A Design Assistant Tool for Optimised Building Energy Retrofit

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Abstract

The construction sector is a major contributor to global resource depletion and environmental impacts. Most buildings still lack energy efficiency, necessitating substantial renovations to reach European climate neutrality by 2050. Energy efficiency measures typically prioritize investment cost and targeted energy performance, often neglecting the environmental impact associated with the production and disposal of the selected materials. This paper presents the development of a design assistant tool that combines sustainability indicators with cost and energy performance, aiming to foster sustainable renovation. Through automated data exchange between Autodesk Revit, CasaClima software and Microsoft Excel, the tool identifies optimal retrofit solutions. Users can choose materials and systems and visualise different retrofit alternatives through a user-friendly interface. The paper describes how the tool is structured to quickly evaluate a wide range of energy efficiency measures.

1. Introduction

The European Union's strategy for achieving climate neutrality by 2050 necessitates a significant transformation in the construction sector due to its high resource and energy consumption. It accounts for about half of globally extracted materials and 25-30% of waste generated in the EU (EURIMA, 2024). Moreover, buildings account for 40% of the EU's energy consumption and 36% of greenhouse gas (GHG) emissions (EURIMA, 2019). Considering that most of the building stock is relatively old and energy inefficient, retrofitting plays a key role in achieving European targets (ECSO, 2021). Retrofitting usually concerns building envelope and systems, prioritising investment cost and targeted energy performance. The embodied emissions associated with materials production and disposal, and those associated with the construction process are often neglected despite they account for 21% of buildings' total emissions (EURIMA, 2023). According to (ECSO, 2021) along with improving energy performance, retrofitting should prioritise an efficient use of resources considering the entire life cycle of a building. This has the potential to significantly reduce emissions, especially if implemented already at the design stage.

Recent studies explore holistic frameworks that consider cost, energy efficiency and environmental sustainability. (Chen et al., 2020) stress the importance of holistic evaluations that incorporate both quantitative and qualitative assessments—like energy consumption, cost analysis, carbon emission reductions, and social perspectives—particularly for residential buildings in Norway. (Rosso et al., 2020) explore the use of genetic algorithms in multi-objective optimisation for building retrofits in the Mediterranean climate, showing how these can tailor retrofit solutions to specific regional needs. (Li et al., 2021) developed a simulation-based optimisation model that assesses design alternatives to balance energy demand with thermal comfort, providing a basis for making informed decisions in retrofit projects. (Fourchal et al., 2017) introduced a decision support tool that automatically generates and ranks building retrofit alternatives based on energy performance, user requirements, benchmarks, and regulations. The tool uses the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method for multi-criteria ranking, offering a systematic ap-

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proach for selecting optimal retrofit solutions.
Despite the development of holistic frameworks, there is often a disconnect between these assessment tools and project design software. (Stratbücker & Mitterhofer, 2017) and (Lai et al., 2023) emphasize the need for better integration between assessment tools and platforms like Building Information Modelling (BIM) to enhance the accuracy and efficiency of retrofits. Regarding this, (Jalaei & Jrade, 2014) propose a methodology that links BIM with energy analysis tools and green building certification systems, facilitating sustainability evaluations at the design stage. (Thravalou et al., 2023) present an integrated approach to propose cost-effective energy efficiency upgrade measures for historic buildings, considering the building envelope, efficient systems, and renewable energy systems using Heritage-BIM tools. However, challenges such as data interoperability still hinder the effective use of BIM as noted by Pereira et al. (Pereira et al., 2021). In fact, sustainability assessment tools such as CasaClima software often operate independently, leading to fragmented and time-consuming assessment processes. Moreover, the literature still indicates a gap in accessible tools that provide this level of integration in a user-friendly interface, which is essential for broad adoption.
In response to these gaps, this paper introduces a design assistant tool that leverages automated data exchange between Autodesk Revit, CasaClima software, and Microsoft Excel to provide a comprehensive analysis of building retrofits. By integrating these platforms, the tool facilitates the identification of optimal retrofit solutions that balance cost, energy performance, and environmental sustainability. Its user-friendly interface allows for easy selection of materials and systems, visualisation of retrofit alternatives, and informed decisions based on a multi-criteria evaluation process.
The choice of the aforementioned software is driven by the goal of creating a useful tool for companies in the South Tyrol region, since the development of the design assistant tool is funded by the South Tyrol Fusion Grant Fund, which aims to foster collaboration between research institutes and companies in South Tyrol, Italy, to promote innovation and development within local businesses.

The structure of the paper is as follows: Section 2 illustrates the methodology for addressing the above-mentioned challenges; Section 3 describes the resulting design assistant tool; Section 4 draws conclusions and gives a brief outlook for possible directions of further research.

2. Method

The methodology applied for the development of the design assistant tool, illustrated in Fig. 1, is based on an in-depth analysis of the CasaClima software and its simulation requirements.

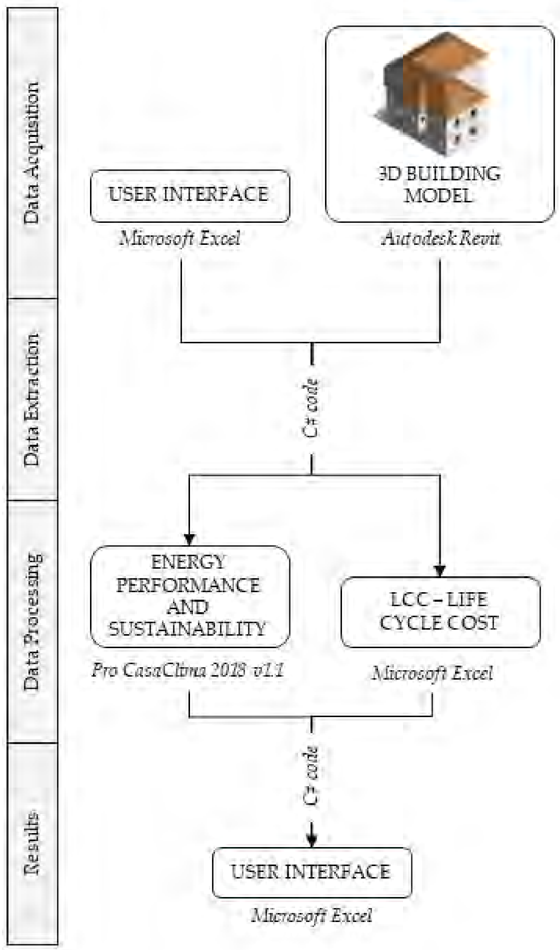

Fig. 1 – Overview of methodology

CasaClima is a comprehensive software used to assess the energy performance and sustainability of buildings, ensuring they meet specific energy efficiency standards outlined in European Directives such as EU 2018/844, 2010/31/EU, and 2012/27/EU.

The software evaluates the energy consumption of buildings, helping architects and engineers design energy-efficient and environmentally sustainable projects. In addition to energy efficiency, CasaClima assesses the environmental and health impacts of buildings, including the eco-compatibility of construction materials, water usage, and indoor environmental quality (Agenzia CasaClima, 2024).

Running a simulation with CasaClima requires users to manually input extensive building information, including geometry, materials, insulation properties, windows, and HVAC system details, into an Excel spreadsheet. Therefore, to promote sustainable retrofitting, the design assistant tool needs to enable users to quickly evaluate various retrofitting options during the design stage, minimising the manual input required. It must also provide a user-friendly interface that not only displays the CasaClima evaluation results but also includes cost data.

The design assistant tool development follows a multi-phase approach. The initial phase focuses on developing an Autodesk Revit plugin to extract data efficiently, enabling automated input into the evaluation software. The second phase introduces a user interface designed to gather additional required data, such as information on heating, ventilation, and air conditioning (HVAC) systems, which cannot be automatically retrieved from the 3D model. Following this, the CasaClima software (Pro CasaClima 2018 v1.1) calculates energy performance and sustainability indicators, with the results being showcased via user interface. The last phase involves integrating the costs of each retrofitting option, determined using the Life Cycle Cost (LCC) method, into the user interface.

Excel Macros combine the data obtained from the various phases by returning a final result while a C# code allows interoperability between Autodesk Revit, CasaClima software, and Microsoft Excel.

2.1 Phase One: Autodesk Revit Plugin

Within the scope of this study, a workflow for efficient data extraction and transfer from Autodesk Revit to the Pro CasaClima 2018 v1.1. software is developed and implemented. Autodesk Revit is a widely used design and engineering software in the construction sector. It is particularly valuable for its capability to create detailed 3D models that are enriched with several data.

For effective assessment, data to be extracted include dimensions, orientations, material information and function of all the building elements. Specifically, this includes every wall, slab, roof, window, and door element that is either facing the external environment or non-heated rooms of the building as well as the area of both non-heated and heated rooms.

To identify the relevant building elements, Revit's built-in categories properties are extended with a set of custom boolean properties. Users must edit these properties before the data extraction to indicate the boundary condition of the building elements. This boundary condition can be either *external*, *terrain* or *non-heated room*. Additionally, users must specify roof types as either *pitched roof*, *flat roof*, or *non-heated attics*, and distinguish between *heated* and *non-heated* rooms. This setup does not require users to manually input this information for every individual element. Revit works with so called *types*. Every instance of the same type will have the same properties assigned. For example, all wall elements of the same wall type have the same layer stratigraphy, materials and boundary condition assigned.

Moreover, a materials library in ASDKLIB file format is created to provide detailed materials information. This library contains materials commonly found in existing buildings, such as brick, EPS and XPS insulation, and lime. Each material in the library is defined by properties crucial for assessment, including thermal conductivity (W/mK), density (kg/m^3), and specific heat capacity (KJ/kgK). These property values are sourced from the CasaClima software materials library, ensuring accurate and reliable calculations.

The Revit's C# programming interface is used to implement the exposure of the custom properties and the automated data extraction into a plugin. These two functionalities of the plugin are exposed through two buttons that are added to the Revit user interface automatically on startup.

Finally, since the CasaClima software is implemented in a Microsoft (MS) Excel spreadsheet, all extracted data could be directly transferred seamlessly by the Revit plugin using MS Excel's C# programming interface, which enables reading and writing data to and from MS Excel spreadsheets through C# code.

2.2 Phase Two: User Interface

In addition to the Autodesk Revit plugin, a user interface is designed to gather additional data related to the building's design, location, and systems. The user interface is implemented within an Excel spreadsheet, organised into four distinct sections to simplify the data entry process. In particular, the data entry sections are:

- Section 0: Project Requirements; this section is designated for entering information related to the number of building's units, area, volume, and the municipality where it is situated.
- Section 1: Existing Building; this section enables the input of details concerning the HVAC system and the roof type (pitched, flat etc.) of the building before retrofitting.
- Section 2: Refurbishment; this section is for entering information about the retrofit solution, including the adjustment of costs if the predefined ones are unsuitable.
- Section 3: Life Cycle Cost; this section allows for the modification of the predefined costs mentioned in section 2.3.

Moreover, the Excel spreadsheet features two additional sections dedicated to displaying the results for energy performance, sustainability indicators, and costs. Specifically, the data output sections are:

- Section 4: Simulation; this section showcases the values associated with different retrofitting solutions in a tabular format.
- Section 5: Analysis; this section presents the results through a series of charts.

To initiate the assessment process and obtain these results, the interface incorporates three buttons created using Excel Macros. Moreover, to evaluate and compare different retrofit alternatives, the Excel spreadsheet includes a retrofit matrix linked to the data entry cells. Each row of the matrix represents a distinct retrofit option. Once the assessment process is started, an Excel macro reads the data from the first row of the matrix, inserts it into the corresponding fields of the CasaClima software, retrieves the result, and writes it into the dedicated sections of the user interface. This process is repeated for each row of the matrix.
Finally, the Excel spreadsheet has instructions accompanying each input and output field to ensure clarity and ease of use.

2.3 Phase Three: Life Cycle Cost (LCC)

The cost evaluation employs a custom-developed Excel spreadsheet, designed based on the LCC method. This spreadsheet primarily calculates the initial investment cost by aggregating expenses associated with the building envelope, HVAC system installation, general site setup, and any technical costs. To ensure accuracy in these calculations, data is sourced from the provincial price list of Bolzano (Provincia Autonoma di Bolzano – Alto Adige, 2024) and directly from user inputs via the interface. Moreover, the spreadsheet adds other costs associated with the building's entire lifecycle to the initial investment cost, facilitating a comprehensive assessment of the total cost. This assessment includes the following costs:

- Energy costs from ARERA (ARERA, 2024) and the Bolzano Consumer Protection Center (CTCU, 2024).
- Maintenance costs from the UNI 15459:2008 (UNI Ente Italiano Di Normazione, 2008).
- Public incentive programs, calculated to be 50% of the total costs and amortised over 10 years.

The assessment excludes replacement costs and residual values to streamline the evaluation. After completing these calculations, the user interface mentioned in section 2.2 displays the costs of different retrofitting options in a tabulated and graph format. This is done by an Excel function that connects the LCC calculation spreadsheet to the user interface, facilitating data exchange.

3. Results

The results of the design assistant tool consist in a series of data presented in an alphanumeric format. The data are visualised both in tabular format and as graphs. The tabular format offers an overview, enabling users to quickly identify the optimal refurbishment strategy. The solutions are ranked, beginning with the optimal one, based on a comprehensive set of criteria. This arrangement allows for an immediate comparative analysis across different options. The information provided for each solution is categorised into three sections:

- Technical Specifications: This section includes the technical details of each solution, including, but not limited to, the thickness of insulation materials and the type of HVAC systems employed.
- Energy Performance and Sustainability: Here, the outcomes derived from the CasaClima calculations are displayed, offering insights into the energy efficiency and sustainability impacts of each refurbishment option.
- Cost Analysis: Costs are detailed in this section, outlining the investment required for each refurbishment strategy.

Through an interactive interface, users can initiate the design assistant tool, with the flexibility to update its input parameters and subsequently refresh the results. Specifically, it allows them to perform the calculation and view the results regarding the building before retrofitting and to obtain the list of possible retrofitting options.

In addition to the tabular representation, users can visualise the results through a series of graphs. Each point on the graph correspond to a different retrofit solution and is linked to its detailed technical specifications listed in the abovementioned table.

To test the automated data exchange capabilities of the tool, a case study is conducted on a multi-storey residential building in South Tyrol, Italy. The focus is on verifying the automated workflow and data exchange between Autodesk Revit, CasaClima software, and Microsoft Excel, rather than on the accuracy of the calculations. A BIM model of the building is created using Autodesk Revit as shown in Fig. 2.

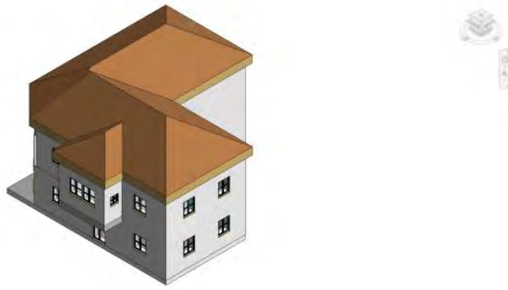

Fig. 2 – BIM model of the multi-storey residential building case study

The building has double-glazed wooden windows and wooden doors. It has external brick walls covered with lime plaster and a pitched roof made of glulam structure and shingles. The model's component and associated materials technical data are detailed in Table 1.

Using these data and user inputs via interface, the tool identified possible renovation alternatives, demonstrating the correct functioning of the automated data exchange. The tool generated several solutions featuring options such as 120 mm, 140 mm and 160 mm EPS or mineral wool insulated walls, upgrading to triple-glazed wooden windows, installing a heat pump and photovoltaic panels, as well as opting for a condensing boiler, biomass heating, or district heating connection.

Fig. 3 and Fig. 4 provide examples of possible results produced by the tool. They illustrate, respectively, the sustainability indicator "Nature" (Agenzia CasaClima, 2024) and the investment costs. The "Nature" indicator scores each solution based on a combination of factors. These include overall energy efficiency of the building, environmental impact of construction materials, efficient use of water resources, high air quality and low-emission materials, measures for radon gas protection, use of natural light, and acoustic comfort. The investment indicator covers the aspects described in section 2.3 of this paper, illustrating the financial implication of each retrofit solution.

These results confirm that the automated workflow functions correctly, enabling efficient data exchange and the generation of renovation alternatives. For being able to discuss the accuracy of the specific values from the results, further evaluations have to be done. This was not part of this study but will be included in future works. Nevertheless, we successfully demonstrated the functionality of the entire toolchain, including the correct implementation of automated data transfer between Autodesk Revit, CasaClima software, and Microsoft Excel.

Table 1 – Technical data of materials in the BIM model

Material	Building component	Thickness [mm]	Thermal conductivity [W/mK]	Specific heat capacity [KJ/kgK]	Density [kg/m³]	Thermal trasmittance [W/m²K]
Hollow clay bricks	External wall	400	0,37	0,88	850	-
Hollow clay bricks	External wall	100	0,37	0,88	850	-
Lime plaster	External wall	20	0,7	0,93	1400	-
Lime plaster	External wall	15	0,7	0,93	1400	-
Glulam timber	Roof	270	0,13	2	495	-
Glulam timber	Roof	70	0,13	2	495	-
Breathable membrane	Roof	0,8	0,16	0,9	1390	-
Clay shingles	Roof	15	1	0,9	1800	-
Glass	Double-glazed windows	24	-	-	-	3,3
Wood-aluminum	Windows frame	65	-	-	-	1,8

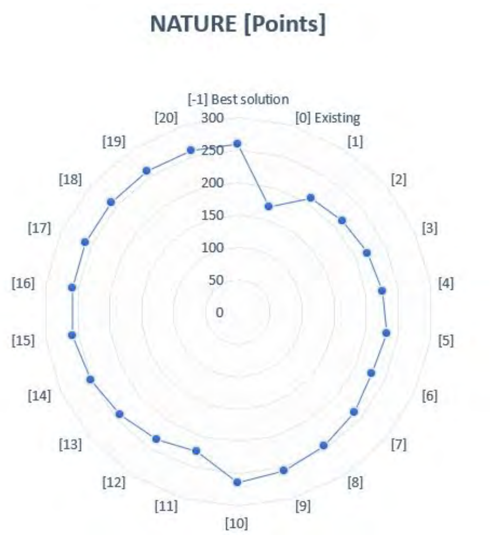

Fig. 3 – Graph illustration of the sustainability indicator for each retrofit solution

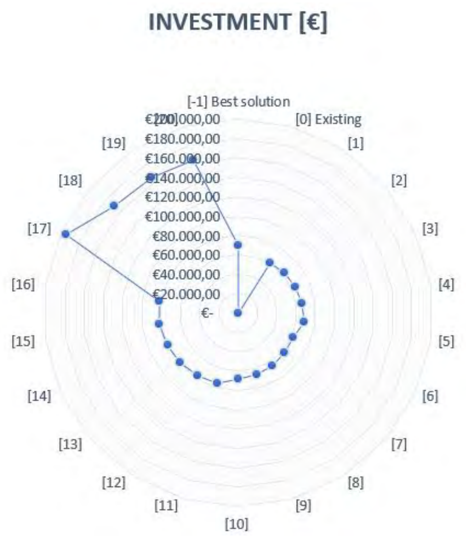

Fig. 4 – Graph illustration of the investment cost for each retrofit solution

4. Conclusions and Outlook

In this paper a design assistant tool for optimised building energy retrofit is proposed and described. The tool aims to foster sustainable renovation by facilitating the identification of optimal retrofit solutions that balance cost, energy performance, and environmental sustainability. To this aim, the tool ensures an automatic data flow between Autodesk Revit, CasaClima software and Microsoft Excel, returning retrofit alternatives through a user-friendly interface.

The tool has proven effective in automating data exchange, significantly reducing the amount of manual data entry required for CasaClima software and minimising associated errors. Despite these improvements, there is great potential for further development.

Firstly, the tool could be enhanced by automating the extraction of HVAC system data directly from the BIM model, which currently requires manual input by the user through the interface. Additionally, the calculation and export of thermal volume, as well as the building's position, could be automated directly from the Autodesk Revit.

Moreover, the current design of the tool is closely tied to the CasaClima software and its parameters, which limits its flexibility. If users wish to evaluate materials not included in the CasaClima database, the tool cannot perform the necessary calculations. This is because the building model must be set according to a specific Autodesk Revit library of materials based on the CasaClima database. Therefore, the tool and the materials library could be expanded to allow for evaluations using other available market software, not just CasaClima software, broadening its applicability and utility. Finally, since this paper primarily focused on implementing and verifying the functionality of the automated data exchange workflow, less emphasis was placed on verifying the accuracy and reliability of the calculation process and its results. Future development will involve applying the tool to actual case studies to validate its effectiveness and accuracy in real-world scenarios.

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