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Appraisal of Sustainable Retrofitting of Historical Settlements: Less than 60% Unexpected Outcomes

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Abstract

The present research aims to assess, from both ecological and economic perspectives, a strategic solution applied to the building sector that can contribute to mitigating the planetary tragedy of the overconsumption of global fossil energy (coal, oil, and gas) and, thus, climate change, along with its dramatic negative impacts on the planet, humanity, and the world's economy. Buildings are the largest consumers of fossil fuel energy, significantly contributing to Greenhouse Gas (GHG) emissions and, consequently, to climate change. Reducing their environmental impact is therefore crucial for achieving global sustainability goals. Existing buildings, mostly the historical ones, represent a significant part of the global building stocks, which, for the most part, consist of buildings built more than 70 years ago, which are aged, in a state of deterioration, and in need of intervention. Recovering, renovating, and redeveloping existing and historical buildings could be a formidable instrument for improving the energy quality of the international and national building stocks. When selecting the type of possible interventions to be applied, there are two choices: simple and unsustainable ordinary maintenance versus ecological retrofitting, i.e., a quality increase in the indoor environment and building energy savings using local bio-natural materials. The success of the "Ecological Retrofitting" Strategy strongly relies on its economic and financial sustainability; therefore, the goal of this research is to underline and demonstrate the economic and ecological benefits of the ecological transition at the building level through an integrated valuation applied in a case study, located in Southern Italy. First, in order to demonstrate the ecological benefits of the proposed strategy, the latter was tested through a new energy assessment tool in an updated BIM platform; subsequently, an economic valuation was conducted, clearly demonstrating the cost-effectiveness of the building's ecological transition. The real-world experiment through the proposed case study achieved important results and reached the goals of the "Ecological Retrofitting" Strategy in existing (but not preserved) liberty-style constructions. First of all, a significant improvement in the buildings' thermal performance was achieved after some targeted interventions, resulting in energy savings; most importantly, the economic feasibility of the proposed strategy was demonstrated.

Keywords: appraisal; valuation; energy; ecological retrofitting; energy efficiency; environmental sustainability; sustainable development; global warming; climate change

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1. Introduction

Nowadays, we are faced with increasingly extreme, frequent, and devastating climatic phenomena; the dramatic effects of climate change are obvious and probably irreversible.

The scientific community, also making use of increasingly accurate mathematical models, has described how the planet's climate is changing in a worrying way and how the responsibility for these changes lies with human activities [1], starting with the excessive use of fossil fuel energy, representing 85% (coal: 28%; oil: 35%; and gas: 22%) of the total energy consumption, compared to the low use of renewable energy one, which is only 15% (Figure 1).

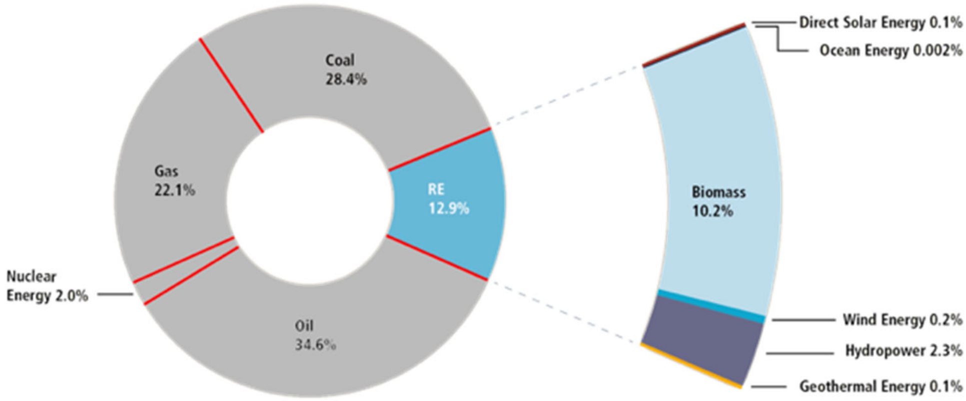


Figure 1. World energy sources in total primary energy supply. Data source: IEA 2021.

Several energy agencies, including the International Energy Agency (IEA), have detected the world fossil energy production to be around 200,000 Tera Watt hour (TWh), while consumption is around 140,000 TWh [2]. Consequently, "global energy-related CO_2 emissions grew by 1.1% in 2023, increasing 410 million tonnes (Mt) to reach a new record high of 37.4 billion tonnes (Gt)", i.e., 37,400,000,000 tonnes [2].

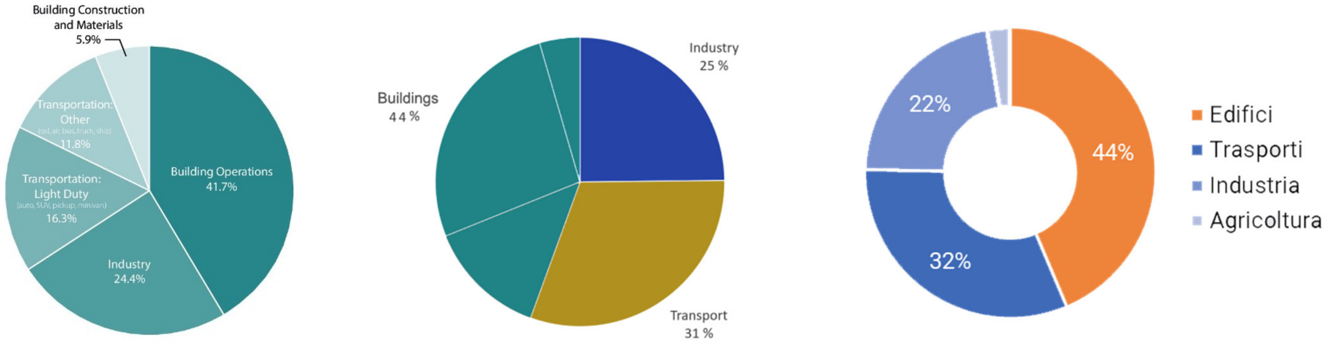
In this framework, the definition and implementation of multi-level climate strategies, which integrate environmental, economic and social objectives, becomes central to guiding the transition towards a sustainable development model.

Among the most responsible sectors for GHG emissions, and resource consumption, the construction sector plays a key role both in diagnosing the problem and in its possible solution. As demonstrated in Figure 2, at the international and national levels, the civil sector, with respect to other sectors, consumes about 45% of total energy from fossil sources for construction processes and for the thermal management of residential as well as nonresidential units, releasing CO_2 emissions into the atmosphere; thus, the building sector is the world's main user of fossil energy, and consequently, it is the greatest polluter and the biggest cause of climate change [3].

Thus, buildings are responsible for a significant part of global energy consumption and, at the same time, offer extraordinary opportunities for improvement through energy efficiency, renovation and decarbonization policies.

To address the ongoing ecological crisis, one of the key strategies involves promoting the environmental transition of the civil sector by pursuing multiple objectives aimed at achieving a permanent and structural reduction in both local and global fossil energy consumption and the resulting greenhouse gas (GHG) emissions.

In the last years, key international and regional policy frameworks have begun to explicitly recognize the transformative potential of the built environment. The Paris Agreement (2015) enshrined the global commitment to keep the global temperature increase to well below 2 °C, stimulating the development of national contributions (NDCs) that often include energy efficiency measures in the building sector [4].



(**a**) (**b**) (**c**)

Figure 2. (**a**) **World** energy consumption by sector. Data source: IEA 2021. (**b**) **EU** Energy consumption by sector. Data source: Eurostat 2022. (**c**) **Italy** Energy consumption by sector. Data source: ISPRA 2021.

The European Green Deal (2019) has made construction a central lever for climate neutrality, promoting programmes such as the Renovation Wave [5].

The UN's 2030 Agenda integrates climate and urban objectives into its Sustainable Development Goals (SDGs) [6].

At national level, tools such as the *Piano Nazionale Integrato per l'Energia e il Clima* (PNIEC) provide an operational framework for the decarbonization of the building stock, in line with European objectives [7].

This regulatory and strategic convergence suggests a paradigm shift, in which construction is no longer considered just a passive or "energy-intensive" sector, but a leading player in the ecological transition.

Thus, in order to make the long-term strategic goal more feasible, many governments have adopted intermediate tactical targets for the civil sector to help mitigate climate change:

- 25% reduction in energy consumption by 2025;
- 25% reduction in carbon emissions by 2025.

Achieving these targets requires both immediate and systemic changes in building practices and materials [8].

Focusing on the national territory, existing buildings, mostly the historical ones, represent a significant part of the Italian building stocks (approximately 90%); the majority of these buildings, with a reinforced concrete structure and masonry infill walls, were built more than 70 years ago and are aged, in a state of deterioration, and in need of interventions [9]. These existing structures significantly contribute to fossil energy consumption and carbon emissions.

According to the *Sistema Informativo sugli Attestati di Prestazione Energetica* (SIAPE) 2025 data, an average Italian household consumes about 201 kWh/m^2 year of fossil energy for their energy management, consequently producing about 41 kgCO_2/m^2 year [10].

Thus, recovering, renovating, and redeveloping existing and historical buildings could be a formidable instrument for improving the energy quality of the building stocks and, consequently, to activate investments in the real estate market and to support technological innovation; a sustainable transformation of these buildings is essential for achieving climate targets, improving public health, and enhancing local economies.

The strategic solution in the civil sector targets a significant reduction in fossil energy consumption and its associated carbon emissions through a process known as "passivation". This involves implementing ecological architectural retrofitting, a method that enhances the thermal performance and environmental profile of existing buildings.

In practical terms, this retrofitting approach consists of coating the entire building envelope with ecological material boards or panels. These natural, non-fossil-based materials are designed to improve insulation, regulate the indoor climate, and minimize energy demand for heating and cooling, thereby supporting both energy efficiency and climate mitigation objectives.

Several commonly used thermal insulation materials in the construction sector—such as expanded polystyrene (EPS), polyurethane foams, glass fiber, and rock wool—raise considerable environmental and energy-related concerns. These materials are typically:

- Energy-intensive to manufacture, contributing to high embodied carbon;
- Derived from fossil fuels or oil-based compounds, reinforcing dependency on non-renewable resources;
- Produced using chemical processes that may involve hazardous substances, potentially affecting both environmental safety and human health.

As a result, while these materials offer thermal performance, their life cycle impacts may undermine broader sustainability goals, particularly those focused on reducing greenhouse gas emissions and enhancing the environmental performance of buildings.

Within the defined strategy, a core component is the improvement of thermal performance in buildings through the use of natural, low-impact materials—a concept referred to as "sustainable efficiency." This approach prioritizes ecological building solutions that minimize environmental harm while maximizing energy performance.

By integrating such materials into retrofitting or new construction practices, this strategy has the potential to significantly reduce global energy consumption and lower the carbon footprint of the civil construction sector, making it a critical pathway for climate mitigation and sustainable development.

As a result, the suggested materials do not originate from fossil sources (i.e., coal, oil, or gas); rather, they are derived from local natural resources in order to encourage the circular economy and support sustainable development, and they must be nature-based to guarantee several co-benefits derived from the ecological interventions.

Furthermore, within the general strategy, the adopted boards and panels made from natural materials—extensively tested in official laboratories—have demonstrated excellent performance across key thermal and ecological characteristics, including:

- Permeability, which supports healthy indoor environments by preventing a buildup of moisture and humidity;
- A thermal phase shift, slowing the transmission of external summer heat indoors;
- Insulation, providing protection against cold winter temperatures and maintaining indoor comfort;
- Soundproofing, which enhances acoustic comfort and overall indoor wellness.

The only obstacle to the buildings' ecological transition is a lack of kno; very often, this "ecological retrofitting" strategic solution is misunderstood as an additional cost with respect to the initial construction cost in new buildings, as well as in the retrofitting of existing ones. In the real world, there is a lack of rigorous economic estimates that immediately highlight the economic and ecological convenience of the buildings' ecological transition.

According to the panorama of the scientific literature, "there is a lack of studies that address the initial and life cycle costs of eco-sustainable buildings" [11]; thus, "is needed to perform a cost analysis to see if building ecological transition makes financially sense from a lifecycle perspective". No comprehensive study has been reported to see whether this strategy makes sense economically" [11]. Additionally, "there are highly inaccurate economic estimates that underestimate the potential cost savings and overestimating the capital costs of energy efficient measures" [12].

The present study is driven by the contradictory nature of the economic valuations concerning the extra construction cost of the ecological retrofitting and the lack of evidence on the associated reduction in energy management costs. Therefore, a scientific integrated valuation, including economic and ecological impacts, must be performed and completed in order to determine whether the reduction in fossil energy consumption in buildings is a structural and permanent benefit regarding income and efficiency, not just a passive reduction in costs.

To support the global mission and to develop upon the authors' previous studies [13–18], the goal of the present study is to experiment and analyze the "Ecological Retrofitting" Strategy applied to the civil sector in a case study through the new Building Energy Performance Simulation Program (BEPSP) in an updated BIM platform; these tests are greatly beneficial in demonstrating the significant enhancement of the thermal performance of existing buildings and the economic feasibility of the ecological interventions such as retrofitting.

Accordingly, the positive effects of the buildings' ecological transition (and passivation) were analyzed in two comparative alternative scenarios:

- The common scenario (or Business as Usual (BAS)), consisting of an ordinary construction that is typical of the 1970s and, therefore, does not require energy processing, which represents a starting scenario for the majority (90%) of the buildings present today globally;
- The sustainable scenario, or "Ecological Retrofitting" Strategy, with energy processing, where innovative and natural techniques and materials are used, which avoid further climate-forcing emissions into the environment.

Therefore, the first methodological step of the present research is the approach of ecologically retrofitting existing buildings by only adopting natural, bio-ecological, and local materials, thus focusing more on the energy savings that can be obtained with only the building's passivation (i.e., not consuming energy) before taking into consideration the integration of green home energy practices.

The second methodological step is the real-world experiment; the "Ecological Retrofitting" Strategy was tested at the building level in an existing building as a case study, situated in Reggio Calabria city, Calabria region, Italy.

The third methodological step is an ecological and financial assessment of energy savings and mitigation of emissions using the most updated BIM tool, which calculates the positive ecological effects of green intervention.

The fourth methodological step of this research involves demonstrating the cost-effectiveness of the "Ecological Retrofitting" Strategy through an economic valuation that estimates the Payback Period of green intervention based on the reduction in the energy demand and avoided CO_2 emissions resulting from passivation, thereby quantifying the positive economic effects of green intervention.

2. Literature Review: The Feasibility of the Ecological Transition of Buildings

The proposed "Ecological Retrofitting" Strategy is based on the international and national scientific literature, which provides several important contributions concerning the economic feasibility of the ecological transition of buildings; these studies appraise the benefits stemming from the energy efficiency derived from the buildings' ecological retrofitting, as reported below.

2.1. The Economic Benefits of the Ecological Transition of Buildings

2.1.1. International Level

At the international level, several studies have focused on the economic benefits resulting from the ecological transitions of buildings.

Among these authors, G. Kats stands out as a pioneer in the economic valuation and cost–benefit analysis of sustainable architecture. The study by Kats et al. (2003) [19] was one of the first to comprehensively aggregate the costs and benefits of green buildings, demonstrating that sustainable interventions represent a sound financial investment. Their findings show that such interventions typically generate savings exceeding ten times the average initial premium necessary to construct a green building. The research also highlights that annual energy savings represent just one of the multiple benefits of sustainable strategies; notably, they constitute the first and most immediate form of return on the higher upfront investment. Thus, "on the basis of energy savings alone, investing in green buildings appears to be cost-effective; the total 20-year present value of financial energy benefits from a typical green building is $5.79/ft" [19].

Moreover, Kats et al. (2006) [20] compared the average extra cost of 30 green buildings between 2001 and 2006 across the USA with a similar kind of conventional buildings; it was identified that green intervention produces numerous economic benefits that exceed the primary extra cost associated with construction: "the financial savings are about $70 per ft^2, 20 times as high as the cost of going green" [20].

Based on the comparative analysis of the actual cost of 150 green buildings against conventional ones, Kats et al. (2008) [21] showed that the green buildings' extra cost is only 1–2% higher than that of conventional buildings. The study also found that the total energy consumption in green buildings is reduced by 33% and that, consequently, energy management costs, over a 20-year period, outweighed the extra construction cost of those buildings [21].

In a study by Kats et al. (2010) [22], another comparison between green buildings and conventional ones was performed, using a sample of 170 buildings. The research showed that the Net Present Value (NPV) of 20 years of annual energy savings in a green building ranged from $4 per square foot to $16 per square foot, depending on the building's construction type and system characteristics [22].

In the same year, a similar study was performed; Bombugala et al. (2010) [23] found that the extra construction cost of green buildings was 20–25% higher with respect to that of conventional buildings; however, the financial savings was ten times higher over the entire life cycle of the buildings [23].

Moreover, according to the World Green Building Council (2013) [24], higher upfront extra costs for green buildings have been found to be proportional to the increased level of environmental certification. Increases in upfront costs in green buildings are often offset by a decrease in long-term life cycle costs, particularly in the case of green buildings that feature energy-efficient building systems [24].

In the end, in addition to the previously analyzed studies, Morris et al. (2007) [25] indicated that "reasonable levels of sustainable design can be incorporated into most building types at little or no additional cost" [25].

The panorama of the international scientific literature highlights the need for further research, analysis, and evaluation. Continued investigation is essential to refine existing cost–benefit estimates and is likely to reveal even greater financial advantages associated with ecological retrofitting and green building practices.

2.1.2. National Level

At the national level, a case study can empirically address the issues raised by the theoretical framework on the economic and ecological impacts of the ecological transition of buildings. Barthelmes et al. (2016) [26] analyzed different alternative scenarios of energy retrofitting of a single-family building in northern Italy; the obtained results showed that retrofitting interventions are profitable. The initial extra investment costs are offset by a reduction in the total energy consumption, which consequently reduces the energy management costs; moreover, the research showed that the cost-optimal measure provides an annual energy consumption of less than about 20 kWh/m^2 year [26].

In the panorama of the scientific literature, especially in the national one, there is a growing interest in identifying the cost-optimal solutions for nearly Zero-Energy Buildings (nZEBs). In this respect, Fregonara et al. (2017) [27] conducted a case study to analyze two types of interventions on a double-family building through an integrated valuation based on both energy efficiency and related costs. The first type of intervention concerned the building's external thermal insulation; the second type of intervention was the integration of green home energy practices. Both the retrofitting interventions allowed for achieving high energy performance, whereas the economic analysis showed a different cost for each solution. According to the obtained results, the retrofitting interventions on the building envelope are the most cost-effective. This retrofitting intervention strategy allows for reducing maintenance costs and maintaining energy performance over time, thus reducing energy consumption [27].

In the same year, a similar study was performed; Zangheri et al. (2017) [28] tested different retrofitting interventions to reach the cost-optimal and nZEB levels in many types of existing residential buildings. Through the application of an economic valuation, the research achieved its goal, demonstrating that "the obtained nZEBs retrofitting interventions proved to be profitable". The research found that the cost-optimal measures allow for a reduction in the buildings' total energy consumption by 36–88%, thus reducing energy management costs [28].

In line with the previous studies, Bottero et al. (2018) [29] highlight that the additional investments required for the retrofitting interventions, for improving the building energy efficiency, are profitable, i.e., the nZEB solutions are positive NPV investments thanks to the important energy savings and consequent reduction in energy management costs [29].

Scientific research also helps technical activity in the territory. Intorbida (2013) [30] compared the operating costs and maintenance costs of an Italian historical building, before and after ecological retrofitting, through an economic analysis that demonstrated the feasibility of the ecological retrofitting. Thanks to the improvement in the energy efficiency and, consequently, the energy management costs, the Payback Period of the initial investment in the case study was about 10 years; additionally, the reduction in the energy management costs produced a positive added value over a 20-year period, overcoming the extra construction cost for about 50% of the initial investment cost [30].

The foregoing positive nature of the previous studies, in terms of the economic and ecological feasibility of retrofitting interventions, has led to the present study. The tests carried out in the proposed case study will help us understand if the "Ecological Retrofitting" Strategy makes economic sense, i.e., if the ecological retrofitting interventions are economically sustainable.

3. Materials and Methods

As stated above, the present research aims to verify and assess the effectiveness, from an ecological point of view, and the feasibility, from an economic aspect, of the existing buildings' "Ecological Retrofitting" Strategy, i.e., the positive effects of ecological transition at the building level. The buildings' ecological transition is achieved through, among other measures, bio-ecological passivation, namely, passive buildings characterized by low energy consumption and a high level of living comfort, thanks to different key elements, such as the thermal external coat; it is an excellent insulation system for walls, roofs, and floors, allowing the building to stay warm in winter and cool in summer, thus avoiding thermal dispersions [31].

The thermal coat reduces fossil energy consumption and consequent CO_2 emissions of existing buildings and new ones [32–35].

The choice of the most efficient material that can be used for thermal insulation is the most important aspect: it must be based on quality, i.e., on the material's performance, characterized by low conductivity and low transmittance. The insulating materials can have different origins (natural, synthetic, and mineral), but natural and local ones, specifically, those that are oil-free, are preferred; if the panels are oil-based, the dependence on fossil fuels will increase.

Cork (Figure 3) and marlstone (Figure 4) are two key raw materials that can be used to manufacture products such as panels and plaster for external thermal insulation, respectively.

(**a**) (**b**) (**c**) (**d**)

Figure 3. Corkboard production process: (**a**) cork tree: located in the municipality of Lamezia Terme (Italy), Calabria region; (**b**) debarked cork plank; (**c**) granulated cork; and (**d**) ecological cork panel. Source: Authors.

(**a**) (**b**) (**c**) (**d**)

Figure 4. Natural hydraulic lime plaster production process: (**a**) marlstone quarry: "Cava Mendicino", located in the municipality of Lamezia Terme (Italy), Calabria region; (**b**) marlstone rock sample; (**c**) ecological plaster; and (**d**) natural hydraulic lime (NHL) plaster. Source: Authors.

Cork panel is a low-energy and eco-friendly material; it is produced using only steam, with no synthetic additives, thanks to its natural resin (suberin). Often powered by biomass from cork waste, its production emits very little CO_2. It is a carbon-negative, renewable, and sustainable material. Cork oak trees absorb more CO_2 during their growth than what is emitted during processing. The bark regenerates every 9–12 years; thus, there is no need to cut down the tree. It is 100% recyclable and biodegradable, and it does not release harmful substances during its use.

Natural hydraulic lime is produced by calcining limestone and clay at lower temperatures (~900 °C) than traditional cement (~1450 °C), resulting in significantly lower energy consumption; it is a simple and low-impact process with no chemical additives. This natural material produces less CO_2 per kilogram than Portland cement. Its unique feature is that it absorbs CO_2 from the atmosphere during curing through a process called carbonation, helping to offset emissions; additionally, it is completely natural, free from VOCs (volatile organic compounds), safe for indoor air quality, and highly compatible with traditional and breathable construction systems.

One of the key elements of these products is their high insulating power and their astonishingly low thermal conductivity:

- Cork panel: 0.043 W/mK;
- Natural hydraulic lime base plaster: 0.066 W/mK.

Table 1 below presents a comparative overview of four common building materials—cork panels, natural hydraulic lime plaster, bricks, and traditional cement—based on key criteria relevant to sustainable construction. These include the following:

- Thermal conductivity, which affects energy efficiency and indoor comfort;
- Environmental impact, considering CO_2 emissions, renewability, and ecological sustainability;
- Cost-effectiveness, expressed as an approximate installation cost per square meter.

Table 1. Comparison of thermal conductivity, CO_2 emissions, and cost of common building materials.

Material	Thermal Conductivity	CO_2 Emissions	Cost
	W/mK	kg/kg	€/m^2
Cork Panels	0.043	−1.80	20.00
Natural Hydraulic Lime Plaster	0.066	0.20	15.00
Polystyrene Panels (EPS/XPS)	0.030–0.040	5.00	10.00
Portland Cement	0.90–1.50	1.00	5.00
Bricks	0.60–0.90	0.30	10.00

Cork and natural hydraulic lime stand out for their sustainability, low embodied energy, and compatibility with historical and eco-conscious construction.

Portland cement and polystyrene, while widely used, have significant environmental impacts despite their low cost.

For projects prioritizing energy efficiency and environmental performance, bio-based and lime-based materials offer long-term advantages.

These natural materials' low thermal conductivities can result in a reduction in the buildings' total energy consumption and, consequently, lower energy management costs, as demonstrated in the following case study through an integrated valuation.

4. Appraisal Method and Tools: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP)

Economic valuations are essential for demonstrating the economic feasibility of a building's ecological retrofitting. The "Ecological Retrofitting" Strategy is able to produce positive cash flows (economic returns) due to savings on energy management costs, thus being capable of recovering the invested capital as soon as possible.

The findings of a preliminary review show that the economic valuation method is based on a cost–benefit analysis (CBA), which measures the economic profitability of projects; it is a useful technique for determining the order of investment projects' priority, i.e., public or private. Thanks to this analysis method, the goods and services that can be obtained from an investment project for its entire duration (benefits) are compared to the goods and services that must be used for the implementation and operation of the project itself (production, opportunity, or operating costs). In this way, it is possible to plan the costs and benefits related to different investment projects, choosing the optimal one for the community in question, e.g., to maximize the collective utility [36,37].

The CBA's operative procedure is divided into several steps. First, the costs and benefits provided by the interventions are identified. Second, a temporal articulation is carried out through the construction of the cash flow. Subsequently, a discount rate (or anticipation coefficient) is assumed; this allows us to discount the cash flows. The final step is the elaboration of the evaluation criteria and the formulation of the final choice [36,37].

The economic convenience analysis is set up through a logical procedure that consists of a comparison between the initial investment costs and the financial benefit, which is assumed to be produced by the retrofitting interventions over the useful life of the same interventions.

The simple relationship between the three economic variables is shown below.

$$P = R - C \tag{1}$$

- P is the profit;
- R is the revenue;
- C is the cost.

If the p value is positive, the retrofitting intervention is cost-effective and should be realized; otherwise, it should not be implemented.

First, to apply the CBA, the discount rate r (intertemporal preference rate between cash today without future well-being or investment for present and future well-being) must be determined. Considering that the revenues are made up of cash flows that are generated during the interventions' useful life, while the interventions' expenditure is disbursed at year zero, there is no contemporaneousness between the outgoing economic flows and the incoming ones [36].

The comparison must therefore be made with the support of actualization coefficients, which are equal to the value of the money available at different times:

$$\frac{1}{q^n} \tag{2}$$

- $q = 1 + r$;
- r is the discount rate.

To determine the economic convenience of the buildings' ecological retrofitting, the following different evaluation criteria have been proposed: the Net Present Value (NPV), the Internal Rate of Return (IRR), and the Payback Period (PBP); these indicators are explained in detail below.

The NPV is a methodology by which the present value of the expected cash flows is defined by discounting them on the basis of the rate of return. Thus, it is the difference between the sum of the expected economic revenues, determined by cash flows, and the initial investment, which is necessary for carrying out the retrofitting interventions. The NPV varies with the variation in the discount rate; it decreases with an increase in the discount rate and vice versa [36].

$$NPV = \sum_{i=0}^{n} \frac{CF_i}{(1+r)^i} - I_0 \tag{3}$$

- CF_i is the cash flow to the i-th year;
- r is the discount rate;
- I_0 is the initial investment cost.

If the NPV value is positive, at the end of the investment's life, the benefits produced will have a discounted amount higher than the investment itself; therefore, the intervention is profitable and a good investment. On the contrary, the intervention should not be carried out, from an economic point of view, if the NPV value is negative.

Another evaluation criterion analyzed to determine the convenience of the investment is the IRR, i.e., the interest rate of the capital for which the NPV = 0 [36].

$$IRR = r \rightarrow \sum_{i=0}^{n} \frac{CF_i}{(1+r)^i} - I_0 = 0 \tag{4}$$

- CF_i is the cash flow to the i-th year;
- r is the discount rate;
- I_0 is the initial investment cost.

The IRR is the capital limit rate for which the NPV = 0, i.e., it is the profitability of an investment. The difference between the NPV value and the IRR value is that the NPV value expresses the overall convenience extended to the entire life of the investment, while the IRR value expresses the convenience per year of life. If the IRR is greater than or equal to the threshold discount rate (previously chosen as a reference), the investment is economically convenient; otherwise, it is not feasible.

However, the indicator that immediately demonstrates the convenience of the investment is the PBP. It is the number of years required for the capital employed to be financially recovered; therefore, it is used to assess the risk exposure time by the investor.

$$PBP = \frac{I_0 - A_f}{R} \tag{5}$$

- I_0 is the initial investment cost;
- A_f refers to any tax breaks;
- R is the annual recovery.

In many cases, the determination of the PBP value is sufficient to define the profitability and the convenience of an investment.

This estimation method was then applied to the proposed case study to assess the economic feasibility and convenience of the "Ecological Retrofitting" Strategy.

5. Case Study: Cadastral Parcel #236, Latin Quarter of Reggio Calabria, Southern Italy

The case study's area covers the historical center of Reggio Calabria (Calabria region, Italy), found in Climatic Zone B (with 772 day degrees). This area was rebuilt after the destructive earthquake in 1908, and it is located between the harbor and the Mediterranea University of Reggio Calabria, in the northern area of the original settlement, named the Latin Quarter (Figure 5).

The experiment was conducted on one of the Liberty urban blocks of the Latin Quarter, i.e., urban block #102 (Figure 6), an interesting Liberty-style architecture built in 1935. It is composed of two residential buildings (cadastral parcels #236 and #144), located side by side and divided by an internal courtyard. This is a significant residential block because it is the first one (in the area) with three floors built in those years.

Specifically, the integrated valuation, economic and ecological, focused on one of these residential buildings: cadastral parcel #236 (Figure 7).

Figure 5. Latin Quarter, Reggio Calabria, Calabria region, Italy. Source: Google Maps, 2022.

Figure 6. Map of the Latin Quarter, Reggio Calabria, Calabria region, Italy. Source: Authors.

Figure 7. Cadastral map 2012, Sheet 121. Source: Cadastral Office of Reggio Calabria.

The case study included 28 residential apartments: 12 on the first floor, 8 on the second floor, and 8 on the third floor. These consisted of very typical (in the area) architectural features: a punctiform structure in reinforced concrete (a base beam, pillars, and a flat roof slab), typical masonry infill walls, and windows characterized by a double glazing and an aluminum frame with thermal break; decorations that are typical of the Art Nouveau style are on the external facades of the building.

Cadastral parcel #236, of urban block #102, showed the opportunity and the feasibility of a green "Ecological Retrofitting" Strategy, allowing a reduction in fossil energy consumption and CO_2 emissions in existing and historical buildings. This strategy provides important economic and ecological results using innovative technological solutions, evaluated and estimated through a new BEPSP in two alternative scenarios:

- The common scenario, with common and unsustainable materials;
- The sustainable scenario, in which passivation is based on bio-organic natural materials.

5.1. Cadastral Parcel #236: Geometric Characteristics

A direct manual geometric survey was performed. The direct survey for the 28 apartments was carried out both externally (Figure 8) and, for the first time, internally (Figures 9–11) in a building; the internal direct survey allowed the authors to introduce two new parameters: the heated area (net area, m^2) and the heated volume (net volume, m^3).

The measurements of the case study are shown below (Table 2).

Table 2. Survey measurements of cadastral parcel # 236.

Total Built Area	Heated Area	Total Average Height	Total Thickness of Slabs	Net Average Height	Total Built Volume	Heated Volume
m^2	m^2	m	m	m	m^3	m^3
2288.26	1830.61	14.00	0.97	13.03	32,035.64	23,843.70

Figure 8. Cadastral parcel #236. Direct external survey drawing, created in AutoCAD ® 3D. [educational version 24.3 (2024)]. Source: Authors.

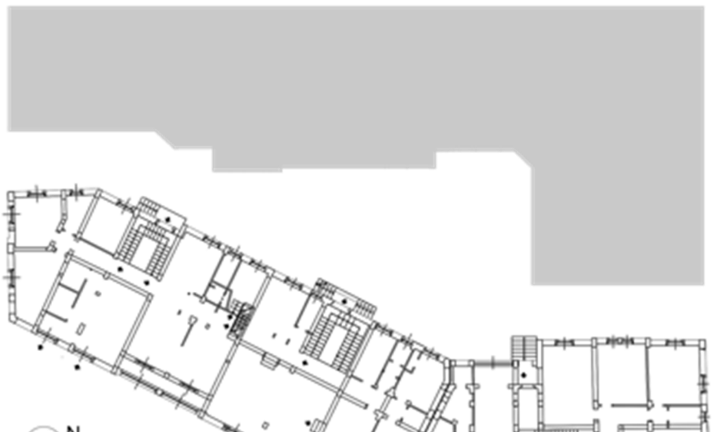


Figure 9. Direct internal survey of the 1° floor. Source: Authors.

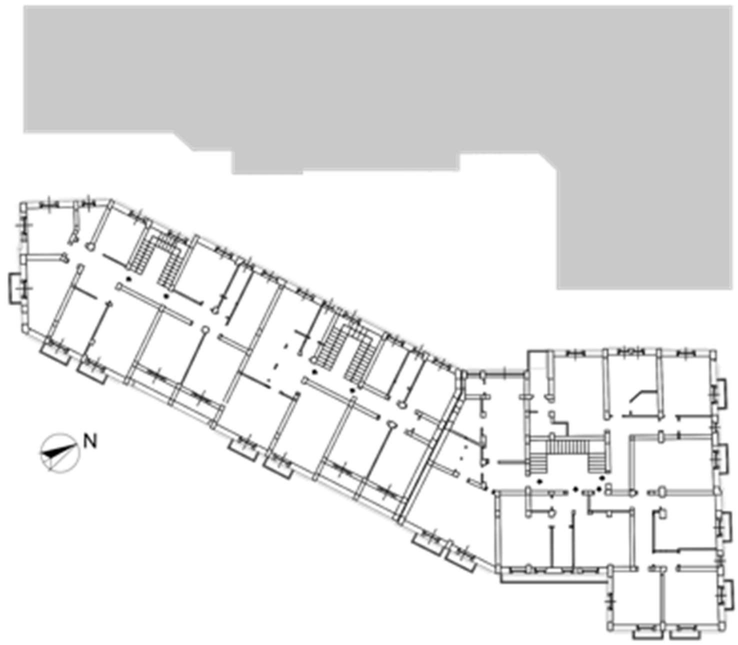


Figure 10. Direct internal survey of the 2° floor. Source: Authors.

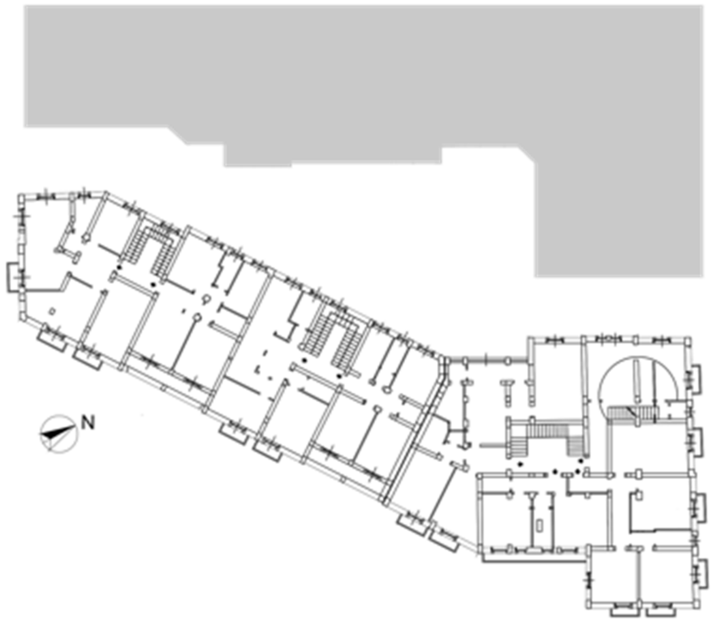


Figure 11. Direct internal survey of the 3° floor. Source: Authors.

5.2. Cadastral Parcel #236: Thermal Characteristics

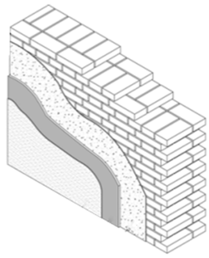
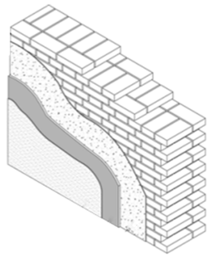
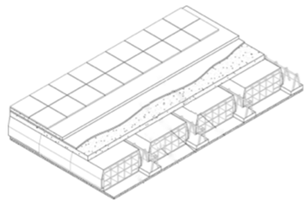
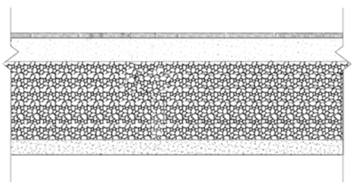
The building's energy performance depends on several factors: orientation, geometry, climate, envelope transmittance (U, in W/m^2K), ventilation, Heating, Ventilation, and Air Conditioning (HVAC) systems, etc. Thus, to assess building envelope performance in the alternative scenarios, energy demand and consumption were calculated in relation to the thermophysical characteristics of the envelope and the HVAC system.

The different technologies for each scenario are summarized in the tables below.

5.2.1. Thermal Characteristics: Common Scenario

In the common scenario, the thermal characteristics of each envelope component are shown in the table below (Table 3). Regarding the HVAC system, for each apartment, one natural gas condensing boiler was installed to serve a single residential unit, providing heating and domestic hot water (DHW).

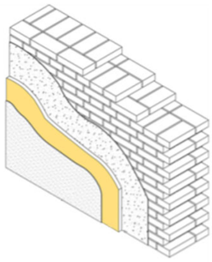
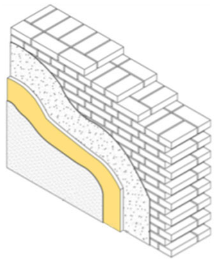
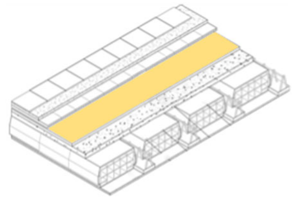
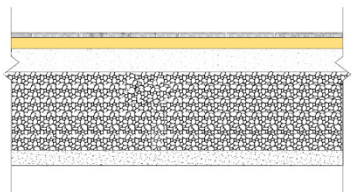
Table 3. Thermal characteristics of the envelope components in common scenarios.

External Walls (1° Floor)	**External Walls (2° and 3° Floors)**	**Roof**
U [W/m^{2}K]: 1.27	U [W/m^{2}K]: 1.53	U [W/m^{2}K]: 2.97
Thickness [m]: 0.446	Thickness [m]: 0.346	Thickness [m]: 0.288
		
Stratigraphy	Stratigraphy	Stratigraphy
(1) External plaster, 31 mm; (2) Bricks, 400 mm; (3) Internal plaster, 15 mm	(1) External plaster, 31 mm; (2) Bricks, 300 mm; (3) Internal plaster, 15 mm	(1) External floor, 15 mm; (2) Cast concrete, 55 mm; (3) Vapor barrier, 3 mm; (4) Concrete slab, 200 mm; (5) Internal plaster, 15 mm
Basement Floor	**Windows**	**Glass Doors**
U [W/m^{2}K]: 2.60	Frame Uf [W/m^{2}K]: 3.40; Glass Ug [W/m^{2}K]: 2.80	Frame Uf [W/m^{2}K]: 3.40; Glass Ug [W/m^{2}K]: 2.80
Thickness [m]: 0.297	Thickness [m]: 1.98 × 1.00	Thickness [m]: 2.90 × 1.00
		
Stratigraphy	Stratigraphy	Stratigraphy
(1) Floor, 12 mm; (2) Concrete basement slab, 85 mm; (3) Compacted gravel base, 200 mm	(1) Aluminum frame with thermal break; (2) Double-glazed window with an air gap between the layers	(1) Aluminum frame with thermal break; (2) Double-glazed window with an air gap between the layers

5.2.2. Thermal Characteristics: Sustainable Scenario

In the sustainable scenario, the energy retrofitting interventions concerned only the opaque and transparent components of the residential building, focusing more on passivation before taking into consideration the integration of the green home energy practices (Table 4); therefore, regarding the HVAC system, it is the same as the common scenario for each apartment.

Table 4. Thermal characteristics of the envelope components in sustainable scenarios.

External Walls (1° Floor)	**External Walls (2° and 3° Floors)**	**Roof**
U [W/m^{2}K]: 0.66	U [W/m^{2}K]: 0.72	U [W/m^{2}K]: 0.43
Thickness [m]: 0.481	Thickness [m]: 0.381	Thickness [m]: 0.329
		
Stratigraphy	Stratigraphy	Stratigraphy
(1) Thermal external plaster of natural hydraulic lime (NHL), 66 mm; (2) Bricks, 400 mm; (3) Internal plaster, 15 mm	(1) Thermal external plaster of natural hydraulic lime (NHL), 66 mm; (2) Bricks, 300 mm; (3) Internal plaster, 15 mm	(1) External floor, 15 mm; (2) Cast concrete, 55 mm; (3) Vapor barrier, 3 mm; (4) Cork panels, 60 mm; (5) Concrete slab, 200 mm; (6) Internal plaster, 15 mm
Basement Floor	**Windows**	**Glass Doors**
U [W/m^{2}K]: 0.56	Frame Uf [W/m^{2}K]: 1.20; Glass Ug [W/m^{2}K]: 1.10	Frame Uf [W/m^{2}K]: 1.20; Glass Ug [W/m^{2}K]: 1.10
Thickness [m]: 0.357	Thickness [m]: 1.98 × 1.00	Thickness [m]: 2.90 × 1.00
		
Stratigraphy	Stratigraphy	Stratigraphy
(1) Floor, 12 mm; (2) Cork panels, 60 mm; (3) Concrete basement slab, 85 mm; (4) Compacted gravel base, 200 mm	(1) PVC frame; (2) Triple-glazed window with an air gap between the layers	(1) PVC frame; (2) Triple-glazed window with an air gap between the layers

As reported in Table 3, the sustainable scenario proposed different retrofitting interventions:

- First, it proposed a new insulating layer outside the external walls (for both types): 6.6 cm of thermal plaster of natural hydraulic lime in order to reduce the wall's thermal transmittance; according to this intervention, the U-wall was lowered by 53% for each type of external walls;
- Second, a new insulating layer was created within the roof stratigraphy: using only 6 cm of cork panels, the U-roof was lowered by about 86%; for this reason, it was the most effective intervention;

- Third, a new insulating layer was also created within the basement floor stratigraphy: using only 6 cm of cork panels, the U-roof was lowered by about 78%;
- Fourth, in order to reduce the transparent envelope components' thermal transmittance, the existing windows and glass doors were replaced with a PVC frame with triple glass. The frame's transmittance (Uf) was lowered by about 65%, and that of the glass (Ug) was lowered by about 61%.

Using only the envelope technologies, the obtained results showed a reduction in the overall building energy consumption and pollution (the overall heating demand was lowered, along with the CO_2 emissions). Thanks to these savings, the energy management costs in the case study were also reduced, as shown in the next section.

6. Case Study: Outcomes of the Integrated Valuation

In order to demonstrate the environmental benefits and the economic feasibility of the "Ecological Retrofitting" Strategy, this section—divided into two subsections—presents a comprehensive integrated assessment conducted in the real-world case study, as described previously. The first subsection focuses on an ecological evaluation, detailing the results in terms of energy savings and the corresponding avoided CO_2 emissions. The second subsection addresses the economic evaluation, highlighting the positive passive financial impacts of the intervention.

6.1. Ecological Valuation

The valuation of the energy performance of cadastral parcel #236 was carried out through a new energy assessment tool, i.e., the BEPSP, in an updated BIM platform, namely, TerMus BIM (educational version 51.00u), distributed by ACCA.

TerMus BIM is a tool that uses a dynamic energy simulation to analyze the buildings' thermal energy performance; this type of simulation allows the evaluation of energy performance under real conditions, taking into account hourly and seasonal variations in thermal loads, occupancy, lighting, and climatic conditions.

The integrated calculation engine in TerMus BIM is EnergyPlus (trial version 8.9.0), one of the most advanced and widely used solvers for dynamic building energy simulation, developed by the U.S. Department of Energy. This software allowed for a detailed simulation of the buildings' energy behavior, considering numerous thermophysical and HVAC system variables.

Additionally, the Energy Plus calculation engine is integrated with 3D BIM modeling, which allows one to import architectural models from DXF/DWG formats. This made it possible to assign thermal properties to the construction elements, define HVAC systems, and use profiles and time schedules.

For the energy simulation, climate data from sources such as Meteonorm were used, which the software uses to accurately simulate local environmental conditions.

Thanks to these features, TerMus BIM made it possible to:

- Evaluate the buildings' actual energy consumption, broken down by zone and service;
- Analyze the efficiency of thermal systems and related emissions;
- Simulate natural lighting and the influence of internal gains;
- Compare different design solutions to optimize energy efficiency.

The energy simulation tool provides the global (*gl*) energy (*E*) performance (*P*) index (EP_{gl}); performances are expressed in kWh/m^2 year for the energy consumption and CO_2 kg/m^2 year for the environmental impact. As the technical standard UNI TS 11300 indicates [38–42], the performance indicators proposed are as follows:

$$EP_{gl} = EP_H + EP_C + EP_W + EP_V + EP_L + EP_T \quad (6)$$

- EP_H is the energy performance index for winter heating (kWh/m^2 year);
- EP_C is the energy performance index for summer cooling (kWh/m^2 year);
- EP_W is the primary energy for domestic hot water (kWh/m^2 year);
- EP_V is the energy performance index for ventilation (kWh/m^2 year);
- EP_L is the energy performance index for artificial lighting (kWh/m^2 year);
- EP_T is the energy performance index for people's transportation (kWh/m^2 year).

So, the EP_{gl} is determined as the sum of each individual energy performance index provided in the reference building, and it is expressed in kWh/m^2 year.

The Table 5 show the results derived from the energy simulation:

Table 5. Cadastral parcel #236. Summary table about energy consumption (in kWh/m^2 y) and CO_2 emissions (in kgCO_2/m^2 y).

Scenarios	EP_{gl}	Scenarios	CO_2 Assessment per Year
	kWh/m^2 year		kg CO_2/m^2 year
BAS	146.11	BAS	27.76
ECO	47.97	ECO	9.41
Δ	98.14	Δ	10.35
%	67%	%	66%

Source: Authors.

The ecological retrofitting (based on natural materials) reached the goal of a strong enhancement of thermal building performance, consisting of significant energy savings because of the key interventions listed above. The total energy savings were around 67%; additionally, the avoided CO_2 emissions were lowered by about 66%. These unexpected outcomes were obtained by simply using a 6 cm thick insulating layer in each opaque component, along with new windows and a glass door (i.e., only adopting the passivation approach for the buildings).

Subsequently, in the next section, the differential investment cost between the two alternative intervention scenarios and the years needed for the payback of this differential investment cost are estimated in order to understand if the success in energy savings (even in a Liberty-style historical building) is bearable in financial terms; it is important to determine if, after the additional and differential initial cost is paid back, the permanent energy saving in the building will create continuing added value.

6.2. Economic Valuation

The "Ecological Retrofitting" Strategy offers both ecological and economic advantages; however, its financial benefits are often overlooked or misrepresented as additional passive costs, rather than being recognized as a strategic and long-term investment in addressing global ecological challenges.

A preliminary economic valuation underlines the convenience of this strategy, not only in ecological terms but also in terms of a favorable monetary result [19–22].

Therefore, the present study also aims to assess if the additional differential cost of the ecological retrofitting, compared to the common scenario's initial construction cost, has a time of return (payback) of the differential cost in a short-term period and if its amount is reasonable, using a 4% discount rate.

The cost-effectiveness of the green interventions necessitates an evaluation of the financial profitability through economic indicators, such as the NPV, the IRR, and the PBP, as previously analyzed.

The results of the economic valuation are shown below.

Appraisal of the Energy Management Costs and CO_2 Emissions

Extensive recent scientific and market research provides quantitative data on energy market prices and the external costs of pollution, most notably, the conservative estimates of the carbon social cost (CSC):

- Thermal energy (€/kWh): 0.25 (derived from national domestic bills);
- Carbon social cost (€/kg): 0.30. Equivalent environmental cost, i.e., the social cost of climate change-related damage from CO_2 emissions: economic losses associated with changes in agricultural productivity; risks to human health; property damage caused by a possible increase in flooding; and loss of ecosystem services [43–49].

The results of the energy management cost in both scenarios are shown in Table 6 below.

Table 6. Cadastral parcel #236. Summary table about energy management costs.

Scenarios	Energy Needed	Heated Area	Total Annual Energy	Energy Price	Management Cost
	kWh/m^2 y	m^2	kWh/y	€/kWh	€
BAS	146.11	1830.61	267,475.51	0.25	66,868.88
ECO	47.97	1830.61	87,816.90	0.25	21,954.23
Δ	98.14	/	179,658.61	/	44,914.65
%	67%	/	67%	/	67%

Source: Authors.

In the sustainable scenario, the monetary cost of annual energy savings is lowered to €44,914.65 by simply using a 6 cm thick insulating layer in each opaque component, along with the new windows and a glass door.

Regarding the energy savings, the Table 7 shows the reduction in costs due to avoided CO_2 emissions.

Table 7. Cadastral parcel #236. Summary table about the costs of CO_2 emissions.

Scenarios	CO_2 Emissions	Heated Area	Total Annual Energy	CSC	Management Cost
	KgCO_2/m^2 y	m^2	kgCO_2/y	€/kg	€
BAS	27.76	1830.61	50,818.50	0.30	15,245.55
ECO	9.41	1830.61	17,221.46	0.30	5166.44
Δ	10.35	/	33,597.04	/	10,079.11
%	66%	/	66%	/	66%

Source: Authors.

The social cost of annual avoided CO_2 emissions is less than €10,079.11 (less than 66% of the emissions costs of the common scenario).

The research provides the total intervention-related construction costs of both scenarios, analyzed by the authors in the previous research [15], where microeconomic analyses of elementary factors were compared to locally available market data, such as regional price lists; the sum of all the "*Lavorazioni*", estimated with Elementary Factor Analysis (EFA), provides the Estimative Metric Calculation (EMC) of the entire intervention.

The total construction investment costs, which do not include the management and maintenance costs of the intervention, of both scenarios are as follows:

- €283,670.92 for the common scenario;
- €337,225.84 for the sustainable scenario.

The ecological retrofitting interventions imply a higher initial construction cost; the difference is only +€53,554.92 = +16% of the common scenario's initial cost of construction.

Even if the common intervention is initially less expensive, and thus more feasible, than the sustainable one, from a financial point of view, it is necessary to analyze the Payback Period (Table 8) of the ecological retrofitting's higher differential cost.

Table 8. Cadastral parcel #236. Payback of the differential cost (€53,554.92).

Year	Monetary Annual Saving	Actual Coefficient	Annual Present Value	Total
n.	€	$1/q^n$	€	€
1	44,914.65	0.96	43,118	43,118
2	44,914.65	0.92	41,322	84,440
3	44,914.65	0.89	39,974	124,415
4	44,914.65	0.85	38,178	162,592
5	44,914.65	0.82	36,830	199,423
6	44,914.65	0.79	35,483	234,905
7	44,914.65	0.76	34,135	269,041
8	44,914.65	0.73	32,788	301,829
9	44,914.65	0.70	31,441	333,269
10	44,914.65	0.68	30,542	363,812
11	44,914.65	0.65	29,195	393,006
12	44,914.65	0.62	27,847	420,854
13	44,914.65	0.60	26,949	447,803
14	44,914.65	0.58	26,051	473,853
15	44,914.65	0.56	25,152	499,006
16	44,914.65	0.53	23,805	522,811
17	44,914.65	0.51	22,907	545,717
18	44,914.65	0.49	22,008	567,726
19	44,914.65	0.47	21,110	588,836
20	44,914.65	0.46	20,661	609,497
Total			**609,497**	

Rate i = 4%. Source: Authors.

The initial extra cost of €53,554.92 for the ecological retrofitting interventions would be paid back in just two years (Table 8), given a very conservative interest rate of 4%. The resulting savings represent a positive added value, as shown in the graph below (Figure 12).

Among the main advantages associated with the ecological retrofitting of buildings, a particularly relevant aspect is the economic convenience in the short-to-medium term, assessed through the payback time of the investment. This period is generally short due to the capacity of such interventions to generate immediate economic benefits, primarily linked to a significant reduction in energy consumption for heating, cooling, and lighting. This decrease in energy demand—achieved through the adoption of natural thermal insulation solutions, the improvement of HVAC systems, and the integration of renewable energy sources—results in substantial annual savings, enabling a rapid recovery of the initial investment [50,51]. This element plays a crucial role in the assessment of the techno-economic feasibility of ecological interventions, especially in a context where the ecological transition of the building stock is receiving growing attention at both regulatory and scientific levels [52–61].

Figure 12. Cadastral parcel #236. Graph of the payback of the differential cost (€53,554.92). Source: Authors.

Energy savings generate multiple benefits, both direct and indirect, as follows:

- Energy and economic benefits. The reduction in energy consumption (kWh) directly translates into lower utility costs, as the energy not used does not need to be paid for;
- Environmental and economic benefits. By avoiding the emission of carbon dioxide into the atmosphere, the strategy prevents the associated environmental damage and the related social cost of carbon. This impact is effectively mitigated through the implementation of the "Ecological Retrofitting" Strategy.

Thus, the results of the cash flows of the CSC over twenty years are as Table 9:

Table 9. Cadastral parcel #236. Cash flows of the carbon social cost over twenty years.

Year	Monetary Annual Saving	Actual Coefficient	Annual Present Value	Total
n.	€	$1/q^n$	€	€
1	**10,079.11**	**0.96**	**9676**	**9676**
2	10,079.11	0.92	9273	18,949
3	10,079.11	0.89	8970	27,919
4	10,079.11	0.85	8567	36,486
5	**10,079.11**	**0.82**	**8265**	**44,751**
6	10,079.11	0.79	7962	52,714
7	10,079.11	0.76	7660	60,374
8	10,079.11	0.73	7358	67,732
9	10,079.11	0.70	7055	74,787
10	**10,079.11**	**0.68**	**6854**	**81,641**
11	10,079.11	0.65	6551	88,192
12	10,079.11	0.62	6249	94,441
13	10,079.11	0.60	6047	100,489
14	10,079.11	0.58	5846	106,335
15	**10,079.11**	**0.56**	**5644**	**111,979**
16	10,079.11	0.53	5342	117,321

Table 9. *Cont.*

Year	Monetary Annual Saving	Actual Coefficient	Annual Present Value	Total
17	10,079.11	0.51	5140	122,461
18	10,079.11	0.49	4939	127,400
19	10,079.11	0.47	4737	132,137
20	**10,079.11**	**0.46**	**4636**	**136,774**
Total			**136,774**	

Rate i = 4%. Source: Authors.

The amount of the avoided CO_2 emissions' social cost over a period of twenty years is about €136,774, thanks to the ecological retrofitting interventions.

7. Discussion

The building sector is one of the main contributors to global greenhouse gas (GHG) emissions, primarily due to the energy consumed for heating, cooling, lighting, and mechanical systems. This energy use directly increases CO_2 emissions, the main driver of global warming. Improving the energy efficiency of buildings—especially the existing stock—is therefore a strategic lever for mitigating climate change.

In Europe, buildings are responsible for about 40% of the total energy consumption and 36% of CO_2 emissions [2].

At the national level, according to the SIAPE 2025 data, an average Italian household consumes about 201 kWh/m^2 year of fossil energy for their energy management, consequently producing about 41 $kgCO_2/m^2$ year [10].

Pollution, mainly produced by energy overconsumption in buildings, has increased considerably due to wrong architectural designs, outdated technologies, and a lack of better-performing materials. Most of the existing buildings are built without considering the thermal and geometric envelope characteristics, the place, and the local climate features; they are focused only on the aesthetic and artistic quality, increasing the energy demand of the HVAC system for indoor comfort.

The combustion of fossil fuels (coal, oil, and gas) to power buildings is a major source of CO_2. According to the IPCC (Intergovernmental Panel on Climate Change), the building sector must reduce its emissions by 90% by 2050 to stay within the 1.5 °C global warming threshold [58–60].

Climate change not only worsens due to the building sector but also affects the performance and resilience of buildings:

- Rising average temperatures, which increase the demand for cooling;
- More frequent extreme weather events, increasing the risk of structural damage, especially to historical buildings;
- Irregular humidity and rainfall, accelerating the deterioration of construction materials.

Therefore, the high energy consumption of buildings is a key driver of the climate crisis. However, this sector also offers the greatest short- and medium-term opportunities for emissions reductions. Acting on the existing building stock—with technically compatible and culturally respectful solutions—makes it possible to:

- Significantly cut CO_2 emissions;
- Adapt buildings to the effects of ongoing climate change;
- Contribute directly to achieving the Paris Agreement and UN 2030 Agenda targets.

Thus, buildings are part of the climate solution through:

- A reduction in energy demand via passive design and efficient technologies;

- The integration of renewable energy (e.g., solar energy, geothermal energy, and heat pumps);
- The development of nearly Zero-Energy Buildings (nZEBs) and positive energy buildings;
- The promotion of the widespread retrofitting of existing buildings.

In Italy, existing buildings, mostly the historical ones, represent about 70% of the building stocks; the majority of these buildings, with a reinforced concrete structure and masonry infill walls, which were built more than 70 years ago, are aged, in a state of deterioration, and in need of interventions [9]. Thus, recovering, renovating, and redeveloping existing and historical buildings through nature-based passivation is a formidable instrument for improving the energy quality of the building stocks and, consequently, to activate investments in the real estate market and to support technological innovation.

Energy retrofits, especially in historical or existing buildings, can significantly support climate goals without compromising cultural heritage, using methods like internal insulation, high-efficiency glazing, heat pumps, and smart building systems; heritage-compatible interventions can reduce emissions by up to 60% [62].

The present research provides a strategic and decisive solution (the "Ecological Retrofitting" Strategy) that can be applied to the civil sector to contribute to reducing the energy consumption in historical as well as existing buildings.

In order to demonstrate the environmental benefits, the convenience and the economic feasibility of the proposed strategy were tested, and the positive effects and impacts of the ecological transition (and passivation) of buildings were quantified through an integrated valuation, using a case study with two alternative scenarios:

- The common scenario, with an ordinary construction;
- The sustainable scenario, or "Ecological Retrofitting" Strategy, with energy processing, where innovative and natural techniques and materials are used: a new insulating layer (6.6 cm thickness), consisting of thermal plaster of natural hydraulic lime, placed outside the external walls; a cork insulating panel (6 cm thickness) within the roof stratigraphy; a cork insulating panel (6 cm thickness) within the basement floor stratigraphy; and new windows with a PVC frame and triple glass.

Using only these envelope technologies, the obtained results, analyzed through a new BEPSP, have led to a 67% reduction in the overall building energy consumption and pollution.

Additionally, an economic valuation was developed, underlining the economic feasibility of the sustainable scenario.

Applied integrated analyses and valuations, performed in the case study, i.e., cadastral parcel #236 of the Latin Quarter of Reggio Calabria, Italy, show how the use of bio-ecological and natural materials, with low thermal conductivities, makes it possible to obtain the following:

- An improvement in building quality;
- A higher indoor thermal comfort and a healthier environment;
- A considerable reduction in the building's total energy consumption;
- A parallel reduction in outdoor pollution produced and introduced into the atmosphere;
- A consequent reduction in the monetary costs for the building's energy management.

Although ecological retrofitting interventions entail a higher upfront construction cost—approximately 16% more than the conventional baseline—the economic assessment demonstrates that this additional investment is rapidly offset by the substantial reduction in annual energy management costs. A conservative interest rate of 4% was used to discount the projected annual energy savings over 20 years, thereby quantifying the outcome.

The obtained results, from the integrated valuation of both scenarios, are very astonishing and encouraging, as follows:

- The energy savings amount to 67%;
- The related monetary annual savings are €44,914.65;
- The amount of avoided CO_2 pollution is 66%;
- The related monetary annual equivalent estimate of avoided CO_2 emissions is €10,079.11;
- The additional construction cost of the retrofitting interventions is only 16% more than the common scenario's initial construction cost;
- The differential extra cost is immediately recovered: the Payback Period of the investment is just two years; from the third year onwards, the added value is always positive.

Therefore, in buildings' ecological retrofitting, the economic factors are highly interconnected and mutually influential in determining the overall feasibility and effectiveness of the intervention. The initial investment cost is often the main barrier, but its impact must be assessed in relation to annual energy savings and reduced operational costs, which determine the Payback Period. A favorable payback, in turn, can facilitate access to credit and improve the bankability of the project, especially when combined with public incentives, tax deductions, or innovative financing mechanisms such as Energy Performance Contracts. Additionally, the post-retrofit property value tends to increase, positively influencing both the owners' decisions and investor evaluations. Finally, external benefits, such as improved air quality, job creation, and social cohesion, while harder to monetize, contribute to strengthening the overall economic sustainability of the intervention when integrated into cost–benefit analyses.

Also, the economic feasibility of the ecological retrofitting interventions is heavily influenced by a range of factors that vary depending on the scale of intervention, from single buildings to entire urban areas.

At the building level, unit costs tend to be high due to the need for customized solutions, limited bargaining power, and low technical replicability. However, when retrofitting is planned at the neighborhood or city level, significant economic advantages emerge: economies of scale reduce material and labor costs, interventions can be standardized, and shared energy systems (such as district heating networks, energy communities, or microgrids) can be integrated. Moreover, the urban level allows easier access to public and private financing, including European funds, green bonds, and public–private partnerships, thanks to greater project visibility and reduced perceived risk. The benefits also expand beyond individual energy savings: positive collective impacts are generated, such as the enhancement of the urban fabric, improved environmental quality, and reduction in energy poverty. In summary, an integrated and coordinated approach at the urban scale enhances not only the environmental sustainability but also the economic viability of retrofitting efforts.

8. Conclusions and Future Research

The research successfully achieved the general empirical objectives defined earlier, providing concrete and measurable evidence on the effectiveness of ecological retrofitting in terms of energy efficiency, environmental impact reduction, and economic feasibility.

The analyzed case study demonstrates the effectiveness of ecological retrofitting in achieving climate and energy goals. Specifically, the intervention resulted in a 67% reduction in energy consumption and in a 66% decrease in CO_2 emissions, highlighting the potential of such strategies in contributing to the objectives set by the Paris Agreement

(2015) and the European Green Deal [5], which aim for carbon neutrality by 2050 and a 55% reduction in GHG emissions by 2030.

However, these outcomes are intrinsically linked to the environmental and technical compatibility of the materials employed. Ecological retrofitting must rely on the use of renewable, locally sourced, and low-impact materials, consistent with the principles of the circular economy and life cycle sustainability assessment [50,51]. Material choices are not only relevant from an environmental standpoint but also play a critical role in minimizing the embedded energy and emissions associated with construction processes.

Furthermore, to ensure that the achieved benefits are maintained and verifiable over time, it is essential to implement long-term monitoring systems for energy and environmental performance. This approach, in line with the recast of the Energy Performance of Buildings Directive (EPBD), allows for the assessment of actual post-retrofit outcomes, early detection of performance gaps, and informed management strategies. Such monitoring supports a feedback loop essential for continuous improvement, ensuring that ecological retrofit projects do not merely achieve theoretical compliance but deliver real, measurable, and replicable climate benefits.

In this regard, ecological retrofitting—when conducted under material compatibility constraints and accompanied by robust performance tracking—proves to be a strategic tool for aligning the building sector with global decarbonization trajectories and fostering resilient and low-carbon built environments.

Furthermore, the research fulfilled the goals set by the authors by integrating theoretical insight with applied knowledge and by contributing meaningfully to the advancement of sustainable practices in the built environment.

It achieved its main objective of acquiring empirical evidence of the significant benefits generated by nature-based thermal insulation, including improvements in health quality, energy efficiency in the case study, as well as its financial feasibility and economic profitability.

The specific set goals were also achieved, obtaining empirical evidence on the astonishing effects of the "Ecological Retrofitting" Strategy, with the following reported outcomes:

- Energy efficiency of the ecological retrofitting;
- Ecological effectiveness of bio-ecological and natural materials adopted;
- Financial profitability over time for the chosen ecological scenario.

The reported results have shown the effectiveness of the research methods; they showed that the existing buildings can be bio-ecologically retrofitted at a reasonably affordable additional initial investment cost, and the cost differential payback is fast and acceptable, occurring over a short period of time.

First, from an ecological point of view, the 67% of energy savings achieved through the ecological retrofitting intervention analyzed in this study places the project in the category of deep or high-performance retrofits, well above the empirical average observed in standard residential refurbishments. The existing literature shows that typical energy savings from conventional retrofit operations range between 7.5% and 26%, depending on the baseline conditions, building typology, climate zone, and depth of intervention [51,61].

This result is consistent with a growing body of research demonstrating that nature-based retrofit strategies, although still less common in practice, can lead to substantially higher energy savings than traditional material-intensive approaches [50,52–60].

From a financial point of view, the economic convenience of the ecological transition has been demonstrated at the building level. The financial analysis shows the ecological and economic advantages of the sustainable scenario over time.

Due to the existing gap in practical implementation and the growing demand from the academic community for assessments of the economic viability of the "Ecological

Retrofitting" Strategy [11], the present study provides answers sought by the international scientific world about these knowledge gaps in economic valuation.

The obtained results demonstrate that energy retrofitting interventions on historical buildings can lead to significant emission reductions—up to 60%—without compromising the cultural and architectural value of the heritage.

These findings have concrete application value for similar projects, as they provide quantitative and methodological evidence useful for guiding decisions in complex contexts, where energy efficiency and conservation are often perceived as conflicting goals. For policymakers, the results offer a scientific basis for updating regulations and incentive schemes, promoting retrofit strategies that are both environmentally sustainable and culturally sensitive. For construction professionals, the technical guidelines that emerged from this study—such as the use of compatible materials, reversibility of interventions, and long-term performance monitoring—serve as operational references for designing effective and replicable solutions. Furthermore, the integrated assessment of economic, environmental, and social impacts makes the proposed model a useful tool for participatory planning, capable of actively engaging local communities, heritage authorities, and investors. In summary, the value of the results lies not only in their technical transferability but also in their ability to inform cross-sectoral strategic choices, contributing to the achievement of climate goals and urban regeneration objectives.

Future objectives can be pursued, based on our results, in order to confirm the reproducibility of the "Ecological Retrofitting" Strategy, from the building level to the municipality level, and promote a global ecological retrofit in a framework of a broader sustainable urban conservation strategy.

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