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An ELECTRE TRI B-Based Decision Framework to Support the Energy Project Manager in Dealing with Retrofit Processes at District Scale

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Abstract: Cities represent the places with the highest environmental and energy impact in the world. Transforming them in a sustainable way has the potential to reduce the pressures of these areas. The building stock could be the driving force behind the energy transition of cities. With this in mind, understanding the priorities of undertaking a massive green regeneration operation becomes crucial to optimizing the use of public funds such as those of the National Recovery and Resilience Plans (NRRPs) that EU Member States have at their disposal. For this purpose, a multi-criteria ELECTRE TRI-B (ELimination Et Choix Traduisant La REalité TRI-B) model was used to provide useful information in prioritizing intervention on the existing building stock to achieve the sustainability targets set at European and international levels. The model was tested on a real case study located in Turin (Italy) to improve the management process by classifying intervention on a building stock characterized by different typologies and construction periods. Looking at the results, the retrofit operations with the highest priority relate to the apartment building sector from 1946 to 1970 and the multifamily building sector from 1919 to 1960. Despite the high initial investment requirements, an ecological transformation of this stock would result in significant reductions in health impacts, more green jobs, and lower resources consumption. The model is useful for managing public policies in this area by providing guidance to the project manager on how to proceed in the provision of ad hoc funds and could optimize the process of local community energy generation.

Keywords: multiple criteria decision aiding (MCDA); ELimination Et Choix Traduisant La REalité TRI-B (ELECTRE TRI-B); energy retrofit; water management; decision making process; project management; scheduling tasks; sustainable development

Citation: Dell'Anna, F. An ELECTRE TRI B-Based Decision Framework to Support the Energy Project Manager in Dealing with Retrofit Processes at District Scale. *Sustainability* **2023**, *15*, 1250. https://doi.org/10.3390/su15021250

Academic Editor: Wen-Hsien Tsai

Received: 27 October 2022
Revised: 16 November 2022
Accepted: 3 January 2023
Published: 9 January 2023

1. Introduction

Based on the principles of sustainability and resilience, governments must decide how to allocate public financial resources to accelerate the ecological transaction of the built environment, taking into account essential factors such as environmental protection, economic feasibility, and social acceptance [1]. Economic analysis, including cost-benefit analysis and discounted cash flow analysis, has widely been utilized extensively to assess the profitability of the investments [2,3]. However, the shortcomings of this strategy in addressing urban contexts have been highlighted, as it fails to take into account the full complexity of the issues at stake and does not allow for the involvement of stakeholders in the decision-making process [4]. Multiple criteria decision aiding (MCDA) methods have gained importance in light of the aforementioned critical issues because they can take into account both financial analysis and other tangible and intangible criteria expressed in physical and qualitative terms, as well as manage social group conflicts [5].

Since buildings account for a significant part of final energy consumption and pollutant emissions in the urban context, reducing energy consumption and improving environmental protection, which are key objectives of EU and international directives, become essential. Renovation programs, in general, are a collection of complex activities that use human, material, and economic resources and are carried out at various times and in various ways. The organization of resources is an important aspect of project management, which seeks to correlate and finalize activities in order to achieve a predefined goal. In fact, these waves of renewal are often supported by public funding, incentives, and financial instruments promoted and financed by governments to help private users [6,7]. These include direct investments and fiscal, financial, and market instruments which is often scarce to meet the full demand. In this sense, it is necessary to understand who should be given support first in order to maximize profits and implement a continuous support process.

This paper’s goal is to investigate the application of MCDA techniques to prioritize energy retrofit operations at the district scale. A detailed MCDA-based assessment framework was proposed to help prioritize alternative energy retrofit strategies for a set of residential private buildings located in the Vanchiglietta district of Turin (Italy), characterized by inadequate building envelopes and inefficient heating, ventilation, and air conditioning (HVAC) systems. In order to assist public decision-makers (DMs), the ELECTRE TRI-B (ELimination Et Choix Traduisant La REalité TRI-B) approach [8,9] was used to rank a set of alternative retrofit options, considering different building types (single-family, terraced, multi-family, condos) characterized by different construction periods. In this way, the model is able to provide the public decision-maker with useful information on where action needs to be taken first in order to maximize the economic, environmental, and social benefits generated by the retrofit process in a neighborhood.

2. Research Background

The key moments of project management are time planning, costing, and the definition of quality standards, as well as the control period of what is planned to prevent the project from becoming unsustainable [10]. The project manager analyses these aspects during the planning phase of the project, using the business plan and the operational plan. While the former seeks to develop a business and financial plan and identify the sources of funding needed to complete the process, the operational plan examines the actions to be taken by defining time, costs, and risks [11]. In the operational phase, the activities scheduling becomes fundamental in the monitoring of the intervention’s progress by assigning start and end dates to each elementary action to ensure that the entire project is completed in accordance with contractual commitments. Furthermore, scheduling provides the client with a tool for monitoring implementation activities and a better understanding of the project’s evolution and the links between its various phases. Finally, scheduling is a tool for bringing all the actors in the construction process together, from the designers to the general contractor, suppliers, and subcontractors, in order to coordinate all operations.

The Gantt chart, program evaluation and review technique, and critical path method are among the methods used in the construction sector to prioritize tasks (Table 1) [12,13]. The first MCDA analysis applications for this purpose have only recently started to appear.

Table 1. Comparison analysis among scheduling approaches.

	Method			
Features	Gantt chart	Program evaluation and review technique	Critical path method	Multiple criteria decision aiding
Aim	Determining how long each task will take.	Determining the minimum time required to complete the project.	Determine the minimum time required depending on cost to complete the project.	Determining an order of priority for intervention considering different evaluation criteria.
Project scope	Great for smaller project.	Ideal for complex project.	Ideal for complex project.	Ideal for complex project.
Flexibility	Easy to modify as possible contingencies change.	Not easy to modify as possible contingencies change.	Not easy to modify as possible contingencies change.	Easy to modify as possible contingencies change.
Stakeholders' involvement	There is no involvement.	There is no involvement.	There is no involvement.	There is involvement.
Results	Easy to understand.	Not easy to understand because of the representation structure.	Not easy to understand because of the representation structure.	Easy to understand.

The bar chart, often known as the Gantt chart, is one of the first and is still frequently used today [14]. It enables straightforward scheduling through the use of a graphical depiction of project activities. Despite its many flaws, this technique is still frequently used for work programs of limited size and complexity, where the use of more sophisticated techniques would be uneconomic. In large work programs, an auxiliary tool for more sophisticated scheduling techniques is indispensable, such as program evaluation and review technique (PERT) and critical path method (CPM), to plan individual activities [15]. The PERT technique enables the creation of a project's schedule through the planning of its activities. This method primarily addresses the program's time-related issues, just briefly addressing its financial issues. PERT places more emphasis on time than cost. Calculations for PERT must be updated and revised frequently for active project control. This labor-intensive task calls for highly skilled staff. The CPM determines a range of potential intervals for each activity and, consequently, for the entire intervention, and then chooses the interval that minimizes the project's overall cost. A thorough analysis of the project's factors, including size, technological complexity, effects, length, and anticipated expenses, as well as the features of the methodology itself, is required before selecting a scheduling method (preparation cost, updating cost, ease of control, communicativeness, adaptability to the project, team involvement, customer interest). This prompts a reconsideration of conventional project management support methods, which may differ in a challenging application context such as urban design.

Multi-criteria methods make it possible to consider different dimensions of the problem at hand, using different qualitative and quantitative criteria. In this way, MCDA methods are ideal for complex problems because they break down the problem into elementary elements and allow the inclusion of the views of different stakeholders who may be interested. In addition, MCDA methods allow flexibility of use, which can refer to the modification of intra-criteria parameters or weights of criteria importance [16]. The results also are easy to understand as the classification into importance classes makes it easy to prioritize. In addition, there is software that makes the implementation of the analysis easy even for the inexperienced. A closer look reveals that there isn't much research on the use of the MCDA method in project management to assist with spatial planning and transformation. Many of the articles in this category share a common interest in infrastructure and the construction industry. The stages of development, building, maintenance, administration of transportation networks, and project supervision are some of the subjects that are taken into consideration [17]. de Miranda Mota et al. [18] used an ELECTRE TRI-C model to assess 25 activities for the building of an energy substation according to three categories and five criteria, which was one of the first implementations of MCDA to prioritize tasks within a project. In order to assist project managers in determining the fundamental timetable by weighing trade-offs between quality, time, and cost objectives, Gagnon et al. [19] introduced a multi-objective approach to project scheduling. In order to decrease risky investments, Heravi and Gerami Seresht [20] suggested a novel methodology to prioritize non-critical tasks in building projects. According to the methodology, the project is discretized into individual activities, and those activities are then assessed using 5 criteria (duration, cost, free float, responsible party, and predecessor). Napoli et al. [21] used ELECTRE TRI-nC method to aid the decision-making process by categorizing alternative energy retrofit actions for public building stock in Apulia Region (Italy) into various categories, each of which expressed a different level of overall performance. Multiple-objective social group optimization, a novel method for time-cost decision-making in generalized construction projects, was introduced by Tran [22].

According to the literature review, small-scale initiatives require only a few evaluation criteria and the involvement of a small number of specialists [18,23,24]. Simple methods such as the Gantt chart can support the scheduling process in some cases [25]. When the scale reaches the urban and territorial scale, the opinions and interests of stakeholders must be taken into account to achieve their objectives [26,27]. This methodological contribution aims to assist project managers in defining planning in the most complex urban retrofit processes in the energy field. When making decisions in this situation, a number of competing objectives supported by numerous stakeholders are taken into account. To address this issue, the ELECTRE TRI-B method was recommended in this study. The proposed framework is novel from a methodological perspective since it provides criteria that are helpful for establishing a schedule for projects of this kind, which are currently understudied. Additionally, the contribution suggests using the model to assist project managers in choosing an appropriate plan throughout the entirety of the project life cycle of a real-world district regeneration for a neighborhood in Turin (Italy).

3. Methodological Framework

This methodological document proposes a framework to support DMs in the time management of a set of sustainable urban regeneration operations. The model is based on five main phases:

1. Structuring the decision-making problem: this is the preliminary phase in which the problem is defined. In this case, the model focuses on the prioritization of different retrofit actions for the residential building stock to allocate resources through fiscal measures.
2. Description of the building stock under examination, in order to collect information on the type of buildings (geometric and heating system characteristics) and proposed retrofit actions. It is possible to identify information on costs (investment and maintenance), environmental costs, and qualitative characteristics of the solutions.
3. Structuring of the multi-criteria model: the building stock is grouped into elementary asset families according to building type and age of construction. Once the evaluation criteria were defined, the performance of each stock was measured for each criterion. This step allows the performance matrix to be outlined.
4. Application of ELECTRE TRI-B: the sorting model is the MCDA method chosen to group the actions into priority groups, ranking them by the level of importance. In

this phase, criteria are weighted, reference profiles are outlined, and priority categories are defined according to the opinions of a group of experts. SRF (Simos-Roy-Figueira) method was used for the weighting step.

5. Definition of guidelines for the development of the master plan: A critical reading of the results was carried out to provide useful guidelines for the DMs involved in the project.

3.1. ELECTRE TRI-B

One of the most well-known ordinal sorting methods is ELECTRE-TRI, an MCDA method from the ELECTRE family of methods [28]. With this approach, each alternative is assessed using a variety of quantitative and/or qualitative criteria [29]. By comparing the alternatives with the profiles that specify the group (or category) boundaries, ELECTRE TRI-B allocates alternatives to preset ordinal groups. F stands for the set of indices of the g_1, ..., g_j, ..., g_n criteria and B stands for the set of indices of the profiles defining the p + 1 groups. b_h is the group C_h upper profile and the group C_h + 1 lower profile, with h = 1, 2, ..., p. The categories to which shares are to be allotted are fully ordered, requiring that the limiting profiles must satisfy the dominance-base separability requirement. The claim that "a is at least as good as b_h" is validated or refuted by ELECTRE TRI-B using outranking relations. The intra-criterial preference information is made up of the thresholds for indifference, preference, and veto (i.e., $q_j(b_h)$, $p_j(b_h)$, and $v_j(b_h)$). The indifference threshold is the point at which the performance of the options and profiles diverge most from each other on the criterion; as a result, the DM views them as indifferent [30]. The performance of the alternatives and profiles that must be significantly different from one another in order for that criterion to be taken into consideration is the preference threshold. The veto threshold identifies circumstances where the DM must reject any outranking relationship suggested by other criteria due to the performance gap between the alternatives and profiles on a particular criterion.

3.2. SRF Method

After setting up the performance matrix, the next stage is the weighing of criteria. As suggested by Figueira and Roy [31], the method selected for the proposed methodological framework is the technique theorized by Jean Simos and revised by Bernard Roy and José Rui Figueira, called the Revised Simos Method. This technique consists of presenting the respondent with cards, one for each criterion. Each criterion is briefly described, the unit of measurement is indicated, whether the criterion is to be minimized or maximized, and a small symbolic image is provided. At first, the respondent is asked to physically rank the cards according to his or her judgment. This is subjective and in line with his knowledge and interests. It is thus necessary to ask the respondent the reasons for the 'preference' of some criteria over others. If the criteria are of equal importance to the respondent, the respective cards should be placed side by side. Next, the DM is asked to insert blank cards to highlight the difference in importance between one or more criteria. Finally, the respondent is asked to express a number indicating how much the criterion placed in the most important position is more important than the least important one. This numerical value is called the z-value. It is advisable to administer the SRF questionnaire to several decision-makers who are experts in various fields and involved in the decision-making process. As a subjective assessment, the weights given to the criteria (and the z-value) will change according to the respondent's judgment. Once the data have been collected, they are entered into the web-based framework DecSpace which processes the weighting.

4. Application

Generally, multi-criteria analyses are used to compare different alternative regeneration scenarios [32–35]. This paper proposes instead to use MCDA to support the project manager in scheduling regeneration activities for a neighborhood by considering a set of criteria. This section will proceed to apply the proposed methodology to a real case study: the Vanchiglietta neighborhood in Turin (Northern Italy). The objective is to prioritize different retrofit actions applied to the district's building stock. The model will not only consider economic aspects, but also other criteria that can describe the different energy efficiency and sustainability measures for the creation of a greener district.

4.1. Vanchiglietta District in Turin

The district selected to validate the framework is Vanchiglietta in Turin, which covers an area of approximately 1 km^2 (Figure 1). It is an area that extends northeast along the main Corso Belgio, starting from Corso Regina Margherita, near the confluence of the Po river and the Dora Riparia. There are two main reasons for this choice. First, this district was built in 1980 and therefore most of its buildings suffer from low thermal properties, are not insulated, and are in need of renovation due to their age. Secondly, as it is not connected to district heating and there is no provision for it, it represents a good opportunity to test the application of strategic scenarios for energy redevelopment.

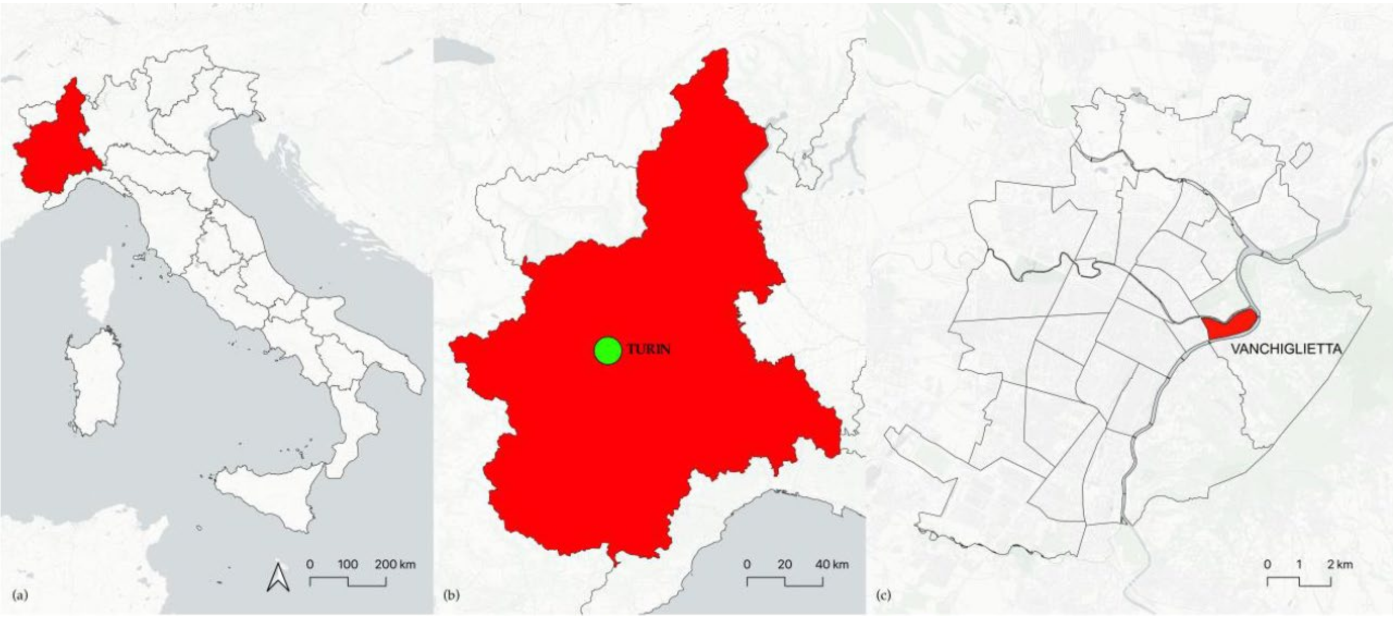

Figure 1. Case study localization. Piedmont Region in (**a**), Turin city in (**b**), Vanchietta district in (**c**).

4.2. District Characterization

Once the goal and the object of analysis have been defined, it is necessary to know the geometric characteristics of the buildings into classes according to the type and age of construction. In order to classify the district's buildings and calculate their total consumption, it was necessary to analyze their characteristics with the help of the Turin City Council Geoportale; an infrastructure of geographical data, which allows for the retrieval of territorial and environmental information. The information that was extracted, for each individual building, was the intended use, period of construction, building area, building perimeter, number of floors, building height, and heated volume. Using this information, it was then possible to learn the characteristics that delineate the buildings in the district. As the study concentrates on the private residential sector, the information on the use made it possible to exclude buildings with a different use. The buildings' footprint area on the ground and height made it possible to classify the buildings according to form factor, in line with the European TABULA project [36]. This classification consists of four classes: single-family houses (SFH), terraced houses (TH), multi-family buildings (MFH), and apartment blocks (AB). The information on the age of construction made it possible to categorize buildings according to the building envelope and heating systems, as also suggested by the TABULA project. The buildings thus classified constitute the evaluation alternatives of the multi-criteria model. In Figure 2, the buildings are shown according to their building size class. As can be seen, the neighborhood is mostly occupied by apartment blocks, as supposed given the high density of housing.

Figure 2. Building characterization according to the typology.

With regard to the era of construction, the estate is characterized by about 30% MFH properties built between 1919 and 1960 and more than 36% AB properties built between 1919 and 1970. The descriptive analyses confirm that the district is a potential example of experimenting with different energy efficiency measures as most of the stock was characterized by poor energy quality (Table 2).

Table 2. Descriptive analysis of Vanchiglietta district building stock typology and construction period.

Building Typology	Construction Period	Surface (m²)	Percentage (%)	Partial Percentage (%)
SFH	before 1919	81	0.05	
SFH	1919–1945	1559	1.02	
SFH	1946–1960	68	0.04	
SFH	1961–1970	3332	2.18	
SFH	1971–1990	2059	1.35	
SFH	1991–2000	284	0.19	
SFH	after 2005	709	0.46	5.3
TH	before 1919	559	0.37	
TH	1919–1945	6177	4.05	
TH	1946–1960	3872	2.54	
TH	1961–1970	4578	3.00	
TH	1981–1990	481	0.31	
TH	after 2005	583	0.38	10.6
MFH	before 1919	444	0.29	
MFH	1919–1945	25,001	16.38	

MFH	1946–1960	21,874	14.33	
MFH	1961–1970	5633	3.69	
MFH	1971–1980	1192	0.78	
MFH	1981–1990	607	0.40	
MFH	1991–2000	1600	1.05	
MFH	2001–2005	2479	1.62	
MFH	after 2005	2128	1.39	39.9
AB	before 1919	275	0.18	
AB	1919–1945	10,534	6.90	
AB	1946–1960	26,384	17.29	
AB	1961–1970	18,605	12.19	
AB	1971–1980	2542	1.67	
AB	1981–1990	3061	2.01	
AB	1991–2000	3276	2.15	
AB	2001–2005	2065	1.35	
AB	after 2005	577	0.38	44.1
Total surface (m^2)		152,618		

In this application, the current state scenario describes the worst-case situation in terms of building condition, assuming that no buildings within the district have already undergone an energy retrofit process. In this case, the current state refers to the original situation of the various buildings characterized in terms of heating systems and transparent and opaque envelopes as per type and year of construction. Depending on the building typology and time of construction, different measures have been assumed to intervene. There were four generic transformation measures identified and they were designed to reduce energy and drinking water consumption by improving the thermal insulation of the buildings, connecting district heating (DH) throughout the district, applying photovoltaic panels, and installing measures to reduce water consumption (installing aerators at the taps and installing dual-flow drainage trays). The measurements were assumed to be based on the era of construction of the buildings as follows. In detail, for buildings constructed before 1945, it was assumed that they had facades with high historical and artistic value. In this case, the installation of roof-integrated photovoltaic panels, the connection to DH, and the installation of water-reducing measures are planned. For buildings constructed after 2005, it was assumed that these already had good architectural features and did not require insulation of the opaque envelope. However, the installation of PVs, DH connections, and measures to curb water consumption could bring improvements in resource consumption. For buildings constructed between 1946 and 2005, on the other hand, all suggested measures are to be applied.

4.3. Multi-Criteria Model Structuring

A set of criteria was selected to evaluate each intervention in the sustainable plan for the district. With regard to the selection of criteria, reference was made to the most common criteria used in questions of this type, including as far as possible all aspects of the hypothesized transformations; energy retrofit of the envelope, implementation of RES, and installation of measures to reduce drinking water. Based on a literature review, a panel of experts selected the most suitable criteria to consider, also taking into account the limitation of information that often occurs in the preliminary stages of such a transformation [5,37,38]. In addition, much attention was given to avoiding redundancy by promoting completeness of assessment, that is, identification of all necessary criteria [39]. In this way, it is possible to ensure the correct outcome of the evaluation and the formation of the performance table. The criteria have been classified into economic, environmental, and social.

Economic criteria family has the objective of quantifying each intervention in monetary terms:

- g_1: Investment costs (€) for the implementation of the different efficiency measures. For the definition of this criterion, the costs for the installation of the external envelope and the replacement of external windows and doors, the connection to DH, the installation of PV, and measures to reduce drinking water consumption were taken into account *[40]*. The initial assumption in implementing retrofit actions is that all assumed actions should be implemented to achieve a satisfactory level of sustainability. In this sense, according to this assumption, for each type of building, all measures will be implemented at the same time. Therefore, the investment costs consider the total investment costs of implementing all assumed retrofit actions. The criterion should be minimized, meaning that interventions that cost the least and maximize the other aspects considered should be favored.
- g_2: Pre-intervention operating costs (€) criterion gives priority for intervention to the most energy-consuming building stock, allowing it to reach its target for energy and drinking water reduction more quickly. In fact, it is proposed to maximize the criterion to favor interventions on the most energy-intensive buildings.

Environmental criteria groups aim to improve the environmental aspect and decrease water consumption:

- g_3: Avoided external costs (€) translates into economic terms the prevented health costs due to the presence of pollutants in the air thanks to PV installation *[38]*. A criterion that maximizes the positive effects of PV is proposed because it is intended to consider the promotion of RES and emphasize its crucial role in the energy transition. A criterion that takes into account the reduction of pollutant emissions for all measures could be indirectly proportional to g_2 criterion and produce an evaluation bias. The criterion is to be maximized.
- g_4: Water reduction (m^3) measures the water that is saved by installing the proposed solutions (i.e., installing aerators at the taps and installing dual-flow drainage trays). For the definition of the criterion referring to the saving of drinking water, reference was made to the various sustainability certifications of the built environment, such as BREEAM, Green Mark, ITACA, and LEED *[41–44]*, which define different thresholds to reward the most virtuous buildings. The criterion is to be maximized.

Social criteria maximize the acceptance of measures by the community.

- g_5: Green jobs (No.) measures the number of new jobs generated based on the investment costs incurred [45,46]. The promotion of new green jobs especially in times of economic stagnation is crucial and also allows for increased investment acceptance by promoting local know-how. The criterion is to be maximized.
- g_6: Visual impact [1–5] measures on a qualitative scale the visual impact of the measures implemented for the different types [47]. Historic buildings are often subject to protection restrictions, and the options in terms of measures to be taken are greatly reduced especially those related to insulation and installation of RES, and not so much those related to drinking water consumption. Favoring interventions on buildings without any artistic merit maximizes the benefits in terms of reduced energy demand [21]. The criterion is to be minimized.

Table 3 shows the performance of each alternative according to the criteria evaluation. In detail, based on previous studies of the analyzed building stock, the performance of the alternatives was defined. For the calculation of investment costs (g_1), reference was made to a typological list developed in Italy regarding the energy retrofit [40]. For the investment cost calculation of water consumption reduction measures, market research was carried out. Pre-intervention operating costs (g_2) were estimated through the TABULA project database [36]. The main reference for measuring avoided external costs (g_3) refers to the Externe project [38], which estimated health-related costs for various energy carriers. Water consumption saved (g_4) was estimated by making the difference between pre- and post-intervention per capita consumption per household. Jobs generated (g_5) was calculated by referring to investment costs incurred and parametric values found in the literature that define the number of jobs per euros spent [45]. The assessment of the visual impact (g_6) of the suggested measures involved a panel of experts who defined the different levels based on the historical-artistic characteristics of the era of construction of the buildings. For buildings built before the 1960s, the highest level was the one, indicating them as having facades and roofs that are unlikely to be altered or replaced. Buildings between the years 1961 and 1990 are characterized by a level of 3, with a good chance of being transformed in the retrofit phase. Buildings constructed after 1990 have a value of 1, to emphasize that these can be easily modified, if necessary, as they do not have historic-artistic value. Since the ELECTRE methods allow for the inclusion within the evaluation model of performance in their original scale, the measurement results were not subjected to pre-processing such as standardization and normalization [48–50].

Table 3. Evaluation criteria, unit of measure, assessment direction (min or max), the performance of alternatives.

Building Typology		**Criteria**					
		g_1	g_2	g_3	g_4	g_5	g_6
Building Typology	**Construction Period**	**Investment Costs**	**Pre-Intervention Operating Costs**	**Avoided External Costs**	**Water Savings**	**Green Jobs**	**Visual Impact**
		€	**€**	**€**	**m³**	**No.**	**1–5**
		Min	**Max**	**Max**	**Max**	**Max**	**Min**
SFH	before 1919	14,108	573	12,071	30	0	5
SFH	1919–1945	271,913	31,052	235,746	435	6	5
SFH	1946–1960	46,627	2209	8542	30	1	5
SFH	1961–1970	2,972,579	75,725	431,541	195	61	3
SFH	1971–1990	1,245,846	20,584	262,598	30	26	3
SFH	1991–2000	171,745	322	33,204	60	4	1
SFH	after 2005	77,607	3476	82,937	30	2	1
TH	before 1919	106,276	19,303	35,010	165	2	5
TH	1919–1945	903,704	103,324	794,226	1515	19	5
TH	1946–1960	2,334,393	54,020	490,613	600	48	5
TH	1961–1970	3,212,195	78,466	574,472	165	66	3
TH	1981–1990	320,838	5309	60,283	30	7	3
TH	after 2005	82,902	4681	72,652	30	2	1
MFH	before 1919	65,548	8654	52,815	60	1	5
MFH	1919–1945	1,850,787	359,081	3,921,868	4230	38	5
MFH	1946–1960	7,638,072	531,021	3,202,932	3195	157	5
MFH	1961–1970	2,118,888	57,825	711,759	435	44	3
MFH	1971–1980	386,467	8613	139,001	135	8	3
MFH	1981–1990	196,788	4088	76,469	105	4	1
MFH	1991–2000	531,404	10,781	201,659	135	11	1
MFH	2001–2005	823,031	7193	309,603	165	17	1
MFH	after 2005	131,798	6175	265,817	165	3	1
AB	before 1919	20,351	6672	40,264	30	0	5
AB	1919–1945	622,977	148,016	1,490,956	990	13	5
AB	1946–1960	8,275,853	361,718	3,495,130	2010	170	5
AB	1961–1970	5,610,217	210,877	1,892,519	1215	115	3
AB	1971–1980	557,605	14,401	282,602	225	11	3
AB	1981–1990	671,558	14,086	358,084	165	14	1

AB	1991–2000	841,229	15,071	383,133	270	17	1
AB	2001–2005	530,437	6480	221,559	105	11	1
AB	after 2005	25,089	1811	61,911	30	1	1

4.4. Weights of Criteria, Intra-Criterial Preference Information, and Reference Actions

In this phase, the DMs are asked to collaborate and express their preferences on the actions to be taken. For the weighting of the criteria, four experts in different fields were selected to give their opinion on the topics of the selected criteria: environmental, social, and economic. A working table was organized to define the order of importance of the criteria considered. Referring to the proposed framework, the chosen weighing technique is the SRF method. The experts recognized the importance of economic criteria when it comes to such large-scale interventions (Table 4). Maximizing results by favoring interventions with lower retrofit investment costs that can support the transition of the most energy-intensive assets with higher operating costs. Economic criteria were therefore also very important. Next, the experts mentioned the criterion of avoiding external costs as important, in order to be as close as possible to the goals of international environmental directives. According to experts, boosting the economy by creating new jobs is an important prerogative, especially in times of economic stagnation. Since the water reduction measures proposed in the renewal plan do not have a great impact in terms of savings, the experts do not consider the relative criterion unimportant. In the last place, the experts place the criterion of the visual impact of the measures, since in any case for each building type, solutions have been integrated into the buildings as far as possible. The experts decided on a single blank card between the criterion of external costs and new jobs generated, to show a slight difference in importance between the criteria considered most important and not. Finally, as the experts consider the criteria to be relatively important for the regeneration operation, the declared z-value is 4.

Table 4. Weights of the evaluation criteria according to the focus group.

Criterion	Position	White Card	Normalized Weight
Investment costs	1		24.6
Pre-intervention operating costs	1		24.7
Avoided external costs	2		21
		1	
Green jobs	3		13.6
Water reduction	4		9.9
Visual impact	5		6.2

An important step in ELECTRE TRI-B is the establishment of reference thresholds. The purpose of this step is to establish the profiles that identify the category boundaries (e.g., high, medium, and low). The procedure consists of studying the values of the criteria to identify the turning point in the final ranking of the alternatives. Two reference thresholds are associated with the three categories: b_0 and b_1 (Table 5).

Table 5. Intra-criterial preference information and reference actions.

	Investment Costs	Pre-Intervention Operating Costs	Avoided External Costs	Water Savings	Green Jobs	Visual Impact
q^{β}	10,000	1000	/	50	/	2
p^{β}	500,000	10,000	5000	500	20	4
b_0	15,000	2000	50,000	100	50	3
b_1	100,000	300	1000	20	15	5

5. Discussion

Looking at the results, it can be seen that the retrofit operations that achieve a high level of priority refer to the AB building sector from 1946–1970 and MFH 1919–1960 (Table 6). This building stock constitutes the largest portion of the entire district. Despite the high initial investment costs, an ecological transition of this stock would provide a high reduction in external costs, more jobs, and a greater reduction in water consumption. Low-priority interventions include properties built before 1919 of type SFH, MFH, and AB. The measures suggested for this stock, limited to the installation of PV, connection to DH, and water abstraction measures fail to provide great returns in environmental and economic terms. This is also the case for newer buildings, which already have a good energy performance and would not make a substantial reduction in the energy balance of the neighborhood.

Few studies have been developed along these lines in the decision-making research field. However, the results obtained seem consistent with other studies developed in this field. Napoli et al. [21], analyzing the public heritage of the Apulia Region in Italy, shows that most of the retrofitting measures related to insulation of the opaque envelope were ranked as the best. In contrast, measures that exclusively involved the installation of a photovoltaic system were identified as the worst. As also demonstrated by Kesavaperumal and Noguchi [51], priority should be given to the design of energy-efficient buildings through the optimal application of passive design strategies for ventilation and thermal comfort.

Regarding the evaluation model, it can be concluded that interpreting the results obtained from the analysis is simple. The division of the alternatives into categories is in their opinion very effective and clear in communicating the results. The weighting of criteria using the SRF method proved to be very easy for the expert group. In addition, the expert group did not find significant difficulties in profiling the categories for the different criteria considered in the analysis.

Table 6. Classification of the alternatives according to the priority level.

Building Typology	Construction Period	Priority	Building Typology	Construction Period	Priority
SFH	before 1919	Low priority	MFH	1961–1970	Medium priority
SFH	1919–1945	Medium priority	MFH	1971–1980	Medium priority
SFH	1946–1960	Low priority	MFH	1981–1990	Low priority
SFH	1961–1970	Medium priority	MFH	1991–2000	Medium priority
SFH	1971–1990	Medium priority	MFH	2001–2005	Medium priority
SFH	1991–2000	Low priority	MFH	after 2005	Medium priority
SFH	after 2005	Low priority	AB	before 1919	Low priority
TH	before 1919	Medium priority	AB	1919–1945	Medium priority
TH	1919–1945	Medium priority	AB	1946–1960	High priority
TH	1946–1960	Medium priority	AB	1961–1970	High priority

TH	1961–1970	Medium priority	AB	1971–1980	Medium priority
TH	1981–1990	Low priority	AB	1981–1990	Medium priority
TH	after 2005	Low priority	AB	1991–2000	Medium priority
MFH	before 1919	Low priority	AB	2001–2005	Medium priority
MFH	1919–1945	High priority	AB	after 2005	Low priority
MFH	1946–1960	High priority			

6. Conclusions

In response to the need for governments to allocate public financial resources, such as incentives, and financial rebates, based on principles of environmental sustainability, energy conservation, and human health protection, an MCDA-based evaluation framework was proposed to select the best energy retrofitting interventions of private residential buildings. The multi-criteria model considered the application of the ELECTRE TRI-B method and included three types of criteria: economic, environmental, and social. The framework was applied to classify a set of retrofit operations to a real case study in northern Italy; the Vanchiglietta neighborhood of Turin. The ELECTRE TRI-B method made it possible to sort retrofitting operations into categories and select those to be prioritized for funding, taking into account not only purely economic and energy criteria, but also visual impact constraints, and the benefits in terms of new jobs and drinking water savings.

The model was able to rank retrofit interventions for different classes of buildings categorized by type and era of construction. The model rewarded retrofit interventions for multifamily buildings (MFH) or apartments (AB) built between the years 1919 and 1960. These in fact are the most prevalent properties within the neighborhood under consideration and are more energy intensive. The worst actions were those that only involved installing a photovoltaic system, DH connection, and water savings solutions in recently constructed or historic buildings.

An essential component of project management, which aims to coordinate and complete tasks to achieve a predetermined goal, is the organization of resources. In a context such as the urban context, helping governments allocate resources, funding, and incentives in an optimized way becomes crucial when it comes to the typically widely diversified private residential stock. The model aims to support public decision-makers in the preliminary stages of design, considering different dimensions of sustainability to define orders of priority for intervention.

One of the advantages of the proposed framework is its feasibility and replicability. Indeed, the method is applicable not only in the case study considered but also in more complex management decision-making processes, e.g., involving a larger-scale system, such as regional and national. However, it could be necessary to adapt the procedure by defining new thresholds and criteria weights in order to have consistent and reliable results. Furthermore, with the change of scale, it will be necessary to involve different stakeholders (also non-technical actors) in the decision-making process, without diminishing the level of objectivity of the model. All these features also provide the possibility of integrating a methodological approach into the regulatory and management instruments regulated at the various institutional levels.

It would have been preferable to include rainwater harvesting solutions in the study to further reduce drinking water needs. However, the market penetration of these technologies is currently so low in the Italian context that its integration in a densely built context such as the one under consideration seems impossible. However, this does not detract from the possibility of including this measure in future transformation scenarios, along with more advanced power generation scenarios. In fact, the study currently considers actions that are easily implemented in the context under analysis. Moreover, the model is prepared for future research to provide prioritizations for interventions for clustering buildings to optimize the process of local community energy generation in relation to localization and building characteristics. With regard to the evaluation framework, future work may involve implementing other more sophisticated ELECTRE family methods, such as ELECTRE TRI-nC, considering other expert panel configurations, different levels for discrimination thresholds, and configurations of category boundaries.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflicts of interest.

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