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IFC-BASED BUILDING RENOVATION SCENARIO GENERATOR

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Abstract

Increasing the building renovation rate is key to drive energy efficiency in the sector and contribute to the European Green Deal. The RenoDSS building renovation scenario generator, developed within the H2020 project BIMERR, generates IFC files that represent potential renovated building configurations based on: (i) the IFC representation of the current building configuration, (ii) potential renovation measures selected by the user and their defined mapping to IFC elements, and (iii) a rule set on how these renovation measures can be combined and applied on the building. The automated and BIM-based approach enables the efficient generation of renovation scenarios, the calculation of renovation scenario KPIs, and the identification of the most suitable scenarios by comparing the scenarios' KPIs. Validation at two pilots has shown substantial time savings at generating renovation scenarios, calculating their KPIs, and identifying the most suitable renovation scenario for the individual renovation project.

Introduction

The European Green Deal aims to achieve climate neutrality in Europe by 2050, with no net greenhouse gas emissions (Commission, 2021a). A crucial strategy to promote energy efficiency and support the objectives of the European Green Deal is to increase the rate of building renovations (Commission, 2021b). In line with this, our research focuses on presenting RenoDSS, an intuitive, BIM-based decision support system developed as part of the H2020 project BIMERR. RenoDSS assists users in exploring various renovation options for buildings, evaluating their impact on building performance, and guiding them towards the optimal choice based on specific constraints such as intervention size, budget, target energy savings, and more.

This paper introduces RenoDSS' innovative BIM-based renovation scenario generator, which automatically generates renovation scenarios according to the user's specified renovation measures. For each generated scenario, RenoDSS calculates energy, economic, and sustainability key performance indicators (KPIs). These KPIs enable users to compare the different renovation scenarios and identify the most suitable one for their needs.

Background

A comprehensive review by Nielsen et al. (2016) examined various approaches in the field of building renovation decision support systems. Out of the 43 approaches assessed, 13 of them proposed renovation actions and automatically generated design alternatives based on predefined criteria. Two approaches closely related to RenoDSS were identified: Jalaei et al. (2015) and Kamari et al. (2019).

In their work, Jalaei et al. (2015) developed a decision support system (DSS) as a Revit plug-in. The DSS utilized the building's BIM model to calculate sustainability, finance, and social wellbeing key performance indicators (KPIs) during the conceptual design stage of building projects. The system relied on numerical models to generate and simulate alternative renovation scenarios, rank them, and assist the user in selecting the most suitable option. The evaluation of renovation scenarios incorporated the Life Cycle Cost (LCC) method to analyze and compare the operational costs of the entire building.

Similarly, Kamari et al. (2019) created PARDIS, a BIM-based decision support system. PARDIS offered functions such as generating and evaluating dwelling renovation scenarios based on specific typologies and constraints, assessing energy, finance, and comfort KPIs, and visualizing the generated scenarios. Implemented as a Revit plug-in, the PARDIS prototype underwent empirical evaluation on an apartment block in Denmark.

In contrast to existing approaches, RenoDSS offers distinctive features. Firstly, it is a web-based system that allows collaborative usage by multiple users, independent of closed-source BIM software. Secondly, RenoDSS utilizes the open industry standard IFC for exchanging building information. The software architecture of RenoDSS is modularized and open to external components. By considering the baseline building configuration and the user's renovation preferences, the RenoDSS scenario generator generates potential renovation scenarios. These scenarios are then passed to the data management module, which subsequently delivers them to the RenoDSS modules for calculating the KPIs associated with each generated renovation scenario. To obtain relevant thermal and life cycle assessment (LCA) building material properties required for KPI calculations, RenoDSS automatically retrieves data from building material databases such as Baubook (Baubook GmbH, 2022), Ökobaudat (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2022), and ASHRAE (National Renewable Energy Laboratory (NREL), 2022).

By incorporating information about the current building characteristics, installed equipment, utility network connections, and interactions with other buildings, RenoDSS aims to enhance the accuracy of estimations and projections compared to existing renovation planning approaches.

Building renovation scenario generator

The generation of building renovation scenarios by the scenario generator involves creating IFC files that depict the renovated building configurations. This process takes into account three main factors: (i) the IFC representation of the existing building configuration, (ii) the user's selection of potential renovation measures, and (iii) a rule set governing how these renovation measures can be combined and applied to the building. These renovation measures are mapped to specific IFC elements, as outlined in Table 1.

Combining renovation measures

Renovation measures, such as the insulation of external walls or the replacement of heating systems, are commonly employed to enhance the energy efficiency, comfort, and life cycle cost of buildings. Table 1 provides a summary of the renovation measures supported by the current implementation of the scenario generator. To streamline the process and reduce the number of potential combinations, it is assumed that each renovated building element can only undergo one renovation measure within a given renovation scenario. For example, in a particular renovation scenario, the façade of a specific building element can either be externally insulated or internally insulated; these measures cannot be combined within the same renovation scenario.

Each renovation measure falling under the categories of façade, roof, and floor is defined by its construction layers and the allowable building materials for each layer. To illustrate, Figure 1 presents the layer configuration for the "Top slab external insulation" renovation measure. The initial layer comprises insulation, which is applied on top of the existing slab. In this particular example, the insulation can consist of either 200mm cellulose or Expanded Polystyrene Insulation (EPS), with a thickness option of 200, 300, or 400mm. The subsequent layer entails plywood, which is placed over the insulation material.

As each renovation measure can be implemented by different material/thickness combinations, the number of potential renovation scenarios is calculated as follows:

$$RM = \prod_{i=0}^{n}\prod_{g=0}^{l}((\sum_{j=0}^{m}\prod_{k=0}^{c}NL_c)+1) \quad (1)$$

- RM: number of renovation scenarios
- i: current renovation measure category façade, roof, floor, fenestration, solar collector, heating system, cooling system
- g current building element group
- j current renovation measure in renovation measure category i
- k current construction or component in renovation measure m
- NL: sum of equal position numbers per layer in construction c or number of equivalent implementations for component c

The rationale behind the RM formula is as follows: Within each renovation measure category (e.g., façade, roof), there are specific renovation measures available (e.g., external thermal insulation system, internal thermal insulation system). Each renovation measure is implemented either through a layer-based construction or a single component and can be applied to different groups of building elements. Building element groups consist of building elements that share similar characteristics. For instance, walls, roofs, slabs, and floors with the same construction would be grouped together. Table 2 illustrates the step-by-step calculation of the total number of renovation scenarios, using example data as a basis.

If a layer-based construction includes multiple material/thickness combinations for a given layer position, the total number of possible combinations is obtained by multiplying the sums of the equal position numbers for each layer. For example, in the construction depicted in Figure 1, there would be 4*1=4 valid layer combinations (4 combinations of insulation material/thickness in layer 1 and 1 combination in layer 2). Table 2 displays the number of valid layer combinations or components in the fourth column.

Since a renovation measure category can consist of multiple renovation measures (e.g., double- or triple-glazed windows for fenestration renovation, as shown in Table 2), and each final renovation scenario contains only one renovation measure per renovation measure category and building element group, we need to sum up the number of potential implementations per renovation measure category and building element group. Additionally, considering that it is also possible to not implement any renovation measure, we add 1 to the sum (refer to Column 5 in Table 2).

Considering that renovation measures can be applied to different building element groups within a single renovation measure category (e.g., applying different renovation measures to various exterior walls), the number of combinations per renovation measure category is calculated by multiplying the potential implementations of renovation measures per building element group, along with an additional option for non-renovation (as illustrated in the previous paragraph and Column 5 of Table 2, for the Façade renovation measure category).

Assuming that only one renovation measure (or none) is implemented per renovation measure category and building element group in a given renovation scenario, the total number of potential renovation scenarios is obtained by multiplying the number of potential implementations per renovation measure category (Column 6 in Table 2).

Whenever the user adds a potential renovation measure, RenoDSS provides immediate feedback on the total combinations, enabling the user to limit the combinations to

Table 1: Renovation measure - IFC element mapping

Name	**Category**	**IFC element**
Envelope insulation		
External thermal insulation system	Façade	IfcWall; IfcWallElementedCase; IfcWallStandardCase
Internal thermal insulation system	Façade	IfcWall; IfcWallElementedCase; IfcWallStandardCase
Flat roof external insulation	Roof	IfcRoof; IfcSlab
Pitched roof internal insulation	Roof	IfcRoof; IfcSlab
Top slab external insulation	Roof	IfcRoof; IfcSlab
Basement ceiling insulation	Floor	IfcSlab
Slab internal insulation	Floor	IfcSlab
Windows replacement		
Double glazed windows	Fenestration	IfcWindow; IfcWindowStandardCase
Triple glazed windows	Fenestration	IfcWindow; IfcWindowStandardCase
Renewables installation		
Photovoltaic panel	Solar collector	IfcSolarDevice
Solar thermal collector	Solar collector	IfcSolarDevice
HVAC system replacement		
Condensing natural gas boiler	Heating system	IfcBoiler
Air to water heat pump	Heating system	IfcPump
Air to air split units	Cooling system	IfcPump

Position	Layer name	Material	Thickness (mm)
1	Insulation	Cellulose spray on insulation (95 kg/m³)	200
1	Insulation	EPS-F (15.8 kg/m³)	200
1	Insulation	EPS-F (15.8 kg/m³)	300
1	Insulation	EPS-F (15.8 kg/m³)	400
2	Board	Plywood and laminated veneer lumber for interior use (375 kg/m³)	35

Figure 1: Renovation measure "Top slab external insulation" and potential building materials for each layer of the construction

a manageable number (up to approximately 500). This is achieved by passing only highly relevant renovation measures and materials to the scenario generator.

IFC file modification

For each renovation scenario, the scenario generator generates an IFC file that represents the renovated building. The data management module then transfers this IFC file to the RenoDSS building energy performance, LCA/LCC, and urban planning modules to calculate the building's KPIs. To accomplish this, we utilize the xBIM Toolkit[1] for loading and modifying the IFC file of the current building configuration. For each renovation scenario, we perform the following steps: (i) identify the specific IFC elements that need to be modified based on the user's selected renovation measures (e.g., IfcWall, IfcRoof, or IfcSlab elements), (ii) remove layers as specified by the user (e.g., old insulation layers), as described in Section , (iii) add renovation layers according to the renovation scenario, (iv) send the modified IFC file to the building energy performance, LCA/LCC, and urban planning modules for KPI calculation, and (v) retrieve the calculated KPIs from the calculation modules and store them in the decision support data structure.

Implementation

Within RenoDSS, the user selects pre-defined renovation measures to enable the generation of renovation scenarios. The renovation measures are defined by the RenoDSS admin user and can be modified by the RenoDSS user within the renovation project context. Based on the global renovation measures defined by the RenoDSS admin user, the RenoDSS user selects those renovation measures which should be applied to a specific renovation project as follows:

1. For each renovation measure category (e.g., façade or roof), RenoDSS identifies those IFC building elements which are relevant to the renovation measure category (based on the IFC elements types such as IfcWall or IfcRoof defined in the renovation measure).

2. RenoDSS groups all IFC building elements with identical constructions and lists them in the dropdown "Building element" – see top left in Figure 2. Grouping identical constructions enables the user to apply renovation measures more efficiently than selecting them for each single IFC element.

3. The current construction of the selected building element is shown in the top middle area of the user interface (see Figure 2). The user must select the conditioned side of the construction to ensure that the scenario generator applies the selected renovation measures on the correct side of the construction.

4. The renovation measures for each building element are selected by the RenoDSS user in the top right area

[1] https://docs.xbim.net/

Table 2: Calculation of total renovation scenarios - example input data (1: renovation measures, 2: renovation measure category, 3: building element group, 4: number of valid layer combinations or components, 5: number of combinations per renovation measures category, 6: number of renovation scenarios

1	2	3	4	5	6
External thermal insulation system	Façade	Exterior wall 1	2	(2+2+1)*(2+2+1)=25	
External thermal insulation system	Façade	Exterior wall 2	2		
Internal thermal insulation system	Façade	Exterior wall 1	2		
Internal thermal insulation system	Façade	Exterior wall 2	2		
Flat roof external insulation	Roof	Roof 1	4	(4+8+4)+1=16+1=17	
Pitched roof internal insulation	Roof	Roof 1	8		
Top slab external insulation	Roof	Roof 1	4		
Basement ceiling insulation	Floor	Floor 1	2	2+2+1=5	
Slab internal insulation	Floor	Floor 1	2		25*17*5*3*3*3*2=114750
Double glazed windows	Fenestration	Windows 1	1	1+1+1=3	
Triple glazed windows	Fenestration	Windows 1	1		
Photovoltaic panel	Solar collector	Roof 1	1	1+1+1=3	
Solar thermal collector	Solar collector	Roof 1	1		
Condensing natural gas boiler	Heating system	Building 1	1	1+1+1=3	
Air to water heat pump	Heating system	Building 1	1		
Air to air split units	Cooling system	Building 1	1	1+1=2	

of the user interface (see Figure 2). Zero or more renovation measures can be selected.

5. As the application of renovation measures often requires the removal of old construction layers or components, the RenoDSS user must indicate at the construction layers (top middle area of the user interface in Figure 2) which layers are removed at which renovation measure application. Each renovation measure is encoded by its identifier (e.g., A and B) at each layer. By clicking on the buttons, the user can change the colour from green to red and from red to green. Red means this layer is removed when applying the renovation measure. Green means this layer will be kept when applying the renovation measure. E.g., when applying external insulation, the old insulation layer is usually removed before applying the new insulation layer.

6. By selecting a specific renovation measure, its layers are shown in the bottom area of the user interface (see Figure 2). The layers are initially copied from the global renovation measures as defined by the RenoDSS admin user. After the layers have been copied into the specific renovation project, the RenoDSS user can modify them as needed. E.g., adding/changing layers and materials, modifying costs, etc.

Figure 3 shows the selection and modification of project-specific renovation measures on the component level. At the component level, building elements are also grouped and we assume that old components are removed before new components are applied as renovation measures.

Within the renovation scenario view the results of the RenoDSS scenario generator and the KPI calculations for each generated scenario are shown. Each renovation scenario is described by its most important KPIs, the list view allows for sorting all scenarios by KPIs. Sliders can be used to filter the renovation scenarios by their KPIs. By clicking on a renovation scenario, the renovation measures of this specific scenario are shown. Building elements which are affected by the selected renovation scenario are colored in red within the building visualization widget.

Validation

The RenoDSS renovation scenario generator underwent validation within the context of two building renovation projects in Spain and Poland. The primary objective of the validation was to identify cost- and energy-efficient renovation options for the external walls of the buildings.

Specifically, in the Polish site, the focus was on improving the energy characteristics of a social double segment residential building. The renovation primarily involved adding new external insulation to the façades, aiming to enhance thermal resistance and prevent thermal energy loss.

On the other hand, the Spanish site aimed to improve the energy characteristics of a residential tower-building. The main goal was to enhance thermal insulation and reduce the façade transmittance, thereby decreasing the energy demand of the building.

During the preliminary User Acceptance validation, it was observed that the RenoDSS user interface was not self-explanatory and required an initial introduction. As a result, users were provided with remote demonstration sessions on concrete building renovation projects of their own choice to familiarize themselves with RenoDSS. These sessions allowed users to configure the project together and understand how missing data could be efficiently completed using the BIMERR building material and component database, which builds upon building material databases such as Baubook (Baubook GmbH, 2022), Ökobaudat (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2022), and ASHRAE (National Renewable Energy Laboratory (NREL), 2022). The validation process indicated that an introductory workshop, followed by a specific renovation project workshop, effectively communicated the functionality of RenoDSS to the users. Furthermore, a detailed user manual was developed as a result of the validation activities to assist new users in utilizing RenoDSS.

Once introduced to RenoDSS, the users, who were renovation managers at respective construction companies, configured potential renovation constructions, selected materials, and defined cost attributes for the external walls within the system. They generated renovation scenarios following the approach described in this paper. The users provided the following feedback regarding the generated renovation scenarios and their corresponding KPIs:

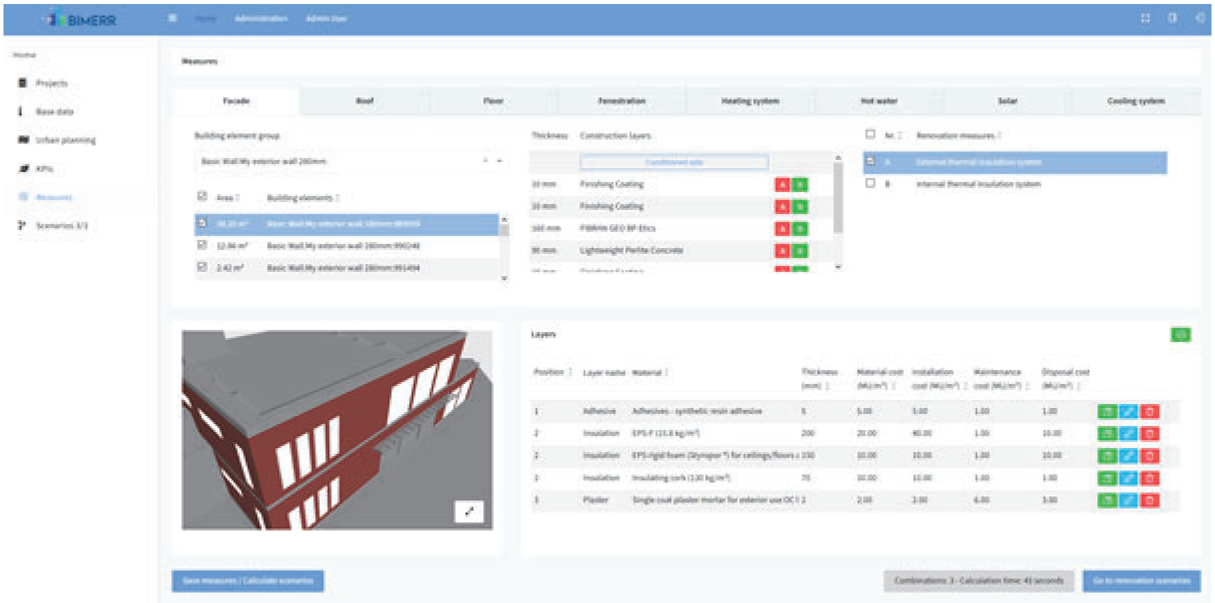

Figure 2: renovation measure view - constructions

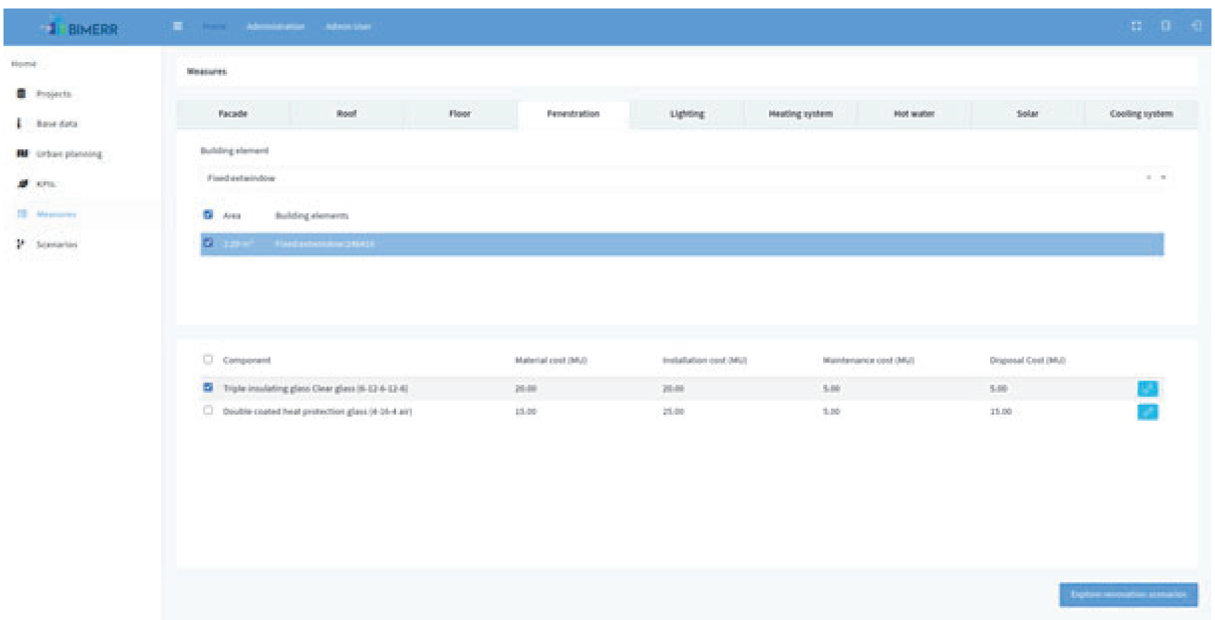

Figure 3: renovation measure view - components

The feedback provided by the users regarding the generated renovation scenarios and their KPIs can be summarized as follows:

- After an introductory explanation, the usage of RenoDSS was straightforward.
- Construction and material default properties could be easily customized to align with the actual building project. The BIMERR material and component database sufficiently supported the mapping of missing building material properties.
- The provided energy, finance, and sustainability KPIs facilitated the filtering and sorting of renovation scenarios, allowing users to collaboratively identify the most suitable option with other relevant stakeholders.
- The provided IFC file enabled users to load the renovation scenario into their BIM tool for further editing.
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Based on the validation activities, certain areas for future improvement were identified and will be addressed in subsequent research endeavors:

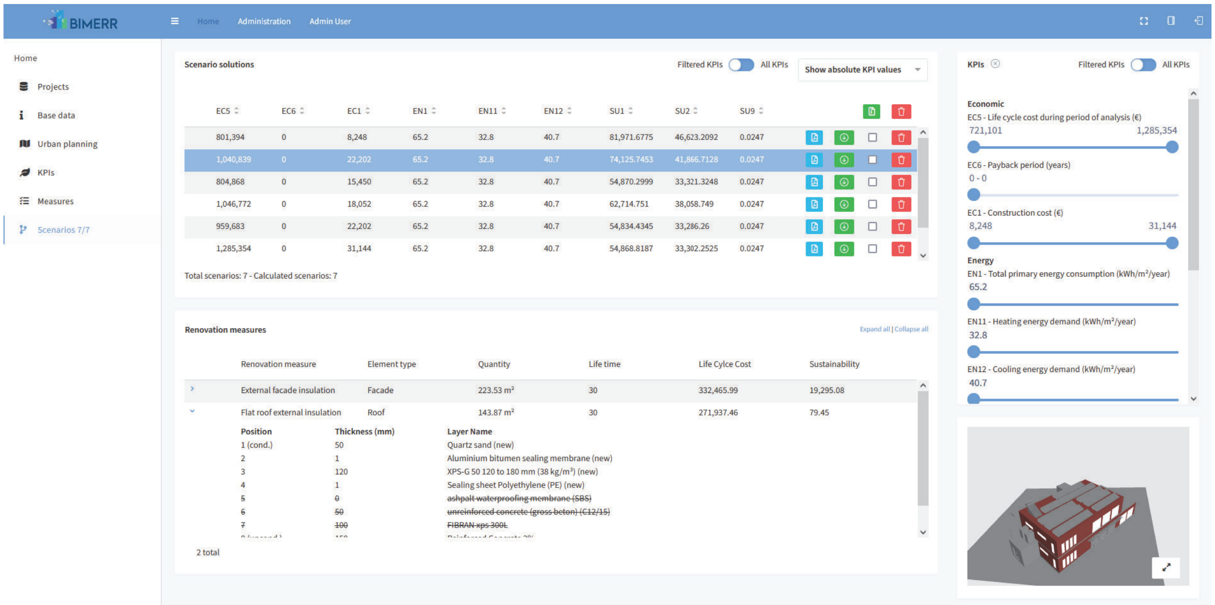

Figure 4: renovation scenario view

- Obtaining financial data for existing materials and components required for the LCA/LCC module (such as maintenance cost and disposal cost) was challenging. In some cases, estimation by the renovation designer was necessary to enable the calculation of corresponding KPIs.

- While RenoDSS provided a wide range of renovation measure materials by default, there was a need to add specific renovation measure components for certain buildings (e.g., custom windows designed for a particular building).

The validation process demonstrated that RenoDSS significantly reduces the time required for (i) identifying potential renovation scenarios, (ii) calculating their energy and LCA/LCC KPIs, and (iii) producing an IFC file for each renovation scenario. Compared to manual approaches supported by other tools, RenoDSS achieved an 80% reduction in time. Within the remaining 20%, RenoDSS accomplished 86% of the tasks automatically, with only 14% requiring manual intervention.

Conclusion and future work

The building renovation scenario generator, developed in RenoDSS, generates IFC files that represent renovated building configurations. These configurations are based on three key inputs: (i) the IFC representation of the current building configuration, (ii) user-selected potential renovation measures and their mapping to IFC elements, and (iii) a rule set governing the combination and application of these renovation measures on the building. For each generated renovation scenario, RenoDSS calculates energy, economic, and sustainability KPIs, providing detailed information on individual renovation measures within the scenario. This includes investment cost and quantity (e.g., pieces, m², m³) for each measure, enabling users to compare and identify the most suitable renovation scenario.

The current implementation operates under certain assumptions and restrictions. Firstly, IFC files must include second level space boundaries (2LSB) data, which is necessary to identify the building's thermal hull. Secondly, material and component properties in the IFC file need to be described using the defined property set (pset) and attribute names that can be processed by the KPI calculation modules.

Future work aims to address and reduce these restrictions in several ways. Firstly, RenoDSS plans to include functionality that allows users to add requirements such as 2LSB or map the IFC pset data structure within the tool itself. This will enhance flexibility and expand the range of applicable IFC files. Secondly, there are plans to differentiate between structural and non-structural building element layers in the visualization and renovation measure selection processes. However, this differentiation will depend on IFC support for such distinctions. Thirdly, RenoDSS intends to introduce additional renovation measures, such as ventilation, and extend the current categories of heating/cooling, hot water, and solar. Fourthly, improvements will be made in the visualization of scenarios, potentially incorporating diagrams that illustrate savings versus costs. Finally, the goal is to successfully deploy and utilize RenoDSS in at least five operational environments, ensuring its practical applicability and effectiveness.

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