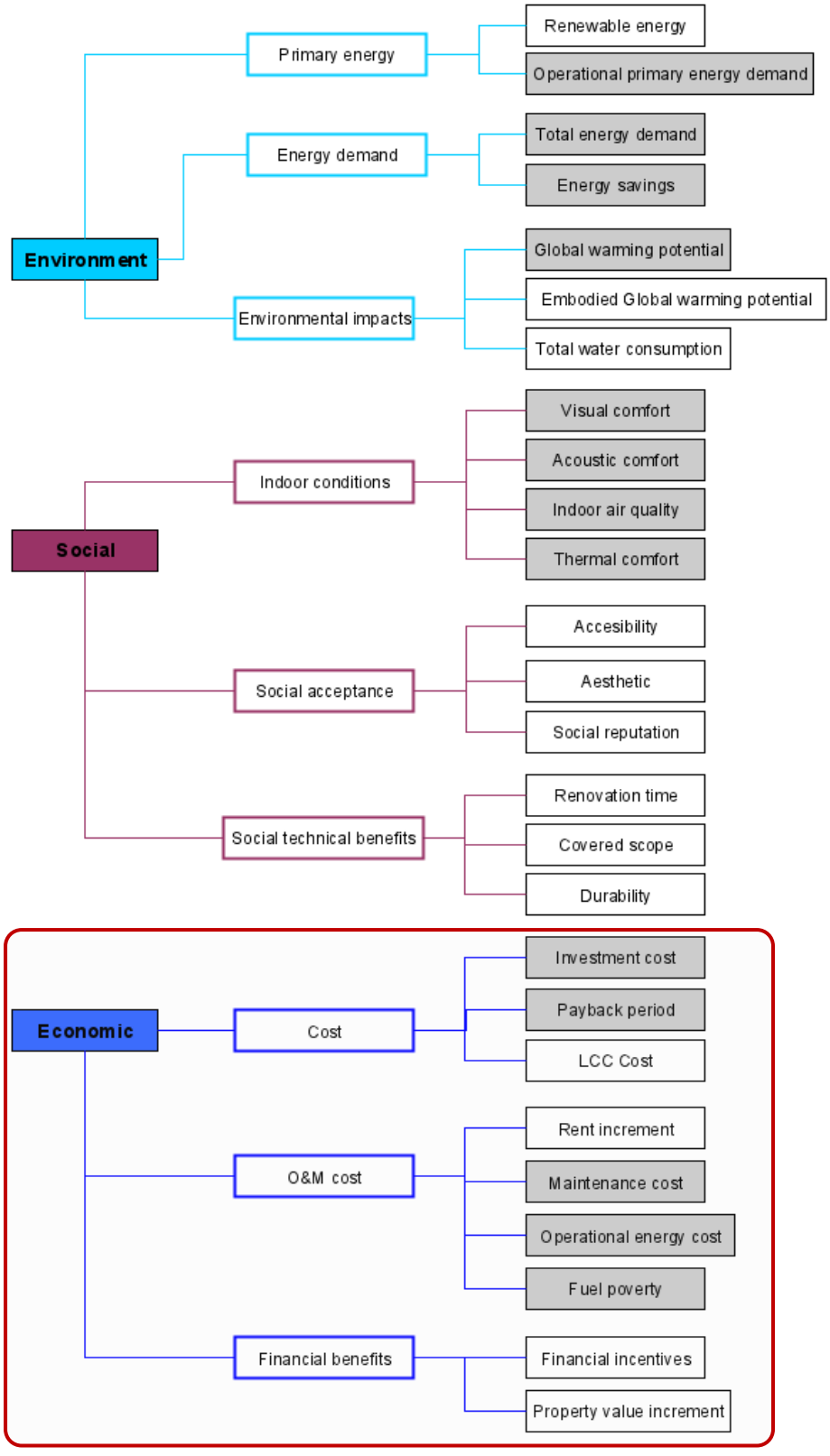


Figure 5: positions this tool well in the overall assessment structure.

1.4.2 Product database and their LCC data

Within the BIM-SPEED Project, a database of building components for deep renovation has been developed to support the renovation design (see Figure 6). The components categories included in the database have been selected as the ones that can provide a contribution to the reduction of overall energy consumption and/or to an enhanced environmental and economic sustainability.

The categories are listed in Table 1, whilst the list of typologies for each category is listed in Table 2.

Table 1: List of components included in the BIMSPEED database

Group	Building Component - Category
Envelope	Material Panel/Roll Facade Ventilated facade Ventilated roof Window/Door
HVAC	Water Heating System Air/Water Conditioning System Small VRF Multisplit Ventilation
DHW	Domestic Hot Water

Table 2: List of Types for all the building components categories

Category	Type
Material	Thermal insulation Acoustic insulation Thermo-acoustic insulation
Panel/Roll	Thermal insulation Acoustic insulation Thermo-acoustic insulation
Facade	Thermal insulation Thermo-acoustic insulation
Ventilated facade	Thermal insulation Thermo-acoustic insulation
Ventilated roof	Thermal insulation Thermo-acoustic insulation
Windows/Doors	Side hung (1 door) Side hung (2 doors) Side hung (n doors) Sliding (1 door) Sliding (n doors)

	Top hung Tilt and turn Pivot vertical Pivot horizontal
Water Heating System	Gas boiler Electric boiler Biomass stove

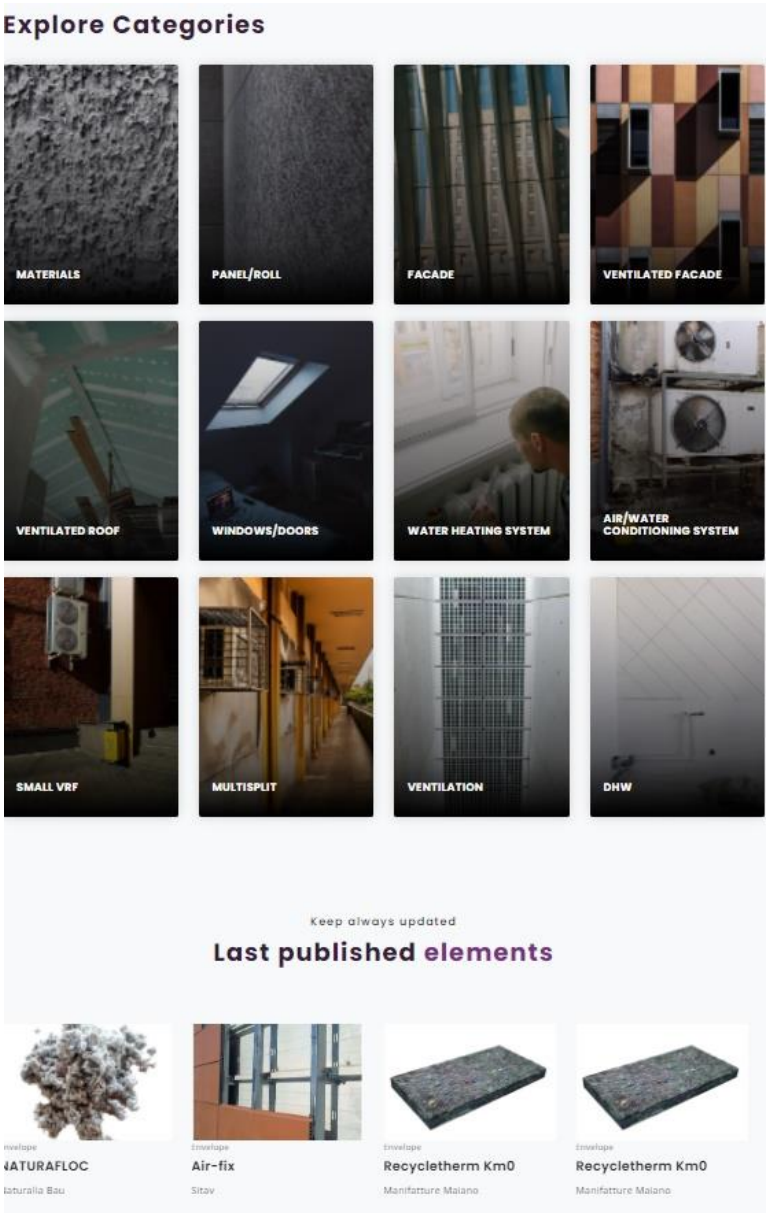


Figure 6: Home page of the BIMSPEED library web portal – www.bimspeedlibrary.com

1.4.3 LCC data of the BIMSPEED library objects

As previously discussed, the objects included in the BIMSPEED library have a list of parameters that gives generic and specific information about the product and its energy and sustainability characteristics. If a new element is added to the library, the user is asked to fill in the wizard procedure of the BIM-SPEED library as shown in Figure 7.

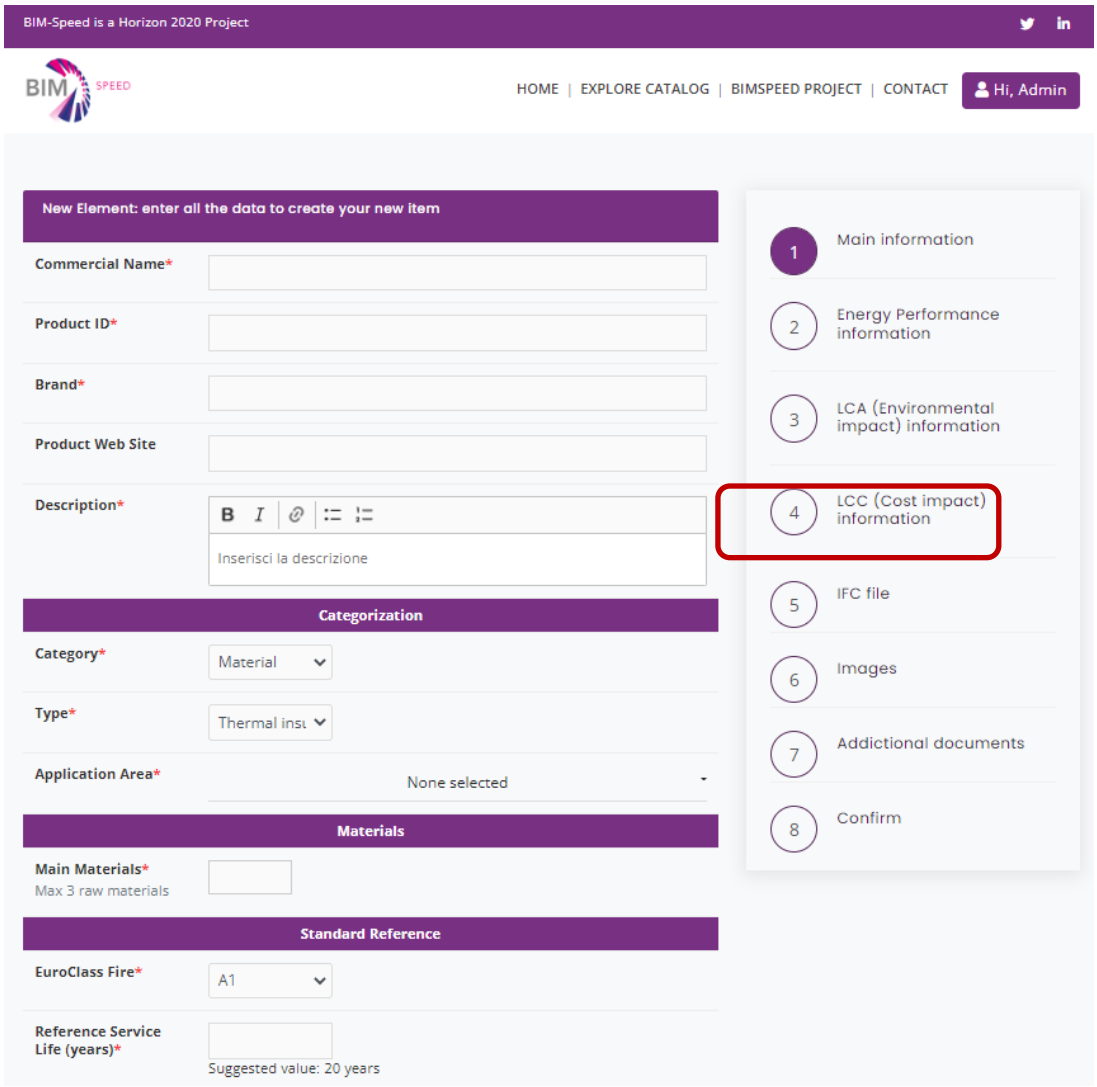


Figure 7: Procedure to create a new element

Step 4 of the wizard procedure is related to the Life Cycle Costing data.

The sustainability package collects the environmental and economic impacts of the building components considering the stages of their life cycle. In particular, the life cycle stages are related to the ('NEN-EN 15804:2012+A1:2013 En' n.d.), which classifies the building product lifetime into four main modules:

- Modules A1-A3 (Production stage), i.e., the extraction and production of the raw materials, the transport to the manufacturing site, and the product manufacturing;
- Modules A4-A5 (Construction stage), i.e., the transport to the installation/construction site and the product installation;

- Modules B1-B7 (Use stage), i.e., all the operations that can happen during the product use, such as maintenance, replacement, rand epair;
- Modules C1-C4 (End of Life stage), i.e., all the operations related to the product End of Life, such as deconstruction, waste processing,

In the LCC package, the information is related to the economic impacts generated during the Production (A1-A3), the Construction (A4-A5), and the Use (B1-B7) stages. In fact, the cost data information is defined based on the LCC ontology (see Figure 8) developed in deliverable 2.2 "BIM Family ontologies for materials, components, HVAC equipment in renovation projects". Table 3 shows the list of the LCC parameters to be included in the BIM-SPEED library. It can be noticed that the list differs for the envelope and HVAC/DHW categories because additional cost info is collected, i.e., the energy cost. Figure 9 shows the procedure for adding the LCC parameters of the BIM object in the web portal.

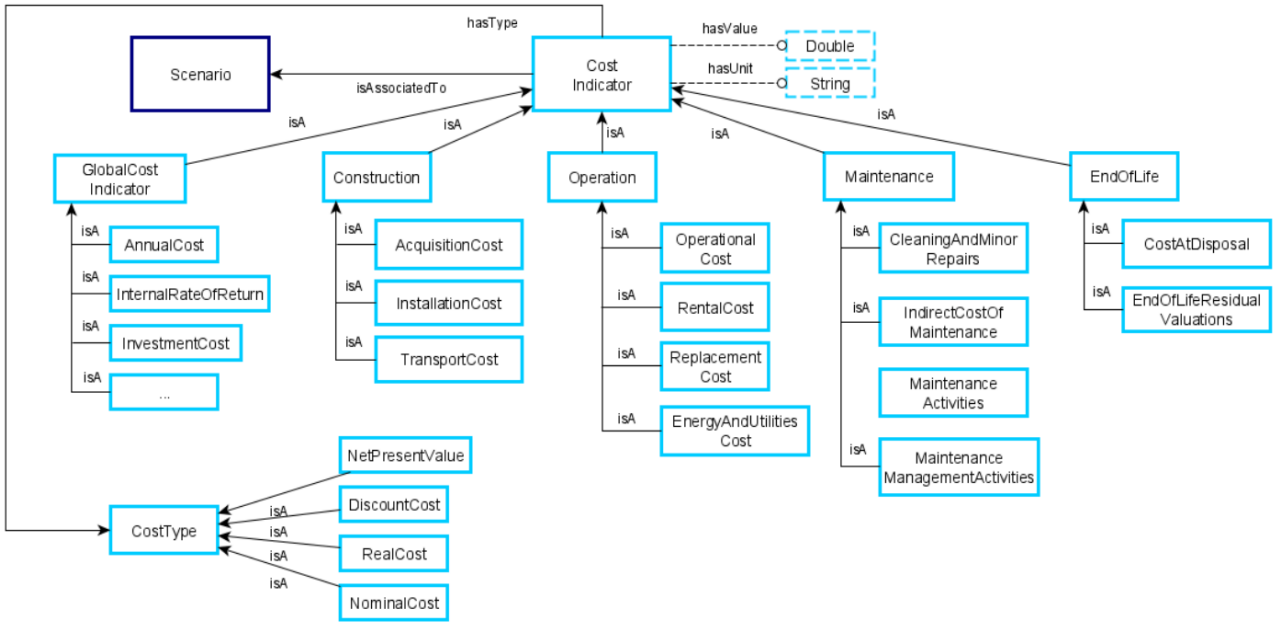


Figure 8: Cost Indicator class as defined in D 2.2

Table 3: List of LCC parameters for all the building components categories

Category	LCC parameters
Material Panel/Roll Façade Ventilated façade Ventilated roof	Functional Unit Price Construction/ Installation Costs Maintenance Costs in RSL
Water Heating System Air/Water Conditioning System Small VRF Multisplit Ventilation Domestic Hot Water	Functional Unit Price Construction/ Installation Costs Maintenance Costs in RSL Operational Energy Costs

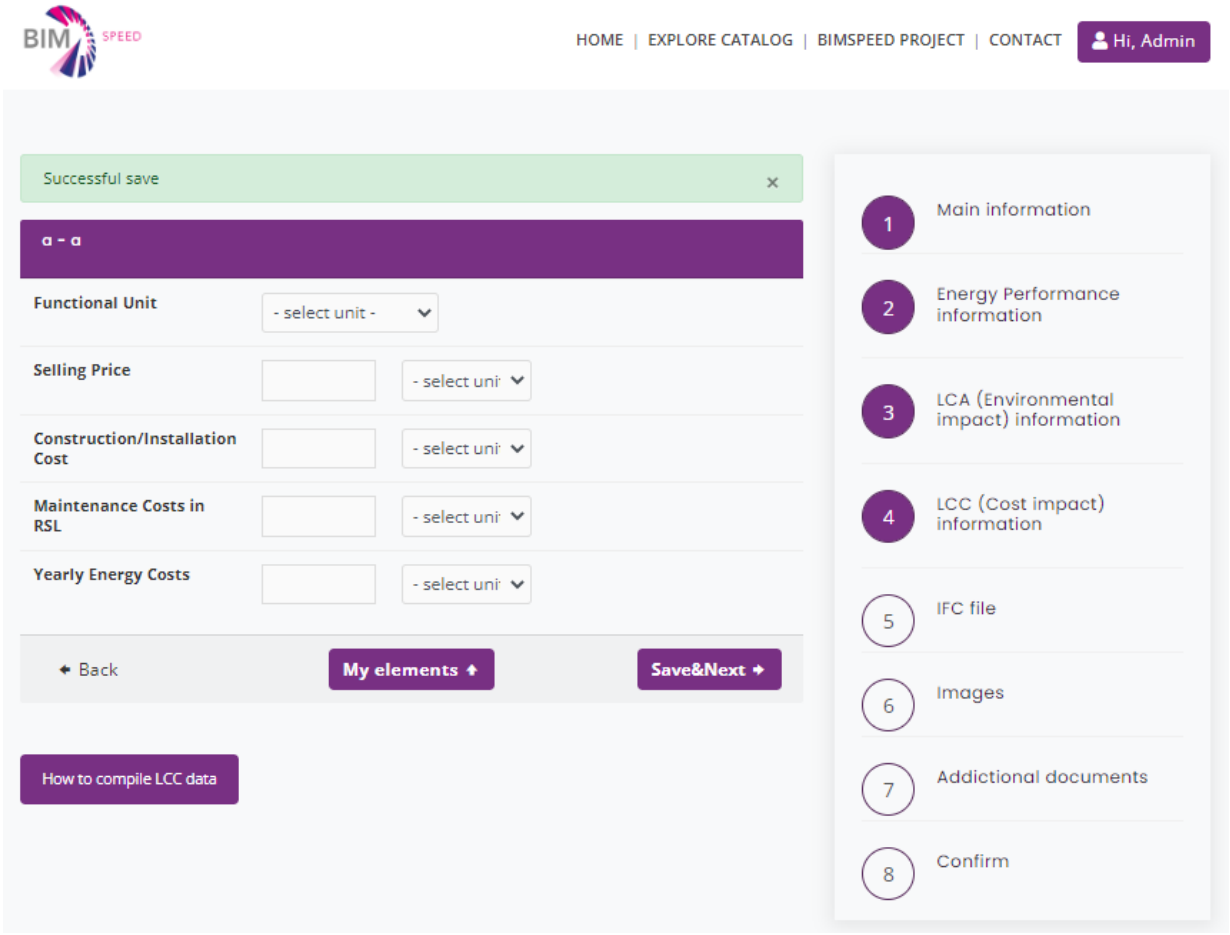


Figure 9: Wizard procedure for adding the LCC data (example for an HVAC of DHW object)

1.4.4 How to compile LCC data

The data included in the LCC package give information on the economic impacts generated by one functional unit of the building component. As discussed above, the data to be collected are Selling price, Construction/Installation Cost, Yearly Maintenance Costs, and Yearly Energy Costs. The costs are in euros (€) and are referred to one unit of building component (e.g., 1 component, 1 m^2 of the component, 1 m^3 of the component, others).

The data needs to be provided by the producer, given that materials, installation procedures, and durability of the components strictly affect the costs.

Nevertheless, the aim of the database is also to give generic and initial information on the sustainability behavior of renovation design, therefore, in case the LCC data are not available, some suggestions are given for the installation, maintenance, and energy costs. It is important to note that the costs should be country specific. In case this is not available a relevant co-efficient should be considered.

Due to the vastness of materials and their combinations, and the market policies, the selling price must always be provided by the producer.

Installation costs

In case the installation costs cannot be provided by the producer, a suggestion is given hereafter.

Installation costs can be obtained as a percentage of the selling price, according to the indication given by the construction sector price lists.

To this end, a study has been performed to extract the installation cost percentages referred to as the selling price from the price lists of two different Italian regions.[1] The following data have been extracted for the BIMSPEED library categories.

Table 4: Suggestions for the compilation of installation costs for each BIMSPEED library category (N/A= Not Available)

Category	Installation cost as % of selling price
Materials	25% (thermo-insulation plaster)
Insulation panels/rolls	18% (roofs) 24% (internal/external walls) 17% (basement) 23% (slab) **An average of 20% could be used if the application area is unknown or generic**
Facades (ETICS)	35%
Ventilated facades	24%
Windows	10%
Doors	8%
Water Heating System	N/A
Air/Water Conditioning System	N/A
Small VRF	N/A
Multisplit	N/A
Ventilation	N/A
Domestic Hot Water	11%

In case maintenance costs cannot be provided by the producer, a suggestion is given hereafter. Yearly maintenance costs can be derived as a percentage of the investment, i.e., selling price + installation costs. The percentages are derived by the European standard (UNE EN 15459-1:2018 n.d.) and confirmed by a literature review. In the case of ventilation, the data are extracted from the literature. The following data have been extracted for the BIMSPEED library types:

[1] Lavori Pubblici e Protezione Civile Regione Campania Lavori Pubblici e Protezione Civile Regione Campania and regione.lombardia.it

Table 5: Suggestions for the compilation of yearly maintenance costs for each BIMSPEED library category (N/A= Not Available)

Component	Yearly Maintenance cost as % of investment cost	
Materials	0%	
Insulation panels/rolls	0%	
Facades (ETICS)	0%	
Ventilated facades	0%	
Windows	1 %	wood
	0,5 %	aluminum
Doors	0%	
Water Heating System	1,5 %	Gas boiler
	1,5 %	Electric boiler
	N/A	Biomass stove
Air/Water Conditioning System	3%	Heat pump
	N/A	Geothermal
Small VRF	3%	Heat pump
	N/A	Geothermal
Multisplit	3%	Heat pump
	N/A	Geothermal
Ventilation	2,5%	Passive
		Controlled
Domestic Hot Water	3%	Heat Pump
	1,5%	Boiler

It should be noticed that an indication is missing for the biomass stove and the geothermal systems since these technologies are quite new.

Yearly energy costs

In the present section, a suggestion for energy costs generated by the annual use of the building component is given in case this data cannot be provided by the producer.

Energy costs include the costs of the yearly consumption of electricity or natural gas. If the component does not use electricity or natural gas sources or they are only used for powering the system, the annual operating costs will be null or incomplete.

Among the technical sheets of the HVAC or DHW systems, indications are often provided in terms of energy consumption (in kWh/year, in kWh, in J, or similar). In some cases, this value is provided in the Energy Label.

Starting from this consumption, the yearly energy costs are evaluated as follows:

$$Annual\ Energy\ cost = Cost\ of\ the\ energy * annual\ energy\ consumption$$

In particular:

- if the energy source is electricity, the cost of the energy is provided at the link https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_household_consumers and the data for Euro Area (EA) is considered, being equal to 0.2322 €/kWh in first half of 2021;
- If the energy source is natural gas, the cost of the energy is provided at the link https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics and the data for EA is considered, being equal to 0.0681 €/kWh in first half of 2021.

Some cases occur and are not limited to the following:

a) In the case of systems for ventilation, the energy consumption can be provided per m2 of ventilated surface. If this happens, a hypothesis of 100 m2 is made;
b) In case the electric consumption is provided in W, a hypothesis of 7 hours per day for 5 months (152 days/year) use can be made2;
c) In case the components use both electricity and natural gas, they both need to be quantified in economic terms;
d) When no information on consumption is provided, this value cannot be given.

Finally, it should be noted that the procedure for suggesting the life cycle costs are referred to new construction and, therefore, they do not include the costs for the demolition of existing components.

[2] Laskari, M., de Masi, R. F., Karatasou, S., Santamouris, M., & Assimakopoulos, M. N. (2022). On the impact of user behaviour on heating energy consumption and indoor temperature in residential buildings. Energy and Buildings, 255, 111657 suggests a heating operation timing related to several user typologies. An average value is considered.

2. LCC and asset management tool

To combine disparate BIM-based elements and available project resources in LCC analysis a tool was developed for the BIM-SPEED project. This chapter details the conceptualization, design, and functional description of the tool.

2.1 Life-cycle costing

Life-cycle costing (LCC) is a financial analysis and decision-making tool. It aims at calculating the effects of a proposed strategy on expenses and incomes over time as well as the required investment at the current point in time.

An LCC can help decide if a proposed long-term investment strategy is financially healthy. By comparing different scenarios (i.e., differing inflation and interest rates) and different strategies (i.e. different expenses and cost-spreading over time) LCC can help determine the most acceptable risk range and return rates.

At its most basic, an LCC is a tabular view of expenses over time (Figure 10). By specifying individual expenses with their recurrence rates (red) the financial impact can be projected onto individual years from left to right considering expected inflation (yellow). Summing this from top to bottom for each individual year yields an expected total investment per year (green).

Summing the projected expenses from right to left yields the nominal total. Considering expected interest for an investment a right-to-left calculation yields the net present value (NPV). (blue)

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

R_t = cash inflow-outflows during a single period

i = discount rate or return that could be earned in an alternative investment in (per same period)

n =number of time periods

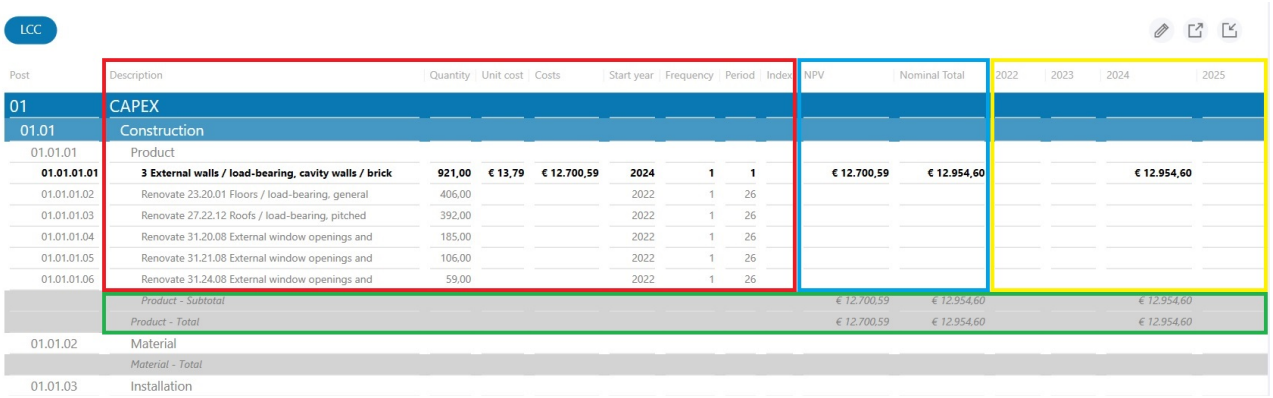


Figure 10: Tabular LCC with areas for data entry (red), projection over time (yellow), reduction for investment (blue), and summation of totals (green).

Similarly, (recurring) benefits, combined with an expected income index yields expected returns over time.

A cumulative total is computed over the expected projections for all expenses occurring from the start of the LCC calculation until period *t*. This figure is typically graphed over time in a bathtub model curve. (Figure 11)

$$CumulativeTotal(t) = \sum_{i=0}^{t}\sum_{j=0}^{n} R_{ij}$$

t = time period

n = number of line items

R_{ij} = cash inflow-outflow in period i for line item j

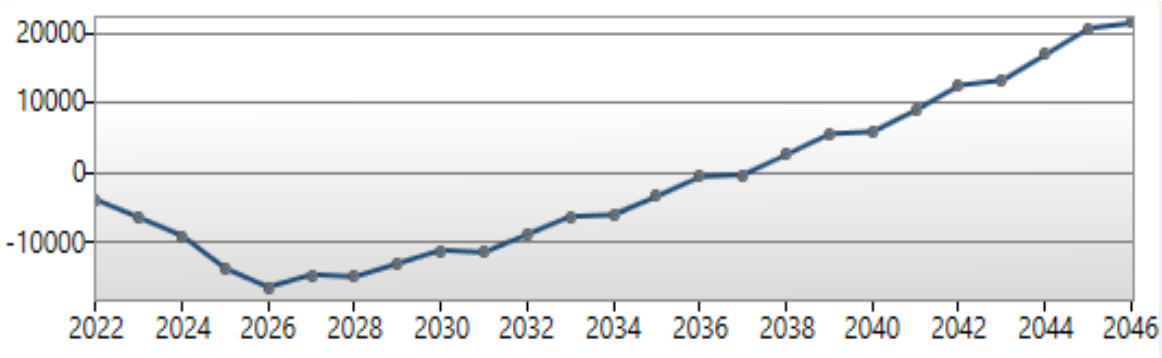


Figure 11: Example graph of cumulative total of LCC

Together this view of expenses and incomes yields insight into the complete financial evolution of an investment strategy. By analysing metrics such as peak expense timeframes, return-on-investment rates, time to break even, and robustness to various inflation/interest scenarios an investor can decide if the proposed strategy is financially healthy or not.

2.2 Tool design

2.2.1 Requirement elicitation

For a BIM-based LCC requirements elicitation identified the following functionalities

1. Create/manage/delete LCC entities
2. Relate LCC to real-estate object
3. View tabular LCC
4. Add/remove rows to/from an LCC table
5. Specify recurring incomes/expenses
6. Specify amount and unit cost
7. Compute yearly projections, nominal total, and net present value for rows
8. Compute totals and cumulative total
9. Organise LCC rows into hierarchical categories
10. Export LCC table
11. Graph cumulative total
12. Filter BIM-model on renovation options

13. Import LCC line items from BIM-model
14. Fill out unit cost information from BIM-SPEED database

2.2.2 Architecture design

The LCC is implemented as additional functionality in the existing RE Suite application RE Asset Management. As such the tool makes use of pre-existing .NET Framework WPF components and available SQL database architecture.

The LCC-components are set up in a Model-View-ViewModel (MVVM) architecture, with the following five main components:

- **LCCView,** the user interface responsible for the presentation of data and forwarding of interaction
- **LCCViewModel,** the backing logic for the view and main hub of LCC-processes
- **LCCModel**, a virtual data model encapsulating a single LCC
- **LCCStorage**, responsible for translation and persisting of the model towards a database
- **LCCCalculator**, applies relevant LCC formulas to fill out the model

An example of the basic load, edit, and save interaction logic between these components is depicted in a UML Sequence diagram. (Figure 13). This architecture is backed by a data model defining the five most important data entities and their interrelations (Figure 12):

- **Objects**, representing real-estate objects
- **LCCEntity**, a singular LCC and its configuration parameters, related to an object
- **LCCCategory**, a (nested) hierarchical named grouping within an LCCEntity
- **LCCData**, a line item, either a child of a category or the entity itself.
- **IFCRelation**, a representation of a relation between an LCC line item and an element in an IFC BIM-model.

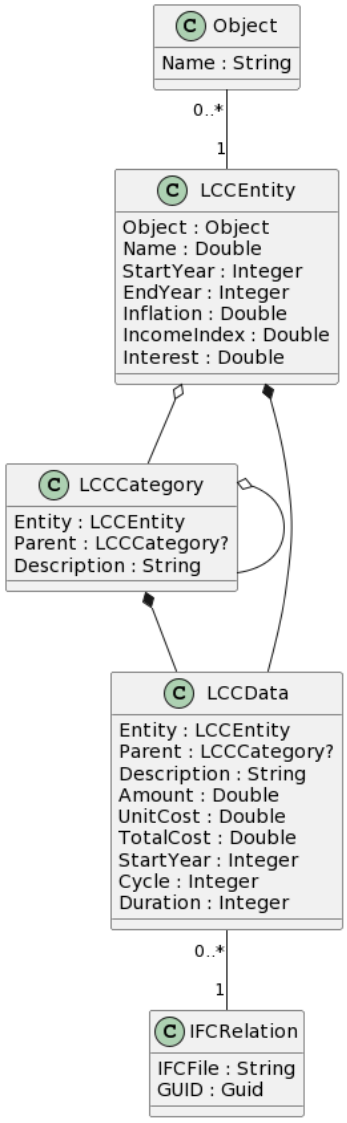


Figure 12: LCC data model

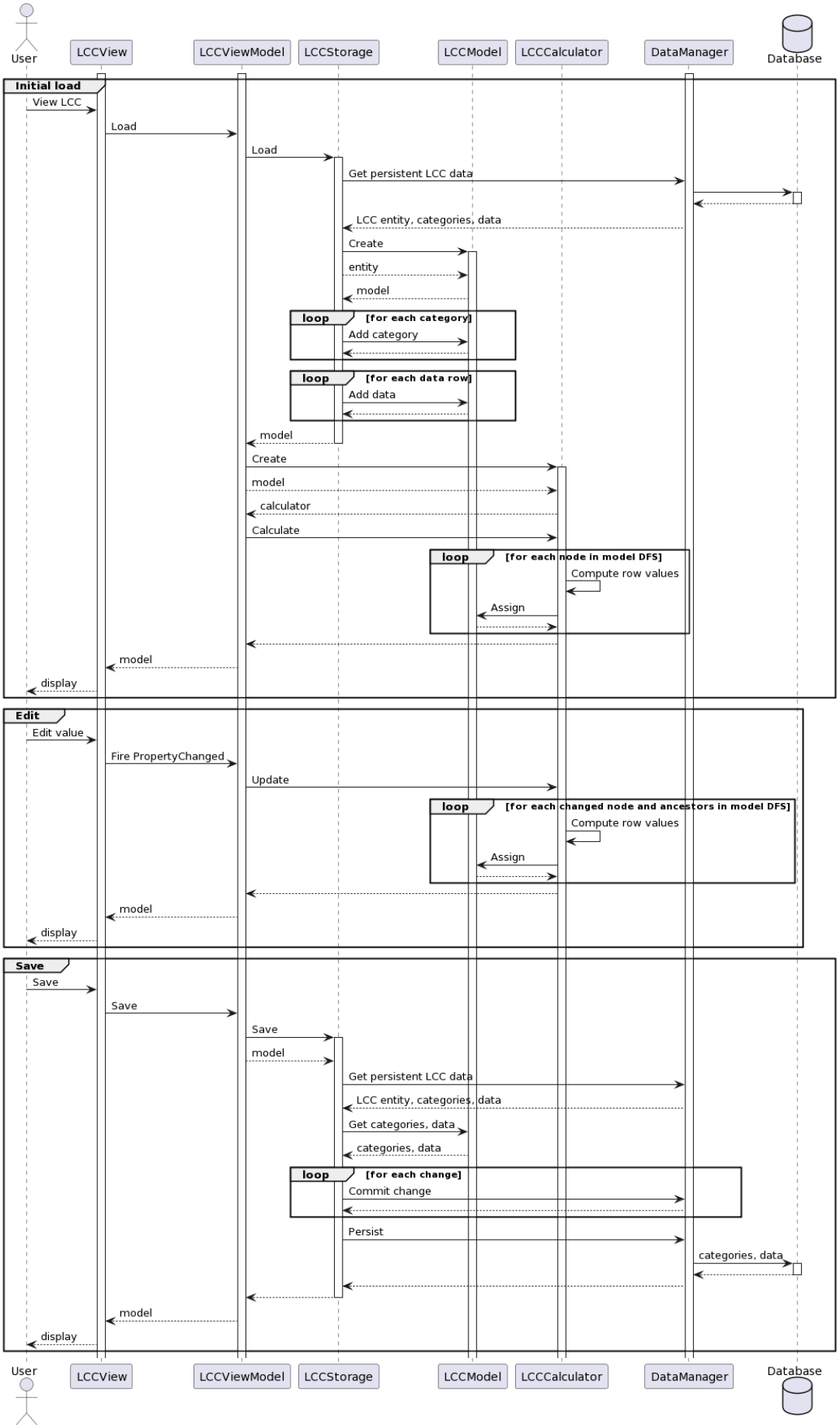


Figure 13: UML Sequence diagram of interaction between LCC tool components

2.3 Functionality

All LCC functionality is integrated in the RE Suite. The tool can be accessed with any web browser by visiting https://demo.demobv.nl and logging in using provided credentials (Figure 14, left**Error! Reference source not found.**).

The RE Suite is composed of various applications, accessible through the application navigator (Figure 14, right). This navigator opens on startup, or by clicking the top button in the process navigator later.

In general, the RE Suite has a three-column layout (Figure 15). On the left is the dark blue process navigator where a general area of work is defined. Every application has its own processes. For example, everything related to LCCs occurs in the application RE Asset Management, within the process LCC.

To the right of the process is the object navigator which consists of a list of contextual data entities relevant to the current process. For example, the process LCC can show a list of available LCCs in the object navigator. By selecting one, its contents are displayed in the third and largest area: the working area.

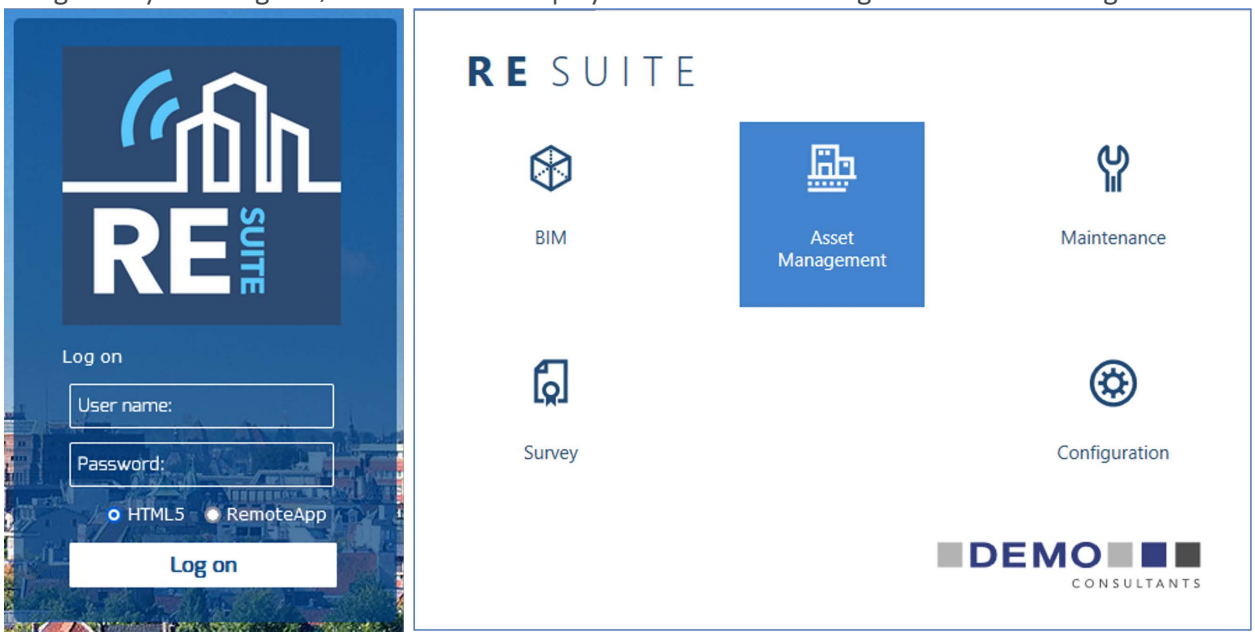


Figure 14: Login to RE Suite (left), Application navigator (Right)

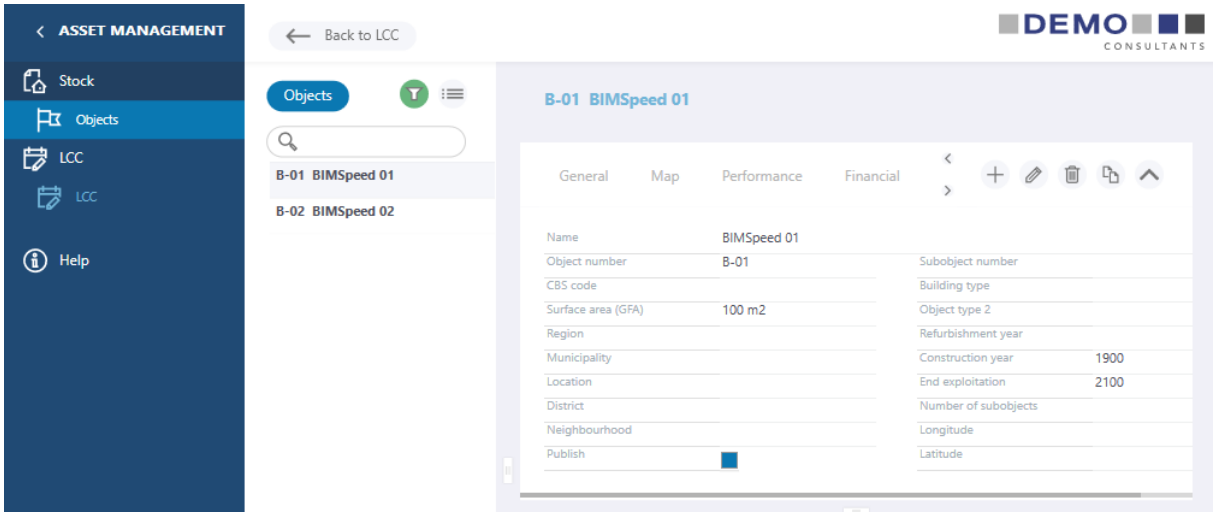


Figure 15: RE Suite general layout of process navigator (left), object navigator (middle) and working area (right)

2.3.1 Integration BIM_Speed platform and RE Suite

A bidirectional connection between the BIMSpeed platform and the RE Suite has been established. Users can navigate between the two platforms, and exchange data between them. When a user is on the BIMSpeed platform, it is possible to reach the RE Suite through the User Interface of the BIMSpeed platform. There are two ways to do this:

1 - Through External Services: As shown in Figure 16, RE Suite is always accessible through 'External Services', which can be reached by clicking the External Services button on the top of any project homepage. If the user clicks on 'Go to the service', the service is triggered.

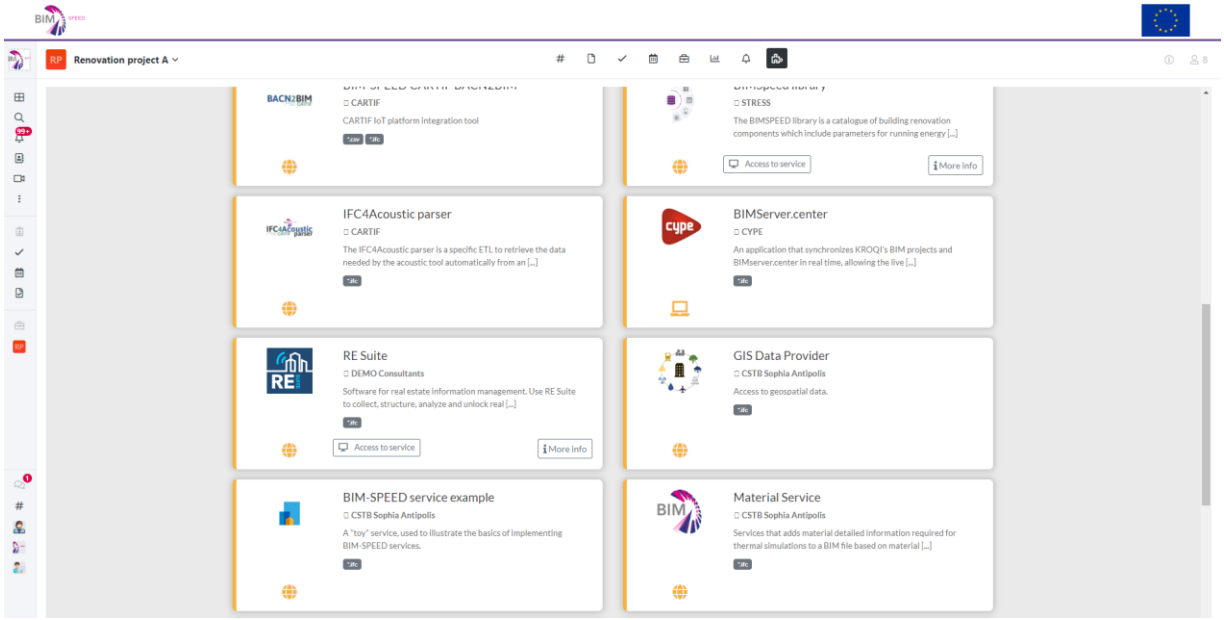


Figure 16: The External Services page with the RE Suite tile

2 - Through IFC's: As shown in Figure 17, RE Suite is registered as a service relevant for IFC files. Any IFC file on the BIMSpeed platform can be directly opened in RE Suite by clicking on the '3 dots' menu of the

IFC file, selecting 'Access to services', and clicking on 'Go to the service'. In the background the webservice of RE Suite is called. After successful login the file is automatically downloaded and shown in the RE Suite 3D viewer. From here multiple BIM related applications are available.

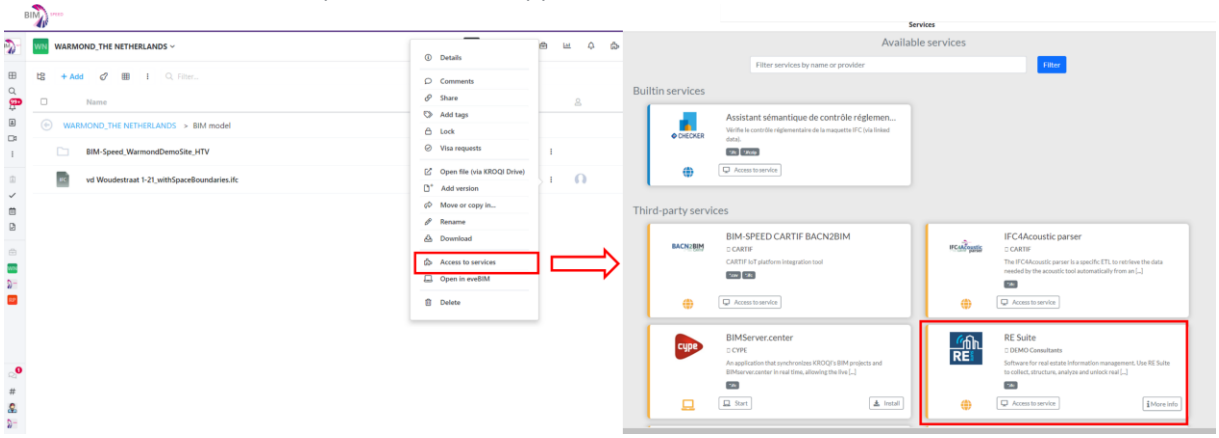


Figure 17: activating the service directly from an IFC file

2.3.2 Manage objects

Most generic LCC functionality is integrated into module RE Asset Management of the RE Suite. In the process Objects, the user can manage a portfolio of real-estate objects. Selecting an existing object in the object navigator shows its details in the working area on the right. (**Error! Reference source not found.**) Buttons on the top-right of the screen allow interaction: either to edit, delete or copy the currently selected object, or to add a new one.

2.3.3 Manage LCCs

The process LCC in RE Asset Management allows the management of individual LCC entities. Opening the process shows the list of existing LCCs related to the previously selected object and its details in the working area. If no LCC's are linked to the current object, an empty list and empty LCC data is shown. Via the tabs 'Objects' and 'LCC' the object navigator can be switched to show objects or the LCC's linked to the currently selected object.

In the working area on the right, the top part shows the properties for the currently selected LCC. The Name serves to give an LCC a recognisable identifier. Inflation, Interest and Income Index influence the calculations in the LCC and are scenario parameters. Start year and End year influence the time projection and the number of columns visible in the LCC below as shown in Figure 18.

The panel also has buttons to add, edit or delete the current selected LCC and a button to collapse this panel. Below the LCC properties, the LCC content is shown in full in a hierarchical table.

The text of the currently selected row is shown in black and bold, as shown below.

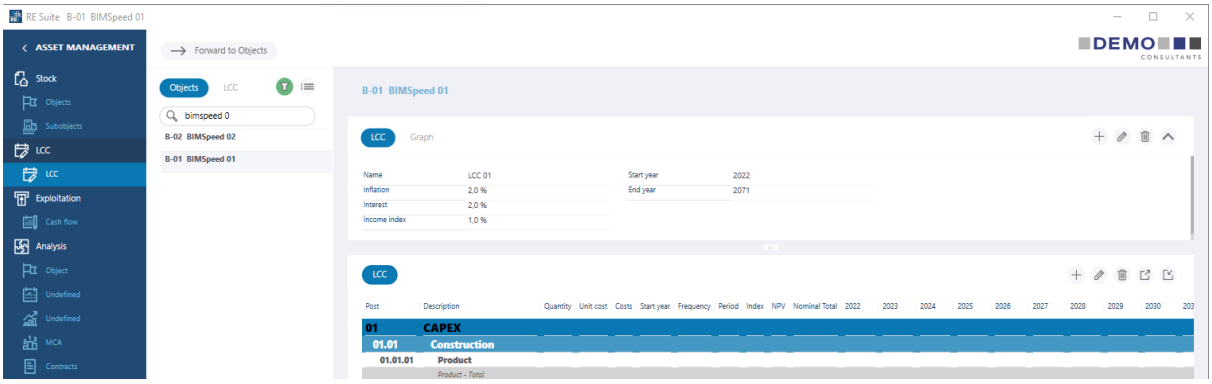


Figure 18: Object with LCC

2.3.4 Data entry and calculation

To add a data row on the top level to the LCC, press the plus symbol. This opens a small context menu presenting two options. Choose to add data row to add a new row to the bottom of the LCC as shown in Figure 19.

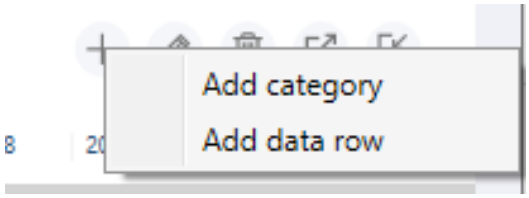
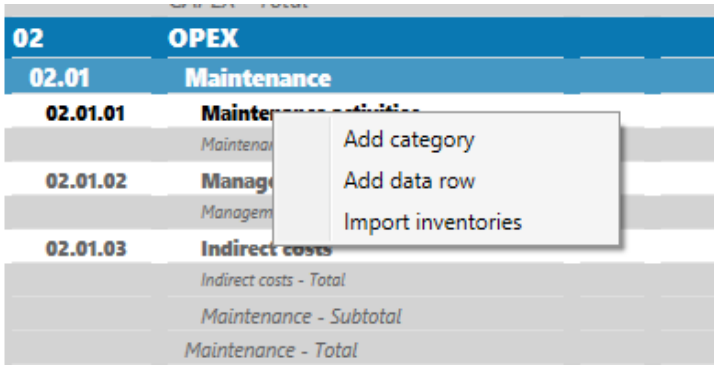


Figure 19: Adding top level row

To add a child row to a category, right-click the category and choose 'Add data row' from the context menu as shown in **Error! Reference source not found.**. This inserts a new row into the table as the last child of the selected category.

The rubbish bin icon on the top right will delete the selected row.



Changes only persist in the database upon clicking save. Choosing cancel will undo all recent edits.

Figure 20: Adding non-top-level row

The LCC table has the following columns to fill out:

- **Description**, a recognisable name for the line item in the LCC
- **Quantity**, an optional field which can be used to compute the Cost
- **Unit cost**, an optional field which can be used to compute the Cost
- **Cost**, which can be automatically computed as Quantity * Unit Cost if both are filled or manually filled out otherwise
- **Start year**, the first year the expense occurs
- **Cycle**, how often the expense reoccurs, e.g., every 3 years
- **Duration**, after how long the expense stops reoccurring, e.g., after 10 years

The remaining columns are computed LCC values. See chapter 2.1 for more information.

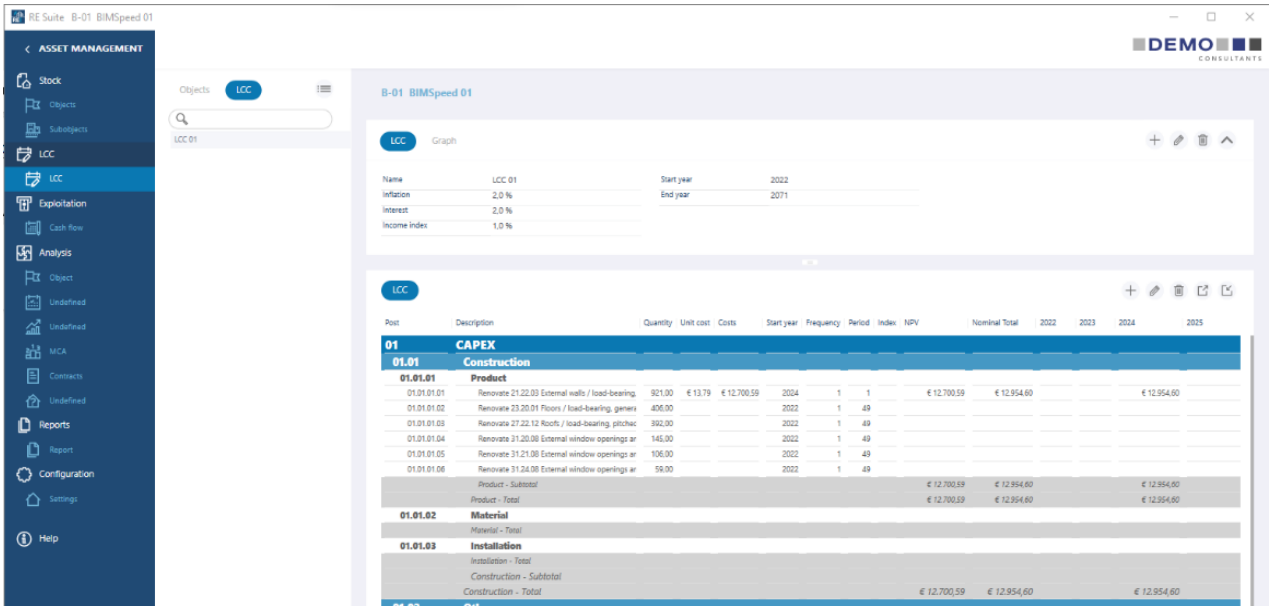


Figure 21: An LCC with several data rows

2.3.5 Organisation in categories

Data rows can be organised in hierarchical categories. An example set of categories is detailed in Figure 3 and can be automatically created for new LCCs. However, the user can always add, edit and delete categories as desired.

Categories only have an editable Name property as their sole purpose is organisation. Categories also have a corresponding totals row to compute a subtotal for the category. Totals rows are coloured grey.

To add a top-level category, click the plus icon in the top right and choose 'Add category' (Figure 19). This will add a new empty category (with a totals row) to the bottom of the LCC.

To add a new category as a child of an existing category, right-click an existing category and choose 'Add category' (**Error! Reference source not found.**). This will add a new empty category (with a totals row) as the last child of the selected category.

The Post column contains an automatically updated hierarchical index within the LCC and allows for easy referencing of individual line items and categories. For example, the third child of the second category has post index '02.03'. Its first child will have post index '02.03.01'.

For ease-of-use nested elements are also visualised indented and with different font sizes and background colours.

To organise an LCC line items and categories can be moved around. Drag a line item to its new desired position by clicking and holding the left mouse button (see Figure 22). While hovering, a horizontal black line shows the targeted position. Categories can similarly also be moved and restructured. Dragging a category is visualised as a light green block the size of the category and all its contents. Take note that a category cannot be dropped on any of its child categories.

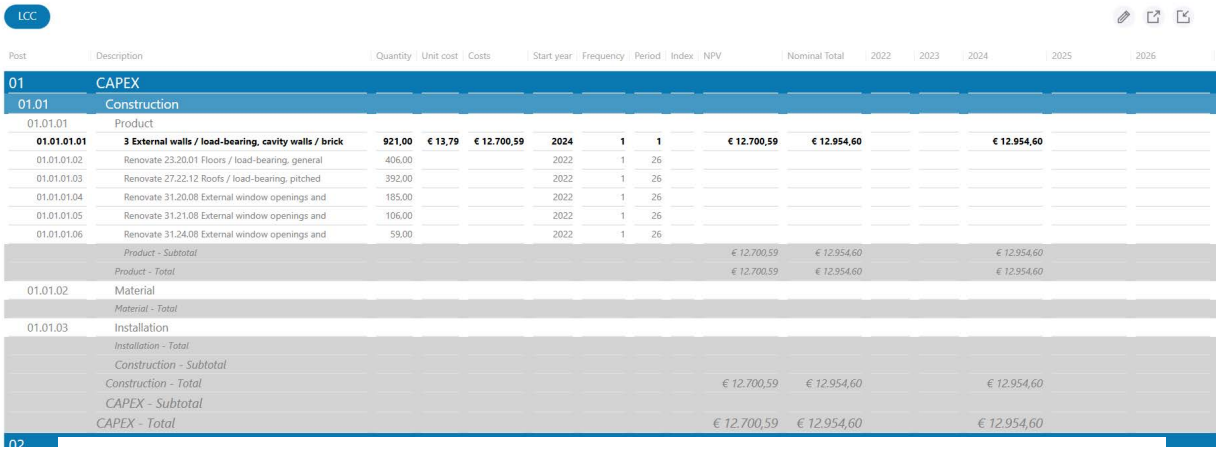
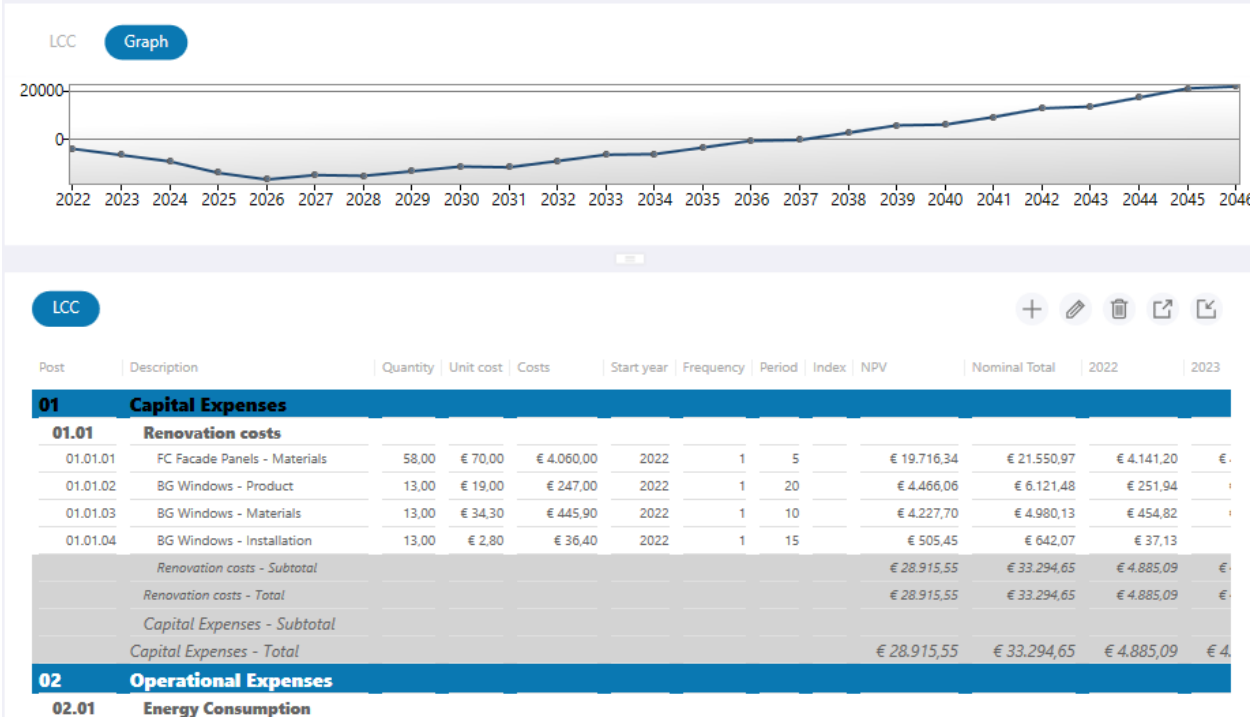


Figure 22: Dragging the selected row and inserting it at the horizontal black line

2.3.6 Interpreting results

At the bottom of every LCC two total rows show the regular and cumulative total. The cumulative total can also be visualised as a graph. In the top panel, with the general LCC parameters, click the 'Graph'



LCC

Post	Description	Quantity	Unit cost	Costs	Start year	Frequency	Period	Index	NPV	Nominal Total	2022	2023
01	**Capital Expenses**											
01.01	**Renovation costs**											
01.01.01	FC Facade Panels - Materials	58,00	€ 70,00	€ 4.060,00	2022	1	5		€ 19.716,34	€ 21.550,97	€ 4.141,20	€
01.01.02	BG Windows - Product	13,00	€ 19,00	€ 247,00	2022	1	20		€ 4.466,06	€ 6.121,48	€ 251,94	
01.01.03	BG Windows - Materials	13,00	€ 34,30	€ 445,90	2022	1	10		€ 4.227,70	€ 4.980,13	€ 454,82	
01.01.04	BG Windows - Installation	13,00	€ 2,80	€ 36,40	2022	1	15		€ 505,45	€ 642,07	€ 37,13	
	Renovation costs - Subtotal								*€ 28.915,55*	*€ 33.294,65*	*€ 4.885,09*	*€*
	Renovation costs - Total								*€ 28.915,55*	*€ 33.294,65*	*€ 4.885,09*	*€*
	Capital Expenses - Subtotal											
	Capital Expenses - Total								*€ 28.915,55*	*€ 33.294,65*	*€ 4.885,09*	*€ 4.*
02	**Operational Expenses**											
02.01	**Energy Consumption**											

Figure 23: LCC with graph

button. This will hide the LCC parameters and show a line graph of the cumulative total in its place. Clicking the export button to the top-right of the LCC table will create a machine-readable .csv file with the raw tabular data of the LCC (Figure 23). This can be used for further analysis or export to other tools.

2.4 BIM-basis

The LCC tool is enriched with BIM-functionality for greater ease of use.

2.4.1 Relating BIM-models

To make use of any BIM-related functionality, the user must first specify which IFC-file contains the relevant BIM-model for the selected object. To do this, switch to the application RE BIM by clicking in the top left of the screen and selecting 'RE BIM' in the application navigator.

In the process Objects in RE BIM, choose the desired object from the object navigator. Click the BIM tab in the working area. This will show the currently linked BIM-model in a 3D viewer (Figure 24). If no BIM-model is linked, we can select one from the available sources:

- The RE Suite SharePoint document exchange platform
- The BIM-SPEED Platform repository

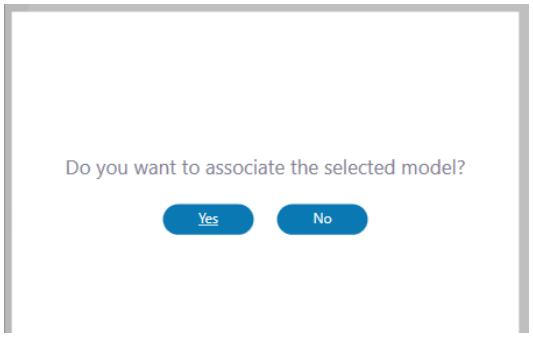


Figure 24: Associate a BIM-model

The object navigator has gained a new tab 'Source'. Select it and click the refresh button to load a list of available files and folders in all available sources.

Navigate to the desired IFC-file and click it. A popup will ask if the user wants to link the BIM-model in the selected IFC-file to the current object. Choose 'yes'. The file will open in the 3D viewer and the BIM-model will be linked (Figure 25).

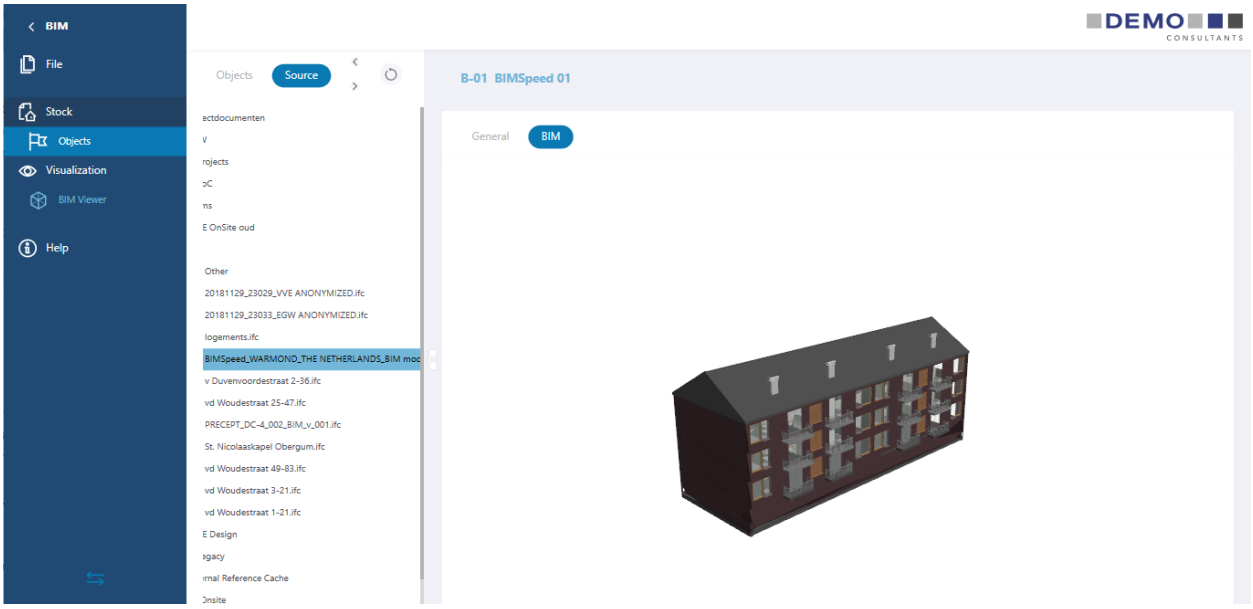


Figure 25: BIM-model in RE Suite

2.4.2 Importing inventories

RE Suite has a list of building components and materials through which a building can be decomposed. Inventorying which of these building components and materials are present in a building produces a list of inventories: the extant building components and their associated quantities.

For the BIM-SPEED project, a decomposition recognition module with quantity take-off was added to the RE Suite. If an IFC-file is suitably enriched (see 3.1), the software can recognise IFC-elements, group them together and import them as inventories. Simultaneously it can use geometric properties to compute an (approximation of) the extant quantity in the building.

To import inventories, switch to application RE Maintenance by clicking the application navigator button in the top left and choosing Maintenance. Choose process 'Edit inventories'.

First, select the desired object in the 'Objects' tab of the object navigator. Second, click the BIM-tab in the working area. This opens the associated BIM-model for the object. Click the 'import' button to start the wizard.

First, the user will be asked if any existing inventory and underlying data may be deleted. The process can only continue if this is the case. Secondly, the user is asked if they want to import all recognised elements or only those marked as renovation options (Figure 26).

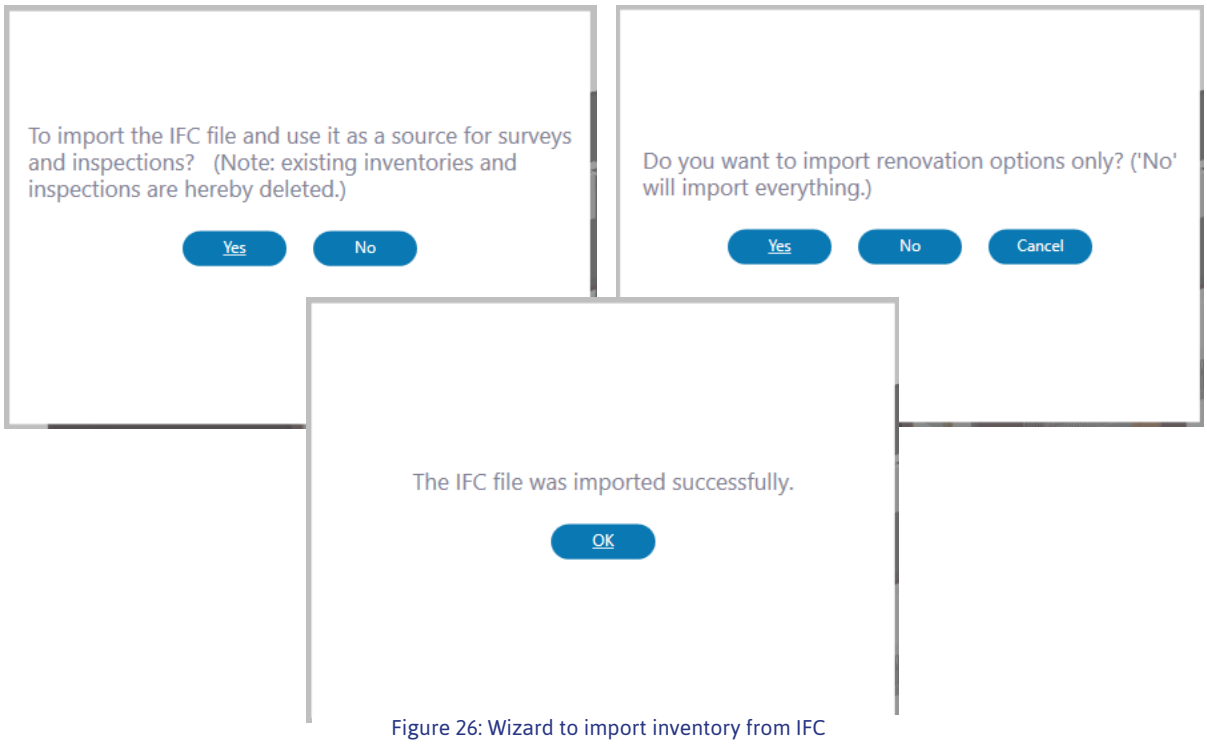


Figure 26: Wizard to import inventory from IFC

The decomposition recognition module searches for a subset of the enrichment properties detailed in 3.2.1:

- NLSfB_element_code
- NLSfB_component_code
- NEN2767_material_code
- (optionally) Renovation_option

It filters on *Renovation_option* if so requested, and tries to match the codes in the IFC properties to the codes in the building component list. Recognized elements are individually listed as inventory rows and the approximate geometrical area is computed and stored in a quantity takeoff. A relation to the IFC element is retained. After a full pass all similar elements are grouped together and aggregated as a full inventory. Thus, all separate IFC elements denoting 'brick load-bearing exterior walls', are aggregated into a single inventory for that building component with as quantity the sum of all inventory row quantities.

For ease of use, all inventories can be imported as line-items in an LCC. If inventories originated from an IFC-file import, the individual element relations are also retained.

To create line-items for each inventory element in an LCC, switch to RE Asset Management using the application navigator and open the LCC process. Select the proper object if it isn't selected already and select or create an LCC to use.

In the LCC, right-click on a category and choose 'Import inventories' (**Error! Reference source not found.**). This will create a line-item for every inventory under the selected category. The amount-column will also be automatically filled with the available inventory quantities.

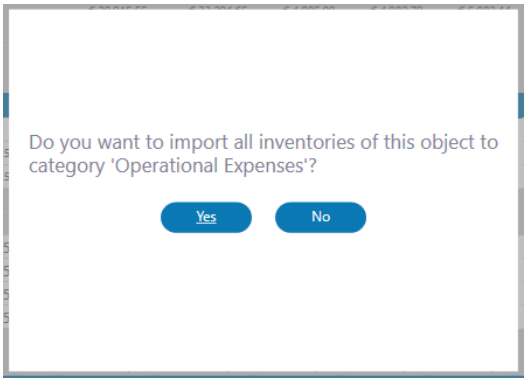


Figure 27: Import LCC line-items from inventory

2.4.3 Importing cost data

The BIM-SPEED project has a database with LCC-information for some elements available (see 1.4). If a relation can be found between line-items in an LCC and elements in the BIM-SPEED database, the unit cost-information can be automatically filled-out.

To search the database the available STRESS REST API[3] is contacted using the *text-search* endpoint to perform a keyword-search. For each line item-the user can specify relevant keywords. For example, the line-item "*Renovate cavity wall with insulation BIMSpeedDB: 226 Panel_100*" will search for *226 Panel_100* in the BIM-SPEED database. If a match is found it will import the available unit-cost information. This feature is very dependent on the population of the BIM-SPEED database, as well as the exposed searchable keywords. In RE Asset Management, in the LCC process, open an LCC and click the 'Enrich LCC' button to the top right of the table. The software will inventory the specified keywords and search the BIM-SPEED database. If any matches are found, the user is prompted to confirm the change. Repeated prompts can be prevented by clicking 'Yes to all'

Unit-cost information is only imported out if it is not already specified in the LCC. Thus, manually input information is never overwritten (Figure 28).

Post	Description	Quantity	Unit cost	Costs
01	**Capital Expenses**			
01.01	**Renovation per m2**			
01.01.01	Panels - Materials			€ 1.209,76
01.01.02	Isolation, BIMSpeedDB: 226 Panel_100	425,00	€ 11,50	€ 4.887,50
01.01.03	Isolation, BIMSpeedDB: 226 Panel_120	255,00	€ 13,79	€ 3.516,45
	Renovation per m2 - Subtotal			

Figure 28: Imported cost-data from BIM-SPEED database

[3] https://bimspeed.strategiedigitali.net/api/doc

3. Demonstration

3.1 Stek demonstration case

One of the BIM-Speed project demonstration cases pertains to four three-story residential apartment blocks in Warmond (Figure 29), The Netherlands. Constructed in 1969, these complexes are owned and managed by the social housing corporation Stek. The apartments are positioned above a semi-sunken basement where people find their own personal storage rooms.

Figure 29: Facade of the demonstration case in Warmond, The Netherlands

Within the BIM-Speed project renovation options for these complexes are considered, such as:

- Add insulation to (some of) the cavity walls
- Disconnect from natural gas
- Use sustainable energy sources for meeting heating demands

The BIM-Speed LCC tool is applied as proof of concept to one of the complexes to gain insight into the financial impact of the renovation options in both expenses and returns.

3.2 Enriching the BIM model

3.2.1 Requirements

For the purpose of demonstrating the LCC tool, the BIM model had to be enriched with additional information, needed to perform the LCC analysis. Besides the geometrical information of elements, which can easily be read from the BIM model, it was also required to have information about the material and element description, following the NEN2767 and NLSfB standards. The goal was to add 5 new parameters to the elements, which are going to be included in the renovation process, namely the:

- NEN2767_material_code
- NEN2767_material_description
- NLSfB_element_code
- NLSfB_component_code
- NLSfB_decomposition_description

Additionally, it was desired to have a parameter which will specify whether the element is going to be renovated or not, so the 6th parameter was added, and that is:

- Renovation_option

An example of an external wall with cavities, which is made of bricks, is going to be renovated and has the following classifications

- NLSfB classification is “21.22 External walls, load bearing, cavity walls”

- NEN2767 classification is “03 Brick”

the parameters would be filled as follows:

Table 6 Example of parameters and values

Parameter	Value
NEN2767_material_code	03
NEN2767_material_description	Brick
NLSfB_element_code	21
NLSfB_component_code	22
NLSfB_decomposition_description	External walls, load bearing, cavity walls
Renovation_option	Yes

Such parameters should be applied to every element in the BIM model, but for the purpose of this task, they were applied only to the elements, which are going to be involved in the renovation scenarios. This includes external walls, windows, roof, and the floor above the basement area.

It was also desired that the group of new parameters is grouped under a property set, which can easily be associated with the BIM Speed LCC analysis. To achieve that, the property set would need to be manually defined.

3.2.2 Implementation

The implementation of enriching the BIM model was performed in Autodesk Revit software. The first step was to define six new project parameters. The type of parameters was defined as “Text” and they were grouped under the section “Text”. Parameters were assigned to Floors, Roofs, Walls, and Windows, as these are the categories which are going to be included in the renovation scenarios. An example of the definition of the parameter “NEN2767_material_code” can be seen in Figure 30.

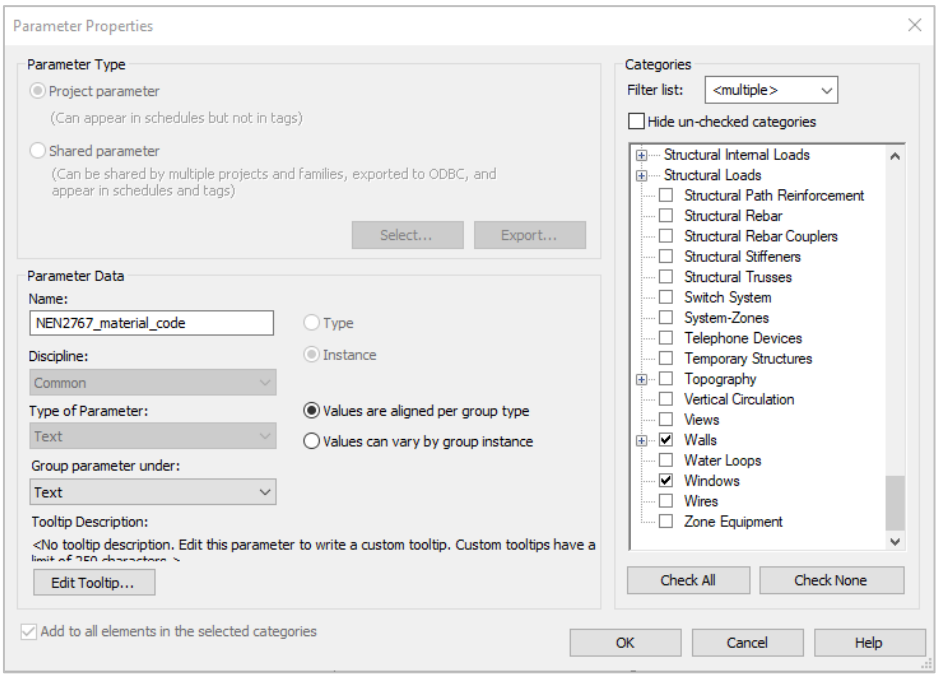


Figure 30 Definition of one of the parameters

By clicking on one of the elements, to which the parameters were assigned, the new parameters can be visible under the Properties section. They are located under the group “Text” as exhibited in Figure 31.

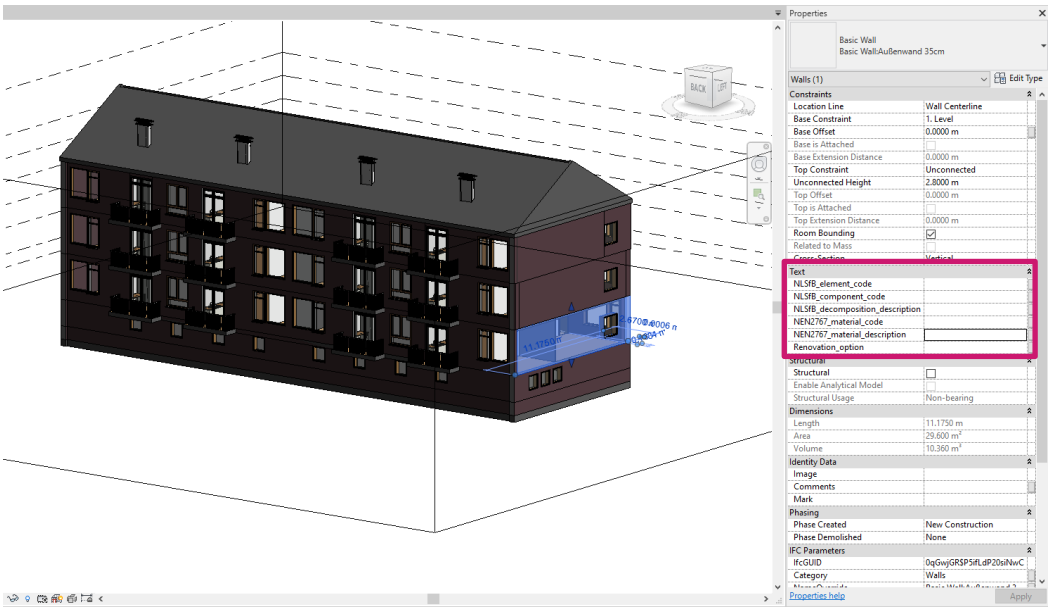


Figure 31 Newly defined parameters

For each element in question, the new parameters had to be filled in with values, as seen in Figure 32 for an example of an external wall.

Text	
NLSfB_element_code	21
NLSfB_component_code	22
NLSfB_decomposition_description	External walls, load-bearing, cavity walls
NEN2767_material_code	03
NEN2767_material_description	Brick
Renovation_option	Yes

Figure 32 Parameters with values

To better monitor the process of filling in the values, a schedule was created, which offered an overview of all the elements from a category. This way no element was left out. From a wall schedule in Figure 33, it can be seen how values were entered for each element. Additionally, adding the parameter "IsExternal" to the list was helpful to differentiate the internal walls, which are not included in the renovation, from the external wall, which are included in the renovation and therefore have "Yes" as a value for the "Renovation_option" parameter.

<Wall Schedule>

A	B	C	D	E	F	G	H
Family and Type	NLSfB_element_co	NLSfB_component_	NLSfB_decomposition_description	NEN2767_material_	NEN2767_material_	Renovation_option	IsExternal
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Außenwand 35cm	21	22	External walls, load-bearing, cavity walls	03	Brick	Yes	☑
Basic Wall: Innenwand 22cm	22	20	Internal walls, load bearing, general	03	Brick	No	☐
Basic Wall: Innenwand 22cm	22	20	Internal walls, load bearing, general	03	Brick	No	☐
Basic Wall: Innenwand 22cm	22	20	Internal walls, load bearing, general	03	Brick	No	☐
Basic Wall: Innenwand 22cm	22	20	Internal walls, load bearing, general	03	Brick	No	☐
Basic Wall: Innenwand 22cm	22	20	Internal walls, load bearing, general	03	Brick	No	☐

Figure 33 Wall schedule

The same process was repeated for the windows, floors, and roof. The below table includes all the different parameter values which were used in the model.

Table 7 Parameter values

NLSfB_element_code	NLSfB_component_code	NLSfB_decomposition_description	NEN2767_material_code	NEN2767_material_description	Renovation_option
21	22	External walls, load bearing, cavity walls	03	Brick	Yes
22	10	Internal walls, non-load bearing, general	03	Brick	No
22	20	Internal walls, load bearing, general	03	Brick	No
31	24	External window openings and windows to fill them, windows revolving on vertical or horizontal axis	08	Glass	Yes
31	20	External window openings and windows to fill them, general (collection level)	08	Glass	Yes
31	21	External window openings and windows to fill them, fixed windows	08	Glass	Yes
27	22	Roofs, loadbearing, pitched roofs	12	Ceramics	Yes
23	20	Floors, load bearing, general	01	Wood	Yes

Once the model was enriched with the information, needed for the LCC analysis, it could be exported as an IFC file. When choosing "Export Revit property sets" as an export option, the newly defined parameters will be exported, but they will be grouped under "Text" as seen in Figure 34, where BIMvision software was used as an IFC viewer.

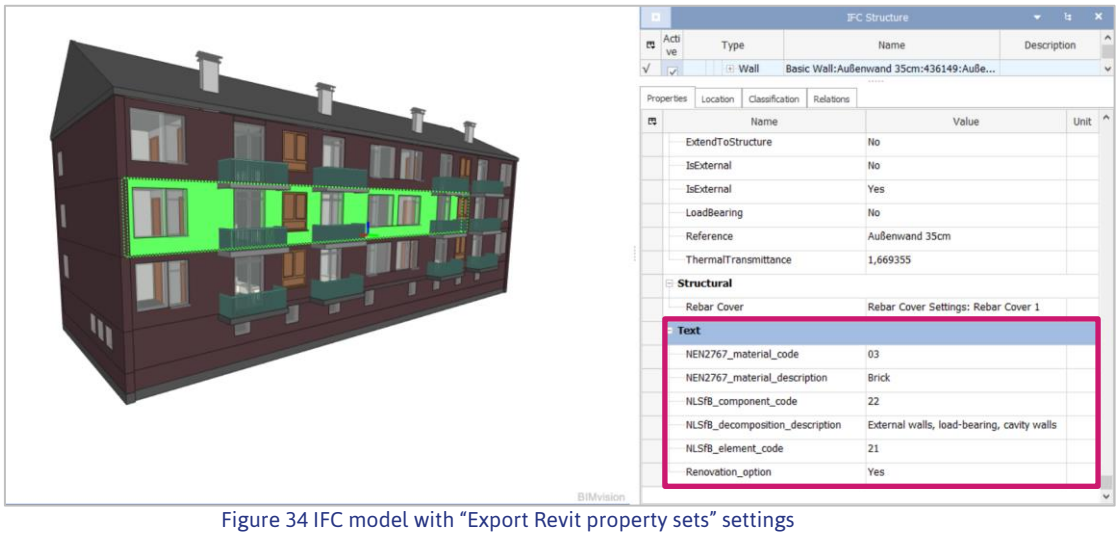


Figure 34 IFC model with "Export Revit property sets" settings

Since it was desired that the group of parameters, which is now called “Text” would be associated with the BIM Speed LCC, a User Defined Property Set had to be first composed, to be used as export options. This was done with a TXT file, which includes instructions for the Property set naming. The TXT file specifies, that the property set name is going to be “BIM_Speed_LCC” and that it will apply to Instances and to every IfcElement. After that, the parameters are listed, together with their Data type and their Revit parameter name. The TXT file can be seen in Figure 35.

```
PropertySet: ⟶BIM_Speed_LCC ⟶I ⟶IfcElement
⟶NEN2767_material_code ⟶Text ⟶NEN2767_material_code
⟶NEN2767_material_description ⟶Text ⟶NEN2767_material_description
⟶NLSfB_component_code ⟶Text ⟶NLSfB_component_code
⟶NLSfB_decomposition_description ⟶Text ⟶NLSfB_decomposition_description
⟶NLSfB_element_code ⟶Text ⟶NLSfB_element_code
⟶Renovation_option ⟶Text ⟶Renovation_option
```

Figure 35 TXT file for User Defined parameters

This TXT file was used in the IFC export settings, under the tab Property Sets, where “Export user-defined property sets” was selected with a tick and by clicking on the Browse button, the TXT file was selected as shown in Figure 36.

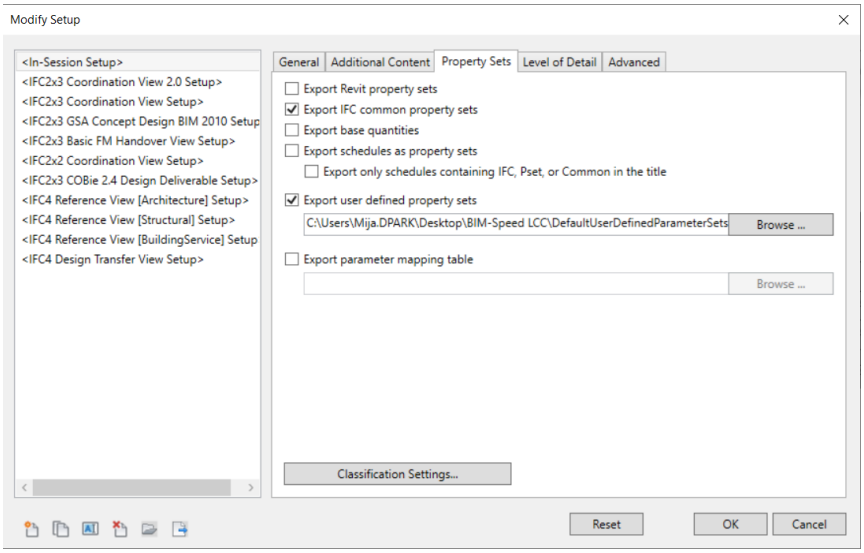


Figure 36 IFC export options

With these settings, the newly defined parameters are now grouped under “BIM_Speed_LCC” as seen from the IFC viewer in Figure 37.

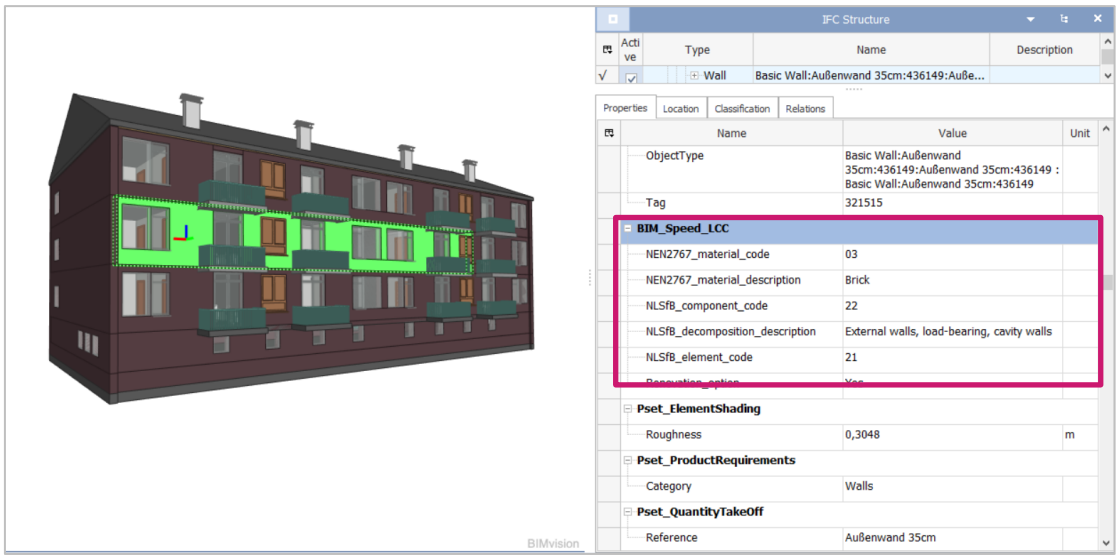


Figure 37 IFC model with "Export user-defined property sets" settings

3.3 Scenario comparison

To evaluate the efficacy of the BIM-based LCC two renovation options are considered for the complex Woudestraat in Warmond, The Netherlands. The renovation concerns applying façade cladding with thermos-acoustic insulation panels. The type of material is in question.
For the purposes of this proof of concept, the financial impact of installation and materials are offset against subsidy and reduced energy costs.

The complex has a BIM model available, and it is enriched as described in chapter 3.2, denoting building decomposition and material specifications as well as which elements are relevant for renovation.
These relevant elements are imported into the LCC Tool as described in chapter 2.4.2. This results in generally available building information.

For each strategy, an LCC is created and pre-filled with default categorisation as depicted in Figure 3. The LCCs are now filled out with details regarding the specific scenarios.
The quantity of the elements marked for renovation can be imported from the BIM model.
The main difference in cost is the choice of insulation panel. By specifying the product name in the LCC and importing unit costs from the BIM-Speed Catalog the total financial impact is immediately calculated.

Upon estimating the reduction in heating costs this yields a cumulative total life cycle costing graph for the two strategies as depicted in Figure 38. As can be seen, while the initial outlay for a more thermally isolation material is higher, the costs are eventually recaptured due to reduced heating costs.

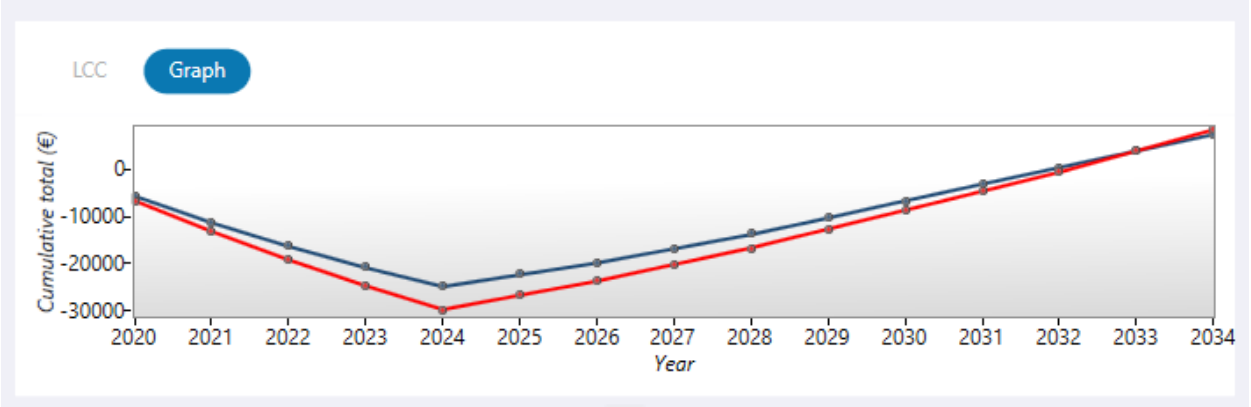


Figure 38: Strategy comparison for different isolation materials. The red line depicts a strategy with more thermal isolation.

To compare how the strategies respond to different scenarios the inflation, interest, and income index parameters can be adjusted. If one of the strategies is only viable in a narrow range of scenario parameters, it can be considered high risk.

4. Conclusion

The BIM-Speed Life-Cycle Costing Tool aids in analysing financial strategies under differing scenarios. Through its inclusion in the BIM-Speed platform, it is fully embedded in existing project workflows. The enhancement into a BIM-based LCC improves useability through automated element recognition and quantity take-off, as well as enrichment through cost-data import from the BIM-Speed catalog.
The demonstration case in Warmond, The Netherlands serves as a proof of concept for the product. As shown in the process, the availability of cost data is an important factor which will affect the accuracy of the calculation.

Future work

The BIM model is currently enriched according to project specifications, although the values used are fully compliant with existing NL/SfB and NE2767-2 standards ('BIM Loket - NL/SfB' n.d.). Mapping of NL/SfB onto IFC and vice versa are, however, active areas of research. Developments in this domain could further enhance the efficacy of the BIM-based LCC. Additionally, since LCC calculation requires assumptions about future behaviour, sensitivity analysis (such as Monte Carlo analysis) can be added to allow for identification of a distribution of possible costs and a range of more and less probable figures for use in calculations.

5. References

- 'BIM Loket - NL/SfB'. n.d. Accessed 14 September 2022. https://www.bimloket.nl/p/542/NLSfB.
- *Directive 2014/24/EU of The*. 2014. *OJ L*. Vol. 094. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0024.
- 'Environmental Life Cycle Costing: A Code of Practice - Society of Environmental Toxicology and Chemistry'. n.d. Accessed 14 September 2022. https://www.setac.org/store/ViewProduct.aspx?id=1033860.
- Liu, Feng, Anke S. Meyer, and John F. Hogan. 2010. *Mainstreaming Building Energy Efficiency Codes in Developing Countries: Global Experiences and Lessons from Early Adopters*. World Bank Publications.
- 'NEN-EN 15804:2012+A1:2013 En'. n.d. Accessed 14 September 2022. https://www.nen.nl/en/nen-en-15804-2012-a1-2013-en-190092.
- 'NEN-ISO 15686-5:2017 En'. n.d. Accessed 14 September 2022. https://www.nen.nl/en/nen-iso-15686-5-2017-en-236967.
- UNE EN 15459-1:2018, European. n.d. 'UNE EN 15459-1:2018 Energy Performance of Buildings - Economic Evaluation Procedure for Energy Systems in Buildings - Part 1: Calculation Procedures, Module M1-14'. Https://Www.En-Standard.Eu. Accessed 14 September 2022. https://www.en-standard.eu/une-en-15459-1-2018-energy-performance-of-buildings-economic-evaluation-procedure-for-energy-systems-in-buildings-part-1-calculation-procedures-module-m1-14/.
- Zuo, Jian, Stephen Pullen, Raufdeen Rameezdeen, Helen Bennetts, Yuan Wang, Guozhu Mao, Zhihua Zhou, Huibin Du, and Huabo Duan. 2017. 'Green Building Evaluation from a Life-Cycle Perspective in Australia: A Critical Review'. *Renewable and Sustainable Energy Reviews* 70 (April): 358–68. https://doi.org/10.1016/j.rser.2016.11.251.