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# DELIVERABLE D7.3
# Life Cycle Cost/ Assessment Module 1

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## ACRONYMS

| Acronym | Meaning |
|---|---|
| BIF | BIMERR Interoperability Framework |
| BIMERR | BIM-based holistic tools for Energy-driven Renovation of existing Residences |
| IFC | Industry Foundation Classes |
| KPI | Key Performance Indicator |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| RenoDSS | BIMERR Renovation Decision Support System |

## EXECUTIVE SUMMARY

This document describes the BIMERR Deliverable D7.3 “Life Cycle Cost/ Assessment Module 1” demonstrator and concludes the first iteration of the development activities in T7.2 “Renovation LCA/LCC module”. This first release of the BIMERR LCA/LCC module provides 16 KPIs about the financial and sustainability impact of the renovation scenario under investigation. The relevant input data is extracted from the renovation scenario’s IFC file. The IFC file is populated with sustainability data from the BIMERR Material and Component Database and project-specific financial data provided by the user via the BIMERR Renovation Support Tools user interface.

The BIMERR LCA/LCC module is based on state-of-the-art technologies and three layers: (i) the Presentation Layer, which allows the user to set his/her preferred data sources for sustainability data and project-specific financial data. The user interface is built upon Angular, Typescript, and NGRX Entity/Store, (ii) the Business Logic Layer which calculates the KPIs based on the IFC file and the financial and sustainability data for the building materials used in the renovation scenario, and (iii) the Data Layer that utilizes PostgreSQL to store preferred data sources, project-specific financial data, and calculated KPIs for faster access at later usage.

In the second release of the BIMERR LCA/LCC module we will (i) implement unit conversions to match IFC units with material units from the BIMERR Component and Material database, (ii) implement the renovation scenario KPI calculation (e.g. life cycle cost), (iii) implement project-specific energy costs, interest rates, environmental costs, and $CO_2$ emission rates based on region-specific global values which are maintained by the administrator role, and (iv) evaluate if the integration of third-party approaches such as OpenLCA provide additional benefit to the RenoDSS user.

# 1. INTRODUCTION

The BIMERR LCA/LCC module provides information about the financial and sustainability impact of the renovation scenario under investigation. Cost is usually one of the most critical parameters in deciding whether to proceed with the renovation effort and needs to be seen on a long-term horizon to properly aid decision making. The LCA/LCC module takes project-specific **purchasing, installation, and maintenance costs** of renovation measures into account. It also aims at accurately estimating **yearly energy cost savings** based on potential renovation measures and the increased energy efficiency figures which are provided by the BIMERR Building Energy Performance module (D7.5). Besides costs, the LCA/LCC module provides **sustainability KPIs** to estimate and compare the overall sustainability impact of potential renovation scenarios.

## 1.1 SCOPE AND OBJECTIVES OF THE DELIVERABLE

D7.3 "Life Cycle Cost/ Assessment Module 1" reports the development activities in the context of Task T7.2 "Renovation LCA/LCC module" of WP7 "Renovation Decision Support System". It documents the first version of the BIMERR LCA/LCC module, which is responsible for providing 16 KPIs about the financial and sustainability of the renovation scenario under investigation.

The objective of this document is to give an overview and documentation of the first stable release of the BIMERR LCA/LCC module and describe:

- Functionalities of the BIMERR LCA/LCC module
- Technology stack
- Communication with the BIMERR data management module
- Assumptions and restrictions of the first and initial release
- Installation instructions
- Usage walkthroughs
- Licensing

The BIMERR LCA/LCC module will be delivered in two releases, in M20 and M30. The second release of the BIMERR LCA/LCC module will be built on the outcome of this deliverable and will contain all planned functionality and enhancements based on the feedback of the pre-validation and validation activities (WP8).

## 1.2 RELATION TO OTHER TASKS/DELIVERABLES

T7.2 “Renovation LCA/LCC module” and therefore D7.3 “Life Cycle Cost/ Assessment Module 1” are related to the following BIMERR deliverables:

- D3.1 “Stakeholder requirements for the BIMERR system”: the business scenarios, use cases, and system requirements described in D3.1 are the basis for the development of the BIMERR LCA/LCC module.
- D3.3 “BIMERR evaluation methodology”: economic and sustainability KPIs described in D3.3 are calculated by the LCA/LCC module.
- D3.5 “BIMERR system architecture first version”: the first version of the BIMERR architecture provided an overview on the BIMERR components, how they communicate to each other and how the BIMERR LCA/LCC module is embedded in the BIMERR Renovation Support Tools.
- T7.1 “Building components database design and development“ provides the BIMERR Material and Component Database which is used by the BIMERR LCA/LCC module as data source for sustainability figures of building materials and components used in the renovation scenarios.
- T8.1 “External Information Availability and Sourcing”: ensures that financial and sustainability data relevant for pre-validation and validation sites is available in the BIMERR Material and Component Database.

## 1.3 STRUCTURE OF THE DOCUMENT

Section 1 describes the scope/objectives of the deliverable and its relations to other tasks and deliverables.

Section 2 gives an overview of the BIMERR LCA/LCC module, its architecture, calculated KPIs, BIF[1] integration plans, technology stack, assumptions, restrictions, installation instructions and licensing.

Section 3 provides and end-to-end walkthrough to show the functionalities on an example building.

Section 4 outlines the research and development plans for the second iteration of the BIMERR LCA/LCC module due in M30.

[1] BIMERR Interoperability Framework

# 2. BIMERR LCA/LCC MODULE

## 2.1 OVERVIEW

The BIMERR LCA/LCC module provides information about the financial and sustainability impact of the renovation scenario under investigation. Based on D3.3 the following economic and sustainability KPIs are provided by the LCA/LCC module:

- Economic
  - Construction cost in €
  - Operation cost during period of analysis in €
  - Maintenance cost during period of analysis in €
  - End of life cost in €
  - Life cycle cost during period of analysis in €
  - Payback period in years
- Sustainability
  - Environmental cost indicator in €/m²
  - GWP100a total global warming potential in kg CO2-eq/m²
  - Acidification potential of soil and water (AP) in kg SO2-eq/m²
  - Depletion potential of the stratospheric ozone layer (ODP) in kg-CFC11/m²
  - Abiotic depletion potential for non-fossil resources (ADPE) in kg Sb-eq/m²
  - Eutrophication potential (EP) in kg PO4-3-eq/m²
  - Abiotic depletion potential for fossil resources (ADPF) in MJ/m²
  - Formation potential of tropospheric ozone (POCP) in (kg ethylene/m²)/m²
  - CO2 emission rate in kg CO2/m²
  - CO2 emissions reduction in %

The necessary input data to calculate these KPIs is obtained from the BIMERR Material and Component Database (which currently contains sustainability data for building materials from the oekobaudat.de[2] database) and project-specific financial data provided by the user. Section 2.7 outlines the calculation steps for each KPI.

[2] www.oekobaudat.de, last access: 10.08.2020

The first version of the BIMERR LCA/LCC module is embedded in BIMERR RenoDSS and available at[3]: https://renodss.xylem-technologies.com/

With regards to terminology and classification of life cycle cost the LCA/LCC module follows ISO 15686-5[4] and focuses on the cost classes highlighted in Figure 1.

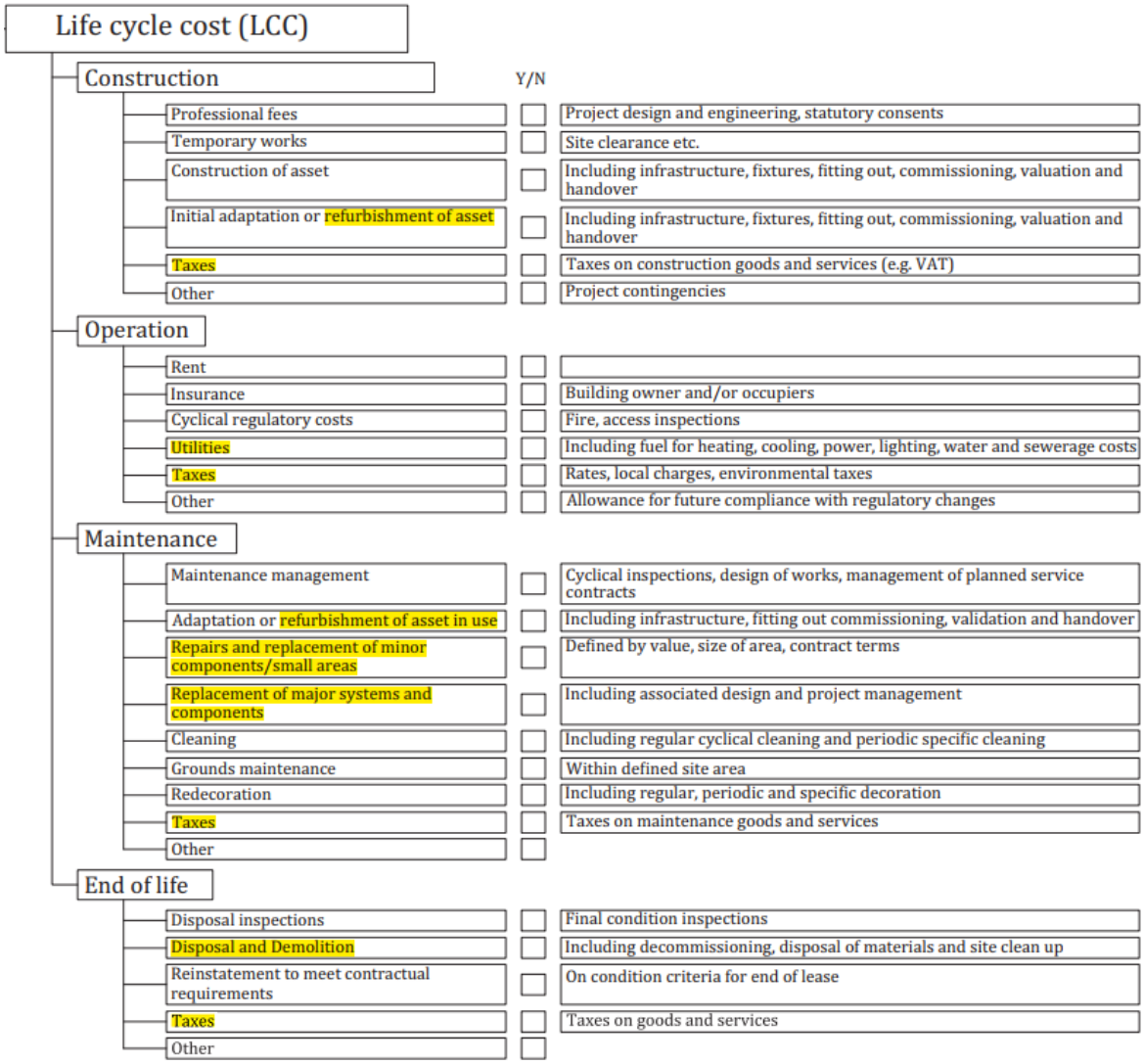


**Figure 1: Typical scope of cost (Source: ISO 15686-5)**

[3] For security reasons the access to RenoDSS is restricted to authorized IP addresses. Please send an email to support@xylem-technologies.com to request access to RenoDSS.

[4] ISO 15686-5:2017 Buildings and constructed assets. Service life planning. Life-cycle costing

- Construction cost involves material and installation costs (including taxes) of the renovation measures,
- Operation cost includes energy costs (including taxes) for heating and cooling the building,
- Maintenance cost includes costs (including taxes) that occur to maintain and replace renovated building elements (renovation measures) during the period of analysis,
- End of life cost include costs for the disposal of renovation measures and site clean up,
- Life cycle cost is the sum of the renovation measures' construction, operation, maintenance, and end of life costs.

## 2.2 ARCHITECTURE

Based on the BIMERR architecture (D3.5), Figure 1 shows the architecture of RenoDSS and its modules.

The main aim of RenoDSS is to put forward an intuitive and easy-to-use interface that illustrates the renovation options, evaluates their impact on the building performance and guides the user through various alternatives towards the optimal choice for given boundary constraints (such as size of intervention, budget, target energy savings, etc.). RenoDSS will offer to the user a renovation configurator that will allow her to explore alternative renovation interventions.

RenoDSS communicates via the RenoDSS Data Management Module with the BIMERR LCA/LCC module. The Data Management Module sends the IFC file, containing all relevant information about the renovation scenario to the LCA/LCC module, which returns the KPIs as listed in Section 2.1.

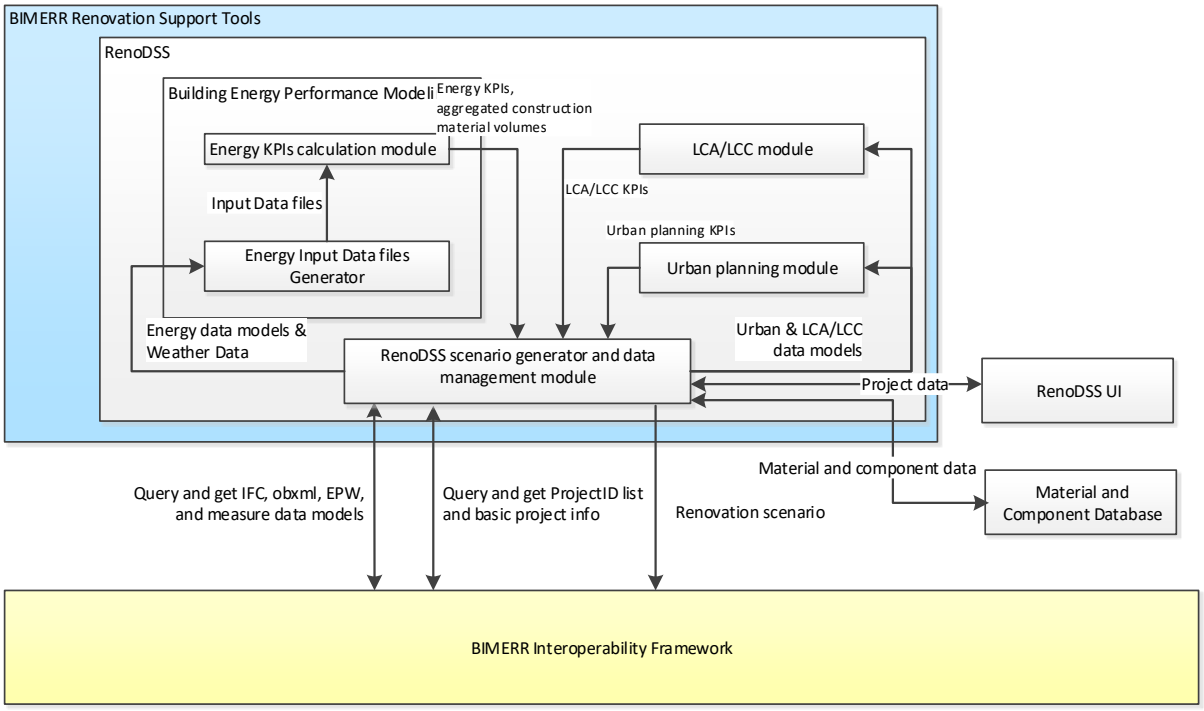


**Figure 2: Architecture of the BIMERR Renovation Support Tools**

## 2.3 PROVISION OF DATA VIA AN INTEGRATION FRAMEWORK

RenoDSS and the LCA/LCC module are intended to be integrated with the BIMERR Interoperability Framework (BIF) by its second release that is expected on M30. The RenoDSS Data Management module will be responsible for querying the IFC file from the BIF and provide it together with the renovation scenario IFC files to the LCA/LCC module. The economic and environmental KPIs of the final renovation scenarios are provided by the RenoDSS Data Management module to the BIF.

## 2.4 RENOVATION MEASURES

Renovation measures such as external wall insulations or new heating systems are technical measures to improve the energy performance, comfort, or life cycle cost of the building. BIMERR renovation measures are stored within RenoDSS and:

- have a name,
- are of type Passive (e.g., external wall insulation), Active (e.g., heat pump), or Renewable (e.g., PV or solar thermal),
- have a reference unit such as $m^2$ or pcs,
- have a lifetime in years,

- are associated to the renovated elements Façade, Roof, Floor, Fenestration, Solar collector, Heating system, and Cooling System,
- are applied to certain IFC elements (see Table 1) such as IFCROOF, and
- are implemented by constructions or components.

The following table shows the renovation measures which are provided by BIMERR.

**Table 1: Renovation measure table**

| Name | Type | Ref. unit | Life-time in years | Ren. Element | IFC element[5] | List of ConstructionIDs or ComponentIDs |
|---|---|---|---|---|---|---|
| External facade insulation | Passive | m² | 30 | Façade | IfcWall<br>IfcWallElementedCase<br>IfcWallStandardCase | ConstructionIDs |
| Internal facade insulation | Passive | m² | 30 | Façade | IfcWall<br>IfcWallElementedCase<br>IfcWallStandardCase | ConstructionIDs |
| External pitched roof insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Internal pitched roof insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Flat roof external waterproof insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Flat roof inverted external insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Top slab false ceiling insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Top slab chamber insulation | Passive | m² | 30 | Roof | IfcRoof<br>IfcSlab | ConstructionIDs |
| Internal slab insulation | Passive | m² | 30 | Floor | IfcSlab | ConstructionIDs |
| Double glazed windows | Passive | m² | 20 | Fenestration | IfcWindow<br>IfcWindowStandardCase | ComponentIDs |
| Triple glazed windows | Passive | m² | 20 | Fenestration | IfcWindow<br>IfcWindowStandardCase | ComponentIDs |
| Photovoltaic panel | Renewable | pcs | 15 | Solar collector | IfcSolarDevice | ComponentIDs |
| Solar thermal collector | Renewable | pcs | 15 | Solar collector | IfcSolarDevice | ComponentIDs |
| Natural gas boiler | Active | pcs | 20 | Heating system | IfcBoiler | ComponentIDs |

[5] https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/, last access: 10.08.2020

| | | | | | | |
|---|---|---|---|---|---|---|
| Condensing natural gas boiler | Active | pcs | 20 | Heating system | IfcBoiler | ComponentIDs |
| Air to air heat pump | Active | pcs | 20 | Heating system | IfcPump | ComponentIDs |
| Air to air split units | Active | pcs | 15 | Cooling system | IfcPump | ComponentIDs |

A BIMERR construction has a name. Example:

**Table 2: Construction table**

| ConstructionID | Name |
|---|---|
| 1 | External thermal insulation system |

A BIMERR layer has a name and a position within the construction. The layer numbering starts at the conditioned side of the construction. Example:

**Table 3: Layer table**

| LayerID | Name | Layer_Position |
|---|---|---|
| 1 | Adhesive | 1 |
| 2 | Insulation | 2 |
| 3 | Plaster | 3 |

The combinations of materials and thicknesses are defined in the following table. Please note that the MaterialID relates to the materials stored in the BIMERR Material and Component Database (D7.1).

**Table 4: Material thickness table**

| MTID | Name | MaterialID | Thickness |
|---|---|---|---|
| 1 | 5mm Adhesive | 1 | 0,005 |
| 2 | 10cm EPS-F | 2 | 0,1 |
| 3 | 15cm EPS-F | 2 | 0,15 |
| 4 | 20cm EPS-F | 2 | 0,2 |
| 5 | 12cm Glass wool | 3 | 0,12 |
| 6 | 15cm Glass wool | 3 | 0,15 |
| 7 | 20cm Glass wool | 3 | 0,2 |
| 8 | 5mm Silicate plaster | 4 | 0,005 |

With the following linker table constructions, layers, materials, and thicknesses can be specified on the project and scenario level. For each combination of material and thickness in the context of

construction or component, layer, project, and scenario, it is possible to define purchasing, installation, maintenance, and disposal costs per reference unit of the renovation measure. Renovation measures in Table 1 are linked via the ConstructionIDs and ComponentIDs (both are globally unique).

**Table 5: Cost and linking table**

| ConstructionID or ComponentID | LayerID | ProjectID | ScenarioID | MTID | Material Cost | Installation Cost | Maintenance Cost per year | Disposal Cost |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 10 | 20 | 0 | 10 |
| 1 | 2 | 1 | 1 | 4 | 20 | 40 | 0 | -10 |
| 1 | 3 | 1 | 1 | 8 | 10 | 20 | 2 | 10 |

## 2.5 IFC AREAS AND VOLUMES

As outlined in the previous section, each renovation measure is associated to IFC elements which relate to the building element to be renovated. The IFC elements defined at each renovation measure are used to extract the areas and volumes of the underlying constructions from the IFC file. The .NET open source xbim Toolkit[6] is used to load and parse the IFC file:

1. The RenoDSS data management module sends the IFC file to the service which hosts the xbim Toolkit. This service is deployed locally on the RenoDSS server.
2. All exterior building elements are extracted from spaces that are associated to IIfcRelSpaceBoundary2ndLevel[7] elements.
3. The area of each exterior building element is retrieved by extracting the first value that is defined as IfcAreaMeasure[8] and part of a property set that is associated to the exterior building element.

[6] https://docs.xbim.net, last access: 10.08.2020

[7] https://standards.buildingsmart.org/IFC/RELEASE/IFC4_1/FINAL/HTML/schema/ifcproductextension/lexical/ifcrelspaceboundary2ndlevel.htm, last access: 10.08.2020

[8] https://standards.buildingsmart.org/IFC/RELEASE/IFC4_1/FINAL/HTML/schema/ifcmeasureresource/lexical/ifcareameasure.htm, last access: 10.08.2020

4. Material names, layer positions, thicknesses and properties are extracted from the building elements' material layers. The volume is calculated by multiplying the extracted area and layer thicknesses.
5. When all elements with their associated properties are collected, they are returned as a response containing the IFC elements in a JSON[9] structure:


```
{
  "type": "IfcWall",
  "name": "Basic Wall:Case1-extwall:182667",
  "globalId": "1ePVfoWu9969NqC_VZUMUC",
  "area": 13.5980160000955,
  "layers": [
    {
      "nr": 1,
      "name": "Gypsum Wall Board",
      "thickness": 0.0216,
      "volume": 0.2937171456020628
    },
    {
      "nr": 2,
      "name": "Concrete, Cast-in-Place gray",
      "thickness": 0.18,
      "volume": 2.44764288001719
    },
    {
      "nr": 3,
      "name": "Gypsum Wall Board",
      "thickness": 0.0016,
      "volume": 0.0217568256001528
    }
  ]
},
{
  "type": "IfcWall",
  "name": "Basic Wall:Case1-extwall:191974",
  "globalId": "2v0UWxqbH41gdGtT5E4QGO",
  "area": 3.48000000000088,
  "layers": [
    {
      "nr": 1,
      "name": "Gypsum Wall Board",
      "thickness": 0.0216,
      "volume": 0.07516800000001901
    },
    {
      "nr": 2,
      "name": "Concrete, Cast-in-Place gray",
      "thickness": 0.18,
      "volume": 0.6264000000001584
    },
    {
```


[9] https://www.json.org/, last access: 10.08.2020

```
            "nr": 3,
            "name": "Gypsum Wall Board",
            "thickness": 0.0016,
            "volume": 0.005568000000001409
        }
    ]
},
```


## 2.6 KEY PERFORMANCE INDICATORS

This section describes how each economic and sustainability KPI is calculated and which data sources are used.

### *2.6.1 EC1 - Construction cost in monetary unit*

The construction costs of a renovation measure include the costs for (i) removing the old component or layers of the construction and (ii) purchasing and installing the new renovation measure (including taxes).

$$CC = \sum_{i=1}^{b} (DC_i + CC_i)$$

CC are the construction cost of the renovation measures
i is the current renovation measure
b is the number of renovation measures applied to the building
$DC_i$ is the disposal cost which occur prior installing renovation measure i
$CC_i$ is the construction cost for renovation measure i including material and installation

The costs are stored per reference unit of the renovation measure for each component or each layer of the construction. The reference unit (e.g., m² or m³) of each layer is multiplied with the material and installation cost stored for this specific context-, scenario-, material- and thickness context in the cost and linking table.

Example: i=2, b=2, $DC_1$=20, $CC_1$=200, $DC_2$=10, $CC_2$=100

CC = 20+200+10+100 = 330

### 2.6.2 EC2 - Operation cost during period of analysis in monetary unit

Operation cost includes energy costs (including taxes) for heating and cooling the building. According to standard ISO 15686-5:2017 it takes expected the energy escalation rate and discount rate in terms of opportunity cost into account. Note that the energy costs are calculated for each energy carrier to take each one's escalation rate and consumption into account.

$$OC = \sum_{i=1}^{b} \sum_{n=0}^{a} \frac{EDi_n * EPi_0 * (1 + e_i)^n}{(1 + d)^n}$$

OC are the present value operation cost during the period of analysis
b is the number of energy carriers used in the building
i is the current energy carrier
a is the period of analysis (30 years per default)
n is the number of years between the base data and the occurrence of the cost
$EDi_n$ is the energy demand of energy carrier i in year n
$EPi_0$ is the energy price of energy carrier i in year 0
$e_i$ is the expected energy escalation rate of energy carrier i
d is the expected discount rate

Example: a=1, b=2, $ED1_0$=50, $ED1_1$=100, $EP1_0$=5, $ED2_0$=25, $ED2_1$=50, $EP2_0$=10, $e_1$=0,02, $e_2$=0,03, d=0,06

OC = 50*5 + (100*5*1,02)/1,06 + 25*10 + (50*10*1,02)/1,06 = 1462,26

### 2.6.3 EC3 - Maintenance cost during period of analysis in monetary unit

Maintenance cost includes costs that occur to maintain renovation measures and replace them after their lifetime during the period of analysis (including taxes). In case of constructions the maintenance costs include all renovated layers, in case of components the component itself.

$$MC = \sum_{i=1}^{b} \sum_{n=0}^{a} \frac{(MCi_0 + CCi_0) * (1 + e)^n}{(1 + d)^n}$$

MC are the present value maintenance cost during the period of analysis
b is the number of renovation measures applied to the building
i is the current renovation measure
a is the period of analysis (30 years per default)
n is the number of years between the base data and the occurrence of the cost

$MCi_n$ is the maintenance cost of renovation measure i in year n

$CCi_n$ is the construction cost for replacing renovation measure i after its lifetime in year n

e is the expected escalation rate for construction and maintenance cost

d is the expected discount rate

Example: a=1, b=2, $MC1_0$=50, $MC2_0$=100, $CC1_0$=25, $CC2_0$=50, e=0,03, d=0,06

MC = 50+25 + (50+25*1,03)/1,06 + 100+50 + (100+50*1,03)/1,06 = 443,63

### *2.6.4 EC4 - End of life cost in monetary unit*

End of life cost include disposal of the renovation measure after its lifetime (including taxes). Please note that this value can be negative if the residual value exceeds the cost of disposal.

*End of life cost = sum of disposal cost for renovated construction layers or component*

$$EoLC = \sum_{i=1}^{b} \frac{EoLCi_0 * (1+e)^n}{(1+d)^n}$$

EoLC are the present value end of life cost during the period of analysis

i is the current renovation measure

b is the number of renovation measures applied to the building

$EoLCi_0$ is the end of life cost of renovation measure i in year 0

e is the expected escalation rate for end of life cost

n the last year of the period of analysis (30 years per default)

d is the expected discount rate

Example: b=2, $EoLCi_0$=100, $EoLCi_1$=200, e=0,02, n=30

EoLC = $(100*1{,}02^{30})/1{,}06^{30}$+ $(200*1{,}02^{30})/1{,}06^{30}$ = 94,61

### *2.6.5 EC5 - Life cycle cost during period of analysis in monetary unit*

Life cycle cost is the sum of the renovation measure's present value construction, operation, maintenance, and end of life costs. Note that the lifetime of renovation measures is not homogeneous and can be below or above the period of analysis.

### 2.6.6 EC6 - Payback period in years

According to ISO 15686-5:2017 the payback period is calculated as the number of years elapsed between the initial investment (construction cost), its subsequent operating cost and the time at which cumulative savings offset the investment. The payback period is the time it takes to recoup the initial investment of an alternative to the base case.

### 2.6.7 SU1 - Environmental cost indicator in monetary unit/m²

Indicator that unites sustainability KPIs (SU2 to SU8) into a single score of environmental costs, representing the environmental shadow price of a product or project. Therefore, the output of SU2 to SU8 is multiplied by their monetary impact per unit as shown in the following table[10].

| KPI | Unit | Monetary unit/unit |
|---|---|---|
| SU2 GWP100a total global warming potential | kg CO2-eq | 0,05€ |
| SU3 Acidification potential of soil and water (AP) | kg SO2-eq | 4,00€ |
| SU4 Depletion potential of the stratospheric ozone layer (ODP) | kg CFC | 30,00€ |
| SU5 Abiotic depletion potential for non-fossil resources (ADPE) | kg Sb-eq | 0,16€ |
| SU6 Eutrophication potential (EP) | kg PO4-3 eq | 9,00€ |
| SU7 Abiotic depletion potential for fossil resources (ADPF) | kg Sb-eq | 0,16€ |
| SU8 Formation potential of tropospheric ozone (POCP) | kg C2H4-eq | 2,00€ |

### 2.6.8 SU2 - GWP100a total global warming potential in kg CO2-eq/m²

Describes how much heat a greenhouse gas traps in the atmosphere in 100 years relative to carbon dioxide. For example, the CO2 equivalent of methane over a period of 100 years is 28. I.e., one kilogram of methane contributes in the first 100 years to the greenhouse effect like 28 kilogram CO2.

[10] The monetary values have been taken from https://ecochain.com/knowledge/environmental-cost-indicator-eci/ and can be adjusted for every scenario of the renovation project.

GWP100a is provided for the life cycle of each building material and component used in the renovation measures by its reference unit. The total global warming potential per square meter floor area of a renovation measure is calculated by:

$$GWP100a = \frac{\sum_{i=1}^{n} GWP100a_i * RU_i}{A}$$

GWP100a is the global warming potential of the renovation measure in kg CO2-eq
i is the current building material or component used in the renovation measure
n is the number of materials or components used in the renovation measure
$GWP100a_i$ is the global warming potential of material or component i per reference unit (e.g., 0,45 kg CO2-eq per m³)
$RU_i$ is the amount of reference units of material or component I (e.g., 27 m³)
A is the floor area of the building

### *2.6.9 SU3 - Acidification potential of soil and water (AP) in kg SO2-eq/m²*

Acidification potential describes the amount of acids emitted to the atmosphere and subsequently deposited in soil and water[11] in the context of the life cycle of materials and components used in the renovation measures per square meter floor area.

$$AP = \frac{\sum_{i=1}^{n} AP_i * RU_i}{A}$$

### *2.6.10 SU4 - Depletion potential of the stratospheric ozone layer (ODP) in kg CFC11-eq/m²*

Is the relative amount of degradation to the ozone layer a chemical compound can cause, with CFC-11 fixed at an ODP of 1[12].

$$ODP = \frac{\sum_{i=1}^{n} ODP_i * RU_i}{A}$$

[11] https://www.sciencedirect.com/topics/engineering/acidification-potential

[12] https://en.wikipedia.org/wiki/Ozone_depletion_potential

### 2.6.11 SU5 - Abiotic depletion potential for non-fossil resources (ADPE) in kg Sb-eq/m²

Refers to the depletion of non-living (abiotic) non-fossil resources and is measured in kilograms of Antimony equivalents[13] per square meter floor area.

$$ADPE = \frac{\sum_{i=1}^{n} ADPE_i * RU_i}{A}$$

### 2.6.12 SU6 - Eutrophication potential (EP) in kg PO4-3-eq/m²

Eutrophication occurs when an ecosystem is saturated with essential non-organic nutrients such as nitrogen and phosphorus compounds, which under natural conditions would only normally be present in small concentrations. When released into water, these substances trigger outbreaks of algae and aquatic plants, which, in turn, leads to a shift in the biodiversity of the ecosystem[14]. The eutrophication potential of the nutrient input is specified in kg (PO4)3- -eq (phosphate equivalent) per square meter floor area.

$$EP = \frac{\sum_{i=1}^{n} EP_i * RU_i}{A}$$

### 2.6.13 SU7 - Abiotic depletion potential for fossil resources (ADPF) in MJ/m²

Refers to the depletion of non-living (abiotic) fossil resources and is measured in kilograms of Antimony equivalents[15] per square meter floor area.

$$ADPF = \frac{\sum_{i=1}^{n} ADPF_i * RU_i}{A}$$

### 2.6.14 SU8 - Formation potential of tropospheric ozone (POCP) in (kg ethylene/m2)/m²

Quantifies the relative abilities of volatile organic compounds (VOCs) to produce ground level ozone[16]. Specified in kilograms ethylene per m² per square meter floor area.

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[13] https://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf

[14] https://www.baubook.info/m/PHP/Fragezeichen.php?S_oekz_Typ=8&SW=16&oegpk2=n&lng=2

[15] https://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf

[16] https://ui.adsabs.harvard.edu/abs/2017AtmEn.163..128J/abstract

$$POCP = \frac{\sum_{i=1}^{n} POCP_i * RU_i}{A}$$

### *2.6.15 SU9 - CO2 emission rate in kg CO2/m²*

Refers to the CO2 emissions per square meter floor area caused by the energy consumption of the building during its operation.

$$CO2 = \frac{\sum_{i=1}^{n} CO2_i * EC_i}{A}$$

| | |
|---|---|
| CO2 | is the CO2 emission rate in kg CO2 per square meter floor area of the building |
| i | is the current energy carrier (power, oil, gas, district heating, etc.) |
| n | is the number of energy carriers used in the building |
| $CO2_i$ | is the CO2 emission rate in kg of energy carrier i per kWh |
| $EC_i$ | is the energy consumption of the building regarding energy carrier i in kWh |
| A | is the floor area of the building |

### *2.6.16 SU10 – CO2 emissions reduction in %*

Describes the CO2 emission reduction per square meter floor area caused by the lowered energy consumption because of implemented renovation measures. The reduction is calculated by comparing the renovation scenario to the baseline scenario in terms of CO2 emissions (SU9).

$$CO2_{red} = \left(1 - \frac{CO2_{reno}}{CO2_{base}}\right) * 100$$

## 2.7 TECHNOLOGY STACK AND IMPLEMENTATION TOOLS

The BIMERR LCA/LCC module is based on state-of-the-art technologies and three layers:

- The Presentation Layer, which allows the user to set his/her preferred data sources for sustainability data and project-specific financial data. The user interface is built upon Angular, Typescript, and NGRX Entity/Store.
- The Business Logic Layer which calculates the KPIs based on the IFC file and the financial and sustainability data for the building materials used in the renovation scenario.
- The Data Layer that utilizes PostgreSQL to store preferred data sources, project-specific financial data, and calculated KPIs for faster access at later usage.

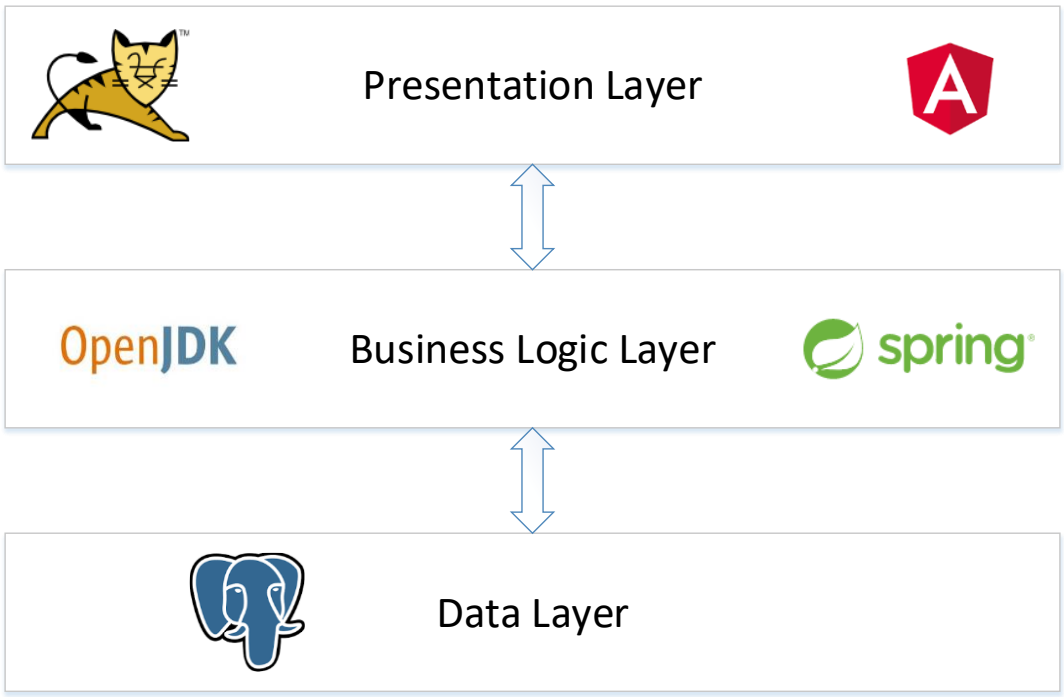


**Figure 3: Architecture of the BIMERR LCA/LCC module**

The BIMERR LCA/LCC modules utilizes the open source technologies and libraries as defined in the following table.

**Table 6: Technologies and libraries used in BIMERR LCA/LCC module**

| Name of the technology/library | Version | License |
|---|---|---|
| Apache Tomcat | 9 | Apache License 2.0 license |
| Angular | 8 | MIT License |
| Typescript | 3.5.3 | Apache License 2.0 license |
| NGRX Entity/Store | 8.5.2 | MIT-style License |
| Java OpenJDK | 11 | GPLv2 |
| Spring Boot | 2.2.1 | Apache License 2.0 license |
| PostgreSQL | 9.5 | PostgreSQL License (similar to BSD/MIT) |
| Hibernate | 5.4.8 | LGPL 2.1 |

## 2.8 API DOCUMENTATION

The communication between the front end (RenoDSS UI) and the back end (LCA/LCC module) is typically through internal APIs. As they serve inter-subcomponent integration purposes they are not documented at this point in detail.

## 2.9 Assumptions and Restrictions

As the development of BIMERR applications is still ongoing and validation activities have not started yet, the first release of the BIMERR LCA/LCC module is based on the following assumptions/restrictions:

- Currently, the unit of measurement is set manually, but not automatically extracted from the IFC file. The IFC unit extraction will be implemented in the second module version.
- Necessary unit conversions are currently not implemented. IFC provides material volume in specific units (e.g., $m^3$), but reference values for materials may also be provided in other units (e.g., per $m^2$, m or kg).
- Currently, the LCA/LCC module calculates the KPIs for the current building configuration, the renovation scenario KPI calculation will be implemented in the second iteration.
- Necessary parameters such as energy costs, interest rates, environmental costs, and CO2 emission rates are currently configured on a global level. In the second iteration these parameters must be set on the project level to reflect different project requirements.
- To keep the runtime of multiple scenario calculations low, the current KPI calculation implementation does not use any third party libraries. In the second iteration we will test if it is feasible to integrate optional third-party approaches such as OpenLCA.

## 2.10 Installation Instructions

The BIMERR LCA/LCC module is part of BIMERR RenoDSS which is accessible via a web-based GUI, and therefore does not require installation or downloading of any component to use it.

## 2.11 Licensing

The KPI calculation schema is public. As parts of the BIMERR LCA/LCC module are based on and integrated into the Xylem business intelligence platform it is a closed source component.

# 3. END-TO-END USAGE WALKTHROUGH TO THE BIMERR LCA/LCC MODULE

This end-to-end usage walkthrough shows the BIMERR LCA/LCC module functionality in the context of the BIMERR RenoDSS system.

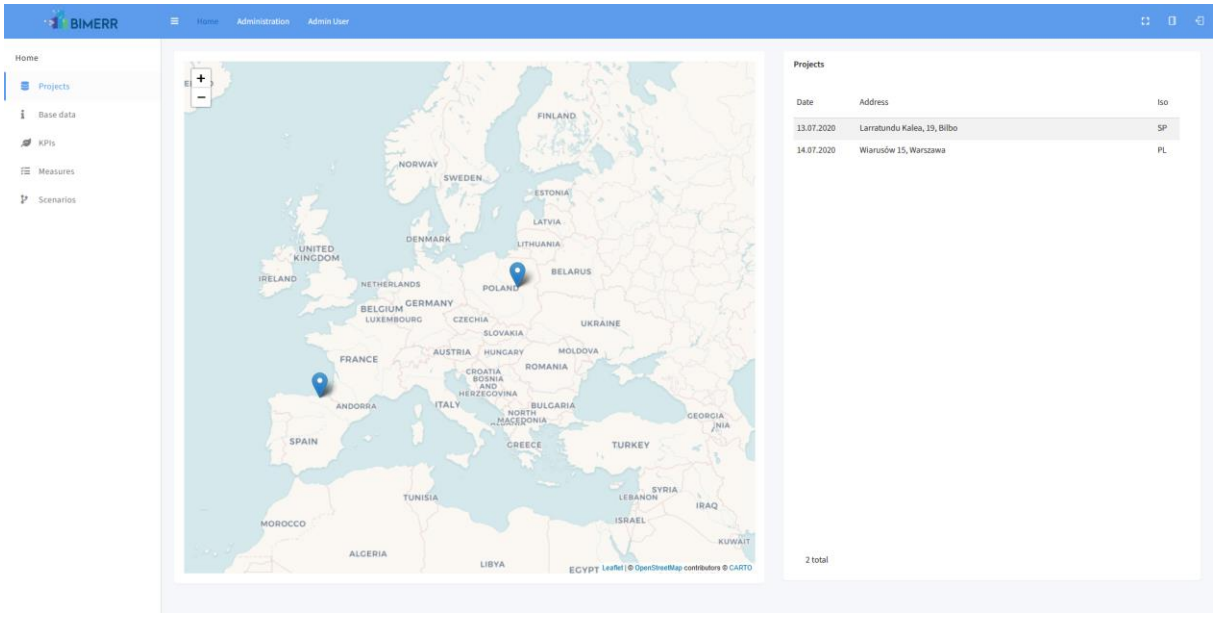


**Figure 4: RenoDSS - project view**

Figure 4 shows the project view of RenoDSS. By selecting a specific project, the corresponding IFC file is loaded (currently from local storage, in the second version of the LCA/LCC module from the BIF) and sent to the BIMERR LCA/LCC module which extracts building materials from construction layers present in the IFC file. Please see Section 2.4 and 2.5 for further details regarding IFC file handling. The LCA/LCC module assumes that building materials in the IFC file (i) are associated to an ID which originates from the BIMERR Material and Component Database and allows the lookup of relevant material properties, or (ii) are directly described with property values and property names which correspond to those in the BIMERR Material and Component Database. By selecting a specific project, the following building view is loaded.

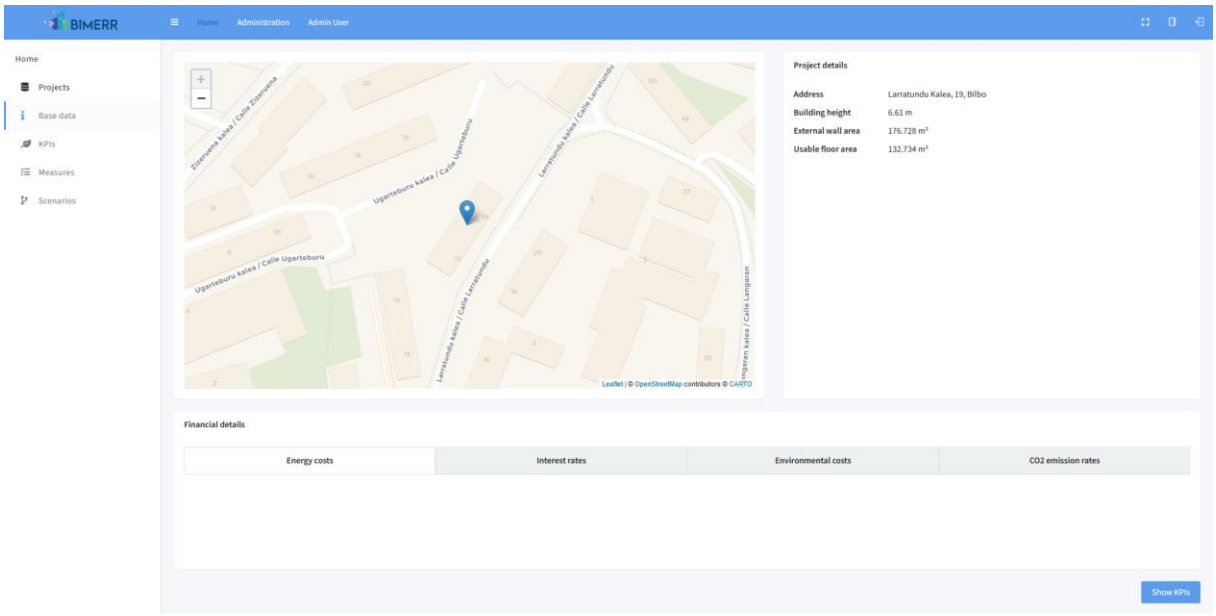


**Figure 5: RenoDSS - building view**

Figure 5 shows the building view and the Financial Details view which will provide a user interface for setting energy costs, interest rates, environmental costs, and CO2 emission rates in the second release of the BIMERR LCA/LCC module. Currently hard coded sample values are used to calculate the LCA and LCC KPIs. By clicking the “Show KPIs” button, the following KPI view is loaded.

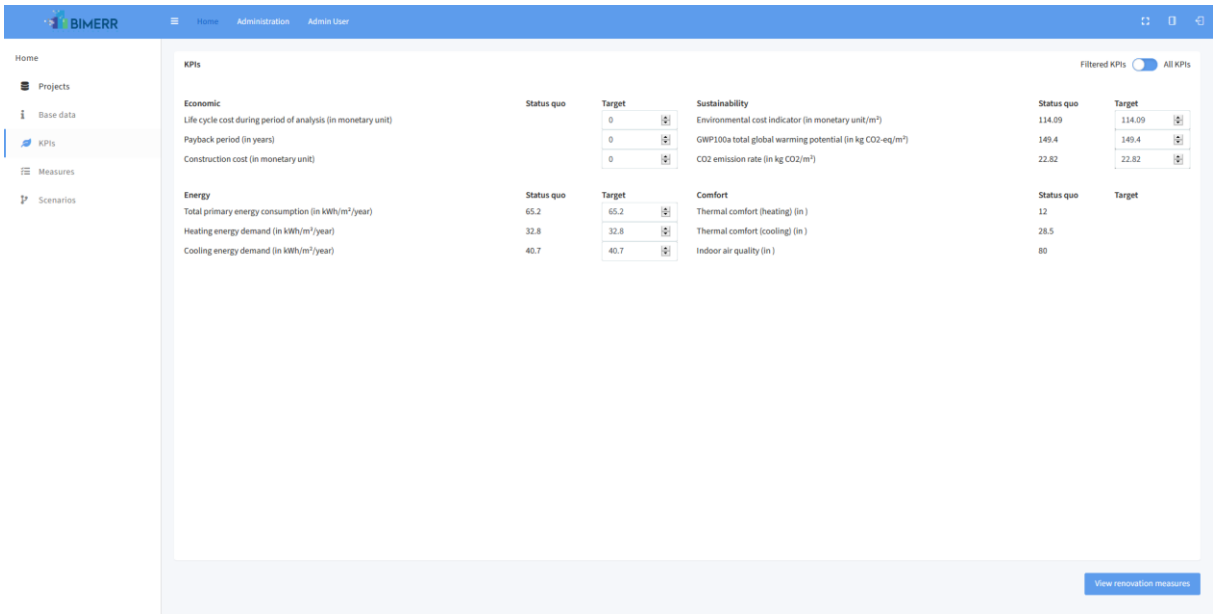


**Figure 6: RenoDSS - simple KPI view**

Figure 6 shows the simple KPI view, i.e., the three most important KPIs in each of the four categories Economic, Sustainability, Energy, and Comfort are shown to the user. While the LCA/LCC module is

responsible for calculating the economic and sustainability KPIs, the Building Energy Performance module is responsible for calculating the energy KPIs.

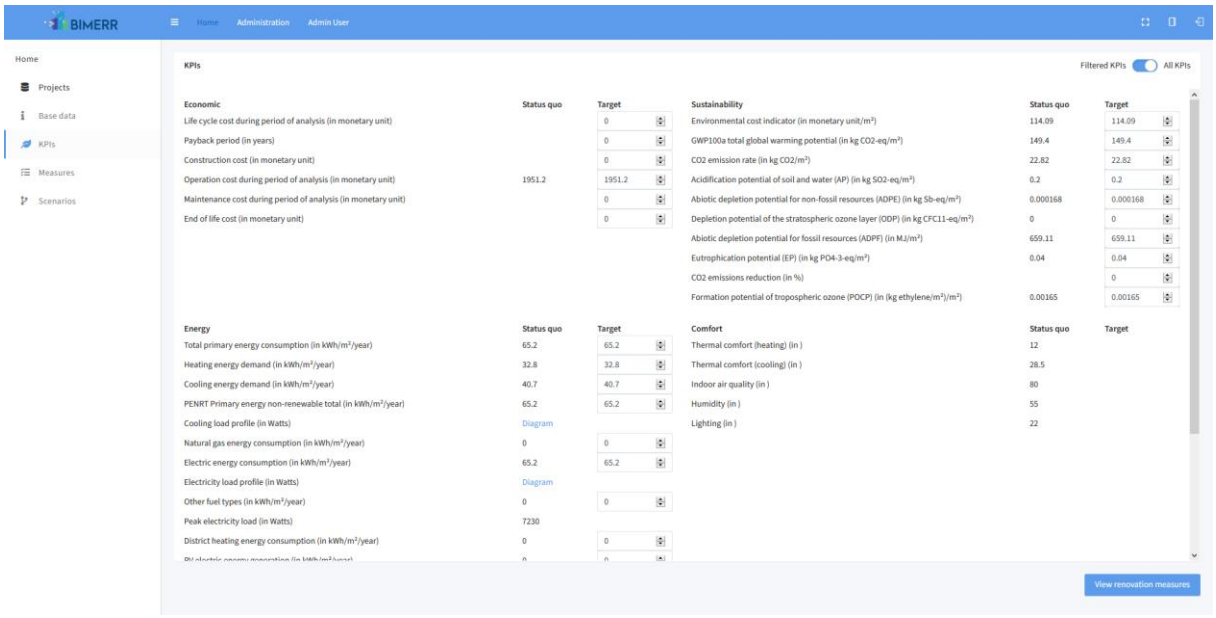


**Figure 7: RenoDSS - extended KPI view**

All KPIs can be visualized by switching to “All KPIs” by the switch in the top right corner within Figure 7. The Status Quo columns in the economic and sustainability categories represent the LCA/LCC calculation results. Please note that only the baseline KPIs are calculated based on the data provided so far (IFC file, Building Energy Performance module results, and financial data such as energy costs, interest rates, environmental costs, and CO2 emission rates. The remaining KPIs (e.g., life cycle cost) can be only calculated for renovation scenarios and will be implemented in the second release of the LCA/LCC module.

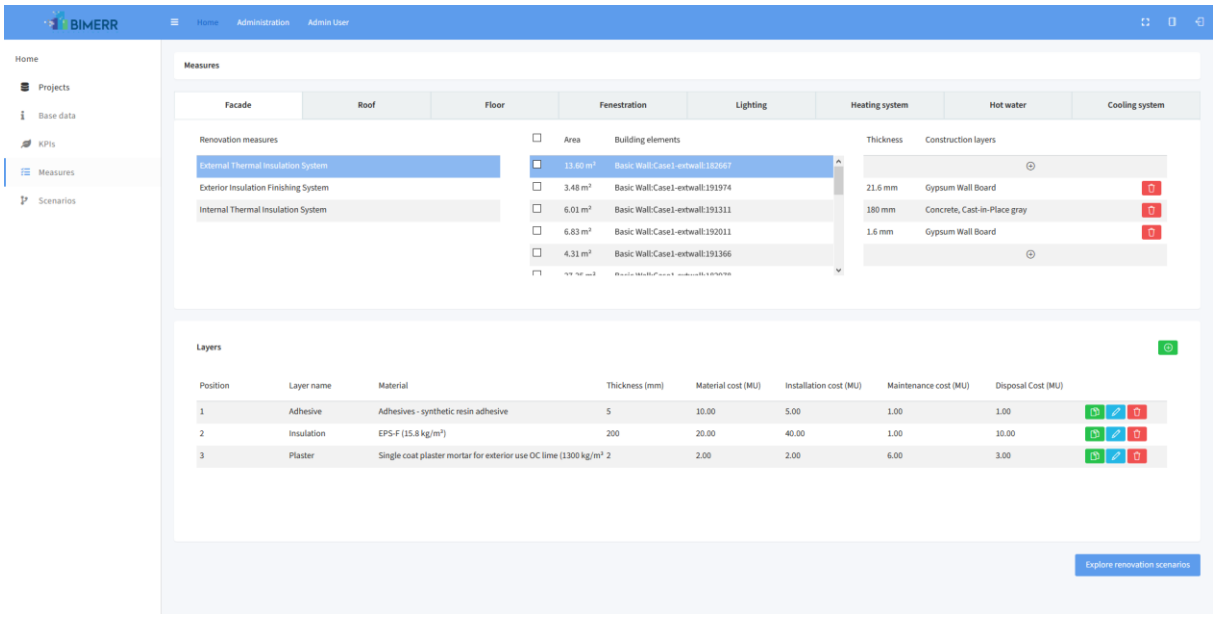


**Figure 8: RenoDSS - project-specific cost view**

Figure 8 shows how the user can change the cost of each material layer. This data is required for the economic renovation scenario KPIs (e.g., life cycle cost). Please note that initially default cost are loaded which were set by the RenoDSS administrator role.

By clicking the “Explore renovation scenarios” button, the Scenario Generator module generates the renovation scenarios and sends each scenario to the LCA/LCC module for calculating the renovation scenario KPIs. Please note that this functionality will be implemented in the second version of the LCA/LCC module as soon as the Scenario Generator module implementation is finalized.

# 4. CONCLUSIONS AND PLAN FOR SECOND ITERATION

The BIMERR LCA/LCC module provides 16 KPIs about the financial and sustainability impact of the renovation scenario under investigation. The relevant input data is extracted from the renovation scenario's IFC file. The IFC file is populated with sustainability data from the BIMERR Material and Component Database and project-specific financial data provided by the user via the BIMERR Renovation Support Tools user interface.

The following extensions are planned for the second release of the BIMERR LCA/LCC module:

- Implementation of unit conversions to match IFC units with material units from the BIMERR Component and Material database.
- Implementation of renovation scenario KPI calculation (e.g. life cycle cost).
- Project-specific energy costs, interest rates, environmental costs, and CO2 emission rates based on region-specific global values which are maintained by the administrator role.
- Evaluation if the integration of third-party approaches such as OpenLCA provide additional benefit to the RenoDSS user.