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Optimizing Energy Renovation in Building Portfolios: Approach and Decision-Making Platform

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Abstract: The building sector contributes significantly to energy consumption and greenhouse gas emissions, with many buildings being energy inefficient. In response, the European Green Deal promotes improving energy efficiency to support decarbonization goals. However, managing energy consumption and integrating data from multiple sources presents challenges, especially for large building portfolios. This study introduces a novel methodology designed to optimize energy renovation strategies, balancing technical, financial, and maintenance considerations. The methodology is implemented in CERPlan 1.0, a web-based decision-support platform that combines data on building energy performance, renovation costs, and maintenance needs. Through simulations, CERPlan 1.0 helps decision-makers prioritize retrofit interventions based on economic criteria while leveraging synergies between energy improvements and regular maintenance. Application of this methodology to real estate portfolios reveals opportunities to enhance cost-effectiveness and energy savings. The results show that integrating maintenance into renovation planning reduces payback times and allows for more comprehensive renovation strategies. The conclusions highlight CERPlan 1.0's potential to improve decision-making, making building renovations more efficient and sustainable.

Keywords: energy renovation; building portfolio management; cost-effective retrofit; decision-support platform

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1. Introduction

The European building sector accounts for 40% of the overall energy consumption and 36% of the greenhouse gas emissions. Given that around 75% of the existing stock is energy inefficient, with 85% of the constructions built before 2001, building renovation plays a crucial role in the European decarbonization process towards 2050. In this regard, the European Commission proposed in 2020 the Renovation Wave strategy [1] to boost the interventions on buildings across Europe.

Nevertheless, only 11% of buildings are renovated each year, and of those, only 1% incorporate energy efficiency improvements. This low rate of energy-efficient renovations is primarily due to a range of barriers, including technical, financial, and social challenges. On the financial side, D'Oca et al. pointed out that these are mainly associated with high investment costs and long payback times, lack of confidence of the investors, and availability of regular funding [2]. Energy efficiency in buildings is not only crucial for reducing operational costs but also plays a significant role in addressing climate change through carbon emission reductions. The building sector, accounting for a substantial share of global carbon emissions, offers great potential for improvements in both energy use and environmental impact. As demonstrated in studies on carbon emission pathways in provincial residential buildings in China [3], and the spatial patterns of carbon emissions in urban residential areas [4], energy efficiency measures are key to reducing carbon footprints at regional and urban scales. This issue is also confirmed by [5] which collected the main drivers and barriers from 296 respondents among users, public owners, and technical and financial stakeholders of building energy renovation processes, and 80% of the stakeholders identified the economic aspect as the main barrier affecting the decision-making process.

A potential solution to overcome these barriers and to increase the potential impact in terms of renovation rate is programming the intervention at the building stock level, especially if a single owner (both public and private) manages a large building portfolio [6,7]. Energy-efficient management of building portfolios is among the major challenges for medium-to-large real estate companies and public organizations.

One of the primary difficulties in managing such portfolios is the collection and integration of vast amounts of data related to building features, maintenance status, and energy consumption. This information, necessary for the definition of an effective renovation plan, usually comes from different sources resulting in difficult collection and integration.

In this regard, the European Commission is fostering the adoption of energy performance certificates (EPC) as a means to collect building information and provide comparable energy efficiency ratings that can be used also for renovation plans [8]. Nevertheless, EPCs usually do not include the actual trend of the building energy consumption as well as the state of maintenance, which provides significant indications for the prioritization of the interventions at the portfolio level [9]. While EPCs can be used for model calibration [7] for building portfolios, the limited accuracy of the data can introduce significant uncertainty that does not suit the scope of a building renovation plan.

Furthermore, another crucial aspect criteria in optimizing the renovation plans for building portfolios is the definition of cost-effectiveness criteria. Some studies have proposed methodologies aimed at defining a renovation schedule for the building stock, based on the definition of detailed energy simulation models on representative buildings [10]. However, these models often require skilled users for the setup and configuration of simulations, significantly limiting accessibility to non-experts and decision-makers. Several tools have been developed to optimize building renovation interventions [11]. For instance, BETTER 1.7.2 (Building Efficiency Targeting Tool for Energy Retrofits) is a software toolkit that benchmarks a building’s energy usage and identifies potential savings opportunities using readily available data [12]. Yet, its emphasis is on the individual building level rather than an entire portfolio. Similarly, COMBAT is a tool that facilitates estimating energy savings and costs for commercial building retrofits, tailored for policymakers and building managers [13]. However, it utilizes pre-calculated simulations that may not capture the specific features of each building. Another tool is CBES (Commercial Building Energy Saver) which provides retrofit analysis for small-medium commercial buildings in California through energy benchmarking and standardized calculations [14]. The broad application is constrained by CBES's specific geographic area and focuses on specific building types.

These tools are, in general, focused on the design stage, supporting the definition of the optimal technology solution for improving building performance. However, the application to entire portfolios for prioritization purposes is limited. A novel tool developed for defining renovation strategies for multiple buildings is the software REDIS, which focuses on the pre-design stage and supports the decision-making considering the cost and the renovation value factor for each building [6].

The current tools often overlook, in the decision-making process, the cost of ordinary and extraordinary maintenance, as well as the potential synergies between renovation efforts and regular maintenance tasks. By combining maintenance with energy renovation interventions, there is an opportunity to increase the efficacy of portfolio management. The methodology proposed by Nägeli et al. couples maintenance with optimal energy renovation and demonstrates a potential energy saving of up to 15% in comparison to state-of-the-art management with interventions after the lifespan [15]. Nevertheless, no budget constraints are considered in the definition of interventions.

In summary, while existing tools address specific aspects of the energy efficiency challenge, they lack a comprehensive perspective across portfolios, maintenance integration, and easy-to-use interfaces needed for widespread adoption and prioritization according to the available budget. There is a clear need for an integrated solution that combines data, analytics, and usability to enable better decision-making on energy efficiency investments across entire building stocks.

This work presents a methodology developed to tackle the current challenges in the renovation management of building portfolios. The core of the approach is to integrate all relevant data to track energy-related costs and key building statistics, simplifying the planning of energy-saving actions and identifying synergies between building components renovation, energy systems improvement, and extraordinary maintenance. This methodology has been implemented in a web platform, named CERPlan 1.0 (Cost-Effective Renovation Plan), designed to support an informed decision-making process. It organizes budget scenarios with a clear and synthetic user interface, allowing for alternative comparisons and the development of a comprehensive renovation plan matching relevant targets for the building portfolio. Thus, the objectives of CERPlan 1.0 are two-fold: (1) to speed up the renovation process by highlighting the intervention opportunities in the building portfolio and finding synergies between various energy-saving solutions, and (2) to create an interface between building owners and the consistency of the portfolio by designing a user-friendly web platform that merges data, analytics, and user inputs.

2. Materials and Methods

This section focuses on the methodology implemented in CERPlan 1.0, a decision management platform that combines energy retrofits with maintenance to achieve a comprehensive approach to building renovation. The main functionalities of CERPlan 1.0 in analyzing the potential benefits of maintenance and energy renovation synergies for the definition of recommendations to decision-makers will be described. Moreover, the approach adopted to effectively organize information from energy audits and to present the consistency of the entire building stock, including energy consumption, maintenance needs, and retrofit opportunities is presented. Considering the interconnections between these factors, CERPlan 1.0 provides tailored recommendations for maximizing energy efficiency and reducing costs for the interventions. This platform is aimed at supporting experts with assessments of the benefits of the retrofit-maintenance integrated approach, ultimately leading to improved sustainability and efficiency of the entire building portfolio.

2.1. Workflow

Within CERPlan 1.0, the planning and prioritization process of the interventions is divided into four distinct phases, each with its specific goals and objectives (Figure 1).

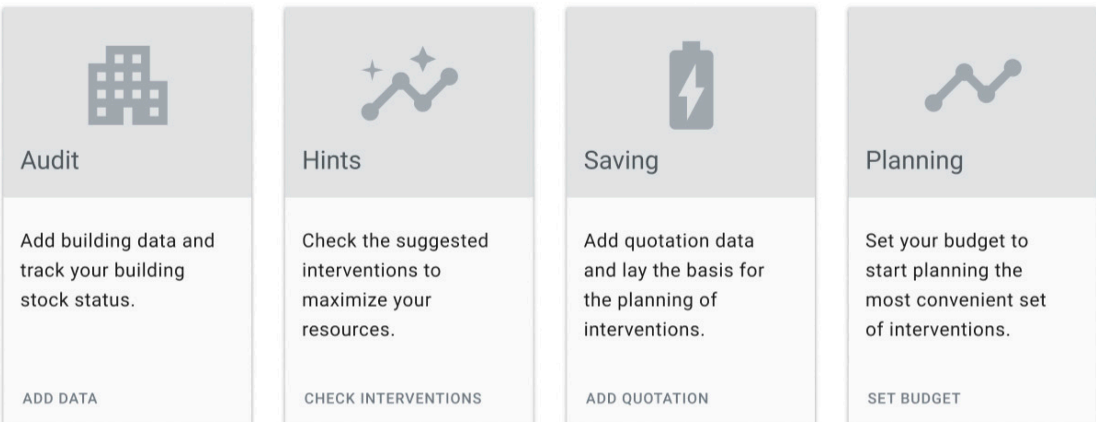

Figure 1. CERPlan 1.0 phase diagram.

Phase 1—Audit: A thorough examination of the building portfolio, including gathering information about the building's physical and structural characteristics, energy usage, and inefficiencies of the envelope and plant components.

Phase 2—Hints: A feasibility study assesses the impact of standardized interventions/energy conservation measures (ECMs), considering standard investment costs, incentives, and costs for both ordinary and extraordinary maintenance.

Phase 3—Saving: Integration of the technical specifications and intervention costs proposed by specialized companies.

Phase 4—Planning: Priority setting of interventions across the entire building stock based on the available budget.

2.1.1. Phase 1: Audit—Organizing Building Energy Data

During the initial phase of the methodology, a thorough energy audit is conducted by specialists to compile and organize all relevant data for the buildings that are to undergo simulations. The information collected is then classified into various categories for optimal data organization:

- General information: Building type and location
- Geometry: Breakdown of dispersing surfaces, including roof, opaque walls, and transparent areas
- Envelope: Thermophysical properties of the building's exterior surfaces
- Heating: Data on heating system generation, distribution, and emissions
- Cooling: Data on cooling system generation, distribution, and emissions
- Hot water: Data on domestic hot water generation and distribution
- Light: Information on the artificial lighting system
- Ventilation: Information on air treatment systems and heat recovery equipment
- Energy consumption: Data on the building's thermal and electrical energy consumption.

While it is not mandatory to complete all sections of the energy audit, the quality of the collected data will influence the energy simulations that can be performed. The more accurate the input, the more detailed the results.

2.1.2. Phase 2: Hint—Automatic Energy Simulation and Cost Analysis

The second phase of the methodology involves processing the data collected during the audit to identify potential energy-saving measures. This phase incorporates automation, leveraging a predefined set of parameters to evaluate various interventions, such as insulation for roofs, walls, and glass, as well as replacements for boilers and chillers.

The costs and services associated with these interventions are regularly updated with current market prices. However, it is important to note that the cost data provided in this study, as advised by experts in 2023, are purely indicative and subject to variation based on the specific characteristics of the building and its location. If the audit section provides information on the age of the envelope and plant elements, costs synergistic with maintenance are subtracted from the hypothetical renovation intervention's overall cost. The methodology considers renovation work to be additional to maintenance work necessary to preserve the building's function [16,17]. Intervention and costs estimated and predefined are described in Table 1.

As a result of the hint phase, a list of interventions associated to a payback time shorter than 10 years is generated. This enables the energy manager or decision-maker to focus on requesting offers from specialized companies for the most viable and cost-effective interventions.

Table 1. Estimated Costs for Predefined Energy-Saving Interventions.

Interventions	Estimated Cost for Renovation
Insulating vertical surfaces with 18 cm of insulation λ = 0.04 W/(m K)	150 €/m²
Insulating flat roofs with 20 cm of insulation λ = 0.04	175 €/m²
Insulating pitched roofs with 20 cm of insulation λ = 0.04	230 €/m²
New windows with U = 0.85 W/(m^2 K), g = 0.6	650 €/m²
Replacing gas boilers and condensing boilers (efficiency 105%)	10 €/kW if $P_{n\ boiler}$: < 35 kW, 88 €/kW if 35 kW < $P_{n\ boiler}$ < 200 kW 80 €/kW if $P_{n\ boiler}$ > 200 kW
Replacing chillers with new chillers with an EER of 4	360 €/kWf if $P_{n\ chiller}$: < 50 kWf 310 €/kWf if 50 kWf < $P_{n\ chiller}$ < 150 kWf

2.1.3. Phase 3: Energy Saving—Real Offers Impact Analysis

The third phase of this methodology focuses on the specific characteristics of individual buildings. Indeed, determining the costs of energy-saving interventions can be challenging since several factors impact the cost of implementation. In particular, the construction site specifications, location, facade decorations, and any obstructions that can complicate the intervention can be included in the model. In this regard, although pre-defined data about the intervention cost are available in the tool, the actual costs through estimates provided by relevant companies and recording them in the energy-saving part of the plan is significant for the calculation accuracy. Actual figures enable the refinement of the calculations, allowing for a more reliable assessment of the energy efficiency measures' practicality. Additionally, phase three assesses the economic and environmental sustainability of the interventions, evaluating factors such as actual energy savings, emission reductions, and the payback period of the invested capital. These elements help determine the effectiveness and cost-efficiency of the proposed energy efficiency measures. This phase also considers cost savings from maintenance, similar to phase two. Calculations can be made for the following types of interventions:

1. External wall insulation
2. Roof insulation
3. Window replacements
4. Heating generator replacement
5. Chiller replacement

Therefore, the specifications of the offers obtained from specialized companies can be inserted in this energy savings section and all the results will be used in the planning phase that allows to define priorities.

2.1.4. Phase 4: Planning—Maximizing Energy Savings Within a Budget

In Phase 4, the primary goal is to prioritize renovation interventions within the available budget to maximize cost-effectiveness. This process begins by defining the total budget for the renovation. To construct the renovation package, CERPlan 1.0 first orders all the simulated interventions according to their payback time. This provides a list of interventions ranked by economic convenience. Starting from the first intervention in the list, CERPlan 1.0 compares its cost to the available budget. If the budget is sufficient, the intervention is added to the renovation package, and the residual budget is updated. CERPlan 1.0 then proceeds to the next intervention in the list, repeating this process until the available budget is exhausted.

Once the package of interventions has been selected, the overall efficiency of the renovation package is calculated in terms of economic savings, emission reduction, energy savings, incentives obtained, and the total cost of the renovation, including the synergies. These calculations allow for an assessment of the renovation package's effectiveness not only in economic terms but also in terms of its impact on energy efficiency and sustainability.

2.2. Calculation Method

2.2.1. Calculation of Payback Time in Energy Retrofit Interventions

Payback time represents a crucial index in the assessment of the economic effectiveness of energy retrofit interventions. It indicates the period required for the economic savings generated by the intervention to compensate for the initial investment, also considering governmental incentives and avoided costs through synergies with maintenance.

In the proposed methodology, payback time is calculated using the following formula:

$$\text{Payback time} = (\text{Intervention Cost} - \text{Governmental Incentives} - \text{Avoided Costs})/(\text{Annual Economic Savings}), \quad (1)$$

where:

- Intervention cost represents the total investment necessary for the implementation of the energy retrofit intervention.
- Governmental incentives include all economic benefits as explained in Section 2.2.3.
- Avoided costs represent the economic savings resulting from synergies with regular maintenance as explained in Section 2.2.4.
- Annual economic savings correspond to the difference between pre- and post-intervention energy costs, on an annual basis.

2.2.2. Energy Demand of the Building for Heating and Cooling

The energy performance for the building envelope is calculated according to the ISO 52016-1:2017 standard [18] using an hourly time step. Climate data for energy simulations are assigned through the building's geographic coordinates from the Photovoltaic Geographical Information System (PVGIS), provided by the European Commission [19]. The efficiency of the heating and cooling systems is determined using the methodology outlined in Directive 2010/31/EU (in Italy UNI 11300 standards), requiring data on the generator, distribution, emissions, and basement insulation. It is assumed that 25% of opaque and transparent surfaces face each orientation.

2.2.3. Government Incentives

The European Union and the Italian government have established a range of policies and incentives to promote energy savings, enhance energy efficiency, and encourage the use of renewable energy sources. These policies aim to reduce greenhouse gas emissions, promote sustainability, and increase the energy efficiency of buildings and industries. At the European level, the Energy Efficiency Directive (EED) [20] sets binding targets for Member States to achieve cost-effective energy savings and encourages the development of energy-efficient products, buildings, and industrial processes. At the Italian level, incentives such as tax credits, subsidies, and loan programs are available to support energy-saving projects and building renovations. Additionally, the Italian government has implemented mandatory energy certification for buildings, which provides information on a building's energy performance and makes it easier for owners to identify opportunities for energy savings.

At the time of writing, CERPlan 1.0 implements the Italian incentive scheme "Conto Energia 2". This incentive scheme is aimed at promoting energy efficiency interventions in the country. The program provides financial incentives for individuals, businesses, and public entities who invest in renewable energy sources and energy-saving technologies. The scheme covers a wide range of interventions, including the installation of solar panels, heat pumps, and insulation, among others.

To further clarify the scope of government incentives for energy-saving interventions, Table 2 presents the typical incentive ranges per unit for specific measures, such as roof and wall insulation, window replacement, and condensation boilers. This table provides a guideline on the potential financial support available, outlining both the minimum and maximum governmental contribution within the established constraints.

Table 2. Range of Government Incentives for Energy-Saving Interventions.

Interventions	Incentive Range
Wall insulation	80–150 €/m^2
Roof insulation	100–250 €/m^2
Window replacement	350–450 €/m^2
Condensation boiler	$P_{n\ boiler}$ <= 35 kWt: 160 €/kWt $P_{n\ boiler}$ > 35 kWt: 130 €/kWt

2.2.4. Degradation of Plant Performance, Component Aging, and Interactions with Regular and Extraordinary Maintenance

The CERPlan 1.0 platform evaluates the cost-effectiveness of renovation projects, focusing on synergies with the maintenance cost of the building and HVAC system elements. To quantify the synergies of an energy refurbishment intervention, the approach estimates an amount of "avoided cost" compared to the needed maintenance intervention. The lifespan of the components is essential in determining the costs required to restore the elements to their original condition. The average lifespan of the components is determined using data from the document "Aging behavior of components and maintenance costs in housing construction" [21], and the restoration costs are considered according to Table 3.

Table 3. Average life and restoration costs of the envelope components assumed in CERPlan 1.0.

Title 1	External Walls	Pitched Roof	Flat Roof	Windows
Age considered for restoration [years]	50	69	40	47
Considered restoration cost [€/m^2]	50	80	80	200
Avoided cost per year [€/m^2y]	1.00	1.16	2.00	4.26

Data for building portfolios are obtained through energy audits or Energy Performance Certificates (EPCs) prepared by qualified professionals. For maintenance-related data, such as the year of the last intervention on building envelope components and the manufacturing year of HVAC components, no specialized expertise is required. This information can be easily gathered from the building's facility management staff or custodians, who typically have access to records of maintenance activities.

The aging model applied to building envelope components does not assume a linear degradation process but rather identifies a specific point at which a component requires restoration. However, for the purpose of economic calculations in our model, we apply a linear depreciation to represent the economic amortization of each component over its life cycle. The thermal performance of building components is considered constant throughout their useful life, while the aging of HVAC systems is modeled separately to account for decreasing efficiency over time, as described in the degradation formulas. [22].

$$COP_{generator} = C_{aging(b)} \times COP_{nominal}, \tag{2}$$

$$EER_{generator} = C_{aging(c)} \times EER_{nominal} \tag{3}$$

where:

$$C_{aging(b)} = (1 - 0.005)\hat{}(Current.year - Manufactured.year), \tag{4}$$

$$C_{aging(c)} = (1 - 0.01)\hat{}(Current.year - Manufactured.year) \tag{5}$$

2.3. Software Implementation and Architecture

The CERPlan 1.0 platform is developed by adopting an approach that combines feature-driven development (FDD) and a code-first approach [23].

Feature-driven development is an iterative and incremental software development approach that centers around building features based on stakeholder priorities. Since FDD involves breaking down a project into smaller, manageable features, each with its own development cycle, our team identified and prioritized features based on stakeholder needs and project goals (Building Creation, Hints Identification, and Planning Interventions). During development, the team used automated testing to maintain code quality and once a feature was completed, it was integrated into the main codebase. The software was delivered in increments, with each iteration adding new features and improvements.

The code-first approach is a software development methodology where the focus is on writing the application code first before creating the underlying database schema. Following this approach, we defined the domain models and relationships in the code, and then the database was automatically generated (subsequently updated) based on the code. We opted for this approach due to its inherent flexibility and simplicity, and the possibility to concentrate on the application's logic rather than the database structure.

Concerning the software architecture, CERPlan 1.0 is based on the Django 3.2, PostgreSQL 12, React 17, and Nginx stack, a modern and robust combination of technologies designed to deliver high-performance, scalable, and user-centric web applications.

The Django backend communicates with the React frontend through RESTful APIs, allowing seamless data exchange and real-time updates. React components interact with the Django backend to fetch and update data, while the PostgreSQL database ensures persistent storage and retrieval of application data. Furthermore, to enhance performance, the system employs Redis message broker support and utilizes the Celery distributed task queue framework for handling long-running calls. At a higher abstraction level, the system is fortified with Nginx, which serves as a protective layer, safeguarding the entire infrastructure (Figure 2).

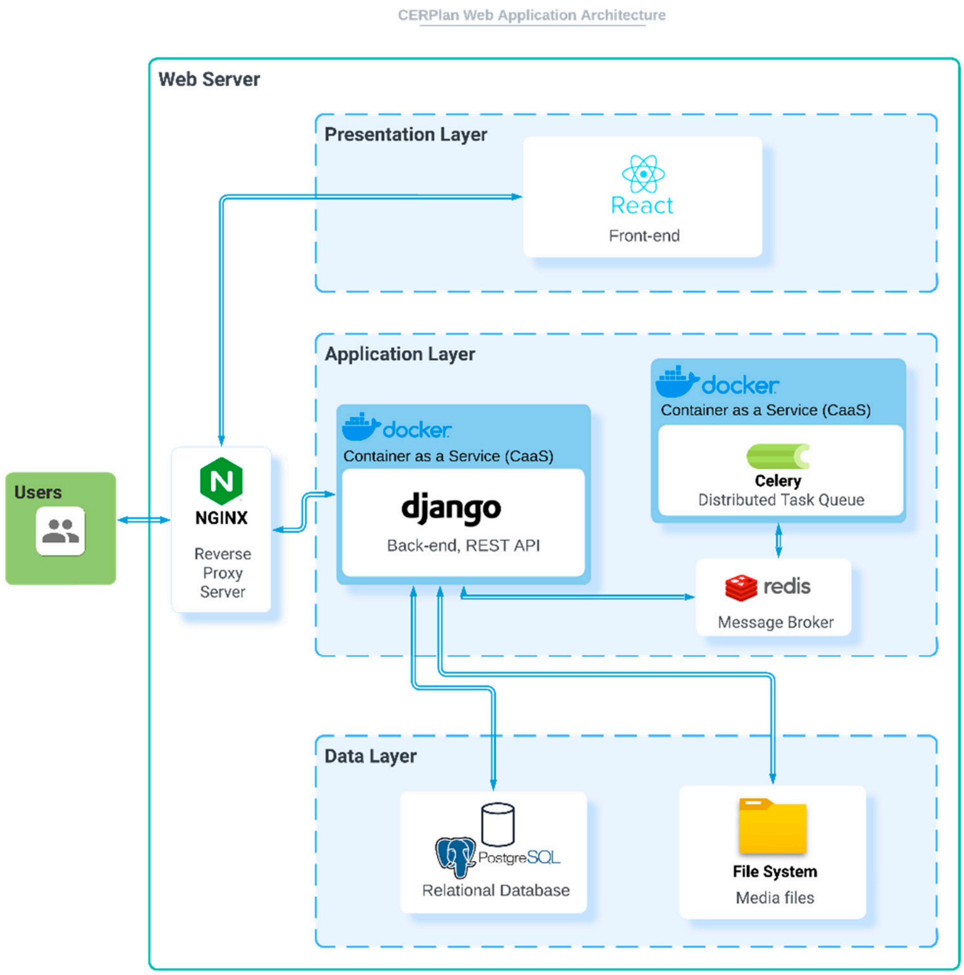

Figure 2. CERPlan 1.0 high-level software architecture.

In addition to its robust architecture, CERPlan 1.0 incorporates essential security protocols to protect user data and ensure safe operation (e.g., SQL injection protection, XSS and CSRF defenses, HTTPS encryption, and secure hosting practices).

2.4. Methodology Testing on a Building Set

The methodology described is applied to defining the renovation plan of a building sample, considering 32 public buildings managed by the Province of Bolzano with different uses, namely offices, schools, boarding schools, outpatient healthcare facilities, and hospitals. Further details about the construction and HVAC system of the analyzed building stock are available in Supplementary Materials (Tables S1 and S2). We established a renovation budget and determined the most advantageous package of interventions for renovation by applying two approaches. In particular, the proposed "synergy approach", which incorporates the maintenance cost by considering the degradation and aging of building components as outlined in Section 2.2.4 is compared with the "traditional approach", which does not account for these synergies. The parameter chosen to determine the best intervention package is the payback period, given its widespread use as an evaluation method by finance professionals.

The buildings are located in the Italian Alps and span a range of altitudes from 270 m to approximately 1300 m above sea level. The buildings also vary significantly in age, with the oldest dating back to 1907 and the newest completed in 2009. To replicate real-world conditions, 20 of the 32 buildings feature both new and old sections, each with unique thermophysical characteristics related to their building envelopes (Figure 3).

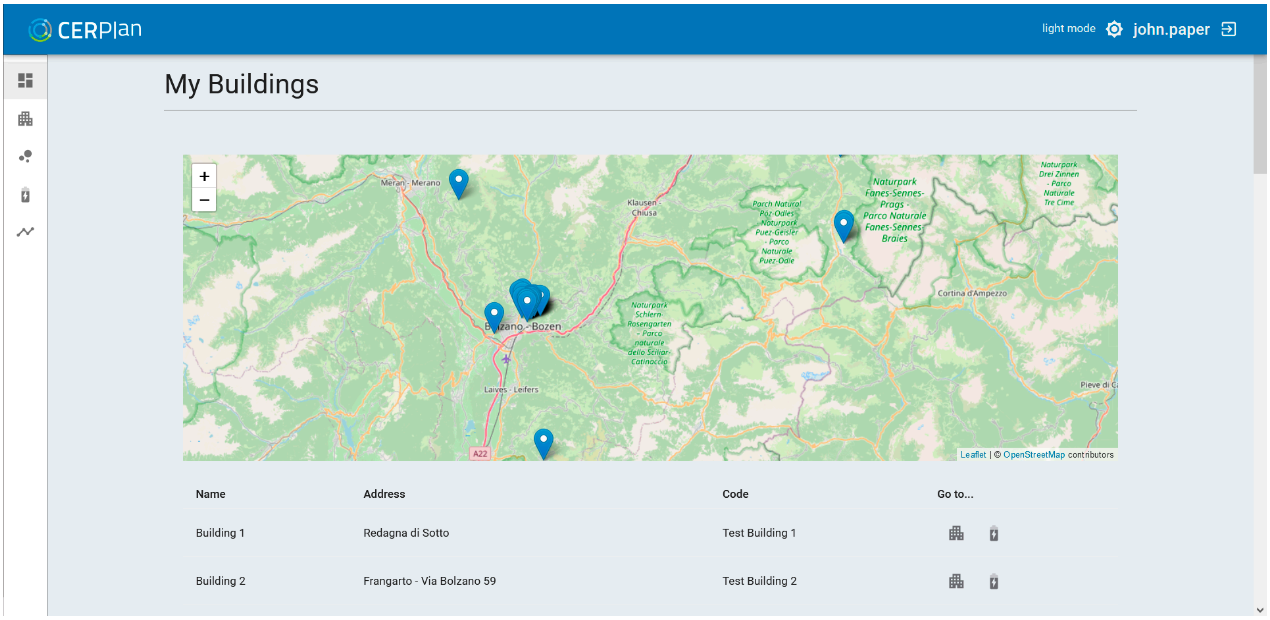

Figure 3. Localization of the analyzed buildings.

For the analyzed sample, 264 potential energy improvement interventions were identified. Out of these, 108 are related to systems, including the replacement of boilers and chillers, while the remaining 156 target the building envelope, encompassing measures such as roof and external wall insulation, as well as window replacements. These 264 interventions collectively represent all possible measures for enhancing energy efficiency across roofs, walls, windows, boilers, and chillers. Then the prioritization of the renovation is carried out according to the synergy approach (implemented in CERPlan 1.0) and the traditional approach.

The initial evaluation of interventions on the test building sample aimed to identify economically advantageous options was conducted using standardized costs and performance. To evaluate the different scenarios by applying the two approaches, a budget of €1,000,000, for the renovation plan of the building sample is considered.

3. Results

3.1. Main Features of the Building Sample

Figure 4 provides an overview of the consistency of the adopted building sample, defined as a representative part of the public building stock managed by the Province of Bolzano. The years of construction are classified according to the periods defined by Ballarini et al. [24]. It is possible to identify a larger share of historical buildings, built before 1945, and constructions developed within the period 1946–1975, before the first Italian regulation for energy efficiency. There are several building typologies, mainly educational buildings (25%), office buildings for public administrative personnel (22%), structures for hospitality (residential, boarding schools, and hotels), and healthcare buildings (19%).

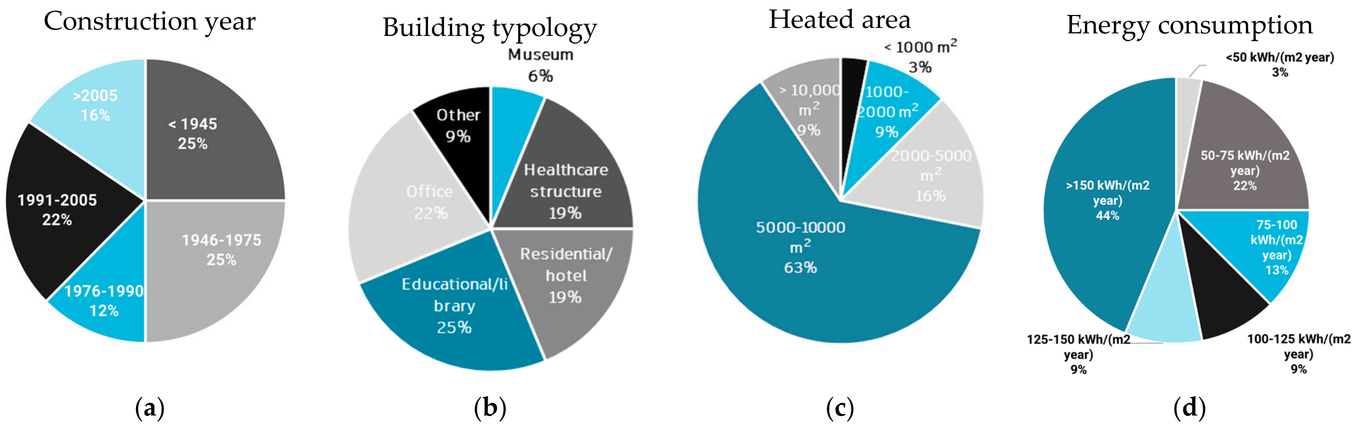

Figure 4. Distribution of the building stock sample according to (**a**) construction year; (**b**) building typology; (**c**) heated area; (**d**) energy consumption.

The analyzed stock presents a significant number of large buildings, namely 72% have a heated surface higher than 5000 m^2. On the other hand, the general energy performance is quite scarce, with 44% of the buildings with a heating energy demand higher than 150 kWh/(m^2 year).

Figure 5 shows the age of the building components identified for the development of the renovation scenarios. Information about the last intervention on the roof, building façade, and HVAC systems was collected and the estimation was performed considering 2023 as the reference year. There are no significant differences among the ages of the different building elements and more than half of the components are more than 25 years old (59% for the envelope, 50% for the HVAC). Moreover, there is a significant number of buildings (19%) presenting envelope elements with a longer interval from renovation than the life span. The detailed data on the envelope and HVAC features for each building analyzed are reported in Tables S1 and S2 of the Supplementary Materials.

3.2. Results of Renovation Plans

This section presents the results of the comparison conducted on the selected building sample between the traditional and synergy approaches. The analysis was conducted in two main phases: a preliminary assessment of potentially interesting interventions (Phase 2: Hint) and the subsequent selection of the most effective interventions based on the available budget (Phase 4: Planning).

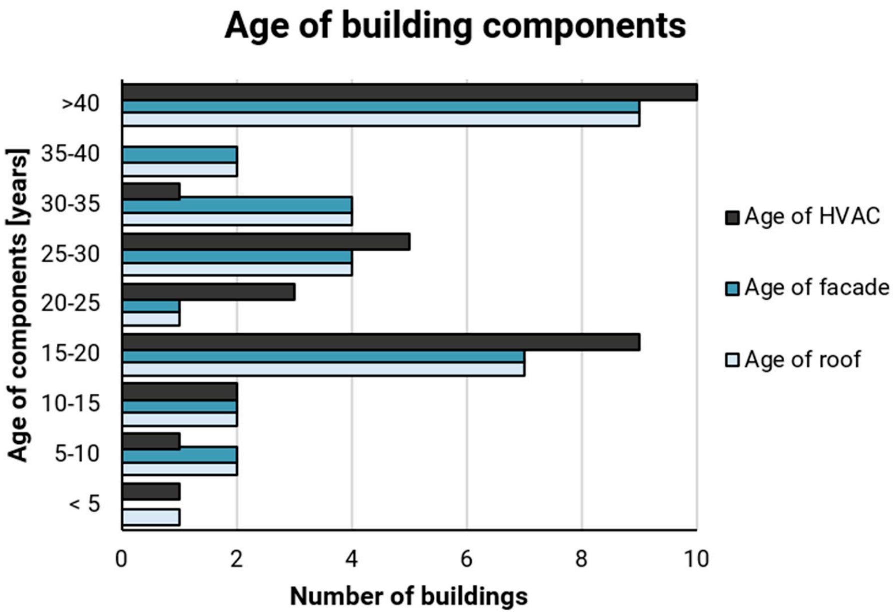

Figure 5. Age of envelope and HVAC systems in the building sample.

In the preliminary phase (Hint), the economic analysis highlighted a significant difference between the traditional approach and the proposed methodology:

- Traditional approach: 99 potentially economically interesting interventions were identified (with a payback time <10 years), of which 93 were related to systems and only 6 to the building envelope.
- Proposed synergy approach: 142 potentially interesting interventions were identified, of which 93 were related to systems and 49 to the building envelope.

This difference arises because the proposed approach, by considering synergies with maintenance, makes more interventions economically viable, particularly those involving the building envelope.

Subsequently, in the planning phase (Planning), a budget of €1,000,000 was set to select the optimal package of interventions from those identified as potentially interesting. The results of this selection show significant differences between the two approaches:

- Traditional approach: 45 interventions were selected, all related to HVAC systems, particularly the replacement of 45 traditional gas boilers with condensing boilers. The average cost per intervention is about €97,995, with an average incentive of €39,198.
- Proposed synergy approach: 33 interventions were selected, of which 5 relate to the building envelope (mainly on the roof) and 28 to systems. The average cost per intervention is €180,108, with an average incentive of €80,210.

The synergy approach concentrates the available resources on a smaller number of buildings (10 compared to 17 in the traditional approach) but allows for more substantial interventions, including those on the building envelope. The 5 interventions on the envelope, which represent about 40% of the available budget, became economically advantageous thanks to the quantification of avoided costs, amounting to €372,176 due to the identified synergies with maintenance needs.

This analysis demonstrates how the proposed approach, considering synergies with maintenance, allows for the identification and selection of a more diverse mix of interventions, including significant measures on the building envelope that would otherwise not have been considered economically advantageous in the traditional approach.

The proposed synergy approach concentrates the available resources on a reduced number of buildings, suggesting interventions on 10 buildings with respect to the 17 involved by the traditional approach, and the potential incentives are significantly higher. In fact, the average investment for the intervention of the synergy approach accounts for

€180,108, with calculated average incentives of €80,210. The traditional approach showed an average intervention cost of around €97,995, with €39,198 of incentives (Figure 6a,c).

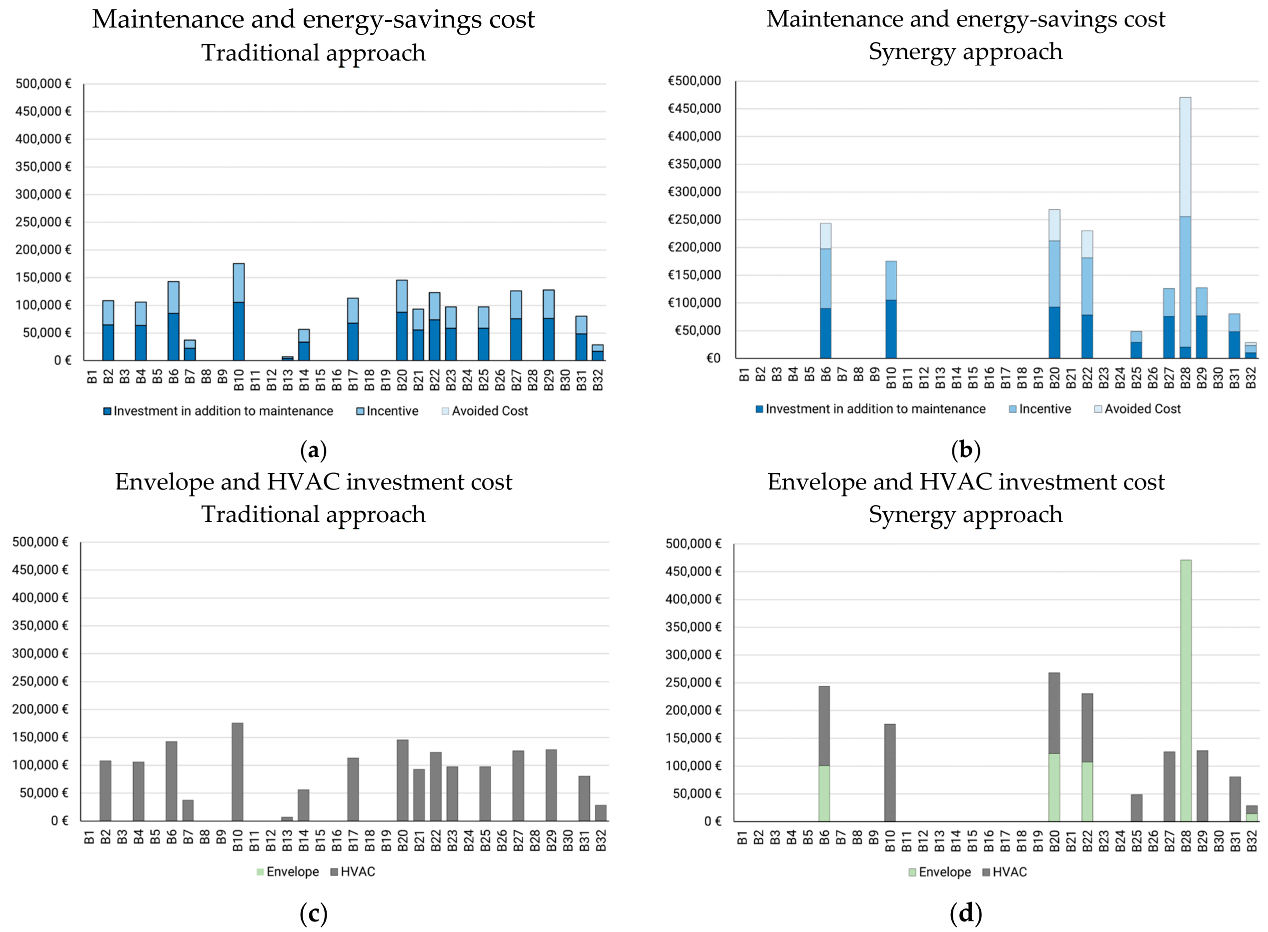

Figure 6. Overview of the investment with the two approaches. (**a**) Maintenance and energy saving cost with the traditional approach; (**b**) Envelope and HVAC investment cost with the proposed synergy approach; (**c**) Envelope and HVAC investment cost with the traditional approach; (**d**) Maintenance and energy saving cost with the proposed synergy approach.

There are significant differences also in the typology of the proposed interventions: the traditional approach recommends, with the available budget, 45 interventions related to the HVAC systems, and in particular, an increase in heating production efficiency with the replacement of 45 traditional gas boilers with condensing ones. Indeed, without considering the synergies with maintenance needs, the renovation of the HVAC system presents a shorter payback time with respect to interventions on the envelope (Figure 6b).

On the other hand, the presented synergy approach suggests 33 interventions with 5 renovations of the building envelope, costing approximately 40% of the available budget and prioritizing the intervention on the building's roof (Figure 6d). The other interventions refer to the replacement of gas boilers.

The five interventions on the envelope gained a more effective economic outlook thanks to the quantification of the avoided cost in the economic model introduced by the synergy methodology, accounting for €372,176 due to the identified synergies with maintenance needs.

Table 4 provides an overview of the main economic figures of the two analyzed approaches.

Table 4. Comparison between the two intervention packages created using the proposed synergy approach and the traditional approach.

	Traditional Approach	Proposed Synergy Approach
Intervention Cost [€]	1,665,912	1,801,079
Incentive [€]	666,364	802,098
Avoided Cost [€]	0	372,176
Final Cost (Intervention cost—Incentive) [€]	999,548	998,982
Investment in addition to maintenance (Investment cost—incentive—Avoided cost) [€]	999,548	626,805
Economic Savings [€/year]	707,739	509,718
Payback time [years]	1.41	1.23

As shown in Table 4, although the reduction in terms of energy consumption and the related economic savings of the synergy approach are lower than the traditional approach, the payback time of the intervention is shorter (1.41 years with the traditional vs. 1.23 years with the synergy approach). Figure 7 presents a more detailed comparison in terms of energy saved and the economic indicators of the proposed renovation between the two approaches. Figure 7a,b report the relation between the renovation cost for the unit surface, showing an average lower energy saving with the synergy approach (21 kWh/m^2 vs. 31 kWh/m^2), but the net investment accounts for 2.63 €/m^2 for the synergy approach in comparison to the traditional approach accounting for 4.44 €/m^2. Figure 7c,d highlight the effectiveness of the interventions in terms of cost of energy saved (€/kWh) in comparison to the unitary cost, with an average of 0.12 €/kWh for the synergy approach and 0.16 €/kWh with the traditional approach.

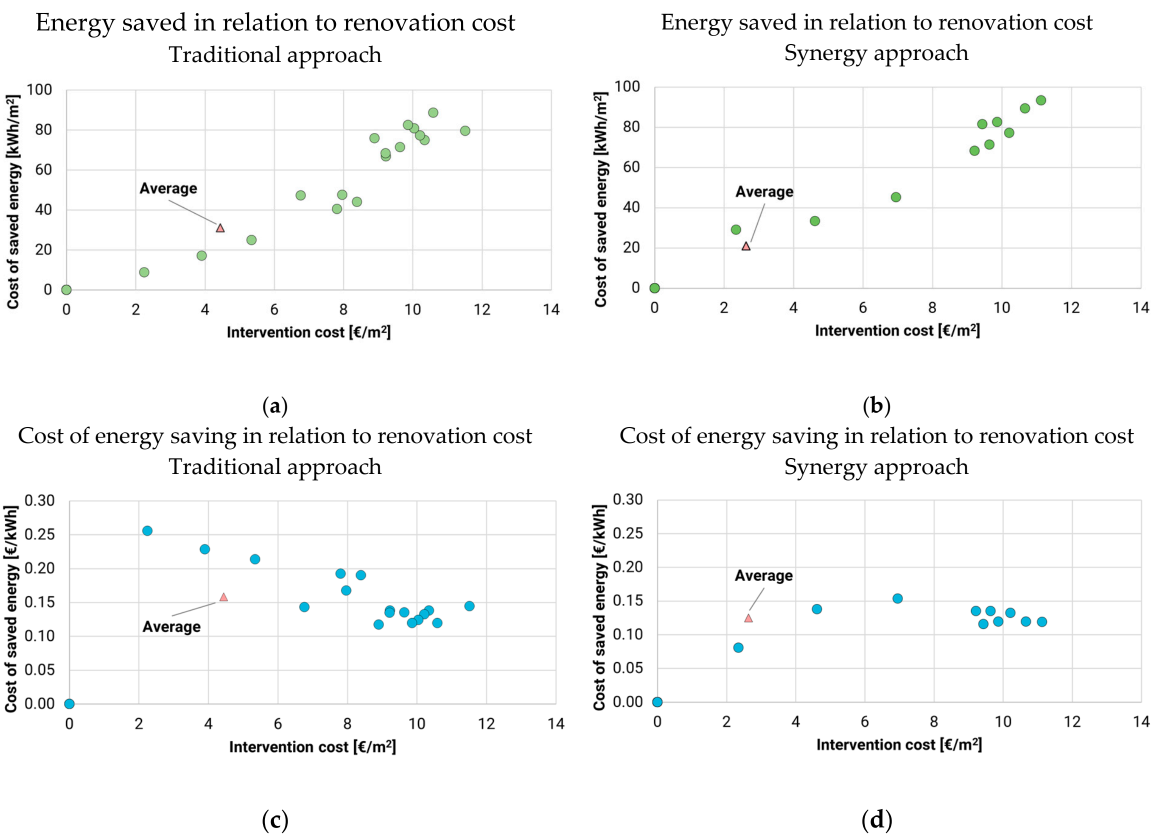

Figure 7. Overview of energy savings and relative renovation cost (**a**) Energy saved vs. renovation cost (traditional approach); (**b**) Energy saved vs. renovation cost (synergy approach); (**c**) Cost of energy saved vs. renovation cost (traditional approach); (**d**) Cost of energy saved vs. renovation cost (synergy approach).

The difference in annual economic savings between the synergy approach and the traditional approach is primarily due to the nature of the interventions. The traditional approach focuses heavily on system replacements, such as boiler and chiller upgrades, which can result in immediate reductions in energy costs. In contrast, the synergy approach integrates both building envelope improvements (e.g., roof and wall insulation) and system replacements, with a more significant emphasis on the envelope.

The synergy approach incorporates savings from reduced maintenance costs. By coordinating energy renovations with scheduled maintenance, the total cost of future repairs and system replacements is lowered, which contributes to the long-term financial and operational efficiency of the building portfolio. This reduction in maintenance costs offsets the lower annual energy savings and contributes to the overall effectiveness of the synergy approach, as reflected in the shorter payback period.

4. Discussion

The building sector accounts for a significant percentage of overall energy consumption and greenhouse gas emissions, with many energy-inefficient buildings and renovation needs. While this study focuses on a specific sample of public buildings located in the Italian Alps, the methodology and CERPlan 1.0 platform have been designed with flexibility in mind. The main elements of the methodology, such as the integration of maintenance and energy-saving strategies, are not inherently limited by regional characteristics. Thus, the core principles and processes can be adapted to various building types and geographical locations. The methodology presented in this work is versatile and can be applied to different real estate portfolios, providing insights into energy savings and maintenance synergies regardless of the building stock's location or specific climatic conditions.

With the recent economic and environmental challenges associated with energy supply, it is essential to focus on energy conservation in buildings to achieve energy independence and reduce energy consumption.

The novel approach presented in this work aims to prioritize energy renovation interventions within a building stock. The key innovation introduced by the methodology in this study, compared to a traditional renovation approach, is the consideration of synergies with maintenance activities. Maintenance represents a key factor in the management of a building portfolio and requires interventions on building components for ensuring building operation and performances [25] entailing periodical investments. By considering synergies with maintenance during the planning of energy retrofit interventions, two significant benefits are achieved. On the one hand, there is a reduction in the general payback time of the renovation. This reduction is largely due to the inclusion of avoided maintenance costs, which amounted to €372,176 in the proposed renovation package. When this value is considered in relation to the total investment (€1,801,079), it accounts for approximately 20.7% of the total cost. This demonstrates that the synergy approach not only accelerates payback times but also makes previously less attractive interventions, such as those related to the building envelope, more economically viable. The second added value is the possibility of introducing the intervention on the building envelope, which is usually not prioritized when cost-effectiveness is evaluated in terms of investment for the interventions and associated energy savings [26]. Energy renovation of the envelope leads not only to an increase in the efficiency of the systems but also to a reduction in the buildings' energy demands throughout the year and an improvement in indoor comfort conditions [27].

Therefore, the introduction in the decision-making process of the potential synergies with building maintenance can lead to an increase in the general cost-effectiveness of the renovation, as demonstrated by the scenarios presented in this paper.

The methodology developed for this study, implemented within the web-based platform CERPlan 1.0, provides a solution that improves the decision-making process, reducing the impact of the barriers undermining the energy renovation [2]. This solution integrates and analyzes data from various sources, providing a comprehensive view of a building's energy-saving potential and identifying synergies between different renovation solutions.

By organizing budget scenarios and comparing alternative solutions, CERPlan 1.0 simplifies planning actions toward energy savings and identifies approaches that are both cost-effective and sustainable.

Building retrofits can maintain the value of assets, reduce costs, mitigate the risks associated with energy procurement, incentivize investment in decarbonization initiatives, and contribute to achieving the ambitious goals set in the European Green Deal.

Limitations of the Study and Future Developments

CERPlan 1.0 allows us to define renovation scenarios for a building stock using EPC data and to prioritize interventions based on economic criteria. This study presents the results of an application to 32 sample buildings representative of the stock managed by the local administration of the Province of Bolzano. The sample mainly includes tertiary buildings located in a specific context with peculiar climate conditions and construction features. This sample cannot be considered representative of the European building stock but represents a real-case scenario for a preliminary demonstration of CERPlan 1.0 effectiveness.

Nevertheless, the application described in this study highlighted the adequate flexibility of the tool and provided preliminary results to compare a traditional renovation approach with the proposed one based on synergies with maintenance. Further analyses are needed to verify, on the one hand, the accuracy of the results and, on the other hand, the reliability of the scenarios. A long-term validation based on real cases that will be analyzed in the post-renovation phase can enable the assessment of estimated energy savings in comparison to actual ones. This validation will contribute to finetuning the energy modeling of the tool and to improving the prioritization criteria.

It is important to underline that CERPlan 1.0 was developed starting from a detailed consultation with the potential stakeholders, namely local public and private real estate managers, that contributed to identifying the main features of the tool. In this regard, it was established that the economic criteria based on the payback time of the renovation was the preferred approach to be initially developed. Nevertheless, as also demonstrated by the analyses presented in this study, the most cost-effective interventions in terms of payback time, considering the synergies with maintenance, can lead to lower energy savings. Therefore, as a key future development, the tool will implement the possibility to define the prioritization criteria according to the needs of the stakeholders (e.g., maximization of energy saving, minimization of CO_2 emissions, etc.).

Moreover, as demonstrated in the literature, building energy renovation can contribute to increasing the building's value in relation to energy saving and the associated co-benefits gained after the interventions [28]. In fact, increased aesthetic value and enhanced comfort conditions can lead to a general increase in the building's value, and the evaluation of this factor represents an interesting feature to be implemented to boost the willingness for renovation.

Another important barrier jeopardizing renovation investment relies on the possible discrepancies associated with the calculated energy savings with respect to the actual ones. The standard EN ISO 15459 [29] provides a series of strategies for evaluating uncertainties in the case of renovation, enabling the evaluation of a range of potential savings. Integrating into CERPlan 1.0 methodology the evaluation of potential uncertainties and the acquisition of actual energy consumption from the energy bill will contribute to increasing the reliability of the results. This development will also enable the provision of consistent scenarios that consider not only a single year of investment but longer-term periods without reducing the reliability of the analyses. These scenarios will be based on the real energy consumption of portfolios for the validation of energy-saving analyses and on the prioritization criteria decided by the stakeholders.

With the above-mentioned developments, the tool will have a broader range of applications, enabling stakeholders to adopt renovation plans that are more detailed and customized.

5. Conclusions

This paper presents a decision-support system that addresses the challenges faced by medium-sized and large real estate companies and public organizations in managing their building stock's energy consumption.

By utilizing this methodology, real estate companies and public organizations can improve energy efficiency in their building portfolio through the definition of effective renovation plans. The new European Green Homes Directive could bring significant changes to the methodology's objective by supporting decision-makers in complying with the energy consumption limits set by the directive. As a result, the CERPlan 1.0 methodology and platform could be used to develop a structured renovation plan that complies with the directive's intermediate limits, helping to avoid stranded assets.

CERPlan 1.0 enables the stakeholders to perform complex evaluations of their building stock. In fact, by analyzing multiple buildings at once, it prioritizes the type of intervention and on which buildings the renovation should be focused according to the economic benefits derived from maintenance synergies. The results presented in this paper are specific to the analyzed stock since it was affected by the building features. Nevertheless, the methodology implemented in CERPlan 1.0 is flexible and enables application to any kind of portfolio.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en17225537/s1, Table S1: Features of existing buildings—envelope; Table S2: Features of existing buildings—HVAC system.

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Data Availability Statement: The building characteristics presented in this study were generated artificially to create a realistic example based on typical construction periods. These data are available in the Supplementary Materials.

Conflicts of Interest: Marco Castagna, Olga Somova, Cristian Pozza, Giuseppe De Michele, Daniele Antonucci, and Federico Garzia are employed by the Eurac Research Institute for Renewable Energy. Roberta Pernetti is employed by the University of Pavia. Marco Castagna discloses the intention to offer consulting services based on the methodology developed and presented in this manuscript. This planned consultancy has not influenced the study's design, data collection, analysis, interpretation, or the decision to publish the results. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results. All other authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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