A multi-criteria decision support method towards selecting feasible and sustainable housing renovation strategies

Abstract

This research presents a decision support method for housing managers to identify the most appropriate renovation strategy, which combines a multi-criteria assessment of ten renovation factors together with an economic feasibility analysis. In contrast to the majority of decision support systems, this method not only assesses the impact of the renovation proposals, but also includes and evaluates the management of the renovation process through a procedure of quantifying and weighting multiple social, technical, and economic variables related to the renovation work. The method, based on two representative cases of housing renovation projects in Sweden, has been designed and tested and is also applicable to other locations, multi-family buildings, and ownership models. Via a graphical display, the results show the impact generated during the work, the benefits obtained after the interventions, and the economic feasibility in different timeframes of each design strategy, which supports housing owners' decision-making and promotes feasible and suitable actions from a multidisciplinary approach. The conclusions highlight the possibility of implementing renovation strategies at various levels and provide policy implications of this method for a cleaner operation in the building sector with responsible management of urban regeneration by generating sustainable renovation rates and satisfactory proposals.

Keywords

Building renovation; Decision support method; Housing owners; Multi-criteria assessment; Multidisciplinary; Renovation strategies.

1. Introduction

European policies strive towards sustainable urban regeneration through the renovation of the existing building stock (European Commission, 2018). Recent reports point out the advanced age of existing residential buildings, and state that more than 40% of European housing stock is over 50 years old (Eurostats, 2019). The majority of these residential buildings require renovation actions at different levels, which justifies the demand of integral assessment models for effective and cleaner decision-making in building renovation to achieve the main goals of energy and greenhouse gas emissions (International Energy Agency, 2017).

At the same time, Europe has an increasingly ageing population: 18% of the population is over 65 years old and this proportion is expected to reach one third by 2050 (World Population Data, 2018). The benefits of a housing renovation are intended to satisfy all population groups in terms of improved quality of life, safety, and comfort (Bouzarovski et al., 2018), but the elderly require special variables and notations to be considered for their specific demands and preferences when choosing renovation actions (Kovacic et al., 2015).

Buildings in need of renovation tend to have higher opportunities for the implementation of energy-saving measures (Stieß and Dunkelberg, 2013), however, more and more studies state that the housing stock also requires many other interventions to comply with current requirements in terms of accessibility, safety, and comfort (Monzón and López-Mesa, 2018; Serrano-Jiménez et al., 2018). In recent years, several methods to support decision-making in renovation projects have been developed (Li et al., 2018), most of which focus on the result of the renovation, but few consider the impact of the process.

This research develops a multi-criteria decision support method, specifically designed for housing renovation, that evaluates and quantifies the multidisciplinary performance of various renovation strategies by including not only environmental and economic variables, but also technical and social parameters during the renovation process that could play a key role in choosing between different levels of renovation and ways of designing the renovation work.

The aim of the paper is to present this decision support method, its development, and its testing based on representative cases, and to discuss the main insights for the decision support in the building renovation field. The contributions of this method are focused on fulfilling the following research tasks: i) Design an open and flexible decision support method for the selection of appropriate renovation strategies for multi-residential buildings that is applicable in a variety of geographical contexts; ii) Identify multiple factors that should be included for the measurement of the impact of social and technical aspects of the renovation process; iii) Combine a multi-criteria impact/benefit analysis together with the return on investment of various renovation alternatives; iv) Communicate the results of the multidisciplinary assessment in a pedagogic manner in order to facilitate the decision-making process for housing managers.

The following sections present a literature review and subsequently the proposed decision support method, which enhances the set of variables and defines the way to quantify them in the multi-criteria assessment and feasibility analysis. Two representative case studies from Sweden are employed iteratively to develop and test the method, and four renovation strategies are compared. Finally, general conclusions and policy implications are discussed regarding the contributions of the decision support method for housing renovation.

2. Literature Review

Recent studies have claimed that, for an effective housing renovation, a multidisciplinary and integral approach should be assumed on the part of the housing owners, by including other social and economic parameters beyond the basic technical and environmental aspects (Bolis et al., 2017; Palermo et al., 2018). Liu et al. (2018) propose a cost-benefit method to evaluate factors relevant to the economic feasibility and the influence of the occupants' behaviour for various renovation proposals. Mangold et al. (2016) demonstrate that in-depth renovations could lead to negative social implications for vulnerable groups, and instead they propose a variation of different levels of action that includes partial renovations. Other studies highlight the importance of paying attention to the residents in order to be able to carry out a smooth renovation process, either by promoting good communication between the property owner and the residents or by acknowledging the worries caused by uncertainties related to the renovation process itself (Femenías et al., 2018). Furthermore, other research enhances the importance of considering the positive or negative visual effects that renovation work can have on the original building, with respect to architectural qualities and heritage values (Mujan et al., 2019).

Regarding existing procedures and tools for the improvement of decision-making, and as a challenge to achieve sustainable housing renovation (Pombo et al., 2016), certain models have considered different occupancy types and the influence of behavioural patterns of the agents involved in the design of effective and adjusted renovation proposals (Liang et al., 2016; Serrano-Jiménez et al., 2019). In the absence of official decision support directives, large variations of the proposed methods and applications can be found. Jensen and Maslesa (2015) incorporate the RENO-VALUE decision-making tool to evaluate the economic and environmental performance of renovation proposals that consider the interests of different stakeholders through the use of interview templates. Alberg Mosgaard et al. (2016) develop a comparative procedure to analyse the stakeholder constellations with respect to energy renovation projects by contemplating three different scenarios. Perera et al. (2018) state that multi-criteria decision-making appears to present a successful approach in the early decision stages for housing owners, by adjusting and combining different parameters for each renovation proposal in accordance with their interests. Finally, Riera Pérez et al. (2018) develop a multi-criteria comparison of three renovation proposals based on sustainability targets, but fail to consider other multidisciplinary variables.

Although all these studies have generated major advances in certain aspects for decision-making in building renovation, there remains a research gap in that most models do not value how the renovation is carried out in itself nor do they value other consequences for the property owners and residents derived from the work. In fact, Nielsen et al. (2016) reviewed numerous decision support procedures for building renovation and concluded that there are very few tools and systems to provide building owners with a broader assessment in order to prioritise and select renovation projects for their portfolio.

This paper fills this knowledge gap by including and measuring the combined impact and benefit of the social, technical, and economic parameters related to the renovation process, which would enable the most appropriate renovation strategy to be identified and decision-making to be focused on a cleaner and more sustainable production. The most valuable contribution of this research involves the incorporation of additional parameters related to the work process, such as duration of work, scale of interventions, relocation of residents, standard improvements, visual changes, and social concerns, none of which have been considered in other decision support systems. For a more process-oriented perspective on building renovation, there is an added contribution regarding how to quantify and graphically show the impact on the residents during the work process, the benefit acquired after renovation, and the economic feasibility in each timeframe.

3. Methodology

The multi-criteria decision support method has been developed through an iterative design process and is based on data and experiences from two on-going renovation projects in different residential neighbourhoods located in the city of Gothenburg, Sweden. The selected case studies incorporate representative parameters that correspond to the large existing housing stock in Sweden, where approximately 50% of the apartments in multi-residential buildings were built between 1941-1975 (Mjörnell et al., 2019). This situation is also reflected in the rest of Europe with a large stock of post-war housing (European Parliament, 2016). Furthermore, the representativeness of the neighbourhoods follows the established guidelines from the Swedish Association of Municipal Housing Companies (SABO, 2019). These case studies present two of the most communal building typologies: high-rise buildings and linear blocks, with significant shortcomings in their conservation status and regulatory non-compliance with current energy and comfort regulations, and whose public property owners need to carry out renovation actions in order to provide the best living conditions for their tenants. Both reference cases have been employed to verify, test, and simulate the proposed method.

3.1. Case studies

The two case studies comprise 700 apartments in total and are managed by owners of public property.

Case 1. Residential district, located in the northwest of Gothenburg, that was built in 1950 (Figure 1a). The neighbourhood consists of several lamellar three-storey buildings and of six-storey tower blocks reaching a total of 300 apartments.

Case 2. Residential area located in the south of Gothenburg that was built in 1961 (Figure 1b). The neighbourhood consists of four twelve-storey lamellar buildings. Each building is divided into four independent staircases and contains almost 100 apartments.

Tables 1 and 2 summarise the basic data, technical information, and building diagnosis for both cases obtained by ocular inspections and the data provided. Meetings and interviews with housing owners have facilitated the identification of needs and considerations related to the renovation process and have provided essential information for decisions to be made regarding influencing factors and variables to be taken into consideration in the decision support method.

In addition, the results of a "post-renovation" questionnaire were aimed at the residents in order to provide inputs to the proposed method. The results helped towards understanding the effects of the renovation work and residents' satisfaction with the finished renovation. The questionnaires contained 61 questions and were delivered to the residents' mailboxes, some of which were sent back to the researchers by mail. The response rate was 29% of a total of 392 apartments (Femenias et al., 2019).

a) Case 1 b) Case 2

Figure 1. Generic photos of the case studies in order to protect their anonymity. Photos: Authors.

Table 1. Basic data, characterisation, and diagnosis of the reference building in Case 1

BASIC DATA

	Year of construction	Apartments (reference building)	Storeys	% of elderly (area)	Annual rent (average)	Surface area per apartment (average)	Initial energy demand
Case 1	1950	18	6	23%	105€/m^2	64m^2	198kWh/m^2

CHARACTERISATION

Envelope	Systems
Façade: Solid brick wall, air cavity, insulation, interior brick partition, and gypsum board.	Heating: Central heating and water radiators.
Roof: Ceramic tile cover, cement mortar layer, insulation, mortar slope formation, concrete slab.	Windows: Wood frames, thermal break and double glazing.
Floor: Concrete slab, ceramic flooring bonded with cement mortar.	Ventilation: Passive ventilation.
Interior partitions: Hollow brick partition with gypsum boarding.	Domestic hot water: Central heating.

DIAGNOSIS

Technical status	Deteriorated and damaged status. Many fissures and damp areas in the façade. Outdated technical systems, such as heating, pipes, and radiators.
Dwelling layout	Confined original dimensions in the rooms and a particularly small bathroom and kitchen.
Outdoor and indoor accessibility	Limited access to the entrance. Absence of a lift. Inadequate accessibility conditions inside the apartments.
Thermal performance	The transmittance values and the energy demand are very high compared to the energy requirements.
Maintenance	During the last 15 years, hardly any action has been taken. There is a general lack of maintenance.

Table 2. Basic data, characterisation, and diagnosis of the reference building in Case 2

BASIC DATA

	Year of construction	Apartments (reference building)	Storeys	% of elderly (area)	Annual rent (average)	Surface per apartment (average)	Initial energy demand
Case 2	1961	24	12	18%	95€/m^2	69m^2	164kWh/m^2

CHARACTERISATION

Envelope	Systems
Façade: Prefabricated concrete panel, air cavity, insulation, interior gypsum board.	Heating: Central heating and water radiators.
Roof: Galvanised metal sheet, insulation, mortar slope formation, concrete slab.	Windows: Aluminium frames, thermal break and double glazing.
Floor: Concrete slab, ceramic flooring bonded with cement mortar.	Ventilation: Mechanical ventilation.
Interior partitions: Lightweight walls with gypsum boarding.	Domestic hot water: Central heating.

DIAGNOSIS

Technical status	Building with an acceptable technical status. Several imperfections and deterioration.
Dwelling layout	There is a lack of suitability especially in the bathroom and an oversized storage room.
Outdoor and indoor accessibility	There are a few problems in accessing the entrance and the use of certain rooms, such as the kitchen and bathroom.
Thermal performance	An improvement is required of the thermal envelope and heating radiators and pipes need replacement.
Maintenance	The roof, façade, and windows were renovated 15 years ago.

3.2. The proposed decision support method

Figure 2 illustrates a general outline of the method that involves the following stages: status report, renovation strategies, multi-criteria assessment, and feasibility analysis before decision-making. One of the main contributions of this model for decision-making with respect to other models is that the performance of each renovation strategy can be assessed and weighted independently for all the influencing factors defined and can be combined with a complementary economic feasibility analysis of the return on investment.

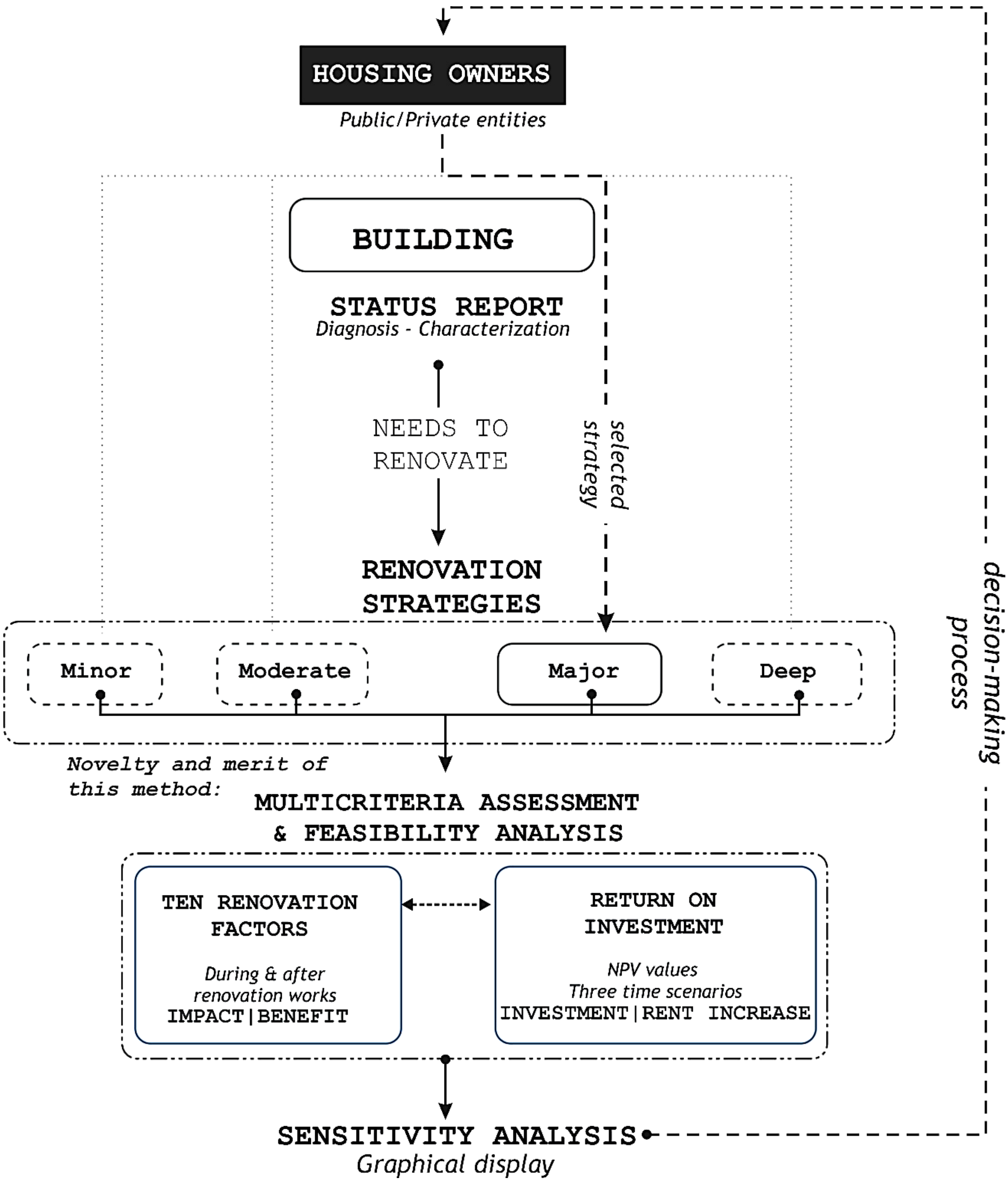

Figure 2. General outline of the multi-criteria decision support method.

3.2.1. Status report

Firstly, the method requires general information on the building that is about to be renovated: demographic data of the residents (age and income groups); rent levels; characteristics of the original construction; diagnosis on any damage; dwelling layout; accessibility conditions; thermal performance; and maintenance plans. This data, gathered from official inspection procedures (AENOR, 2015; Boverket, 2016), historical documents, statistics, meetings, and interviews with the residents and the owners, generates a complete report of the building status.

3.2.2. Renovation strategies

Based on the status report, various renovation proposals are designed to comply with building regulations and demands. These proposals are embedded in different renovation strategies with a certain number of actions, which can be altered depending on each case. The renovation strategies represent different levels of renovation, from a few actions to an in-depth renovation that could require residents' relocation during the renovation. The criteria for grouping the renovation proposals into different strategies are flexible and depend on each urban and socio-economic context from different countries. Several guiding renovation and economic parameters from the Swedish context have been defined for each strategy, based on previous renovation databases and studies (Farahani et al., 2018; Lind, 2014). The main indicative renovation strategies are:

Minor. Covering renovation proposals with investment costs of less than 100,000€ or 200€/m^2. The interventions are usually carried out outside the individual dwellings: either on the envelope or in the communal outdoor areas. The renovation process does not interfere with the residents and the normal use of the apartments.

Moderate. Investment cost between 100,000€ and 300,000€ or between 200€/m^2 and 500€/m^2. The interventions are usually carried out outside or in the communal areas of the building, although specific operations inside the apartments can also be included. The renovation slightly interferes with residents and the normal usage of the apartments.

Major. Strategy that considers renovation proposals with an investment cost between 300,000€ and 500,000€ or between 500€/m^2 and 1,000€/m^2. Global interventions, such as actions that affect the entire building envelope, are considered on the building envelope and in communal areas and can also include considerable changes inside the apartments. The work process of these actions significantly interferes with the residents' daily use and could limit the private use of the apartment for short periods and entail the relocation of physically vulnerable residents.

Deep. Strategy that covers renovation proposals with an investment cost over 500,000€ or more than 1,000€/m^2. Integral refurbishment actions are considered across the whole building. The work is intense and would require the relocation of residents for a period.

3.2.3. Multi-criteria assessment

This model incorporates numerous quantitative and qualitative variables both during and after the renovation work, which have been organised into diverse influencing factors proposed for the decision support method. These multidisciplinary variables not only correspond to those considered by industrial standards, but also include other social, economic, and constructive variables obtained from the results of discussions with housing managers and responses from the questionnaire, which have shown that housing renovation is a complex process that generally causes discomfort and inconvenience for the occupants. These ten proposed factors contribute towards other research studies with multidisciplinary notations and an extension of certain factors during and after the renovation work, such as standard improvements, visual changes, social concerns, and relocation, along with an economic feasibility analysis based on the return on investment which would allow more feasible strategies to be adjusted for each context.

The ten factors, related to the technical, social, and environmental fields, evaluate the impact and benefit of each strategy during and after the renovation work. These factors are: duration, scale, technical complexity, relocation, social concerns, noise and nuisance, waste production, energy reduction, standard improvements, and visual changes. Different quantitative and/or qualitative variables are obtained from industrial standards, regulations, interviews (knowledge in use/practice by property managers), other research studies, or general knowledge regarding housing renovation (AENOR, 2015; Boverket, 2016).

All these factors are weighted independently for the comparison and selection of the most significant valuations according to the various circumstances, and are grouped into different subsections in order to assume a comprehensive approach to the impact or benefit. Table 3 gathers the variables of each factor, and presents the weighting procedure for obtaining normalised values in a 0-10 range. The calculations are mainly based on assigning a score for each variable (x) in relation to its possible maximum score (x_{max}). The factors are defined as follows:

Duration is the total time needed to carry out the renovation work. The duration is measured from the start of the physical intervention in terms of a number of weeks, months, or years. For this variable, the expected time is weighted (w_{f1}).

Scale defines the size of the interventions and the place where the renovation actions are carried out, and distinguish between outdoor spaces, indoor communal spaces, and inside the apartments. For its evaluation, the results are weighted (w_{f2}) based on three degrees of action: precise, partial, and total.

Technical complexity assesses the renovation work according to the construction techniques and the level of complexity in each architectural element. The elements of the building are grouped as: interior partitions and room distribution (including bathroom and kitchen), technical systems (ventilation and air-conditioning), vertical communication core (staircase and lift), building envelope (façade, windows and roof), and structure and foundation. An evaluation of the elements, techniques and complexity is carried out and a final weighted value (w_{f3}) is obtained.

Relocation assesses the impact of the residents' relocation or the restricted access to certain communal or private services or rooms during the renovation work. Various scenarios are considered regarding complete relocation, or temporarily disabled spaces are considered, and a final value is weighted (w_{f4}).

Social concerns measure the residents' perception of the renovation with respect to uncertainty regarding the renovation process, the possible effect on the private economy from a rent increase, and the quality of the information and communication plan. Various situations are taken into account and a final value is obtained (w_{f5}).

Noise and nuisance from the renovation that will affect the residents, such as dust, loud banging, and drilling during the renovation work. This factor focuses on recognising the type of noise, dirt, loud knocking, and drilling and how often they occur, in order to attain a final weighted value (w_{f6}) according to the set of actions.

Waste production values the volume and weight of waste materials generated during the renovation process. The ranges that are defined have been limited based on specific databases and studies (WBDG, 2018). Both volume and weight are weighted equally and a total weighted value is obtained (w_{f7}).

Energy reduction assesses the reduction of operational energy demand in kWh/m^2 as a percentage for each renovation strategy. These values can be obtained by using energy simulation tools. The ranges defined in Table 1 are delimited by the official procedure ("DOE2", 2017). The energy reduction is measured from its original state to after the renovation, and a weighted value for the reduction and percentage (w_{f8}), is obtained.

Standard improvements assess the increase in quality as compared to the initial state of the building in the form of different scores regarding design (D), accessibility (A), safety (S), and indoor comfort (I). The standard improvement factor also considers whether the renovation improvements have a permanent, seasonal, or occasional benefit according to the service, use, and operation for the residents in their daily life. The set of variables are weighted in a final value (w_{f9}).

Visual changes value the positive or negative effect on the exterior changes with respect to architecture, aesthetics, and heritage. This factor is a qualitative assessment of changes with respect to the original architecture, local building tradition, and preservation programme. The quantification of this factor may be positive (benefit) or negative (impact) depending on the final result, the type of changes, and the patrimonial protection of the building. A weighted value is obtained (w_{f10}) as the final result.

Table 3. Factors, variables, and weighting expressions of the multi-criteria assessment.

FACTOR	VARIABLES	WEIGHTING
1.Duration *(impact)*	-Time: [1] <1 week; [2] 1-4 weeks; [3] 5-8 weeks; [4] 3-4 months; [5] 5-6 months; [6] 7-9 months; [7] 10-12 months; [8] 1-2 years; [9] > 2 years.	$w_{f1} = \frac{x}{x_{max}} * 10$
2.Scale *(impact)*	-Outside (O); Indoor communal spaces (CS); Inside apartments (I): [1] Precise; [2] Partial; [3] Total.	$w_{f2} = \frac{\sum(x_O, x_{CS}, x_{IA})}{\sum x_t} * 10$
3.Technical complexity *(impact)*	-Elements involved: [a] Interior partitions and room distribution. [b] Technical systems. [c] Vertical communication core. [d] Building envelope. [e] Structure and foundation. -Techniques: [P] Prefabricated construction. [S] On-site components. -Complexity: [1] Low; [2] Medium; [3] High.	$w_{a,b,c,d,e} = \frac{\sum x * n_i}{x_{max} * n_t} * 10$ - - - - - - - - - - - - - - - $w_{f3} = \frac{\sum(w_{a,b,c,d,e})}{\sum w_t} * 10$
4.Relocation *(impact)*	-No relocation: [a] Limited uses. [b] Temporarily restricted access to building envelope. [c] Temporarily restricted access to communal spaces. [d] Temporarily restricted access to apartment rooms. [e] Temporarily restricted access to technical infrastructure. -Yes. Period: [1] <1 week; [2] 1 week-1 month; [3] 1-3 months; [4] 3-6 months; [5] Over 6 months.	*No:* W_{f4} *= 0-5* → $\bar{x}[a,b,c,d,e]$ *Yes:* W_{f4} *= 5-10* → x=*[time]*
5.Social concerns *(impact)*	-Perceptions: [a] Uncertainty in the process. [b] Rent increase. [c] Quality of the information and communication plan. -Impact: [0] No impact - [5] High impact	$w_{f5} = \frac{\sum x * n_i}{x_{max} * n_t} * 10$
6.Noise and nuisance *(impact)*	-Perceptions: [1] Minimum nuisance. [2] Occasional noise and dust. [3] Noise and dust but no drilling. [4] Noise, dust, and drilling. [5] Constant noise, a lot of dust, and little drilling. [6] Constant loud noise, dust, and drilling.	$w_{f6} = \frac{\sum x * n_i}{x_{max} * n_t} * 10$
7.Waste production *(impact)*	-Volume(m^3): [a] 1-5; [b] 5-10; [c] 10-20; [d] 20-30; [e] 30-50; [f] 50-100; [g] 100-200; [h] Over 200. -Weight(tonnes): [1] 1-5; [2] 5-10; [3] 10-20; [4] 20-30; [5] 30-50; [6] 50-100; [7] 100-200; [8] Over 200.	*volume = 0-5* → $\frac{x}{x_{max}} * 10$ *weight = 0-5* → $\frac{x}{x_{max}} * 10$ $w_{f7} = volume + weight$
8.Energy reduction *(benefit)*	-kWh/m^2 reduced after renovation: [a] 1-5; [b] 5-10; [c] 10-20; [d] 20-30; [e] 30-50; [f] 50-70; [g] 70-100; [h] Over 100. -% reduced with respect to the original state: [1] 1-5; [2] 5-10; [3] 10-20; [4] 20-30; [5] 30-40; [6] 40-50; [7] 50-70; [8] Over 70%.	*kWh/m^2 = 0-5* → $\frac{x}{x_{max}} * 10$ *% = 0-5* → $\frac{x}{x_{max}} * 10$ $w_{f8} = kWh/m2 + \%$
9.Standard improvements *(benefit)*	-(D)esign; (A)ccessibility; (S)afety; (I)ndoor comfort: Impact: [1] Low; [2] Medium; [3] High. -·Frequency: [a] Occasional; [b] Seasonal; [c] Constant.	$w_{f9} = \frac{\sum(x_D, x_A, x_C, x_S)}{\sum x_t} * 10$
10.Visual changes *(impact/benefit)*	-Visual modification; heritage values: +/- [1] Low; +/- [2] Medium; +/- [3] High.	$w_{f10} = \frac{\sum(x_O, x_{CS}, x_I)}{\sum x_t} * 10$

3.2.4. Feasibility analysis

The property owners or the tenants also require an economic assessment of the renovation process in order to make decisions according to their specific interests. This multi-criteria assessment method is therefore complemented by a feasibility study that thoroughly evaluates the return on investment and economic trend of each renovation strategy based on the investment cost, the rent income, and other economic flows such as energy reduction and maintenance costs. The total economic reinvestment of each strategy is measured by the Net Present Value (NPV). This concept considers the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The NPV is evaluated according to equation [1], where a is the year of operation, r the discount rate, and C_f the annual cash flow (in-out).

$$NPV = \sum_{1}^{a} \frac{C_f}{(1+r)^a} \qquad [1]$$

The annual cash flow (C_f) is calculated as a function of the renovation investment cost, the increased rent after the renovation, the maintenance cost per year, and the annual economic savings due to the reduction in energy use. The increased rent should consider both the increase because of the location and the extra increase due to the renovation work. This factor also highly depends on the number of apartments in each renovated building. The year of operation (a) in the calculation of the NPV usually defines three different timeframes to assess the feasibility in each period: short, medium, and long term, established as 5, 15, and 30 years, respectively. Lastly, the discount rate (r) is used in discounted cash flow analysis to determine the present value of future cash flows. The determination of this value depends on the economic trend of each region (Short et al., 2005). This economic evaluation therefore provides the housing owners with economic information complementary to the multi-criteria assessment obtained, which can determine the final decision of renovation proposals.

The application of this economic analysis in the two cases has quantified the investment-reinvestment profitability within three different timeframes, short (5 years), medium (15 years), and long term (30 years). The percentages of rent increase, through gradual incrementation over the first 15 years, have been set in accordance with standard practice in Gothenburg (Hyresgastforeningen, 2018; SABO, 2019). This information is gathered from various interviews held with property owners regarding their real experience.

4. Results and analysis

This section presents the results of testing the method in each of the case studies. The renovation strategies are analysed through the proposed method (Figure 1) for the two case studies in order to evaluate their multi-criteria performance and economic feasibility. The actions of each strategy can be adapted to each renovation and can comprise the following actions:

Minor: 1| Repair exterior cracks, fissures, and damp patches on façades; 2| Seal window frames; 3| Repair drainage pipes and damaged parts of the roof; 4| Improve entrance portal accessibility with a ramp; 5| Adapt the main access door.

Moderate: 1| Implement exterior EPS-insulation and repair the façade and roof; 2| Replace windows; 3| Adapt accessibility of the portal access; 4| Renovate bathroom.

Major: 1| Implement exterior insulation and repair the façade and roof (EPS); 2| Replace windows; 3| Install or replace lift; 4| Completely adapt portal access; 5| Renovate bathroom and kitchen; 6| Replace central heating, radiators, and pipes.

Deep: 1| Implement exterior insulation and repair the façade and roof (EPS); 2| Replace windows; 3| Install or replace lift; 4| Completely adapt portal access; 5| Renovate bathroom and kitchen (fixtures and fittings, and finishing); 6| Improve room redistribution; 7| Replace ventilation and central heating (radiators, pipes, and ventilation ducts). Deep strategy involves the relocation of the residents for several months, and hence the costs and the impact must be considered in the subsequent analysis.

4.1. Multi-criteria assessment

The results obtained for the four renovation strategies for each of the ten factors are presented in Tables 4 and 5 and Figures 3 and 4, and are in accordance with the weighting variables defined in Table 3. With help from the graphical display of the results, the calculated impact and benefit for each factor can be illustrated and renovation strategies can be evaluated according to the different interests of property owners and residents.

Table 4. Multi-criteria assessment of Case 1

	MINOR	MODERATE	MAJOR	DEEP
Duration	1-4 weeks	3-4 months	7-9 months	10-12 months
	2.2	*4.4*	*6.7*	*7.8*
Scale	O:2 CS:n.a. I:-	O:3 CS:n.a. I:1	O:3 CS:1 I:2	O:3 CS:2 I:3
	2.2	*4.4*	*6.7*	*8.9*
Technical complexity	a:- b:- c:S1 d:S1 e:-	a:S1 b:- c:S1 d:S1 e:-	a:S2 b:P2 c:S3 d:S2 e:S3	a:S3 b:P2 c:S3 d:S2 e:S3
	1.3	*2.0*	*7.7*	*8.4*
Relocation	No. Limited uses	No. Disabled spaces [b,d]	No. Disabled spaces [b,d,e]	Yes. 1-3 months
	1.0	*2.0*	*3.0*	*8.0*
Social concerns	a:1 b:1 c:2	a:3 b:2 c:2	a:4 b:4 c:3	a:5 b:5 c:4
	2.7	*4.7*	*7.3*	*9.3*
Noise and nuisance	Occasional noise	Noise and no drills	Constant noise and little drilling	Occasional noise
	3.3	*5.0*	*8.3*	*1.7*
Waste production	1-5m^3 5-10t	10-20m^3 20-30t	30-50m^3 50-100t	50-100m^3 100-200t
	1.9	*4.4*	*6.9*	*8.1*
Energy reduction	5-10kWh/m^2 4%	30-50kWh/m^2 32%	70-100kWh/m^2 48%	Over 100kWh/m^2 55%
	1.9	*6.3*	*8.8*	*9.3*
Standard improvements	D:1c A:1b S:1a I:-	D:2c A:2b C:2c I:1b	D:3c A:3c C:3b I:3b	D:3c A:3c C:3b I:3c
	1.9	*5.0*	*8.8*	*9.4*
Visual changes	O:+1 CS:0 I:0	O:+3 CS:+1 I:+1	O:+3 CS:+2 I:+2	O:+3 CS:+2 I:+3
	1.1	*5.6*	*7.8*	*8.9*
OVERALL SCORE	Impact | Benefit (14.6/70) | (4.9/30) **21% | 16%**	Impact | Benefit (26.9/70) | (16.9/30) **38% | 56%**	Impact | Benefit (46.6/70) | (25.4/30) **67% | 85%**	Impact | Benefit (52.2/70) | (27.6/30) **74% | 92%**

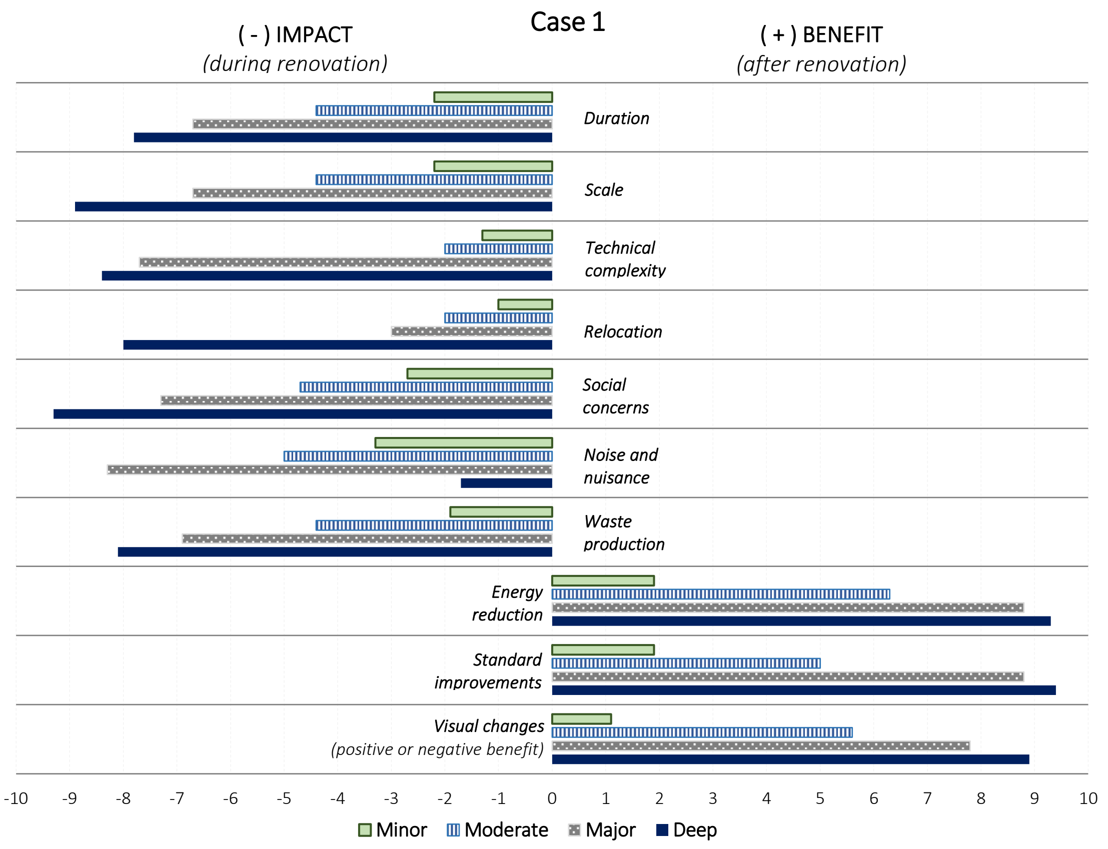

Figure 3. Graphic performance of each renovation strategy in Case 1.

Table 5. Multi-criteria assessment of Case 2

	MINOR	MODERATE	MAJOR	DEEP
Duration	5-8 weeks	5-6 months	10-12 months	1-2 years
	3.3	*5.5*	*7.8*	*8.9*
Scale	O:2 CS:- I:-	O:3 CS:- I:1	O:3 CS:1 I:2	O:3 CS:2 I:3
	2.2	*4.4*	*6.7*	*8.9*
Technical complexity	a:- b:- c:S1 d:S2 e:-	a:S2 b:- c:S1 d:S3 e:-	a:S2 b:P3 c:S1 d:S3 e:S1	a:S3 b:P3 c:S1 d:S3 e:S1
	2.0	*4.0*	*6.2*	*6.8*
Relocation	No. Limited uses	No. Disabled spaces [b,d]	No. Disabled spaces [b,c,d,e]	Yes. 3-6 months
	1.0	*2.0*	*4.0*	*9.0*
Social concerns	a:1 b:1 c:2	a:2 b:2 c:2	a:3 b:4 c:3	a:4 b:5 c:4
	2.7	*4.0*	*6.7*	8.7
Noise and nuisance	Minimum nuisance	Noise and no drilling	Constant noise and little drilling	Occasional noise
	1.7	*5.0*	*8.3*	*1.7*
Waste production	5-10m^3 5-10t	20-30m^3 20-30t	50-100m^3 100-200t	100-200m^3 100-200t
	2.5	*5.0*	*8.2*	*8.8*
Energy reduction	1-5kWh/m^2 3%	30-50kWh/m^2 28%	50-70kWh/m^2 42%	70-100kWh/m^2 48%
	1.2	*5.6*	*7.5*	*8.8*
Standard improvements	D:- A:1b C:- I:-	D:2c A:2b C:1c I:1b	D:3c A:2b C:3b I:3b	D:3c A:2b C:3b I:3c
	0.4	*4.4*	*7.5*	*8.1*
Visual changes	O:+1 CS:0 I:0	O:+2 CS:+1 I:+1	O:+2 CS:+1 I:+2	O:+2 CS:+1 I:+3
	1.1	*4.4*	*5.6*	*6.7*
OVERALL SCORE	Impact | Benefit (15.4/70) | (2.7/30) **22% | 9%**	Impact | Benefit (29.9/70) | (14.4/30) **43% | 48%**	Impact | Benefit (47.9/70) | (20.6/30) **68% | 69%**	Impact | Benefit (52.8/70) | (23.6/30) **75% | 79%**

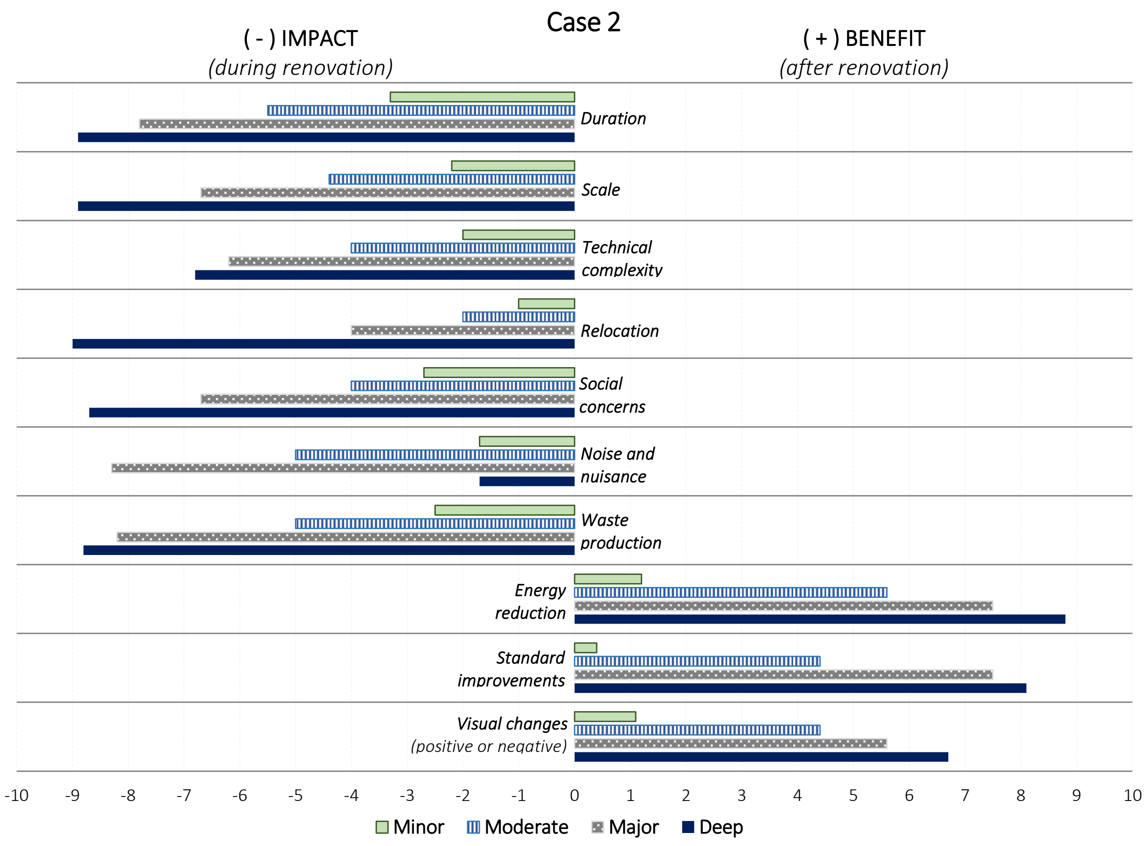

Figure 4. Graphic performance of each renovation strategy in Case 2.

The diagrams of the results (Figures 3 and 4) show the impact on the left and benefit on the right, for all 4 strategies. The usefulness and merit of displaying the results in this way is that housing owners can independently assess the performance of specific factors as well as consider the overall score obtained.

The results demonstrate that intense levels generate higher negative impact during the renovation work while simultaneously bringing greater benefits after renovation. In both cases, the minor renovation strategy shows lower benefit values but also low impact during the renovation, which might be suitable for specific adjustments with a short-term perspective. The moderate strategy generates a balance regarding benefit and impact during the renovation process, and is appropriate for a medium-term perspective. Finally, the major and deep strategies introduce extensive renovation, with major improvements for the building and benefits for the residents, although with a large impact during the renovation work itself.

However, there are significant variations in the partial and overall scores in the assessment of the two neighbourhoods since they depend on many factors, including those of building typology, conservation status, and occupant behaviour. By focusing on the results of Case 1, it can be observed that certain action strategies generate greater benefits by improving the accessibility and the building envelope, without compromising visual architectural details. In addition, there is a much higher technical complexity impact in major and deep strategies, mainly due to the installation of a lift and to kitchen and bathroom renovation. Finally, the poor thermal performance of the original envelope, mainly related to the composition of the façade and windows, justifies that moderate, major, and deep strategies are highly beneficial for energy reduction. Regarding Case 2, the large size of the building implies a longer duration of work and greater waste generation, although there are already lifts that simply require replacement, thereby making their renovation work less complex.

Lastly, substantial differences are observed in the display of results in Figures 3 and 4 for the same renovation strategy depending on the reference building, which allow housing owners to detect the main particularities and design the proposals to reduce the impact of certain factors prior to starting renovation work. It is also observed that there are several important factors, such as visual changes, standard improvements, and technical complexity, whose scores vary widely according to the building typology, especially regarding the size, the building materials, and the previous accessibility, safety, and comfort conditions. Furthermore, this study provides evidence that the way to manage the renovation work influences social concerns regarding the quality of the information provided prior to and during the renovation. It is also shown to influence the trust built up between tenants and housing owners in order to communicate the aim of the renovation, and how they can deal with the potential increased living costs.

4.2. Feasibility analysis

Table 6 shows the NPV results for each strategy for the short, medium and long term. The total investment costs, which have been budgeted according to a real measurement of each reference building from the national price database (SABO, 2019), have also been considered, as have the annual maintenance costs after renovation. For their calculation, a discount rate of 5.5% has been used, in accordance with current economic studies in the Swedish case (Lind, 2014). An annual rent increase has also been taken into account according to the location in the city and its prospects of revaluation (Hyresgastforeningen, 2018). The NPVs that exceed 0€ indicate that there is an economic benefit for the owners following the completion of the renovation project.

Table 6. Economic assessment of the two case studies for the four renovation strategies.

	MINOR	**MODERATE**	**MAJOR**	**DEEP**
CASE 1				
Renovation investment (€)	82,100	169,270	352,270	584,670
%rent increase	7.5%	18%	30%	45%
NPV: Short term (€) *5 years*	-70,975	-145,925	-315,700	-533,000
NPV: Medium term (€) *15 years*	-35,500	-58,500	-170,100	-317,000
NPV: Long term (€) *30 years*	-9,825	27,200	-17,050	-82,150
CASE 2				
Renovation investment (€)	75,600	179,650	377,650	678,700
% rent increase	7.5%	18%	30%	45%
NPV: Short term (€) *5 years*	-61,350	-150,525	-331,650	-613,000
NPV: Medium term (€) *15 years*	-14,100	-37,250	-143,100	-332,650
NPV: Long term (€) *30 years*	24,700	78,000	59,400	-23,500

The results from Figures 5 and 6 contribute towards the identification of the economic performance, the trends, and the evolution of each renovation strategy in the two cases. This diagram complements the multi-criteria assessment as a way of examining the economic profitability. The economic line of each strategy marks the viability of the proposal. Therefore, it is useful to complement this economic evaluation with a sensitivity analysis where the payback period of each strategy is displayed.

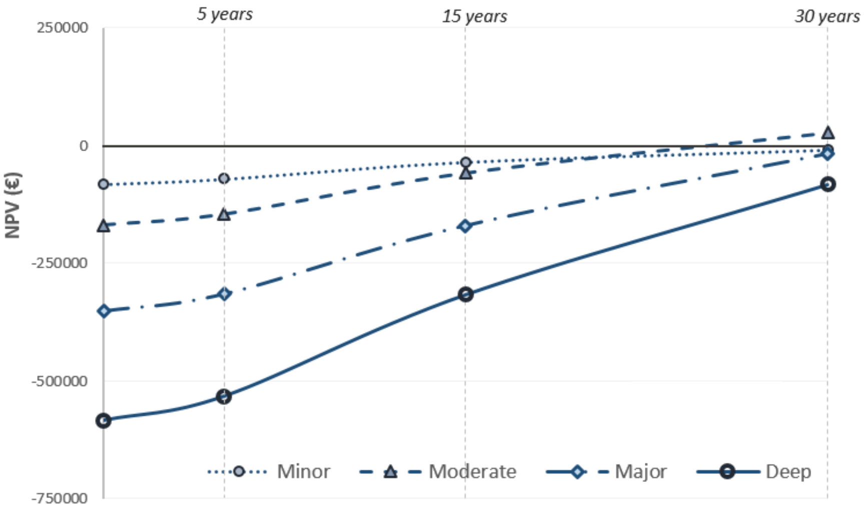

Figure 5. Economic performance, Net Present Value, of each renovation strategy in Case 1.

Figure 6. Graphic performance of each renovation strategy in Case 2.

According to these results, the minor strategy shows a horizontal trend, and, in certain cases, it fails to reach the 0 level that is necessary to cover the investment. However, there is no economic risk because the investments are low. The moderate strategy presents a medium-term reinvestment period, generally between 15 and 20 years, and it involves a secure investment that is compatible with moderate benefits. The major strategy has a high recovery trend and offers payback periods between 15 and 30 years, and may even exceed 30 years. Lastly, the deep strategy, which considers the residents' relocation in order to reduce negative impacts during the work, presents the greatest recovery trend, but needs long periods of over 30 years to start making a profit.

On comparing these two neighbourhoods, it is observed that in Case 1 the return on reinvestment is lower than that in Case 2, mainly because the costs are covered by a lower density of buildings and a smaller number of residents. It can be deduced that housing areas with a higher occupation density are more profitable when financing integral actions.

This feasibility analysis can also facilitate housing owners or other stakeholders in managing the renovation of the housing stock by providing clear information on the return on the investment in each socio-economic context, which in turns helps in deciding which renovation strategy is the most suitable in terms of economic profit and of timeframe in which to recover the investment. In the case of lesser strategies, the benefits are lower and it may also be necessary to repeat certain work, while in the case of intense strategies, housing owners have to consider the percentage of ageing population, the socio-economic level of the occupants, and the tenants' willingness to cover the costs.

As an overall discussion, the results obtained show the existing duality between generating the least possible impact during the renovation work and providing the greatest benefit after the renovation. The model demonstrates that any renovation strategy introduces an impact or a benefit for many variables that are highly dependent on the renovation effects and economic interests. Therefore, the application of the method and the performance obtained in each case highlights the importance of the building typology, the design of the renovation strategies, and the potential increased rental rates, by demonstrating that each renovation project requires an integral assessment in its early design stage.

Lastly, the scope of application of this method can be extended to a wide range of geographic locations, multi-family building typologies, and ownership models. The design of the method enables its adaptation to various conditioning factors, whereby it is possible to extend or reduce this method according to each context without altering its operation. In fact, instead of assessment methods focused on a single discipline or from a single perspective, an application of this method to certain case studies used in the literature review would provide useful information regarding the impact of renovation work and the payback periods, especially in the work carried out by Liu et al. (2018), Perera et al. (2018), and Riera-Pérez et al. (2018), which would lead to greater optimization for the selection of renovation strategies.

5. Conclusions

This multi-criteria decision support method introduces a new multidisciplinary approach to support housing owners in their evaluation and selection of renovation strategies or renovation levels. This method extends beyond industrial practices and, with respect to other decision support systems, contributes new implications regarding how to include and measure the combined impact or benefit of multiple parameters related to the renovation process itself. The novelty of this method is that a multi-criteria assessment is carried out while including social and technical factors related to the renovation work, such as duration, technical complexity, relocation, noise and nuisance, social concerns, standard improvements, and visual changes.

One of the main contributions and merits of this method with respect to other assessment models of housing renovation is that it combines a quantification of the impact, both during and after the renovation work, together with an economic feasibility analysis based on the return on investment in different timeframes, thereby providing owners and promoters with a multidisciplinary report of each strategy for the appropriate choice. The method facilitates decision support for housing owners by quantifying the effect of renovation strategies, organised into ten influencing factors, in order to discuss the impact on certain variables and to guarantee greater satisfaction in the work execution. Furthermore, the model contributes with a particular way of weighting and displaying the results which enables the most appropriate renovation strategy to be identified for each context. This provides an appropriate system: to facilitate discussions with residents and other stakeholders; to show the social, technical, environmental, and economic consequences for policy makers; and to introduce new implications towards promoting a more efficient housing renovation.

The usefulness of this research is that it demonstrates that cleaner and more sustainable management of housing renovation requires new assessment models and a graphical display of results that incorporate multidisciplinary information from social, technical, environmental, and economic disciplines. New mechanisms for practical perspectives and policy implications for a cleaner operation in the built environment are introduced herein, with an easy-to-understand overview of how different aspects interfere in the final performance, which strives to offer the results in a pedagogic manner in order to facilitate decision-making. The model extends beyond that which is promoted by European guidelines, which implement deep renovations, by establishing renovation strategies at various levels and with different timeframes that provide short-, medium- and long-term solutions.

Finally, the proposed method focuses on its main weakness: that of dependence on the active participation of users and housing owners to collect data, demands, and interests to obtain a multi-criteria assessment and discussion for decision-making. Future research therefore needs to continue improving and adjusting participatory procedures and assessment tools for new decision support methods involving a variety of agents, from housing owners to residents. Therefore, subsequent studies should further develop this model with respect to additional environmental factors, different ownership models, and other new technical and social factors, in order to validate decision-making in relation to any housing context and renovation demand.

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