

Article

Renovation Wave in Europe: Low-Carbon Design for the Refurbishment of Social Housing in Southern Italy

Giacomo Di Ruocco 

Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano, Italy; gdiruocco@unisa.it

Abstract: The public housing stock, called social housing, in Italy was developed between the 1950s and the 1980s. As of today, the first residential developments are almost nearing their end-of-life age and are in need of urgent and intensive renovation. The European Commission, with the Renovation Wave, has set a goal of doubling the rate of building renovation over the next 10 years, reducing emissions, improving energy performance, and promoting decarbonization. Renovation interventions, including structural, functional, energy, and plant upgrading interventions, etc., are to be preferred over integral demolition and reconstruction interventions, which have significant repercussions in terms of managerial and social discomfort. The case studies examined concern renovation interventions aimed at energy efficiency, functional adaptation of housing, as well as façade restyling. The design variants analyzed were evaluated in terms of CO_{2e} emissions, according to life cycle inventory (LCI) and Environmental Product Declaration (EPD) approaches. This approach has a twofold purpose: to propose design guidelines, with low CO_{2e} emissions, through hypotheses of variants in the case studies, and to propose, to the economic operators, economically advantageous bidding scenarios in the procurement process.

Keywords: Renovation Wave; refurbishment; social housing; low-carbon design



Citation: Di Ruocco, G. Renovation Wave in Europe: Low-Carbon Design for the Refurbishment of Social Housing in Southern Italy. *Buildings* **2024**, *14*, 1535. <https://doi.org/10.3390/buildings14061535>

Academic Editor: Charalampos Baniotopoulos

Received: 28 March 2024

Revised: 9 May 2024

Accepted: 21 May 2024

Published: 25 May 2024



Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

On 14 March 2023, the European Parliament approved the revision of the European EPBD [1], which is necessary to realize the Renovation Wave, i.e., a wave of renovations of more than 35 million buildings and the creation of up to 160,000 jobs in the construction sector. The renovation of public and private buildings was identified in the European Green Deal as a key initiative to promote energy efficiency in the sector and achieve these goals. The Renovation Wave aims to at least double the annual rate of energy renovation by 2030 and, in addition to reducing emissions and creating green jobs in the construction sector, which is dominated by local businesses, to improve the overall living standards of Europeans. The Renovation Wave initiative is based on the National Long-term Building Renovation Strategy, other aspects of the Energy Performance of Buildings Directive, and the buildings aspects of each EU country's National Energy and Climate Plans (NECPs). The strategy identifies three areas of focus:

- Tackling energy poverty and worst-performing buildings;
- Redevelopment of public buildings;
- Decarbonization of heating and cooling.

With some 40 million Europeans unable to afford to adequately heat their homes in 2022, renovations will help address energy poverty. They can improve the health and well-being of vulnerable people while reducing their energy bills—as outlined in the Commission's 2020 Recommendation on Energy Poverty, which was part of the Renovation Wave initiative—and subsequently also highlighted in the Commission's Recommendation on Energy Poverty, published in October 2023.

Due to the need for the renovation of the existing building stock, this study aimed to pursue the convergence of the following objectives:

- (1) Energy–environmental sustainability: energy–environmental retrofitting of buildings, encouraging design strategies that promote the circular economy of the construction sector;
- (2) Social sustainability: renovation of the building stock through major renovations in order to improve the quality of life of occupants, with the involvement of occupants through various forms of participation;
- (3) Functional and aesthetic sustainability (restyling): opportunities to improve the architectural and urban quality of the territorial context to which the building complexes to be renovated belong.

The innovative aspect of this research is demonstrating that it is possible to design a renovation intervention with a low emission impact that simultaneously achieves energy retrofitting, building heritage renovation, and aesthetic restyling.

2. State of the Art

2.1. Energy–Environmental Sustainability

The UNFCCC's Paris Agreement at COP 21 in 2015 [2] set out to mitigate the global temperature rise to 1.5 °C relative to preindustrial levels by 2050. This requires strategies that encourage a rapid transition to renewable and fossil-fuel-free energy. Globally, the construction sector accounts for about 28 percent of total atmospheric CO_{2e} emissions [3]. Therefore, a major contribution to reducing emissions must come from renovating existing assets to improve energy performance in the operational phase through the use of better-performing energy production systems (for heating, cooling, and domestic hot water production) with reduced emissions [4,5].

Renewable energy plays a key role in addressing the challenges of fossil fuel depletion and climate change and has gained an increasing share in the energy mix worldwide. For example, about 30 percent of electricity generation in the UK between April and June 2017 came from renewable sources [6]. The EU is one of the pioneers in promoting decarbonization and the use of renewable energy, as reflected in its target of a 20 percent reduction in greenhouse gas emissions, a 20 percent increase in the use of renewable energy, and a 20 percent increase in energy efficiency by 2020 compared to 1990 levels [7].

Policies to decarbonize and increase renewable energy production in the building sector encourage the deployment of sustainable buildings or buildings with net-zero energy status (NZEB) [8].

Flores [9] aimed to develop a value-based framework that will support a building stock model and subsequent retrofit models, documented in a web-tool platform. The framework involves three main steps: (a) mapping of buildings in a GIS system, documenting baseline energy consumption and the embodied CO_{2e} of the existing building; (b) full life-cycle assessment (WLCA) and non-energy benefits (resilience coefficient, health, productivity); and (c) assessment of the environmental impact of the existing building stock and design of solutions to reduce consumption.

The study by Balaras and Dascalaki [10] summarizes the main EU instruments, regulations, and directives related to the built environment that have been introduced, are in place, and are being planned to achieve short- and medium-term energy and environmental goals. Their overview also provides relevant data and quantifies key performance indicators that reflect past trends and current emissions, renewable energy use and energy efficiency, energy use intensities, along with short- and long-term EU targets that are mainly related to the building sector. The pace of restructuring needs to accelerate, and restructuring should be deeper [3].

Central and local governments around the world are translating carbon reduction targets into policies and action plans for modernizing the existing building stock. As a policy, in September 2023, the European Commission unveiled Directive 2023/1791 [1], which provides a common framework of measures to promote energy efficiency in the

Union to ensure that targets for energy efficiency improvements are met. This common framework is intended to contribute to the implementation of Regulation (EU) 2021/1119 of the European Parliament and of the Council and to the Union's security of energy supply by reducing its dependence on energy imports, including fossil fuels. The requirements of Directive (EU) 2023/1791 are minimum requirements and do not prevent individual member states from maintaining or introducing more stringent measures. Such measures must be in accordance with EU law. Where national legislation provides for more stringent measures, member states shall notify the Commission.

The plan describes ambitious goals and the enormous challenges and barriers to be overcome for Europe's building stock. It makes it clear that research and innovation will be needed to overcome these barriers [11].

2.2. Social Sustainability

At the same time, there is a need to modernize a large part of the residential housing stock in order to improve the quality of life and well-being of the occupants (social sustainability). This process is, moreover, necessary to trigger a productive and dynamic construction process in order to ensure affordable housing. The wave of renovation has generated an increase in research on sustainable building renovation (SBR) [12,13].

Scientific studies have highlighted the main barriers to sustainable building renovation, which can be divided into economic and informational aspects. Among the economic barriers is the landlord/tenant dilemma [14]. Building renovation is mainly initiated because maintenance backlogs accumulate to the point of extreme deterioration and the obsolescence of building components. Therefore, to promote sustainable renovation, including energy improvements, financial incentives are important factors, but it is also important to take into account the different interests of various stakeholders. It is necessary to develop new tools to increase the volume of SBR and methods to evaluate these tools.

So far, most research has focused on deep building renovation: deep energy renovation defines a renovation that captures the full economic energy-efficiency potential of improvements, with a main focus on the building envelope, which enables very high energy performance (global building performance) [15].

One of the main arguments in favor of deep renovations is that they are a necessity to achieve radical improvements in energy efficiency. However, a recent study in Sweden noted a tendency for building associations to move toward implementing partial renovation strategies or over time [16]. There is a need for research on the diversity of current and potential new strategies for SBR, including renovation over time [17], whether of individual building projects, building portfolios, or neighborhoods.

The renovation process has been studied in several research articles, but mostly in terms of case studies and dominated by preconceptions of rational decision making and the development of normative guidelines. There are only a few examples of broader cross-sectional studies investigating specific aspects of restructuring processes among a larger sample of projects, companies, professionals, and/or countries. One example is the study by Gluch et al. [18]. More in-depth descriptive and cross-sectional studies of SBR processes are needed to achieve a deeper understanding of different renovation subprocesses, e.g., data collection on buildings prior to renovation, the actual use of tools in different renovation subprocesses, and the characteristics of processes for different types of buildings and organizations.

There has been intensive research and development of tools and systems to support the decision making, design, and evaluation of SBR projects [19–21], but only a few with a focus on project portfolios [22–24]. In addition, methods for assessing social sustainability are underdeveloped, as is the consideration of architectural and historical values [25], and there is a lack of integration in the assessment of different sustainability indicators. Only a few attempts to integrate different values can be found [26]. Therefore, there is a need to develop more holistic methods for prioritizing and assessing the sustainability of building renovation.

Although there has been a greater technological emphasis in previous studies on SBR, there is a growing interest in considering the perspectives of building users [27–29]. This more social perspective is critical as more research is needed that can support the push from the demand side, including building owners, facility managers, and end users, to reveal and guide unmet needs and discover new opportunities.

The increased political attention to SBR makes it important to investigate and demonstrate the contribution SBR can make in relation to solving major societal challenges, for example, in relation to the UN Sustainable Development Goals, climate change, energy transition, circularity, industrialization, digital transformation, affordable housing provision and equality, heritage conservation, social value, and quality of life.

2.3. Functional and Aesthetic Sustainability

Intervening on an existing building is a necessity dictated by several urgencies that generally start from simple and individual reasons, described as follows by Alberto Alessi: “One builds on the built environment simply because it is economically advantageous to exploit the work already done by others; or because it is impossible to obtain sufficient permits or building indices to carry out new construction in coveted areas such as those where ‘historic’ buildings are often found” [30]. Intervening in the existing built environment can become an opportunity to improve building performance, enhance the overall functionality of the building, and, if, with reference to social housing, new patterns of contemporary living and new user profiles can be taken as data for redesign. In many European cities, this strategy has already begun several decades ago through densification (vs. sprawl) operations, aimed at volumetric redesign, at the same time as the redevelopment of the existing building, especially in terms of energy [31].

The same principles were reiterated by Reale [32]: “[...] densification policies are proposed as credible practices to achieve sustainability goals, such as the reduction of energy consumption climate-changing gas emissions, considering that more than half of the world’s population resides in cities and large metropolitan areas [...]”. Sprawl strategies have been extensively documented in the recent experiences of Bijlmermeer in Amsterdam, Technopark in Zurich, and Karl Marx Allee in Berlin. These experiences are not limited to the definition of simple interventions preordained to increase urban density tout court but are intended to direct growth based on transformations aimed at raising the level of quality of the built environment through the integration of new performance (energy, structural, plant engineering, etc.), as well as with the introduction of appropriate functional mixes and the provision of adequate levels of ecological and environmental endowments” (Ferrante et al., 2012) [33].

Spanish’s study [34] also aligns with this direction: “[...] if our age slows down the growth and expansion of cities, the theme of critical rethinking on the ‘already done’ acquires a decisive ethical and cultural value since it modifies the very idea of progress. This notion can no longer be automatically linked to the idea of development and growth, as Pasolini had already specified in a premonitory essay [...], but rather to that of a deeper sense of civility and responsibility. Operating on the existing status quo is an ever-present action in the history of cities and means respecting the identity of places and acting on successive stratifications, as has always been the case in the history of European cities [35].

From the analysis of the literature, the redevelopment strategies that predominantly emerge are as follows:

- Building replacement, a radical intervention involving the demolition of the existing built-up area and new construction; it is the extreme rationale, to be applied when there are no physical and social prerequisites and requirements such that an artifact can be reused over time.

This option is often considered suitable for suburbs [36] where, for some, it seems that the “principle of erasure and rapid replacement should prevail rather than that of durability, that is, of the city building on itself over time, on its morphological footprints and traces” ([37], p. 86). Building replacement poses the problem of the disposal of those

indeconstructible structures that produce waste, as well as the erasure of the intangible heritage of architectural design experience, often never completed, and the identity heritage formed over time.

- Construction on the built, an operation that involves layering and overlaying on the existing built. Some of Herzog&de Meuron's projects, including the aforementioned Hamburg Philharmonic, are indicative. In general, an awareness of the work is maturing that brings the theme of building on the built back to the center of architectural and urban design practice, which is accompanied by extended critical attention to the notion of heritage and the common good ([37], p. 88).
- Transformation, more or less profound. This is an operation that produces results of different intensities in which volumetric addition and subtraction play a key role, practiced according to different criteria, intensities, and dimensions (Figures 1 and 2). The current condition of the urban building stock, especially in Europe, at a time of impending economic crisis has made transformation one of the few feasible programs through which we attempt to combat the waste that played a decisive role in triggering the crisis, the waste of energy, time, and resources of all kinds due to the unnecessary movement of men and goods [...]. Architecture is continually transformed by those who design and build it, but it is also true that, considering it as an expression of the society and culture of a given time, it resembles something like a living organism that undergoes continual metamorphoses [38]. There are interventions that contemplate refunctionalization, understood as an intervention aimed at giving a new destination compatible with the context. In Vienna, the "Gasometers", decommissioned in 1984, were declared a national monument. They were used in various ways and by various entities for ten years until, in 1995, the government decided to hold an international design competition to restore the four monuments. Jean Nouvel (creator of the creation of a covered plaza with a translucent roof that, through a play of refractions, synthesizes the old–new pair), Coop Himmelbau (creator of the addition of three volumes to the existing façade), and Manfred Wedhorn, who adopted the "greener" approach, adding terraces and interior gardens, were, respectively, chosen for Gasometers A, B, and C. In contrast, the design of Gasometer D was entrusted to Wilhelm Holzbauer [39]. The other cases represent interventions in the transformation of buildings and contexts that originally arose with residential use, which, over the course of redevelopment, maintained the same purpose.



Figure 1. Transformation (additions, selective demolitions), Montpellier, redevelopment of social residential building.



Figure 2. Transformation (selective demolition), Leinfelde residential building (source <https://www.sfa.de/en/projekte/haus-06/> (accessed on 27 March 2024)).

3. Tools and Methods

The life cycle assessment (LCA) methodology is a popular and shared tool for evaluating the most sustainable design choices. To mitigate environmental impacts, it is necessary to focus on a comprehensive view of the building organism based on its entire life cycle, with reference to the reduction in the embodied energy in building materials. The latter (embodied energy (EE)) is considered the energy needed at all stages of life, from cradle to grave; embodied energy is 40 percent of the total energy of a building with a lifespan of 50 years. Manufacturers in the construction industry are also required to have environmental certifications of construction products (EN ISO14025) [40], implementing the product with life cycle inventory data, i.e., carbon footprint. The study, as a whole, focuses on identifying design choices (morphological, spatial, technological, materials) with lower environmental impact.

The goal of research is to reduce CO_{2e} emissions by at least 55% compared to a baseline scenario. For methodological development, the tools used reference BS EN 15978:2011—Sustainability of construction works—Assessment of environmental performance of buildings—Calculation method [41]—Figure 3. With reference to Figure 1, the modules under study were A1, A2, A3 (production phases); C1, C2, C3, C4 (end-of-life phases); D (post-end-of-life benefits). Modules A4–A4 and B were excluded from the survey voluntarily, as they were considered modules less susceptible to variation between different restructuring scenarios.

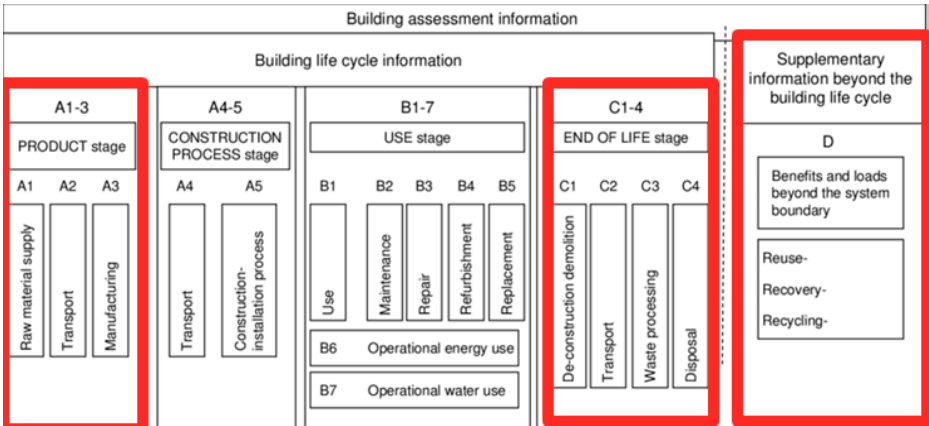


Figure 3. BS EN 15978:2011—Sustainability of construction works—Assessment of environmental performance of buildings—Calculation method [41]. The outline in red highlights the areas under investigation.

- Module ‘A’ is inherent in the choice of materials; the database used for this phase (from cradle to gate) is the University of Bath’s Inventory Carbon&Energy (ICE) [42]. In the case of composite products, reference was made to the Environmental Product Declaration (EPD) inventory.
- Module ‘C’ includes the deconstruction of the building and the transportation of materials to disposal or recovery/recycling sites. Emissions reported in the data sheets of demolition equipment and their time of use were used to calculate the EC.
- Module ‘D’ includes the impacts/benefits associated with demolition, transportation, and waste disposal/treatment. Potential positive impacts however can be obtained from reuse and recycling after end of life.

3.1. Concept Design

Technological retrofit interventions generally take place through four main actions on the existing building: replacement, integration, addition, and subtraction (Figure 4):

- Replacement involves the replacement of functional elements or parts with others of superior performance or new performance not guaranteed by the original elements;
- Integration concerns the addition of building elements to existing parts such as sub-systems or building components, which are parts that are not removed but remain in situ and are, possibly, subject to maintenance and restoration, with the purpose of increasing existing performance or adding new performance;
- Addition concerns the action aimed at adding technical elements, parts of buildings or entire volumes to the building, as an extension of the original building (Figure 5);
- Final subtraction concerns the action aimed at eliminating technical elements, factory parts, or entire volumes in order to achieve new or higher performance due to the new configuration of the building.

	homogeneous	heterogeneous	homogeneous	heterogeneous	homogeneous	heterogeneous
	accretion		budding		saturation	
on the roof						
to the envelope						
at roof/envelope						
in facade (closure and addition of technical surfaces)						
on the ground floor/basement						

Figure 4. Classification of interventions (by accretion, budding, and saturation) for façade, roof, and footing (source: Luisa Califano, 2011) [43].



Figure 5. Addition models (source: Sara Parlato 2014) [44].

3.2. Construction Scenarios

For the purpose of EC calculation, the building was decomposed into the main technological units: structure, intermediate floor and roof. The construction phase, referred to in both design solutions (1–2), consists of 4 possible scenarios: Scenario C1 (starting situation—baseline); Scenario C2 (adoption of secondary raw materials); Scenario C3 (alternative technological solutions); Scenario C4 (reduction attributable to chemical properties of the material and technological solutions adopted). Scenario C1 (starting situation—baseline): In this phase, there is an analysis of the entire project, starting from its characteristics and critical issues. EC factors related to the use of virgin materials are evaluated. Scenario C2 (adoption of secondary raw materials): Secondary raw materials are adopted, where possible, consisting of scrap from the processing of raw materials, or materials derived from waste recovery and recycling. Such recycled products have a significantly lower EC factor than virgin raw materials. Scenario C3 (alternative technological solutions): A further reduction in EC factors is achievable through the use of “dry” technologies compared to traditional “wet” methodologies. Scenario C4 (reduction in the amount of EC through the use of negative-impact materials): Due to their physicochemical properties, wood products and derivatives are likened to true carbon incubators (carbon capture storage); LCI databases attribute negative EC factors to them.

3.3. Demolition Scenarios

For design solution #2, invasive demolition works are envisaged. The possible demolition scenarios (dependent on the final destination of the waste materials), are reuse, recycling, landfill disposal.

3.3.1. Scenario D1—Reuse

Italian (minimum environmental criteria) and EU (LEED, LEVELs, etc.) regulations require that, in renovation, maintenance, and demolition operations, at least 70% by weight of the nonhazardous waste generated during the demolition and removal of buildings must be sent to operations of preparation for reuse, recovery, or recycling. Thus, 30 percent refers to the amount of CO_{2e} inherent in materials destined for landfill, while for the remainder, 70 percent, where possible, “as-is” reuse takes place (possibly on the construction site itself), also omitting transportation.

3.3.2. Scenario D2—Recycling

Recycling of building materials is a more sustainable alternative to landfilling. Compared to the reuse scenario, the recycling of materials, although it diverts them from the landfill, nevertheless involves processing that requires energy resources relative to the treatment and processing of decommissioned materials. The prevailing materials, reinforced concrete and bricks, do not have a purpose at the end of their lives in reuse, predominantly envisaging recovery in the form of recycling or disposal. The model related to the calculation of CO_{2e} emissions for materials destined for recycling involves the following parameters: weight of material, type of treatment, type of machinery, hourly power of machinery, hourly amount of treatment, total hours of treatment, total energy required, incorporated carbon efficiency (EC), and total value of incorporated carbon.

The emission factor varies according to the power supply of the machinery used for demolition; CO_{2e} is then calculated for transporting the waste to the appropriate treatment sites considering the destinations closest to the site: these are calculated based on the assumed number of trips (according to the maximum volume that can be transported by the vehicle), the kilometers traveled (distance of the site to the recovery site), and the average emission factor of the vehicles.

3.3.3. Scenario D3—Disposal

For the management of construction materials produced by the various activities carried out at the construction site, the Italian Ministerial Decree No. 186/2006, concerning the management of nonhazardous waste, must be taken as a regulatory reference. For all materials resulting from demolition, a list of them is made with their weight in kilograms. The EC coefficient corresponds to the production phase (from cradle to gate), related to modules A1, A2, and A3, assuming, as the most negative scenario (baseline), total disposal in landfills. A rate related to transport is then added, i.e., the kilograms of CO_{2e} generated on the way from the construction site to the appropriate landfill. Based on the maximum volume that can be transported by the vehicle, the emissions due to transport are calculated, taking into account the number of trips, kilometers traveled (yard landfill distance), and average emission of heavy vehicles (668 g/km) (Figure 6).

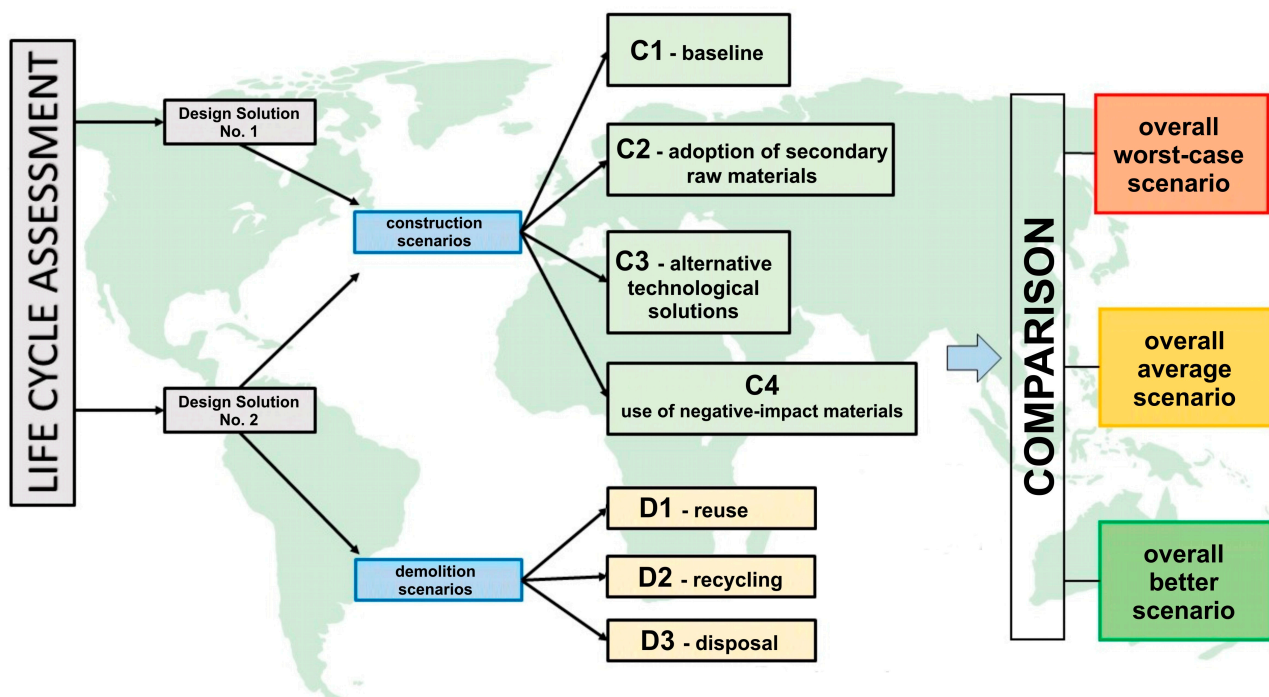


Figure 6. Methodological framework.

3.4. Methodological Approach

The output target is to exceed the 55% threshold (in terms of CO_{2e} emission reduction) compared to a baseline scenario. The two project assumptions (of which the second one also includes a demolition phase) are analyzed separately, so that the worst scenarios (C1 + D3), the intermediate scenarios that do not allow the European threshold to be exceeded, and finally the best scenarios (C4 + D1) that should allow as an expected result the pursuit of the set objectives.

Depending on the various scenarios, project, or demolition, the various contributions of embodied CO_{2e} are taken into account: materials; machinery and equipment; transportation; treated materials, with recycling/recovery process. The methodological equation is

$$\sum CO2e_{total} = \sum CO2e_{embodied} + \sum CO2e_{machines} + \sum CO2e_{transport} + \sum CO2e_{recovery \text{ and } recycling}$$

The comparison is calculated using the following equation:

$$\sum CO2e_{project \ 1} \leq \sum CO2e_{project \ 2} \leq \dots \sum CO2e_{project \ n}$$

Figure 7 shows the calculation methodologies referring to the different scenarios analyzed.

SCENARIOS C1-C2-C3-C4				CONSTRUCTION					
class of technology unit under analysis	no.	length	volume	area	density	unit weight	weight per linear meter	weight per unit area	total weight
	[adim.]	[m]	[m³]	[m²]	[kg/m³]	[kg]	[kg/m]	[kg/m²]	[kg]
elevation structure									
.....									
intermediate floor									
.....									
roofing slab									
.....									
envelope									
.....									
SCENARIO D1									
DEMOLITION (reuse)									
technical element	embodied carbon								
	disposal rate incidence (30%)			reuse rate incidence (70%)			TOTAL		
	[kgCO _{2e}]			[kgCO _{2e}]			[kgCO _{2e}]		
.....									
.....									
.....									
SCENARIO D2									
DEMOLITION (recycling)									
technical element	70% incidence of total weight	treatment	machinery used	hourly power	quantity processed in 1 hour	total hours of treatment	energy used	CO2e emission factor	embodied carbon
	[kg]	[kgCO _{2e} /kg]	[kgCO _{2e} /kg]	[kW/h]	[kg/h]	[h]	[kWh]	[kgCO _{2e} /kWh]	[kgCO _{2e}]
.....									
.....									
.....									
SCENARIO D3									
DEMOLITION (disposal)									
technical element	70% incidence of total weight		no. truck trips		kilometers traveled	average emission factor for heavy-duty vehicles		carbon emissions for transportation	
	[kg]		[adim.]		[km]	[kgCO _{2e} /km]		[kgCO _{2e}]	
.....									
.....									
.....									

Figure 7. Carbon emission calculation methodologies referring to different scenarios.

4. Case Study: Refurbishment and Restyling of a Social Housing Complex in Southern Italy

4.1. Description of the Case Study

The output goal WAS to exceed the 55% threshold (in terms of CO_{2e} emission reduction) compared to a baseline scenario. The methodology (Figures 6 and 7) was applied to the two design ideas, energy efficiency as well as functional adaptation and façade restyling, inherent in an ideal renovation project to the “Le Minime” project in Battipaglia (near Salerno, southern Italy), a typical example of 1940s social housing (Figures 8 and 9). Battipaglia is a neighborhood that initially arose in the suburbs and was later incorporated by the growth of the city. The planimetric layout, with a regular shape, responds to the logic of postwar housing based on rigid subdivision. Today, this housing complex is in a situation of total abandonment and in a general state of decay.



Figure 8. Photos of the current state.



Figure 9. Current view of the residential complex.

4.2. Design Hypotheses

Two design hypotheses were developed for the purpose of this research: one less invasive (scenario 1) and another more invasive (scenario 2). The first design solution did not involve demolition of the existing volume but only additions to achieve functional adaptation of the dwellings. The second scenario, on the other hand, involved demolition works through subtraction-added operations.

The choice of these scenarios deliberately excluded possible further scenarios such as simple maintenance, conservative restoration, total demolition, and reconstruction.

The building taken as a reference for the design simulation has two levels, each of which houses 3 apartments of about 50 m². Multiple destinations and interventions are possible, as the neighborhood needs a good intervention to recover the built-up area, as well as a recovery of sociality and its diversification. One of the design constraints was leaving unchanged the gallery typology, a typological feature that connotes the housing complex today. Interstory heights are also maintained, and super elevation is planned in

both scenarios. Demolitions are planned for the entirety of the interior infill wall faces, as well as partially on the envelope. Both interventions have similar characteristics, such as the use of steel for the integrated parts due to the flexibility, lightness, and strength of the material.

4.3. Design Solution No. 1: Construction

The first design idea (Figures 10–12) is based on the conservation approach, in which the basic idea of the adopted methodology is encapsulated. Importance is given to the settlement context, the gallery type, preserving it, and intervening minimally with the envelope. The use will remain predominantly residential, where, however, space will be given to some commercial establishments to diversify and intensify the categories of new users, providing new services to citizens. The current layout is maintained and an extension toward Renaissance Square of 1.5 m is planned, as well as a 3 m elevation for the entire building body, in order to meet the vital need for larger spaces and at the same time be able to allow a diversification of the same. The additional space is essential and useful for everyday life.

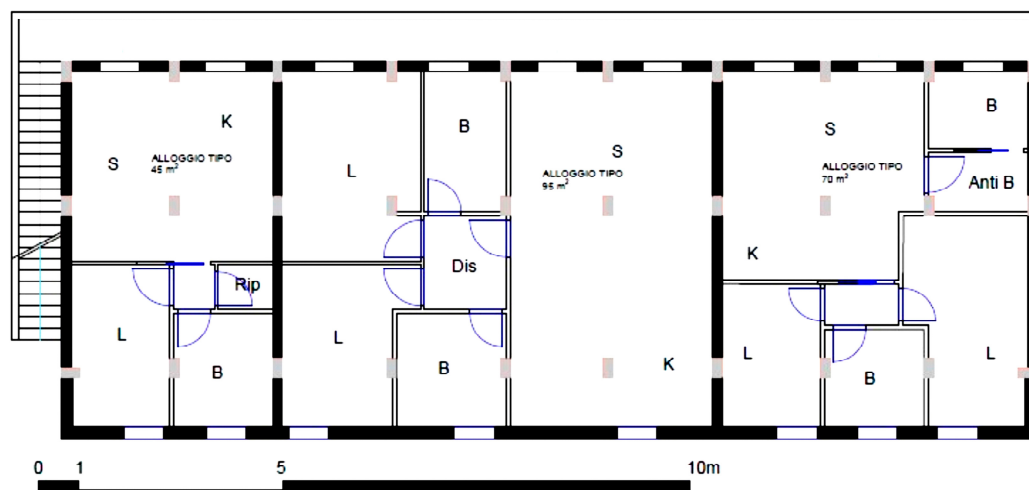


Figure 10. Design solution No. 1: type-plan.

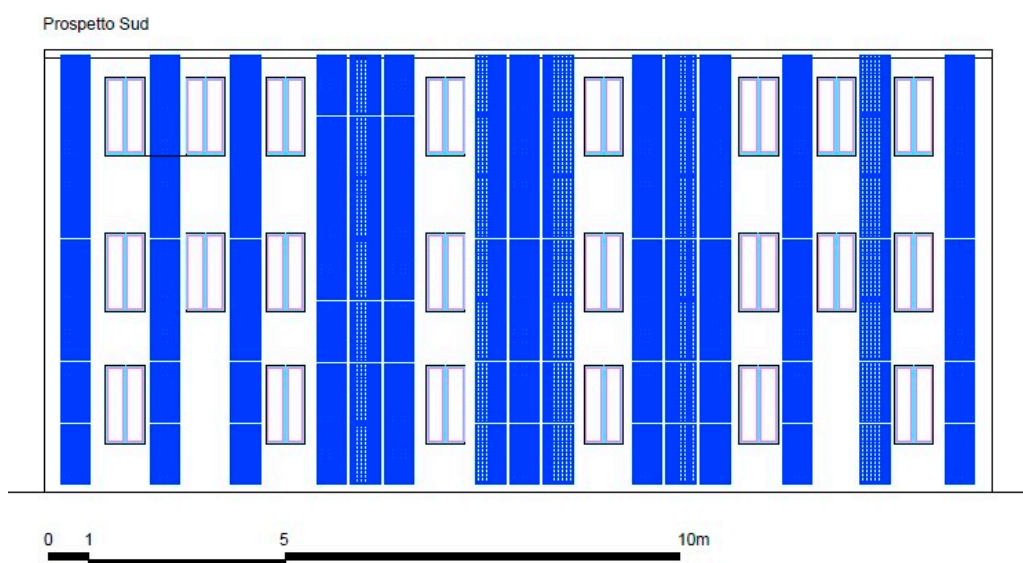


Figure 11. Design solution No. 1: front elevation.

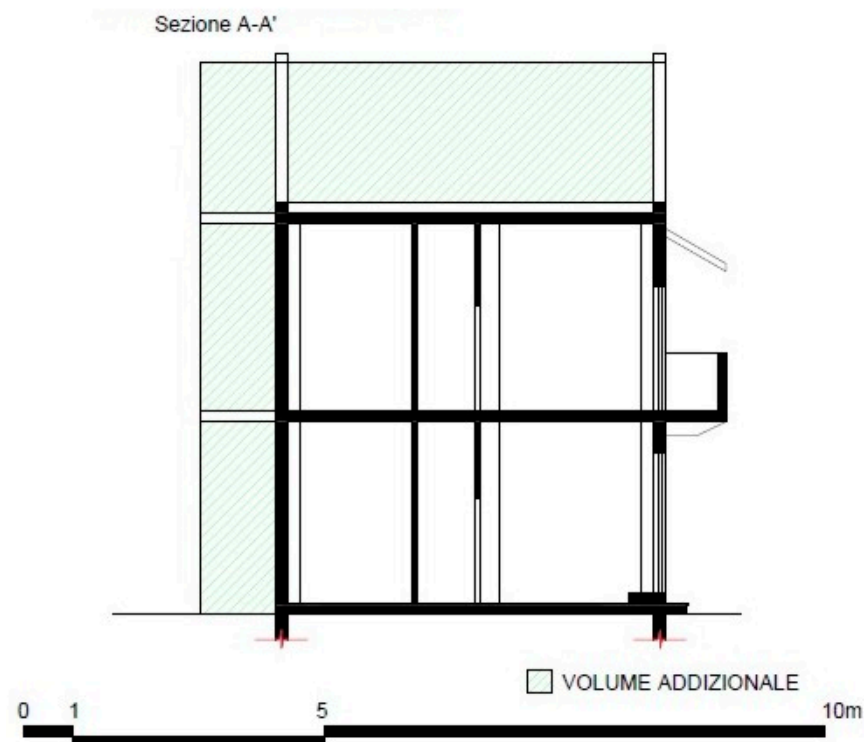


Figure 12. Design solution No. 1: transversal section.

The design solution 1 includes the addition mode of extension on the roof and façade.

- The addition structure on the south front is steel, consisting of HEB180 columns, edge beams with IPE330 profiles, interior beams with IPE220 profiles, and IPE120 secondary beams. IPE 330 profiles were retained for the central part.
- The external envelope, which forms the façade on the additional body, consists of photovoltaic panels on the elevation, alternating with appropriate openings. A 15 cm-thick rock wool insulation layer is provided, incorporated within HEB180 load-bearing metal profile, a 10 cm air gap with modular breaks of 100×50 mm steel box profiles such that a 12.5 cm thick fiber cement slab can be attached, followed by an exterior finishing layer. To the latter are doweled 50×50 mm supports for fixing the photovoltaic panels on the façade.
- The intermediate slab has a steel structure, as well as IPE 330 and IPE 220 profiles; secondary IPE220 profiles are structured, proceeding towards each other in the slab stratigraphy by 1.5 mm thick corrugated metal sheet, structural screed with 12.5 cm electro-welded mesh, a 10 cm rock wool insulation layer, a 5 cm bedding screed, and 1.5 cm terracotta flooring. At the soffit, a lightweight metal structure is used for a gypsum-fiber paneled ceiling.
- The roofing has dry stratigraphy, a steel structure, IPE330 and IPE220 profiles, and IPE220 secondary profiles, on which 1.5 mm corrugated metal sheet rests, followed by screed with 12.5 cm electro-welded mesh, a 0.5 mm PVC waterproofing sheet, a 16 cm rock wool layer, an EPS layer, and finally a 3 mm waterproofing sheathing. As a finish on the soffit, there is a light metal structure for a false ceiling in gypsum-fiber paneling (Figure 13).

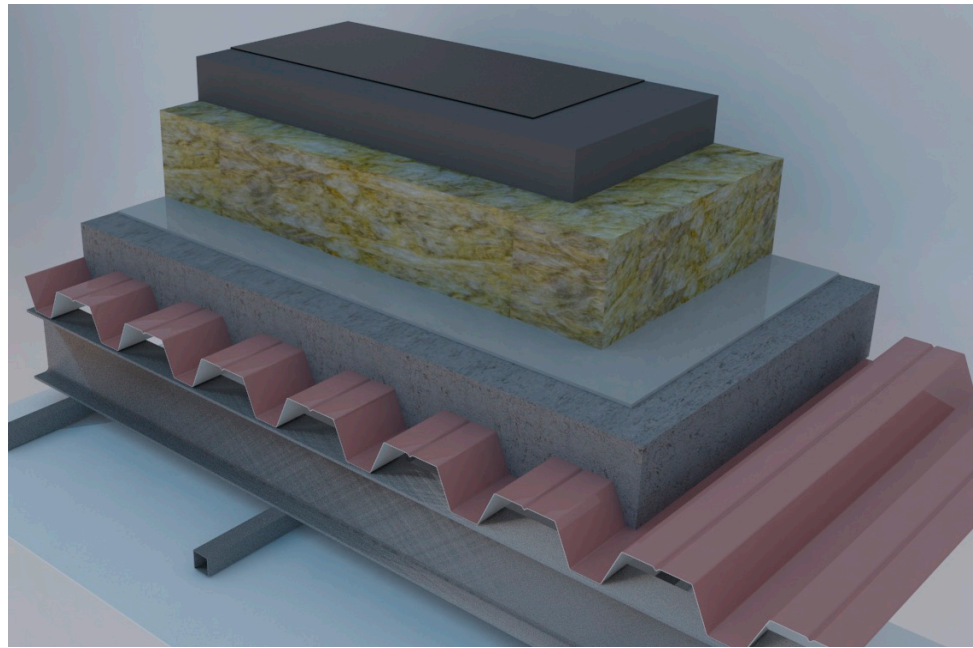


Figure 13. Technological stratification of the roof slab.

4.4. Design Solution No. 2: Demolition + Construction

Design Solution No. 2 (Figures 14–16) involves an invasive approach with major demolition in order to also achieve a restyling result for the complex. This solution, like the first one, also envisages a 1.5 m extension towards Renaissance Square, but, in this scenario, the addition is not uniform but variously displaced along the original building body. In this scenario a 3 m elevation is also planned for some parts of the building body in order to meet the need for larger spaces and at the same time allow their diversification. The emptying of the ground floor allows an urban integration of the complex, creating a connection between Risorgimento Square and Garibaldi Street. At the elevation of Via Garibaldi, half of the entire ground floor is emptied to give the building a pedestrian portico, serving the businesses present on the ground floor. All this promotes places of aggregation and a social diversification for the entire neighborhood. The demolition part, moreover, affects all the interior infill, so that new larger residential spaces can be created that also allow for diversification of the resident population. The exterior envelope is demolished at the 1.5 m exterior extensions, so that the interior spaces can be expanded and made more livable. The building body consists of a ground floor and a second floor. On the ground floor, in this scenario, a large part of the ground floor is planned to be cleared so as to generate a connection with the adjacent square. The additional body, with a steel structure, is not continuous on the façade but follows an alternation of solids and voids, leaving part of the existing envelope in evidence. The façade is integrated with photovoltaic panels (BIPVs). The technological construction features for solution No. 2 are the same as those described for solution No. 1.

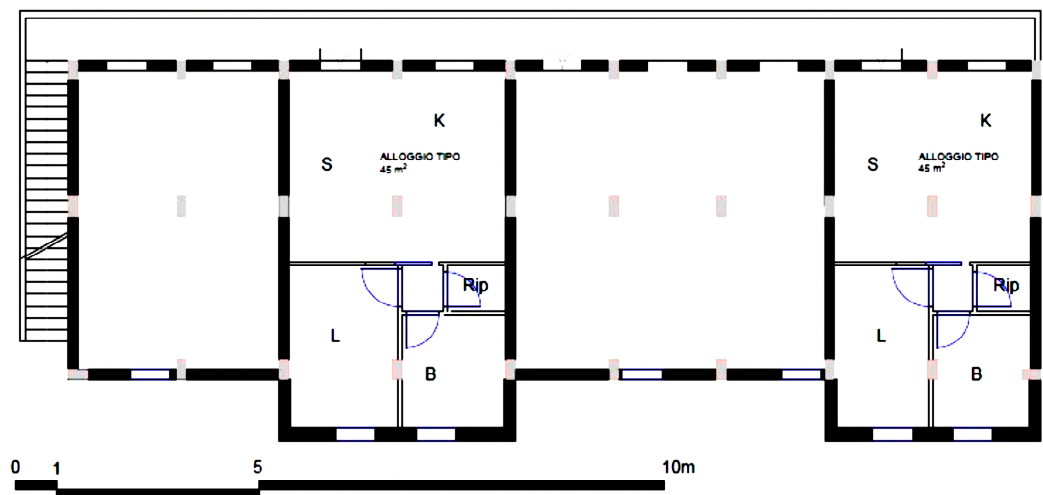


Figure 14. Design solution No. 2: type-plan.

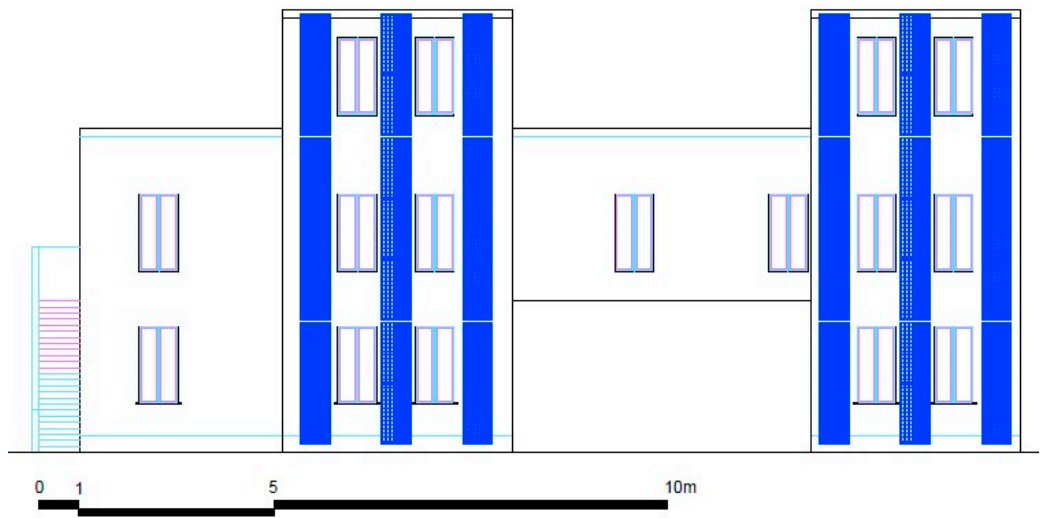


Figure 15. Design solution No. 2: front elevation.

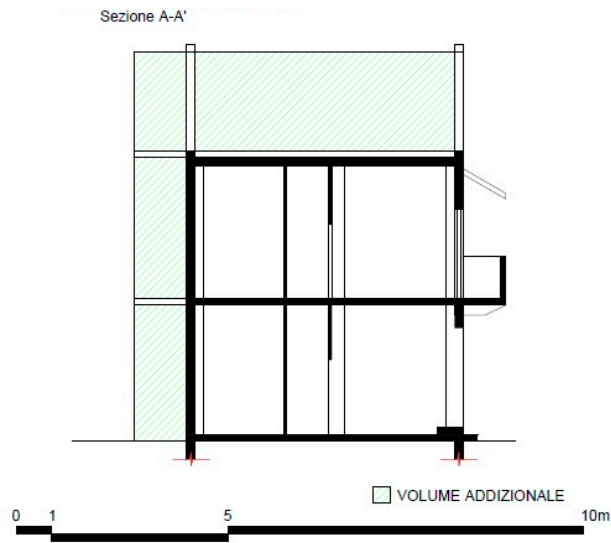


Figure 16. Design solution No. 2: transversal section.

5. Application to Case Study

5.1. Design Solution No. 1

An inventory of materials was made for the considered building body, and the weight in kilograms was calculated for each material.

5.1.1. Scenario C1—Starting Situation (Baseline)

This scenario was translated in terms of the amount of embodied carbon by associating the “coefficient of embodied carbon primary” contained in the “ICE database” with each material.

5.1.2. Scenario C2—Adoption of Secondary Raw Materials

In this scenario, the materials in the project were also associated with the coefficient of embodied carbon; however, the coefficient to be considered in the database was the “coefficient of embodied carbon secondary”. The inventory specifies that during recycling, many facilities have different recycling rates and processes, which is precisely why in the latest version of the database, “V3.0”, of these coefficients was abolished, and only those where the recycling process was almost unchanged were kept. For this reason, the coefficient was applied only to certain materials, namely, steel. For steel beams, a recycling rate of 98 percent was considered, while for corrugated sheets, concrete casting must be taken into account and thus a recycling rate of 70 percent.

5.1.3. Scenario C3—Alternative Technological Solutions

The technological interventions carried out are

- Replacement of insulation material with one with low- CO_{2e} emissions; rock wool is replaced with wood fiber panel.
- Replacement of interfloor construction technology; the present stratigraphy (floor with a “wet” system) is replaced with “dry” technology (Figure 17).

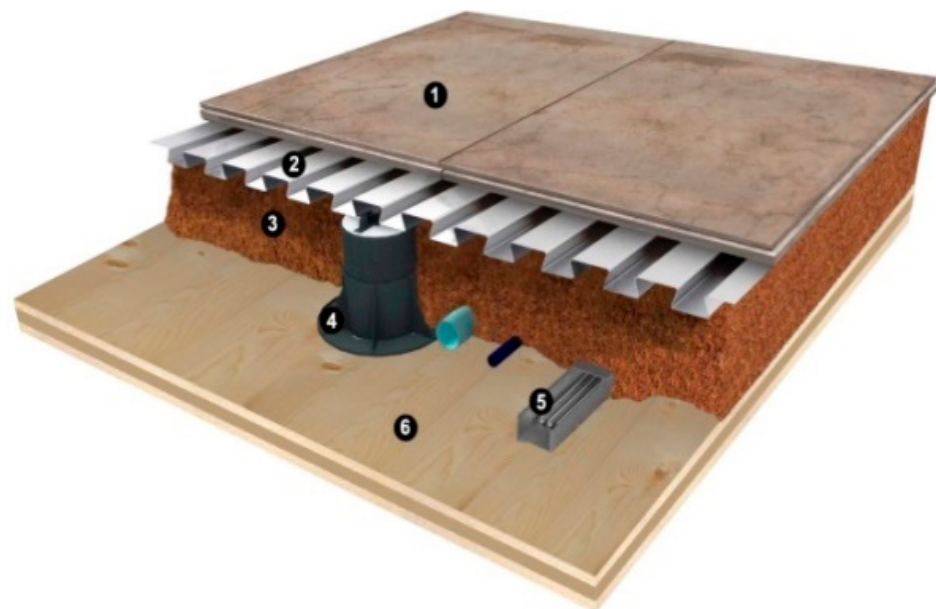


Figure 17. Interfloor slab solution. From top to bottom: (1) 18 mm wood–cement panel, (2) 0.8 mm trapezoidal sheet metal, (3) cork granules, (4) plastic support, (5) implants, (6) 120 mm X-Lam panel.

5.2. Design Solution No. 2

5.2.1. Demolition

The second, more invasive project involves demolition with partial emptying of the ground floor and demolition of part of the south-side façade. A list of the materials to be

demolished was made, and their weight in kilograms was calculated before proceeding to quantify the CO_{2e} in the various scenarios.

5.2.2. Scenario D1—Reuse

The reuse scenario involves using the building elements as-is by providing for hydro pulping, which is a high-pressure jet that removes impurities. It is assumed that, where possible, materials are reused on-site. Bricks can be reused for paving. Therefore, emissions from transportation are zero. The walls are assumed to be demolished with a grapple excavator, and debris handling is performed with a crawler excavator with bucket.

5.2.3. Scenario D2—Recycling

The items I considered are all recyclable so they need treatment according to their future use. The treatment needed is crushing and screening; by doing so, the plaster can be used for subgrade screeds and fills. The bricks can be repurposed as a second raw material or as subgrade. The mortar can be reused for fills. The destination plant was considered to be at a distance of 4.5 km from the construction site and had the ability to recycle/recover inorganic substances.

5.2.4. Scenario D3—Disposal

In this scenario, the weight of individual building elements and materials is associated with the internal carbon coefficient selected from the “inventory of carbon and energy”. The following images represent the view of the complex in its current state (Figure 18); the 3D virtual representation of the first design solution (Figure 19); and the 3D virtual representation of the second design solution (Figure 20).



Figure 18. Actual photo of the building under study.



Figure 19. View of design solution no. 1.



Figure 20. View of design solution no. 2.

6. Results and Discussion

6.1. Results of Design Solution No. 1

Figure 21 shows the results of the methodology applied to design solution #1, where we only have the design phase. Scenario C2 is the one with the very first carbon reduction due to the use of recycled materials. These solutions have lower embodied carbon because, mainly, the carbon rate due to raw material sourcing is lost (LCA module A1). In scenario C3, further emission reduction is still sought, so alternative technological solutions are considered, preferring “dry” technologies (X-lam panels, cork, and concrete–wood), rather than “wet” (rock wool, concrete, trapezoidal sheet metal) materials. Vegetable fiber materials allow for significant CO_{2e} reduction; however, given the presence of steel structures, which significantly affect the final result, it is still not satisfactory for achieving the European target. In scenario C4, aspects intrinsically related to plant materials are considered, in particular, their carbon storage property.

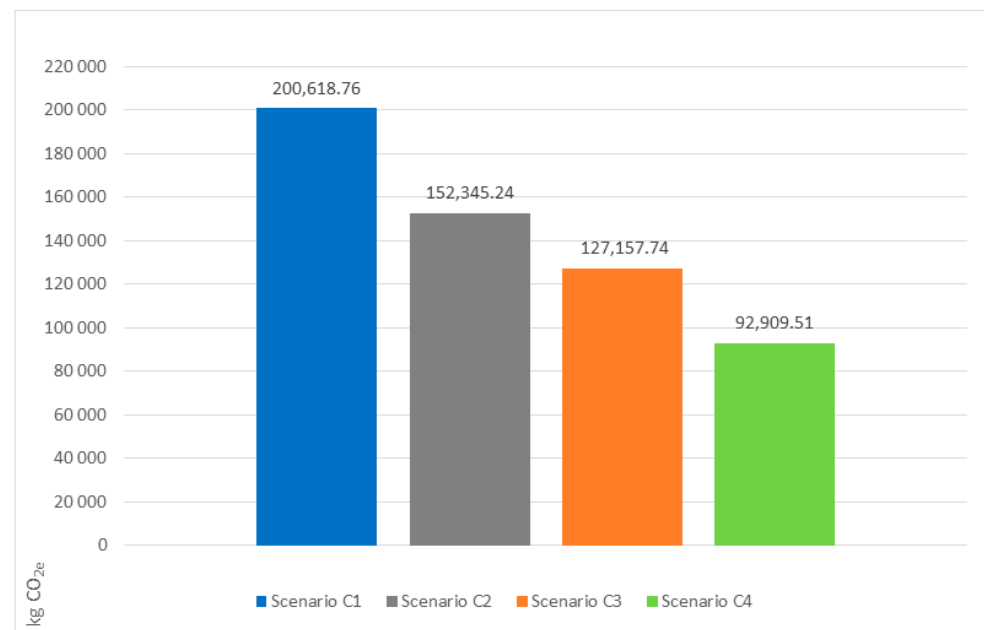


Figure 21. Embodied carbon factor for design solution No. 1.

This allows us to obtain negative embedded carbon coefficients since, by using such materials, we are removing carbon from the environment. This allows us to achieve further significant carbon reductions, approaching 70 percent in the present case. Of course, this is also closely related to the volume of material used, which allows the parameter to grow as volumes increase. The following graph highlights the difference expressed in kg CO_{2e} between the various design scenarios. Figure 20 highlights the percentage reduction in carbon emissions incorporated in the different project phases, with a target of −55%. The graph in Figure 22 shows the ideal scenario that exceeds the initial target: scenario C4 achieves a reduction in CO_{2e} emissions of 67.52% compared to the baseline scenario.

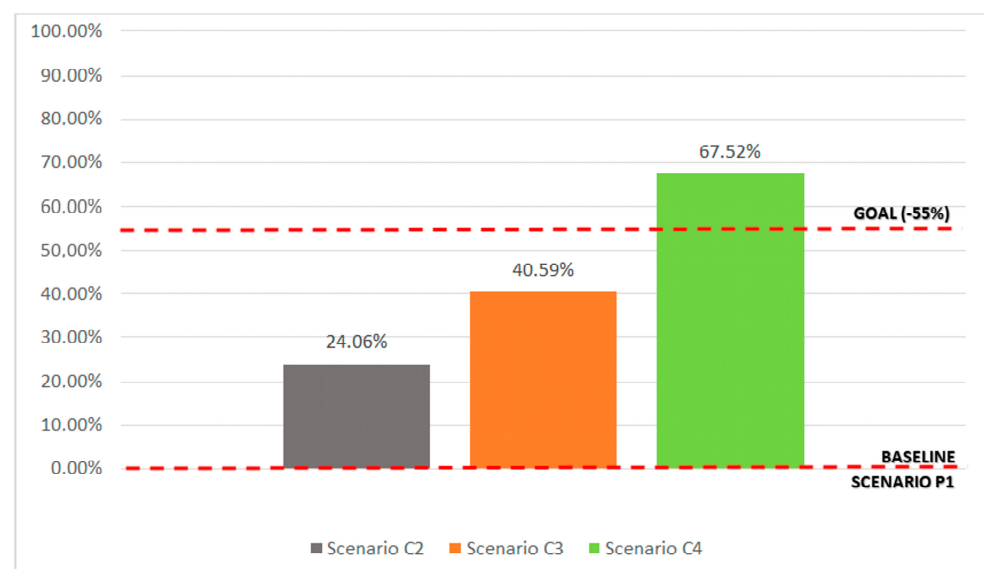


Figure 22. Incidence of CO_{2e} emission reduction (design solution No. 1).

6.2. Results of Design Solution No. 2

Analyzing the results related to design solution No. 2 (Figure 23) it can be seen that the emissions range from 102,807 kg CO_{2e} for the C1 (baseline) scenario to 43,141 kg CO_{2e} for the C4 scenario. Again, analyzing the different scenarios, for scenario C2, the

percentage reduction is below 55%. The same is repeated for scenarios C3 and C4, where the replacement of the “wet” slab (rock wool, concrete, trapezoidal sheet metal) with a “dry” one (X-lam panels, cork, and concrete–wood) is planned. Scenario C4, as shown in Figure 24, allows for an exceedance of the threshold, mainly due to the carbon storage properties of the materials used for the interfloor slab and partly in the roof structure. Scenario C4, as can also be seen in the following graph, thanks to the carbon storage properties, allows us to exceed the 55% threshold.

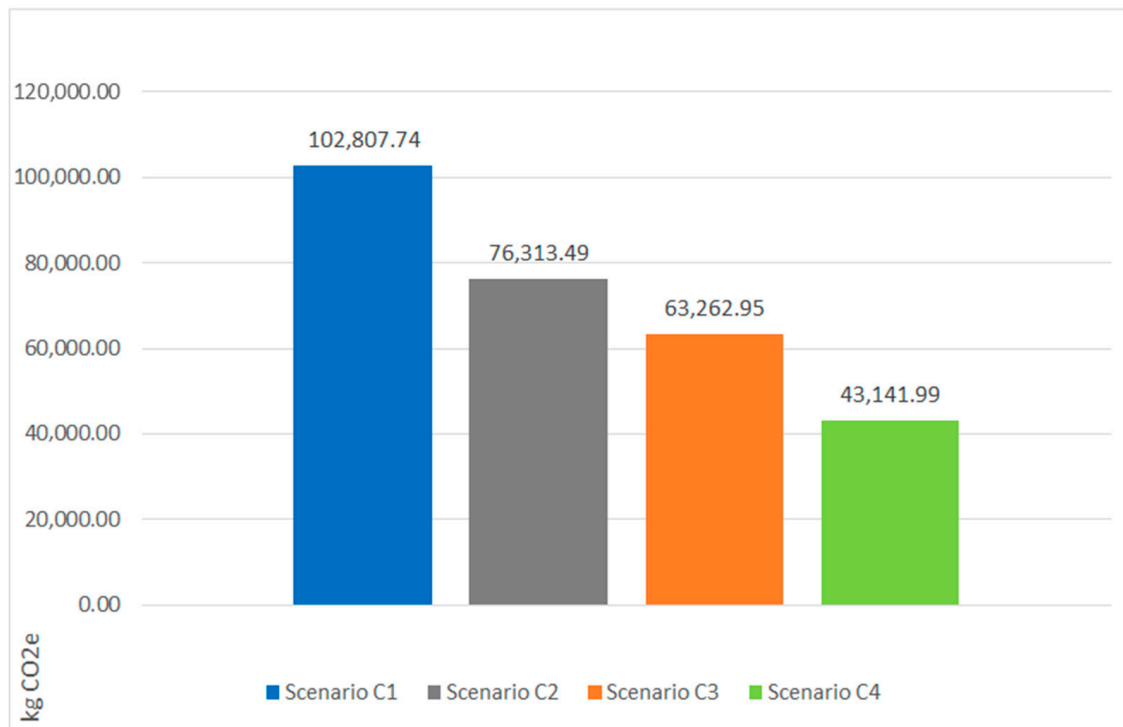


Figure 23. Embodied carbon factor for design solution No. 2.

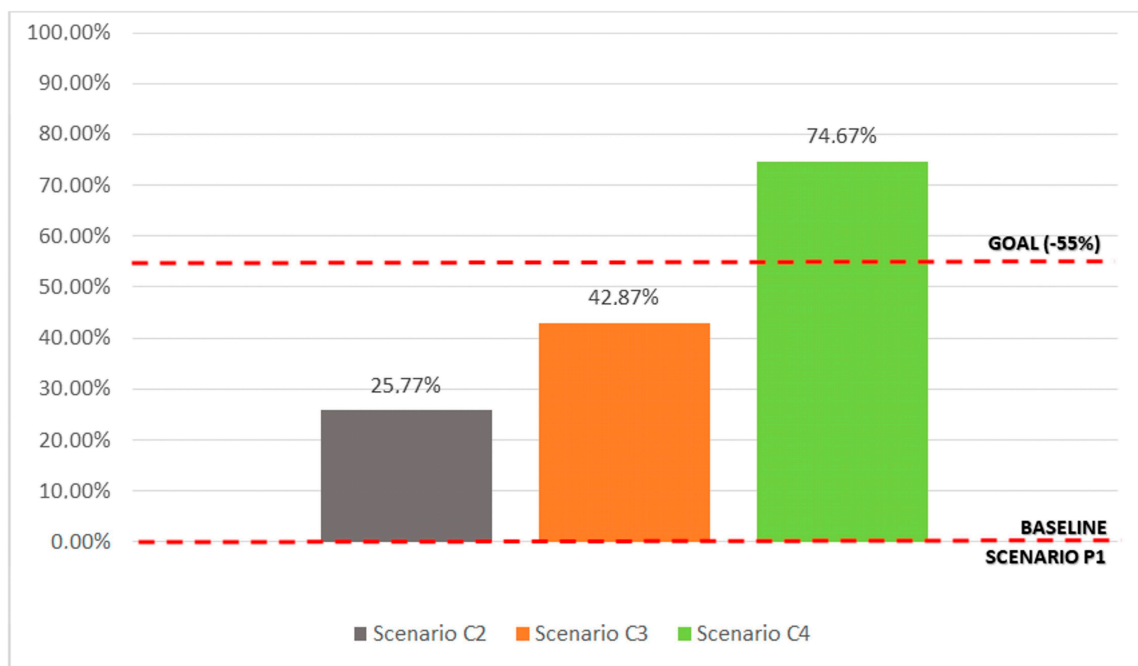


Figure 24. Design solution No. 2: possible combinations of the construction and demolition scenarios.

In scenario C3, the replacement of the intermediate floor slab takes place with “dry” technology, but this does not allow for an exceedance of the target, standing at 42.87%. Considering the aspects intrinsically related to plant materials, in particular their carbon storage property, it is possible to reach the target with scenario C4, with a percentage reduction of 74.67%. Thus, the last scenario presents itself as indispensable for exceeding the European goals, as well as shows that an extension of the intervention would succeed in leading to climate neutrality by 2050, given the important percentage achievement of this approach.

Relative to the design solution 2, the results of the demolition scenario are finally combined with the possible design scenarios (Figure 25): an “overall worst case scenario” (C1 + D3) is thus identified, which involves the sum of the embodied kilograms of carbon from scenario C1 (baseline situation) and scenario D3 (landfill disposal); then, an “overall intermediate scenario” (C3 + D1); finally, the “overall best scenario” (C4 + D1), which allows the predetermined threshold (−55% CO₂e) to be exceeded, resulting from the combination of the C4 project scenario (reduction attributable to the chemical properties of the material and technological solutions adopted) with the D1 scenario (reuse/recycling) (Figure 26). Analysis of the results shows how thoughtful design choices, both at the design and demolition stages, can lead to the achievement of rewarding goals. It is often thought that demolition is, in any case, more impactful than other more conservative scenarios. Instead, when checking the final percentages, in addition to achieving the European goals in the third combination, one can also see a slight increase in the percentage reduction of carbon by making appropriate choices at the design stage while providing for invasive demolition choices.

As can be seen from the graph in Figure 27, by making appropriate design choices, it is possible to intervene even more invasively from a demolition standpoint and achieve even better results (not assumed at the outset) inherent in the reduction in embedded carbon.

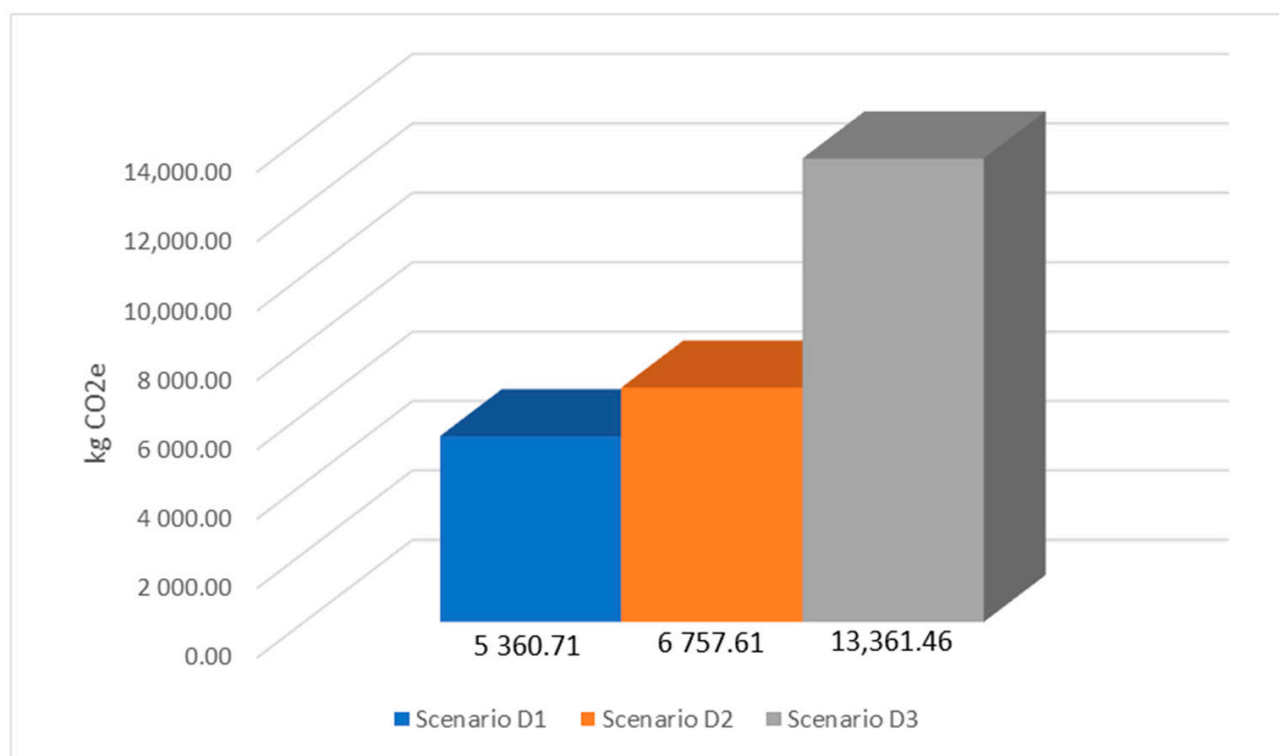


Figure 25. Embodied carbon emissions related to the demolition phase (project No. 2).

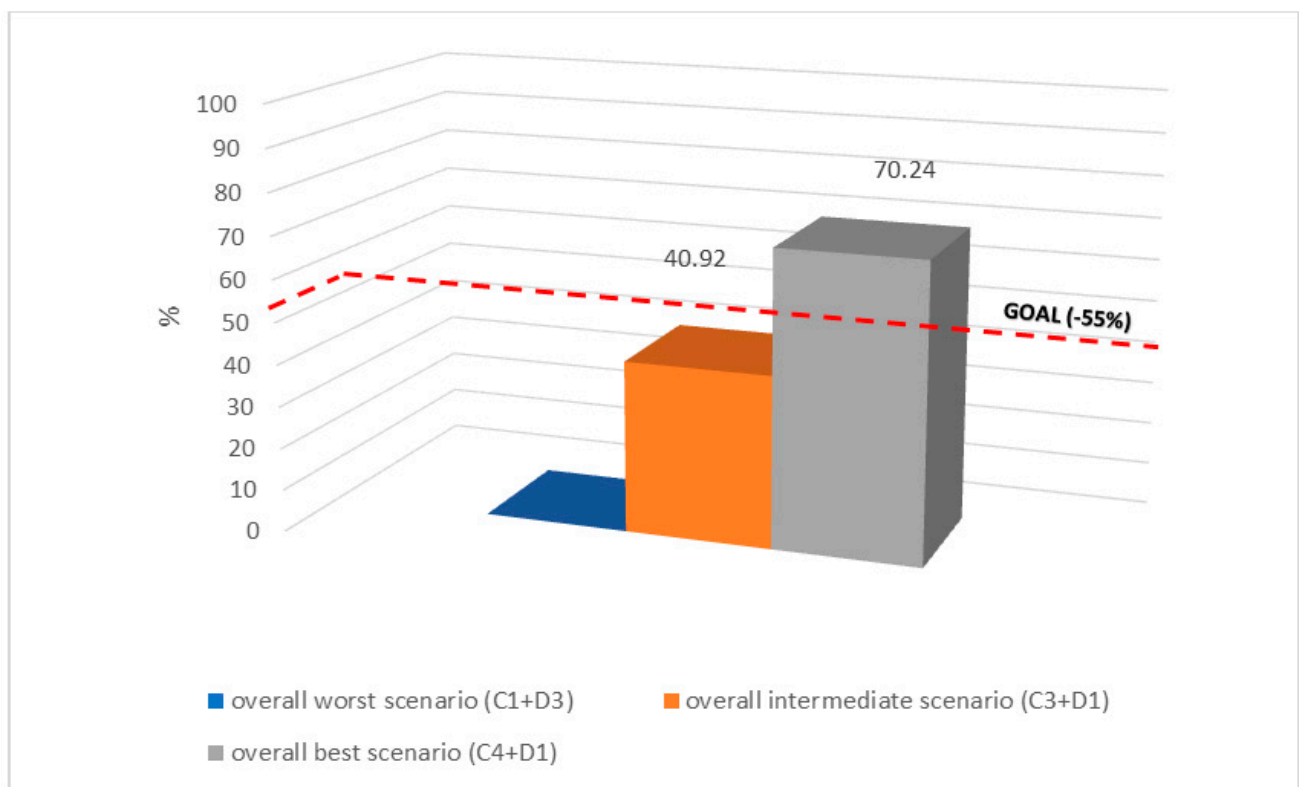


Figure 26. Design solution No. 2: possible combinations of scenarios.

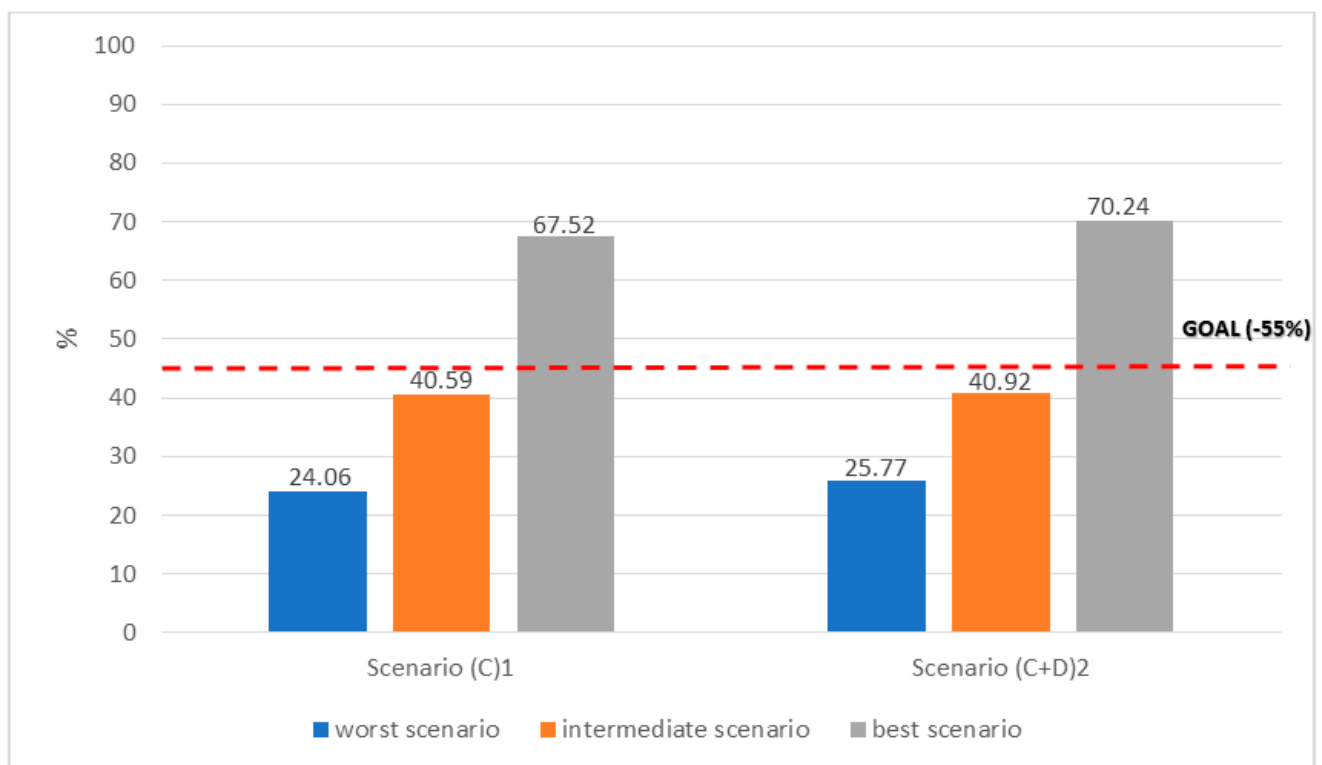


Figure 27. Comparison in terms of percentage reduction in CO₂e between the design solutions: No. 1 (construction) and No. 2 (demolition + construction).

7. Conclusions

The Renovation Wave is the strategy defined by Europe for the energy upgrading of existing buildings: energy efficiency, affordability of renovations, decarbonization, and integration of renewables in buildings. The strategy defines some basic principles that guide the development of the building sector and the improvement in the environmental impact of buildings and integration. Specifically, three main themes are defined in the strategy:

- Reducing energy poverty and the number of low-performing buildings; fostering renovations for low-income groups through minimum energy performance standards coupled with financing that limits residents' spending.
- Renovating public buildings (e.g., administrative, educational, and healthcare facilities); orienting public agencies toward the principle of energy efficiency and increasing the annual renovation obligation so as to foster a pathfinder role for public infrastructure in terms of building renovation, thus serving as a model.
- Modernizing building heating and cooling systems to decarbonize the EU building stock, harness local renewable energy potential, and reduce the EU's dependence on fossil fuel imports.

This study demonstrated the feasibility of achieving the goals required by the Renovation Wave and the European Union's target (EU Regulation 1119/2021) of reducing CO_{2e} emissions by at least 55 percent in the building sector.

For this purpose, two design solutions were developed, one less invasive and one more invasive, assuming the possible, most frequent renovation scenarios. Scenarios other than renovation, such as maintenance, restoration, and demolition–reconstruction, were intentionally excluded (because they were not functional for the purpose of this research). For each of the solutions, possible environmental impact scenarios (in terms of CO_{2e} emissions) were assumed for both the construction and demolition phases.

The methodology was applied to two design hypotheses for the reconfiguration and rehabilitation of a building in the social housing complex in the city of Battipaglia (near Salerno, southern Italy). The results showed that design solution 2, which is more invasive, has a better environmental impact than design solution 1, which is more conservative. The results show a greater sustainability of “dry” systems compared to “wet” systems, with the former being a more sustainable end-of-life management phase, also noted in the disassembly plan provided in the Italian Minimum Environmental Criteria. In addition, the use of sustainable materials has enabled a significant reduction in embodied carbon; the technological system made of wood and its derivatives also provides an effective response in the decarbonization process. The results showed that it is possible to achieve a greater reduction in environmental impact while performing a reconfiguration, rehabilitation, and restyling intervention of social housing.

Funding: No funding has been provided for this research.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on Energy Efficiency and Amending Regulation (EU) 2023/955. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2023_231_R_0001&qid=1695186598766 (accessed on 20 May 2024).
2. Paris Agreement. Paris, 12 December 2015. Available online: https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en (accessed on 20 May 2024).
3. IEA. Perspectives for the Clean Energy Transition: The Critical Role of Buildings. International Energy Agency. 2019. Available online: <https://www.iea.org/reports/the-critical-role-of-buildings> (accessed on 20 May 2024).
4. Pomianowski, M.Z.; Johra, H.; Marszał-Pomianowska, A.; Zhang, C. Sustainable and energy-efficient domestic hot water systems: A review. *Renew. Sustain. Energy Rev.* **2020**, *128*, 109900. [CrossRef]

5. Zhang, S.; Ocloń, P.; Klemeš, J.J.; Michorczyk, P.; Pielichowska, K.; Pielichowski, K. Renewable energy systems for building heating, cooling and electricity production with thermal energy storage. *Renew. Sustain. Energy Rev.* **2022**, *165*, 112560. [\[CrossRef\]](#)
6. Greenwood, D.; Walker, S.; Wade, N.; Munoz-Vaca, S.; Crossland, A.; Patsios, C. 30-Integration of High Penetrations of Intermittent Renewable Generation in Future Electricity Networks Using Storage. In *Future Energy*, 3rd ed.; Improved, Sustainable and Clean Options for our Planet; Elsevier: Amsterdam, The Netherlands, 2020; pp. 649–668. [\[CrossRef\]](#)
7. Dechezleprêtre, A.; Nachtigall, D.; Venmans, F. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *J. Environ. Econ. Manag.* **2023**, *118*, 102758. [\[CrossRef\]](#)
8. Rabani, M.; Madessa, H.B.; Nord, N. A state-of-art review of retrofit interventions in buildings towards nearly zero energy level. *Energy Procedia* **2017**, *134*, 317–326. [\[CrossRef\]](#)
9. Flores, I. A value-based framework from Building Stock Model to Retrofit Model. *Int. J. Environ. Sci. Sustain. Dev.* **2024**, *9*, 20–31. [\[CrossRef\]](#)
10. Balaras, C.; Dascalaki, E. Decarbonizing the European Building Stock-Past-Present-Future. In Proceedings of the International Building Decarbonization 2022 Conference, Athens, Greece, 5–7 October 2022. [\[CrossRef\]](#)
11. Wade, F.; Visscher, H. Retrofitting at scale: Accelerating capabilities for domestic building stocks. *Build. Cities* **2021**, *2*, 800–911. Available online: <https://www.research.ed.ac.uk/en/publications/retrofit-at-scale-accelerating-capabilities-for-domestic-building> (accessed on 20 May 2024). [\[CrossRef\]](#)
12. Jensen, P.A.; Maslesa, E.; Berg, J.B.; Thuesen, C. 10 questions concerning sustainable building renovation. *J. Affect. Disord.* **2017**, *143*, 130–137. [\[CrossRef\]](#)
13. Jensen, P.A.; Maslesa, E.; Berg, J.B. Sustainable Building Renovation: Proposals for a Research Agenda. *Sustainability* **2018**, *10*, 4677. [\[CrossRef\]](#)
14. Ástmarsson, B.; Jensen, P.A.; Maslesa, E. Sustainable renovation of residential buildings and the landlord/tenant dilemma. *Energy Policy* **2013**, *63*, 355–362. [\[CrossRef\]](#)
15. Shnapp, S.; Sitjà, R.; Jens Laustsen, J. Global Buildings Performance Network 2013. What Is a Deep Renovation Definition? Technical Report. Global Buildings Performance Network. 2013. Available online: https://www.gbpn.org/wp-content/uploads/2021/06/08.DR_TechRep.low_.pdf (accessed on 20 May 2024).
16. Femenías, P.; Mjörnell, K.; Thuvander, L. Rethinking deep renovation: The perspective of rental housing in Sweden. *J. Clean. Prod.* **2018**, *195*, 1457–1467. [\[CrossRef\]](#)
17. Fawcett, T. Exploring the time dimension of low carbon retrofit: Owner-occupied housing. *Build. Res. Inf.* **2014**, *42*, 477–488. [\[CrossRef\]](#)
18. Gluch, P.; Gustafsson, M.; Baumann, H.; Lindahl, G. From tool-making to tool-using—and back: Rationales for adoption and use of LCC. *Int. J. Strat. Prop. Manag.* **2018**, *22*, 179–190. [\[CrossRef\]](#)
19. Mjörnell, K.; Boss, A.; Lindahl, M.; Molnar, S. A Tool to Evaluate Different Renovation Alternatives with Regard to Sustainability. *Sustainability* **2014**, *6*, 4227–4245. [\[CrossRef\]](#)
20. Malmgren, L.; Mjörnell, K. Application of a Decision Support Tool in Three Renovation Projects. *Sustainability* **2015**, *7*, 12521–12538. [\[CrossRef\]](#)
21. Malmgren, L.; Elfborg, S.; Mjörnell, K. Development of a decision support tool for sustainable renovation—A case study. *Struct. Surv.* **2016**, *34*, 3–11. [\[CrossRef\]](#)
22. Gade, A.N.; Larsen, T.S.; Nissen, S.B.; Jensen, R.L. REDIS: A value-based decision support tool for renovation of building portfolios. *J. Affect. Disord.* **2018**, *142*, 107–118. [\[CrossRef\]](#)
23. Osterbring, M.; Camarasa, C.; Nageli, C.; Thuvander, L.; Wallbaum, H. Prioritizing deep renovation for housing portfolios. *Energy Build.* **2019**, *202*, 109361. [\[CrossRef\]](#)
24. Nägeli, C.; Farahani, A.; Österbring, M.; Dalenbäck, J.-O.; Wallbaum, H. A service-life cycle approach to maintenance and energy retrofit planning for building portfolios. *J. Affect. Disord.* **2019**, *160*, 106212. [\[CrossRef\]](#)
25. Thuvander, L.; Femenías, P.; Mjörnell, K.; Meiling, P. Unveiling the Process of Sustainable Renovation. *Sustainability* **2012**, *4*, 1188–1213. [\[CrossRef\]](#)
26. Serrano-Jiménez, A.; Femenías, P.; Thuvander, L.; Barrios-Padura, A. A multi-criteria decision support method towards selecting feasible and sustainable housing renovation strategies. *J. Clean. Prod.* **2021**, *278*, 123588. [\[CrossRef\]](#)
27. Mangold, M.; Österbring, M.; Wallbaum, H.; Thuvander, L.; Femenías, P. Socio-economic impact of renovation and energy retrofitting of the Gothenburg building stock. *Energy Build.* **2016**, *123*, 41–49. [\[CrossRef\]](#)
28. Buser, M.; Carlsson, V. What you see is not what you get: Single-family house renovation and energy retrofit seen through the lens of sociomateriality. *Constr. Manag. Econ.* **2017**, *35*, 276–287. [\[CrossRef\]](#)
29. Tjørring, L.; Gausset, Q. Drivers for retrofit: A sociocultural approach to houses and inhabitants. *Build. Res. Inf.* **2019**, *47*, 394–403. [\[CrossRef\]](#)
30. Alessi, A. Riguardare lo spazio. In *Materialegrno 4*; Lo Spazio Ritrovato: Milano, Italy, 2011.
31. Daglio, L. Nuovo Suolo: Riuso e Recupero Delle Superfici in Quota Degli Edifici in, “Costruire Nel Costruito. Architettura a Volume Zero”, Collana Architettura e Città. Argomenti di Architettura, Milano 2012. 2012. Available online: <https://re.public.polimi.it/handle/11311/692634#WE7i-rLhCR0> (accessed on 20 May 2024).
32. Reale, L. Densità, città, residenza. In *Tecniche di Densificazione e Strategie Anti-Sprawl*; Gangemi Editore: Roma, Italy, 2008.

33. Ferrante, A.; Cattani, E.; Bartolini, N.; Semprini, G. La riqualificazione energetica e architettonica del patrimonio edilizio recente. Il caso dei quartieri di edilizia residenziale pubblica. IN_BO. *Ricerche E Progetti Per Il Territorio, La Città E l'architettura* **2012**, *3*, 251–276. [[CrossRef](#)]
34. Spagnolo, R. La rigenerazione urbana come problema di ri-composizione architettonica. In *Marta Calzolaretti, Domizia Mandolesi (a cura di); Rigenerare Tor Bella Monaca*: Macerata, Italy, 2014; p. 83.
35. Calzolaretti, M. Perché Tor Bella Monaca. Il programma di ricerca. In *Marta Calzolaretti, Domizia Mandolesi (a cura di); Rigenerare Tor Bella Monaca*: Macerata, Italy, 2014; p. 17.
36. Sicignano, E. La demolizione quale esorcismo del male sociale: Il caso delle Vele di Scampia a Napoli. In *Rita Maria Borboni; Città&Criminalità*: Pesaro, Italy, 2005; pp. 233–241.
37. Valente, I. Consolidare e ri-misurare i margini urbani: Una ricerca progettuale per Tor Bella Monaca. In *Marta Calzolaretti, Domizia Mandolesi (a cura di); Rigenerare Tor Bella Monaca*: Macerata, Italy, 2014.
38. Portoghesi, P. *Materia n.44-45*; Quarzo Editor, Reggio Emilia: Milano, Italy, 2012; pp. 35–39.
39. Wien, Gasometer D, Wilhelm Holzbauer, Blick aus einer Dachwohnung. 2001. Available online: <https://www.alamy.com/wien-gasometer-d-wilhelm-holzbauer-2001-blick-aus-einer-dachwohnung-image221171876.html> (accessed on 20 May 2024).
40. *EN ISO 14025:2010*; Environmental Labels and Declarations—Type III Environmental Declarations—Principles and Procedures (ISO 14025:2006). SIST: Ljubljana, Slovenia, 2010.
41. *BS EN 15978:2011*; Sustainability of Construction Works—Assessment of Environmental Performance of Buildings—Calculation Method. BSI: London, UK, 2011.
42. Embodied Carbon-The ICE Database. Available online: <https://circularecology.com/embodied-carbon-footprint-database.html> (accessed on 20 May 2024).
43. Califano, L. Additions to the Built in Retrofit Strategies. Doctoral Thesis, University of Naples “Federico II”, Napoli, Italy. Available online: http://www.fedoa.unina.it/8970/1/Califano_Luisa_24.pdf (accessed on 27 March 2024).
44. Parlato, S. Re-Inhabiting the City, the Strategy of Addition as an Opportunity for Densification. Ph.D. Thesis, University of RomaTre, Department of Architecture, Rome, Italy, 2014.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.