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Ensuring proper management of building renovation based on an optimised decision-making model: Application in schools and social housing from southern Europe.

A Serrano-Jiménez[1,2*], C Díaz-López[1,4] Á Barrios-Padura[1,2] and M Molina-Huelva[2,3]

[1] Department of Building Construction I. University of Seville. Reina Mercedes 2. 41012. Seville (Spain).
[2] Institute of Architecture and Building Science (IUACC). University of Seville. S Reina Mercedes 2. 41012. Seville (Spain).
[3] Department of Building Structures. University of Seville. Reina Mercedes 2. 41012. Seville (Spain).
[4] Department of Building Construction. University of Granada. Severo Ochoa 1. 18071. Granada (Spain).

[*]E-mail: *aserrano5@us.es*

Abstract. One of the main challenges for architects and technicians is the efficient management of the built environment, in response to the growing deterioration and obsolescence in the building stock. This research introduces the design, development and application of a novel decision support system that assesses the multidisciplinary advantages or disadvantages of different intervention strategies, mainly focused on schools and social housing. The concept of the model aims to gather, interrelate and weight different renovation factors and variables, according to technical, social, energy and economic parameters, quantifying results on the impacts, consequences and benefits of each renovation strategy and providing practical outcomes in the design, construction, management and maintenance stages. This study uses schools and multi-family buildings, located in southern Europe, to apply and test the system iteratively in both building typologies, serving to adjust the calculation model and demonstrate its operation and replicability. The results are classified according to different intensity levels with their corresponding design alternatives along with a graphical output of results for decision-making. This model is expected to contribute to policy-making by introducing new theoretical and practical renovation guidelines, with a rational adjustment of proposals and ensuring effective and feasible action strategies in the built environment.

Keywords: building stock, decision support system, building renovation, schools, social housing.

1. Introduction

One of the main urban challenges, on a global and European scale, is based on guaranteeing an efficient and sustainable regeneration of the building stock, through the identification of appropriate action levels that ensure the satisfaction and feasibility of renovation works in each context, improving the quality of life of an increasingly ageing population in the built environment [1,2]. In Europe, building renovation acquires a key role since more than 40% of existing buildings are older than 50 years, not only in housing building typologies but also in public uses, such as schools, in which more than 60% were built before 1980 [3]. This background increases the need to design new multidisciplinary assessment systems for urban regeneration and building renovation strategies, from different disciplines, that qualify and quantify the suitability of actions in the housing stock or in schools under a rationalised process [4].

Recent research studies highlight the importance of integrating social and economic criteria, together with the essential technical field, to assess efficiently the different alternatives in renovations works [5]. Moghtadernejad et al. [6] enhanced the usefulness of multi-criteria decision-making methods for architects and technicians and introduced a particular model particularly applied to façades. Riera-Pérez et al. [7] introduced a multi-criteria approach to compare different urban renewal scenarios with a graphical display of results as a mechanism that contributes to facilitate decision-making in building renovation. Serrano-Jiménez et al. [8] incorporated a specific accessibility assessment procedure for social housing with elderly occupants by using a weighting model to quantify the suitability of mobility actions through appropriateness, priority and feasibility indices. Finally, Olsson et al. [9] introduced a new approach for assessing renovation measures in order to identify appropriate target levels in early project stages for administration, giving an effective way to evaluate different strategies and introducing the factor of consequence for its valuation.

Although there are numerous research studies applied to residential use in the initial stages, there is a lack of support systems for decision-making, based on multi-assessment models, that allow flexibility and openness to adapt and be transversal to the different building uses, such as schools, that belong to public administration under different socioeconomic contexts [10]. On the one hand, there are numerous existing buildings in a vulnerable and deteriorated situation that demand urban and architectural regeneration guidelines with feasible criteria [11], and also the establishment of different action levels, avoiding to always promote deep renovation works, which normally are considered unfeasible in their multiple dimensions [12]. On the other hand, various research studies highlight the lack of comfort that exists in outdoor areas and indoor environments of schools [13], which shows a demand for multidisciplinary research that provide flexible tools that could be adaptable to different building uses, along with other starting circumstances.

Regarding the construction process, although the European regulations predominantly focus on optimising the energy efficiency of existing buildings [14], there are other key parameters related to the technical and construction process when deciding the feasibility of the renovation process [15]. Thus, the research starts from the premise that energy efficiency must be ensured together with a technical, economic and social viability, in the selected multidisciplinary factors, identifying advantages and inconveniences when deciding renovation strategies.

This research presents the design, development and testing of a multidisciplinary assessment system of building renovation strategies that serves to facilitate decision-making and contribute to a proper management of urban regeneration, being tested both in the housing stock and existing schools from southern Europe. One of the novelties compared to other studies is the flexible and open nature of the new designed system to be applied in different building uses, by assessing 10 renovation factors based on fulfilling technical inspections and users' interviews both in private and public buildings. The paper aims to identify and quantify an innovative weighting system to serve as decision support system by drawing together both technical and socioeconomic factors to present them in an understandable way for experts and non-experts and also by incorporating an assessment model based on 3 main indices: 1. Impact, 2. Consequences and 3. Benefits of different intervention strategies within building renovation.

The paper deals with the complexity of integrating and evaluating multiple influencing factors linked to retrofitting works, taking into account that it is not possible to interpret many of these factors in a completely neutral and data-driven way. Actually, the manuscript also introduces the design of a graphical display of results that allows visualising the weighted values of 10 renovation factors and determining the choice of the most appropriate and most satisfactory strategies for each context. These insights of this new assessment model facilitate designers and developers the adjustment of renovation proposals to each socioeconomic context in different building and thereby ensuring a proper management and maintenance of new retrofitting interventions.

Once the paper introduces and justifies the topic, the following sections describe the designed methodology, the selected case studies to apply and test the model, and subsequently incorporates a numerical and graphical output of results along with their discussion according to the renovation strategies. These results and the developed methodology itself lead to methodological and particular conclusions of the research, towards highlighting the usefulness of this multi-criteria assessment model.

2. Methodology

This section defines a particular assessment and decision-making model applicable to existing buildings, social housing and schools, by incorporating multidisciplinary patterns for assessing multiple renovation factors through a sensitivity analysis linked to building renovation. The innovation of the model is based on a weighting model that quantifies the benefits, consequences and impacts of different renovation strategies. To this end, it is intended to show the breadth of building uses where it could be applied and also the variety of strategies or action packages that could be designed to be assessed and quantified. Figure 1 shows a graphic outline for the procedure to be performed, including the 3 analysis items that are taken into account for each case study: Impact, Consequence and Benefit.

The proposed multi-assessment model has been iteratively developed according to the technical, social, energy, and economic characterization, that are commonly obtained from the processes prior to, during and after the development of retrofitting works, involving technical visits, surveys and interviews that gather significant data and characteristics, for which it has been a continuous process of back and forth to design iteratively the weighting model and the graphical output of results.

Regarding a greater explanation of the tools to be used, the research has followed and expanded the methodological resources established in previous studies [16,17], regarding the development of a technical inspection sheet that marks the state of conservation, the constructive characterization and the technical and energy evaluation of the building in its envelope and interior spaces. Moreover, it has been combined with a series of user questionnaires related to obtain the satisfaction level, on a 1-5 Likert scale, the needs and demands of users to be taken into account in the design of renovation strategies and other open-ended questions for receiving diverse information on each building daily operation.

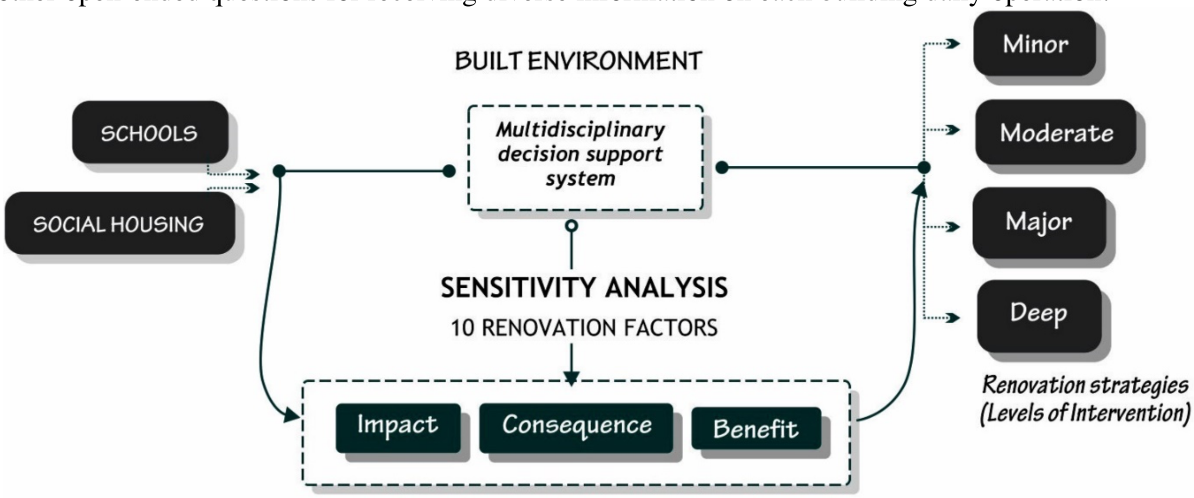

Figure 1. General outline of the procedure developed in this research.

The outline details a scope of application that is especially focused on multi-family social housing, generally built before 1980, as well as schools from that same construction period, prior to national energy regulations and having served more than 40 years of service, being obsolete, deteriorated, and out of the required comfort conditions.

For the selected school and residential neighborhood, defined in subsection 2.1., a technical diagnosis has been carried out, led by architects, which has made it possible to obtain the required retrofitting actions, their corresponding investment costs, as well as other factors inherent to the required renovation works, such as the duration, energy saving simulations, waste quantification, among others, which will serve to obtain a pre-renovation assessment of each strategy. These data have been combined with users' responses to short surveys and conversations, both in schools and in residential neighborhoods.

The selected factors and subcategories have been the result of gathering objective information necessary to take into account from the different disciplines, integrating different contributions of related studies in the literature review, as well as the incorporation of other complementary qualitative aspects that complete the information of diagnosis and represent an important valuation to facilitate decision-making in building renovation. All these factors are weighted independently in a 0-10 range for the comparison and selection of the most significant valuations according to the various circumstances in order to assume an integral approach related to the: 1. Impact, 2. Consequences or 3. Benefits. Eq.1 gathers all the variables and presents the weighting procedure for obtaining normalized values in a 0-10 range for each factor. The calculations are mainly based on assigning a score for each variable (x) in relation to its possible maximum score (x_{max}) among the different variables that make up each factor.

$$\text{[Eq. 1]} \quad w_f = \frac{x}{x_{max}} * 10$$

The factors are defined as follows:

Impact | Duration is the total time expected to completely carry out the renovation work. The duration is measured from the start of the physical intervention, in terms of weeks, months, or years, until the works are completely finished and ready to service.

Impact | Scale defines the size of the interventions and the place where the renovation actions are carried out, differentiating between outdoor spaces, indoor communal spaces, and inside the apartments or classrooms. For its evaluation, the results are weighted based on three action degrees: punctual, partial, and total.

Impact | Technical complexity considers the complexity of the retrofitting works according to the construction techniques and the access to each architectural element or construction phase. The elements of the building are grouped as: interior partitions and room distribution (including wet rooms), 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 complexity and techniques and complexity is obtained.

Consequence | Relocation or unusable spaces takes into account possible residents' or students' relocation or the restricted access to certain communal or private services or classrooms during the renovation work. Various scenarios are considered regarding complete relocation, or temporarily disabled spaces are considered, and a final value is weighted.

Consequence | Users' worries measure the users', both residents and students or teachers, perception of the renovation with respect to uncertainty and evidence-based regarding the renovation process, the possible effect on the social perception, economy or any other improvement, and the quality of the available information and communication plan through different variables that are taking into account in interviews and small surveys for obtaining a final weighted value.

Consequence | Noise and nuisance from the renovation that will affect the users, such as dust, loud banging, and drilling during the renovation works. This factor focuses on recognizing the type of noise, dirt, loud knocking, and drilling and how often they occur, according to the consequences for the schools and housing daily life if relocations do not exist.

Consequence | 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, both volume and weight are equally weighted and a final value is obtained.

Benefit | Energy reduction assesses the reduction of operational energy demand in kWh/m^2 and a percentage for each renovation strategy. These energy saving values can be obtained by using DOE2 simulation tools. The energy reduction is measured from its original state to after the renovation, and a weighted value for the quantity range and the percentage of reduction is obtained.

Benefit | Standard improvements assess the increase in quality as compared to the initial state of the building in the form of different scores regarding Design, Accessibility, Safety, and Indoor comfort. 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 users.

Benefit | Visual changes value the positive or negative effect on the exterior changes with respect to architecture, aesthetics, and heritage. This parameter has been selected as a result of perceiving the social importance of visual changes in the perception of users at the end of the work, beyond other types of changes or results, visualization stimulates the provided benefit after a renovation. The quantification of this factor may be positive or negative depending on the final result, the type of changes, and the patrimonial protection in social housing or schools.

The data from the school and the housing typology were gathered through technical visits and meetings with their users, trying to contact with the main responsible members of the schools and the presidents of the housing community. The research has been developed thanks to the collaboration of a research team made up of architect, as well as with a contribution of knowledge of sociologists regarding the questionnaires, the interpretation of social results and the weighting of the perceptions of the users. Therefore, this multidimensional evaluation procedure should be applicable in any other residential neighbourhood or school as a means to assess the feasibility of renovation, depending on the socioeconomic context of each location and the particular demands of the occupants.

2.1. Case studies

This study presents two reference building typologies from educative centres and social housing as case studies: built before 1980, isolated blocks, with significant shortcomings in their conservation status and regulatory non-compliances with respect to current energy and comfort regulations. In both buildings their users demand certain renovation actions in order to provide better teaching and living conditions. Both reference cases have been used to verify, apply and test, and simulate the proposed model.

The selected school and neighbourhood are located in the Andalusian region, in Spain, in Córdoba and Seville respectively. In Spain, where around 55% of buildings were built before 1980 [18], so there are many similar schools or residential neighbourhoods facing the same needs for renovation, thereby demonstrating and testing the usefulness of this model. Both case studies areas are defined below:

A) Primary school that was originally built in 1944 and partially renovated in 1983 in the municipality of Villa del Río. The school is compound of 4 linear buildings of two storeys, entailing around 26 classrooms, with a regionalist style with sloping tile roofs and with higher towers in the extremes of each building. The main shortcomings of this building are the lack of thermal insulation, some damage due to humidity and poor quality of the materials that make up the windows and the deterioration of the wood on the roof. Figure 2 presents an aerial imagen and a generic picture of the school typology.

B) Residential neighbourhood of 9 closed blocks, that are composed by 4 linear buildings with connecting links in the corner. The buildings were originally built in 1942 and partially renovated in 1976 and entail around 324 multi-family apartments. The multi-family buildings also present a regionalist style with sloping tile roofs. The main shortcomings of this building are the lack of thermal insulation, damage due to humidity, certain cracks, and an important breach in accessibility conditions and dimensions. Figure 3 presents an aerial imagen and a generic picture of the urban typology.

Figure 2. Case A. School building. Photo: Authors

Figure 3. Case B. Social neighbourhood. Photo: Authors

Table 1. Basic data, characterisation, and diagnosis of the school in Case A

BASIC DATA

	Year of construction	Classrooms	Storeys	Year of renovation	Num. of users	Surface area per classroom (average)	Initial energy demand
Case A	1944	24	Gr. + 1	1983	450 approx.	34m^2	175kWh/m^2

CHARACTERISATION

Envelope	Systems
Façade: Mortar cladding, Solid brick wall (40cm) and gypsum coating.	Heating: Central heating and water radiators by diesel.
Roof: ceramic tile roof, cement mortar slope formation, wood structure.	Cooling: No colling unless teachers' room.
Floor: Concrete slab, ceramic flooring bonded with cement mortar.	Windows: Iron frames, no thermal break and glazing.
Interior partitions: Hollow brick partition with gypsum boarding.	Ventilation: Natural ventilation.

DIAGNOSIS

Technical status	Deteriorated and damaged status both inside and in the exterior façade. Many fissures and damp areas in the façade. Outdated technical systems, such as heating, pipes, and radiators.
Classroom layout	Width original dimensions in the classrooms, considerable height and particularly big size in windows
Accessibility	Limited access to the top floor. Absence of a lift. Inadequate accessibility conditions outside and inside
Thermal performance	The transmittance values and the energy demand are very high with respect to the energy requirements
Maintenance	During the last 25 years, only punctual actions have been taken. There is a general lack of investment

Table 2. Basic data, characterisation, and diagnosis of the multi-family building in Case B

BASIC DATA

	Year of construction	Num. of buildings	Storeys	Year of renovation	Num of dwellings	Surface per apartment (average)	Initial energy demand
Case B	1942	54	Gr. + 2	1983	324 approx.	69m^2	154kWh/m^2

CHARACTERISATION

Envelope	Systems
Façade: Mortar cladding, Solid brick wall (24cm), air chamber, interior brick partition and gypsum coating.	Heating: No heating unless electric local heating.
Roof: ceramic tile roof, cement mortar slope formation, concrete slab.	Cooling: No colling unless particular splits.
Floor: Concrete slab, ceramic flooring bonded with cement mortar.	Windows: Iron frames, no thermal break and simple glazing.
Interior partitions: Hollow brick partition with gypsum boarding.	Ventilation: Natural ventilation.

DIAGNOSIS

Technical status	Appearance of the buildings deteriorated, with loss of material, humidity and important cracks. Windows and thermal envelope outside the current energy regulations
Dwelling layout	Narrow and confined rooms, with small bedrooms and low headroom. Interior natural lighting is insufficient in many cases
Accessibility	Limited access to the dwellings through stairs, reduced useful widths and inaccessible access to the portal
Thermal performance	The transmittance values and the energy demand are very high with respect to current energy requirements
Maintenance	During the last 40 years, only punctual actions have been taken. There is a general lack of maintenance

2.2. Renovation strategies criteria

Minor. Covering renovation proposals with investment costs of less than 10,000€ or 50€/m^2. The interventions are usually carried out outside the dwellings or classroom: either on the envelope or in the communal outdoor areas. The renovation process does not interfere with the normal use of students or inhabitants.

Moderate. Investment cost between 20,000€ and 50,000€ or between 50€/m^2 and 100€/m^2. The interventions are usually carried out outside or in the communal areas of the building, although specific operations inside the classrooms or 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 50,000€ and 100,000€ or between 100€/m^2 and 200€/m^2. Global interventions, such as actions that affect the entire building envelope, are considered outside the building and in indoor communal areas and can also include considerable changes inside the rooms or classrooms. The work process of these actions significantly interferes with the users' daily use and could limit the use of certain rooms of the school or the apartment for short periods and entail the relocation of users.

Deep. Strategy that covers renovation proposals with an investment cost over 100,000€ or more than 200€/m^2. Integral refurbishment actions are considered across the whole building. The work is intense and would require the relocation of students or residents for a period.

3. Results

This section presents the weighted results of testing the model in both case studies, providing the designed renovation strategies and their corresponding multidisciplinary performance (Table 1 and Figures 4 and 5) from different technical, social and environmental factors for each strategy and each case study. Additionally, the results will be outlined in a graphical output of values that will facilitate decision-making, being this graphical output of results tested for its future application in a digitized tool (Reprograma-tool).

The proposed actions for each strategy, that can be adapted to each case study, are:

Minor: 1| Repair exterior cracks, fissures, and damp patches on façades; 2| Seal window frames; 3| Repair drainage pipes and damaged parts of the tiles roof; 4| Place a ramp in the main entrance door of the school or in the portal for an accessibility improvement; 5| Adapt the main access door.

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

Major: 1| Implement exterior XPS-insulation and repair the façade and roof; 2| Replace windows; 3| Install or replace an elevator; 4| Completely adapt portal access; 5| Renovate all wet rooms; 6| Replace central heating, radiators, and pipes.

Deep: 1| Implement exterior XPS-insulation and repair the façade and roof; 2| Replace windows; 3| Install or replace lift; 4| Completely adapt to entrance and portal access; 5| Renovate wet rooms; 6| Improve rooms redistribution; 7| Replace ventilation and central heating (radiators, pipes, and ventilation ducts). Deep strategy involves the relocation of users for months, and whose costs must be considered in the analysis.

Table 3. Main results weighted after having taken into account multiple renovation factors.

		MINOR	MODERATE	MAJOR	DEEP
IMPACT | Duration	A	**1.4** | 2-4 weeks	**4.6** | 2-4 months	**6.3** | 5-7 months	**8.0** | 12 months
	B	***2.2*** *| 1-5 weeks*	***4.4*** *| 3 months*	***6.7*** *| 4-6 months*	***7.4*** *| 10 months*

IMPACT | Scale	A	**2.5** | Only outside	**5.6** | Partial outs. & insid.	**8.1** | Total outs. & part. Inside	**8.9** | Total outside & inside
	B	***2.2*** | *Part out. & insid.*	***4.4*** | *Outs. & part. Insid.*	***6.7*** | *Outs. & insid.*	***8.9*** | *Total outside & inside*
IMPACT | Tech. complex.	A	**1.5** | Low - 2 phases	**3.9** | Medium – 3 phases	**7.1** | Medium-High - 4 phases	**8.0** | High- all phases
	B	***1.3*** | *Low – 1.5 phases*	***2.0*** | *Medium – 2 phases*	***7.7*** | *Medium-High- all phases*	***8.4*** | *High – all phases*
CONSEQ. | Relocation	A	**1.0** | No. Limited uses	**2.1** | No. Disabled spaces	**4.2** | No. Disabled classrooms	**9.6** | Yes. 3-6 months
	B	***1.8*** | *No. Limited acts*	***2.7*** | *No. Disabled rooms*	***4.4*** | *No. Partial. Disabled.*	***9.0*** | *Yes. 2-4 months*
CONSEQ. | Users' worries	A	**3.5** | *Disinformation*	**4.3** | Uncertainty & disin.	**7.7** | Uncert. & partly feasible	**8.0** | Uncert. & unfeasible
	B	***3.6*** | *Non-priority*	***6.5*** | *Uncertainty*	***8.5*** | *Uncert. & unfeasible*	***9.8*** | *Unfeasible*
CONSEQ. | Noise & Nuis.	A	**3.2** | Occasional	**4.7** | Noise & no drills	**7.8** | Constant noise & drilling	**9.0** | High noise & drilling
	B	***3.3*** | *Occasional*	***5.0*** | *Noise & no drills*	***8.3*** | *High noise & drilling*	***6.6*** | *Relocated. Occasional*
CONSEQ. | Waste produc.	A	**2.4** | 10m^3 15-20t	**5.1** | 25m^3 20-30t	**6.9** | 40m^3 80-90t	**8.6** | 60m^3 120-130t
	B	***1.9*** | *5m^3 5-10t*	***4.4*** | *10m^3 15-20t*	***6.9*** | 25m^3 30-40t	***8.1*** | 40m^3 100-110t
BENEFIT | Energy savings	A	**1.8** | 5-10kWh/m^2 2%	**5.3** | 25-50kWh/m^2 24%	**7.0** | 80-120kWh/m^2 41%	**8.2** | Over 150kWh/m^2 48%
	B	***1.9*** | 5-10kWh/m^2 4%	***6.3*** | *20*-40kWh/m^2 32%	***7.8*** | 70-100kWh/m^2 48%	***8.6*** | Over 100kWh/m^2 55%
BENEFIT | Stand. Improv.	A	**2.3** | D:L A:L S:- I:M	**6.4** | D:M A:M S:L I:M	**7.5** | D:M A:M S:M I:M	**9.5** | D:H A:H S:M I:H
	B	***1.9*** | D:L A:- S:- I:M	***5.2*** | D:M A:L S:M I:M	***8.0*** | D:M A:M S:M I:H	***8.4*** | D:H A:M S:M I:H
BENEFIT | Visual changes	A	**0.8** | Low-out.	**7.0** | Med. Out-Low ins.	**7.5** | Med. Out-ins.	**8.8** | Med. Out.-High insid.
	B	***1.1*** | *Low-out. & ins.*	***6.6*** | *Med. Out-ins.*	***8.1*** | *Med-High out-insid.*	***9.6*** | *High Out-High insid.*

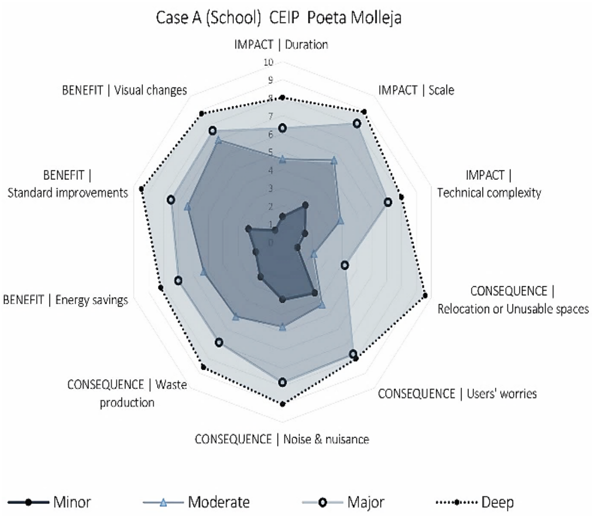

Figure 4. Multidsciplinary results diagram for Case A

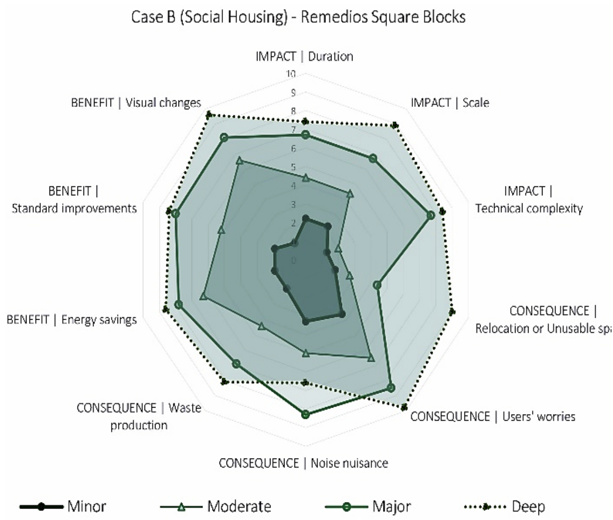

Figure 5. Multidsciplinary results diagram for Case B

4. Discussion

Table 3 and Figures 4 and 5 define the performance of each renovation strategy with respect to the 10 main selected factors, allowing a sensitivity analysis to be carried out through the graphical output of results. The results show a variation in the weighting of the results between the school and the residential neighbourhood. Although the renovation actions are the same, the impact, consequences and benefits incorporated vary according to the building use, demonstrating the operation of the model. This weighted valuation facilitates technicians, policy-makers and promoters to compare the best choice of renovation strategy for their decision-making and, consequently, in the design of the final proposal.

Regarding the particular results of the school Case A, the quantitative and qualitative jump of each strategy in the final values is observed. For the minor strategy, although the impact on duration and technical complexity are very slight for the user, the benefit obtained is reduced, with low improvements in the Design (D) or accessibility (A) conditions, but with no consequences in other aspects. Likewise, a quantitative jump is observed in the moderate strategy, with valuations above 5 in the benefit parameters (5.3, 6.4 & 7.0), which shows that it can be a feasible option with medium-low impacts and consequences. Finally, similar quantitative values are observed between the major and deep strategies, without great variations according to each parameter except in the consequences generated by the relocation of the students, which allow assessing the benefits and consequences of each strategy of greater intensity. These last two strategies demonstrate the great potential for energy savings in schools (7.0 & 8.2) while generating uncertainty and little feasibility in the perception of users (7.7 & 8.0).

Regarding the weighted results in case B Social housing, a higher difference is observed in some specific factors (Impact, Scale or Noise & nuisance), existing a constant between strategies, while in other factors (Standard improvement, relocation or unable spaces, and technical complexity) the variation between strategies is significant. In addition, it is observed how the profit factors obtain notable results in major and deep strategies, while the moderate strategy has an intermediate benefit with reduced impact and consequences.

Comparing the obtained values between educational and residential uses, it is observed that there are significant variations between both calculations and the final graphical outputs. In schools, the users' worries and the consequences of relocation are less intrusive than in residential use, however, there are other factors such as the waste generation or the energy saving values that are higher. For these case studies, it is observed that the moderate action introduces higher benefits in schools than in social housing, whose original state is very difficult to adapt in certain parameters of Design (D), Accessibility (A) or Indoor comfort (I). In short, the model works and adapts to each building use, adapting the impact, consequence and renovation benefit variables and then weighting their values over the established maximums of each of its dependent quantitative and qualitative variables.

It can be understood that the investment cannot be excessive in some schools or in social neighbourhoods, due to the economic limitation of the administration or property owners, however, this system allows experts and non-experts to see from a visualization the different degree of advantages and disadvantages that the different strategies provide, thus serving to report the degree of benefit and impact of the different investments and forcing reflection on making a greater effort to promote the renovation of buildings. Both the economic investment and the value obtained in each of the factors related to the renovation must be considered in the final decision-making to guarantee the satisfaction, viability and effectiveness of the works.

5. Conclusions

This paper presents an integrated assessment model for the built environment whose main aim is to promote a proper decision-making in the building renovation to ensure feasible and efficient strategies and provide the administration an evidence-based tool that contributes to sustainable urban regeneration. The designed assessment is based on 10 selected parameters, both qualitative and quantitative, organised according to 3 main indices: Impact, Consequences and Benefits, which allow evaluating the advantages and disadvantages of retrofitting strategies and different degrees of economic investment.

This decision support model for building renovation is an ambitious work, that must continue in development, which will need careful implementation and adaptation to different uses, but represent an important advance to have significant outcomes towards a sustainable and eco-efficient urban regeneration process. The insights of this new tool can incorporate integral information, feasibility and efficient criteria in the renovation proposals, being different renovation alternatives previously assessed by the 10 selected factors. Additionally, this research incorporates important insights for public agents, promoters and policy-makers that allow adjusting guidelines for future national and international guidelines to promote decision support systems towards a successful building renovation planning.

This research demonstrates the complexity of the building renovation process and its multidisciplinary influencing factors, by including technical data from inspections developed from architects and technicians along with social responses from different questionnaires and interviews developed during different in situ visits. One of the main insights of this research is that it assumes that the renovation involves a process of discomfort and inconvenience for the occupants that can be adjusted to reduce the impact and benefit according to the type of works to be carried out, trying to reduce the duration, scale, noise and inconvenience or the technical complexity of the works. The development of this decision-making model for the administration represents a relevant contribution to sustainable urban regeneration, reducing risks by its application and having greater certainty of the potentials and benefits through decision-making. The selected factors can be used to outline urban regulations, giving importance to improving the visual appearance after the intervention, the improvement of architectural standards (design, accessibility, safety and indoor conditions), as well as increasing energy savings.

Focusing exclusively on the performance of each strategy throughout the testing application in this manuscript, the strategies have been doubly evaluated in order to demonstrate their variations, the flexibility of the model and discuss the multi-factor performance, giving a sample of validity and operation. In addition, the usefulness of rendering the advantages and disadvantages of the integral renovation process allows certain strategies to be adjusted and/or some actions within each strategy to be modified in order to reduce the impact or consequence of a work, or improve the benefit achieved. In this way, achieving a viable and effective balance between the different agents of the process, administration, developer and/or users of the building requires that this type of model incorporate flexibility and adaptability to different circumstances, this being one of the greatest values and potentials of this investigation.

According to the results obtained, one of the findings confirmed by this research is that there is no unique and optimal strategy without having previously analyzed the technical and socioeconomic context of each case of application. It also illustrated the importance to consider the residents' views as well as their preferences, in order to create a technically, economically and socially balanced renovation proposal. Therefore, this proposed model is expected to be useful for policy-making by introducing new multidisciplinary guidelines, with a rational adjustment of proposals and promoting feasible renovation actions in the built environment.

The paper establishes the basis for future research to develop a complete model for decision-making in building renovation, according to different strategies, and to include various disciplines of analysis through the impact, consequence and benefit provided from each renovation proposal in different building uses, such as residential or educative. Additionally, the system of diagnosis, evaluation, quantification and representation of results that is designed generates practical recommendations for developers, designers, and builders previously and during the development of the renovation process: design, calculation, construction, management, and maintenance, along with the economic investment.

Although the paper contributes to expanding knowledge and management in the building renovation, integrating technical, economic, social and environmental information to understand the impact, consequences and benefits that renovation works entail, providing methodological outcomes which help to satisfy an increasingly demand from architects, technicians and developers. One of the main limitations of the study, which will continue to be developed, is the determination of an ideal balance to combine technical data with social and economic data under a rigorous, standardized and regulated criterion, without distinction between the subjective and objective part, and that can A pilot tool will be developed soon, currently in a beta test version, whose name will be "Re-program tool".

Finally, as additional future studies derived from this research, the set of databases used for the design and weighting of each of the factors will be adjusted and classified, including a higher content on data obtained from numerous technical visits and participation surveys, and information from energy and waste databases that allow weighting each factor. In addition, to synthesize the weighting and valuation process and avoid jumps between the established qualitative levels, it is intended to establish a particular cluster object - subject, short term - long term, and benefits - risks in a 2x2x2 matrix model, in order to systematize the weighting process for the graphic output of results in building renovation.

6. References

[1] World Health Organization 2015 World report on Ageing and Health. http://apps.who.int/iris/bitstream/10665/186463/1/9789240694811_eng.pdf.
[2] Kovacic I, Summer M and Achammer C 2015 Strategies of building stock renovation for ageing society *J. Clean. Prod.* **88** 349-357. doi:10.1016/j.jclepro.2014.04.080.
[3] Eurostat 2021 *European Statistical Dashboard for European Union*. https://ec.europa.eu/eurostat.

[4] Nielsen N, Jensen R, Larsen T and Nissen S 2016 Early-stage decision support for sustainable building renovation – A Review *Build. and Environm.* **103** 165–181. doi:10.1016/j.buildenv.2016.04.009.
[5] European Union 2015 *Sustainable regeneration in urban areas urbact ii*. http://urbact.eu/capitalisation-and-dissemination.
[6] Moghtadernejad S, Chouinard L and Saeed-Mirza M 2018 Multi-criteria decision-making methods for preliminary design of sustainable façades *J. of Build. Eng.* **19** 181-190. doi:10.1016/j.jobe.2018.05.006.
[7] Riera-Pérez M G, Laprise M and Rey E 2018 Fostering sustainable urban renewal at the neighbourhood scale with spatial decision support system *Sustain. Cities Soc.* **38** 440-451. doi:10.1016/j.scs.2017.12.038.
[8] Serrano-Jiménez A, Blandón-González B and Barrios-Padura Á 2021 Towards a built environment without physical barriers: An accessibility assessment procedure and action protocol for social housing occupied by the elderly *Sustain. Cities Soc.* **76** 103456. doi:10.1016/j.scs.2021.103456.
[9] Olsson S, Malmqvist T and Glaumann M 2016 An approach towards sustainable renovation – A tool for decision support in early project stages *Build. and Envir.* **106** 20-32. doi:10.1016/j.buildenv.2016.06.016.
[10] Carpino C, Bruno R and Arcuri N 2020 Social housing refurbishment for the improvement of city sustainability: Identification of targeted interventions based on a disaggregated cost-optimal approach. *Sustain. Cities Soc.* **60** 102223. doi:10.1016/j.scs.2020.102223.
[11] Mercader-Moyano P, Flores-García M and Serrano-Jiménez A 2020 Social housing refurbishment for the improvement of city sustainability: Identification of targeted interventions based on a disaggregated cost-optimal approach. *Sustain. Cities Soc.* **62** 102422. doi:10.1016/j.scs.2020.102422.
[12] Femenías P, Mjörnell K, Thuvander L 2018 Rethinking deep renovation: The perspective of rental housing in Sweden *J. Clean. Prod.* **195** 1457-1467. doi:10.1016/j.jclepro.2017.12.282.
[13] Serrano-Jimenez A, Hiruelo-Pérez J, Ramírez-Juidias E and Barrios-Padura A 2021 Identifying design shortcomings and heat-island effects in schools located in warm climates: An outdoor environmental assessment procedure based on remote sensing tools *J. of Build. Eng.* **43** 103209. doi:10.1016/j.jobe.2021.103209.
[14] European Commission 2018 Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency *Official Journal of the European Union*.
[15] Liu B and Rodríguez D 2020 Application of multi-objective optimization model to assess the energy efficiency measures for the cases of Spain *J. of Build. Eng.* **38** 102144. doi:10.1016/j.jobe.2020.102144.
[16] Serrano-Jiménez A, Lima M L, Molina-Huelva M and Barrios-Padura Á 2019 Promoting urban regeneration and aging in place: APRAM – An interdisciplinary method to support decision-making in building renovation *Sustain. Cities Soc.* **47** 101505. doi:10.1016/j.scs.2019.101505.
[17] Serrano-Jiménez A, Lima M L, Barrios-Padura Á and Molina-Huelva M 2020 Integrated urban regeneration based on an interdisciplinary experience in Lisbon *Psyecology* **11(1)** 64-77. doi: 10.1080/21711976.2019.1643660.
[18] INE Spanish National Institute of Statistics 2021 *https://www.ine.es/*

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