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An AHP-Based Methodology for Decision Support in Integrated Interventions in School Buildings

Pierfrancesco Fiore [1,*], Giuseppe Donnarumma [1], Carmelo Falce [1], Emanuela D'Andria [1] and Claudia Sicignano [2]

1 Department of Civil Engineering, University of Salerno, 84084 Fisciano SA, Italy; gidonnarumma@unisa.it (G.D.); cfalce@unisa.it (C.F.); emdandria@unisa.it (E.D.)
2 Department of Civil, Building and Environmental Engineering, University of Naples 'Federico II', 80138 Napoli NA, Italy; claudia.sicignano@unina.it
* Correspondence: pfiore@unisa.it; Tel.: +39-089-96-4127

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Abstract: The recovery and requalification of built heritage are, in Europe and all over the world, a central issue in relation to current international policies. In recent years, there has been a considerable growth in research within this field, favoring the implementation of intervention methodologies in the real estate assets of public and private property. With this study, we intend to focus attention on the redevelopment of existing school buildings, taking into account, from an integrated perspective, different aspects related to energy and environmental retrofit, the improvement of seismic safety, and socio-economic assessments. A significant impact of the study that was carried out will be favoring the more disadvantaged classes and a reduction in school drop-out, which in some cases is caused by the decentralized dislocation of the complexes or by inadequate structures. The research consists of the development of a tool to support the planning and programming of interventions for school building modernization, with a view to environmental, economic, and social sustainability. In order to take into account the multiplicity of the aspects considered, among the methods of multi-criteria analysis for decision-making aims the Analytic Hierarchy Process (AHP) method was applied, which allowed us to analyze and compare different alternatives through evaluation criteria, reaching the definition of a priority scale. This process makes it possible to identify those interventions that achieve the best compromise between community needs and the planners' goals. The evaluation procedure is validated through the application on a concrete case study, which is a school building located in the province of Avellino, in the south of Italy.

Keywords: school buildings; schools for all; requalification; decision support system; AHP method

1. Introduction

About 40% of Europe's real estate heritage is made up of outdated buildings, built before 1960. Of this large cut, 25% have a different destination than the residential one. Within this category are also included school buildings, which represent almost a fifth. The available data [1] also show that in recent years there has been an increase in primary energy consumption in relation to the non-residential buildings sector. This condition is alarming, since the non-residential sector has an average specific energy consumption 40% higher than the equivalent value for the residential sector.

This situation has led, at the European level, to the implementation of a series of development strategies aimed at the reorganization, regeneration, and upgrading of the built environment. In this specific case is included the EU Directive 2012/27 EU, updated by EU Directive 2018/2002 EU, which in point (17) provides for the need to "set an annual renovation rate for buildings owned by the central government in the territory of a Member State and occupied by it in order to improve their energy performance" and, moreover, in art. 5 states the "exemplary role of the public authorities' buildings", determining the requirement for state administrations to ensure an annual efficiency equal to "3% of the total useful covered area of heated and/or cooled buildings owned by their central government".

Therefore, in addition to the increasingly pressing goals of decarbonization in building energy savings regarding the need to realize new buildings in the NZEB (Nearly Zero Emission Building) category, the EU countries are called primarily to engage in the renovation of public buildings. This argument allows us to understand how current an issue the recovery of the built environment is. European regulations have an inevitable impact on school buildings and, consequently, on the very high student and teacher population. Eurostat estimates show that the student population of the 27 European countries in the period 2013–2020 includes 108 million learners [2], while teachers reach about 5 million [2]. These categories are exposed to a potential risk, since they spend more time indoors at school than at anywhere else except their own home [3]. Furthermore, at the moment only half of the concerned buildings are involved in energy efficiency interventions [4]. For these reasons, starting from 2013 the European Parliament, on the basis of the goals clarified in the Parma Declaration of 2010 [5], has funded the SINPHONIE project [6] focused on school environment monitoring for the health of its occupants and involving 23 EU countries. This program has had the merit of providing the right tools and methodologies to fully investigate the characteristics of the schools' indoor environments, with greater attention on the assessment of indoor air quality, but with special measures also for structural safety, plant functionality, and energy efficiency. The European policies allow us to understand how necessary an integrated and holistic approach is to undertake strategies for school building control, monitoring, recovery, and design.

In Italy, most school buildings were built during the economic boom at the turn of the 1960–70s [7]. According to the available data [8–12], more than 60% of these buildings do not comply with modern technical standards on seismic prevention, have structures made of materials that are potentially harmful to the health, and show a significant lack of energy efficiency and indoor comfort fields. From 2015, the MIUR—Ministry of Education, University and Research—with Law 107/2015, has guaranteed stable access to the data collected by the School Building Registry [13]. This is articulated in a main node, belonging to the central government, and in regional nodes in order to ensure a careful analysis and reconnaissance of the territory. Currently, the school building stock includes 40,160 active buildings; 54% of these real estate units are provided with a static test certificate, 24% are in compliance with the fire prevention certification, 39% are equipped with usability, and only 13% were built in compliance with modern anti-seismic criteria.

The recovery and redevelopment of the school building heritage are central topics in the international research field [14].

The adaptation of school structures that follows represents positive value in terms of socialization and daily cultural exchange, as well as cohesion between social classes through the implementation of didactic and participatory methods inspired by sharing and welcoming [15].

It is clear, moreover, that the didactic quality, with additional use of extracurricular activities, could be of a higher level, with available spaces and structures that are more suitable for the purpose, as they may result from requalification processes.

The renovation of school building heritage requires the evaluation of many aspects of functional, economic, and social order, as well as safety, comfort, and energy/environmental sustainability. In this context, in the reference literature it is possible to find the use of multi-criteria analysis methods and, in particular, of the Analytic Hierarchy Process (AHP) method [16]. Some studies use the method mentioned above for the assessment of seismic vulnerability [17–19] and seismic risk [20] in order to determine a hierarchy of interventions. Ilumin et al.'s research [21] is aimed at identifying a priority scale of maintenance interventions on existing school buildings in order to ensure their full efficiency from a post-disaster perspective. A second line of studies deals with the identification of the most appropriate site for the construction of new school buildings, through the choice of indicators that can be used in multi-criteria evaluation [22–24]. Rosa and Haddad's research [24] focuses on the identification of a family of criteria that help the decision-maker to formulate an intervention strategy to ensure the sustainability of existing school buildings. Other contributions concern the definition of indicators to be applied to scheduled maintenance processes: Marzouk and Awad's research [25] uses the multi-criteria method to identify a representative index of the maintenance status of the analyzed building in order to define a scale of intervention priorities. López-Chao et al. [26] verify the relationship between the architectural quality of school spaces and student performance through the AHP method. The quality of the indoor spaces is further investigated in the study conducted by Cochran Hameen et al. [27]. This publication assesses the quality of indoor spaces (IEQ) in relation to indicators related to the occupants' well-being and productivity. The aim of the research is to allow administrations to make wise choices for the allocation of available economic resources. A different approach is followed by Hassan et al. [28], who focus their research on the use of the multi-criteria method to compare design choices and identify the optimal cost for the construction of new school infrastructure. Guarini et al. [29] propose a multi-criteria evaluation methodology to support intervention planning on existing school facilities, distinguishing between total renovation works, regulatory adjustment, and distributional changes. Belleri and Marini [30] analyze the dual link between the energy requalification and seismic retrofitting of existing buildings in relation to the environmental impact that such interventions may determine. To evaluate these connections, the authors propose a methodology that allows the estimation of the environmental impact related to seismic risk in the field of global sustainability analysis. Fiore and Donnarumma [31] used the method both with reference to the general existing building in order to evaluate the convenience of the recovery vs. demolition/reconstruction and to the rationalization and upgrading of the school building heritage in the associated management of services in consortia between small municipalities [32].

The aim of this work is the definition of a methodology that allows one to choose the most suitable requalification intervention according to an integrated perspective. Unlike the sectoral approach proposed by some literature studies, the method to be developed simultaneously considers several aspects related to the redevelopment of an existing school building without taking into consideration structures of historical-architectural interest. This issue needs to be addressed through a process of investigation that uses criteria and indicators of a different nature than those considered in order to conduct an analysis that fulfills the aims of the research. Both according to the European policy strategies and to the authors' vision, an integrated and multidisciplinary approach is needed with respect to the complexity of the school building redevelopment issue, within which the variables to be controlled are several. Paragraph 2 describes the methodology adopted—i.e., the AHP method, which, by its nature, allows procedural simplification in the problem analysis. Paragraph three examines the criteria chosen for the analysis. Meanwhile, in paragraph four the method will be applied to a concrete case study, identified in a school building located in the province of Avellino in the south of Italy. In the following paragraphs five and six, a discussion of the results and conclusions is reported.

2. Methodology

The multi-criteria analysis for decision-making purposes is a strategy of analytical approach aimed at supporting the decision-maker in case he has to operate with a high number of alternatives and conflicting evaluations. Multi-criteria methods are used in the organization and synthesis of complex information from a decisional point of view [33]. The MCDA, Multiple Criteria Decision Analysis, is adopted in all those domains where it is not effective to directly adopt an optimization method, as there are many decision criteria. In practice, an MCDM, Multiple Criteria Decision Making, process must be based on distinct but complementary operational steps. They can be divided into:

- Definition of the problem, goals, and criteria;
- Determination of decisional variables and restrictions;
- Analysis of alternatives, estimates of values attributed to goals, criteria, and the final decision;
- Implementation of the decision and possible re-evaluation of the choice [34].

It was decided to use an MCDM methodology because of some intrinsic advantages of the process that can be found in the speeding up of the process, the reduction in uncertainty, the possibility of modifying the choice of criteria and goals according to one's needs, the transparency of the decision-making process, and the feedback action that consists of updating the choices following evaluation processes.

In this case, reference will be made to a deterministic method and to a single decision-maker; this is the case of the hierarchical analytical process, AHP.

The hierarchical analysis method allows the resolution of several problems at the same time, identifying the best alternative by breaking the main question down into many equal problems which can be analyzed by a method of comparison in pairs [35].

The flow chart of the proposed methodology consists of ten steps with similar importance in order to identify the best solution to any problem under examination. The operations that, in sequence, allow us to reach the problem solution are analyzed:

1. Identification of the research purpose and determination of the choice goal.
2. Definition of alternatives—i.e., the different steps that can be undertaken to provide a solution to the problem under investigation.
3. Choice of criteria by which to evaluate alternatives. This phase implies a technical and intrinsic knowledge of the sector to which the alternatives to be compared belong.
4. Compilation of the alternatives matrix (shown schematically in Table 1), made up of the generic element M_{ij}. It will be of order nxm, where n corresponds to the number of rows, or alternatives, and m to the number of columns, or criteria. The operation involves assigning to each criterion the value it assumes in relation to the examined alternative.
5. Transformation of qualitative judgements into quantitative judgements—i.e., the possible presence of non-numerical judgements counted in the matrix cannot be tolerated; consequently, such judgements must be translated into numbers. The process generally used to translate the qualitative data into numbers is to divide the range [0; 1] into a number of subsets equal to the number of judging alternatives and to assign to each alternative the average value that can be calculated for each subset. For example, in the case of 3 alternatives (1. low, 2. medium, 3. high), the definition range [0, 1] should be divided into three sub-ranges: [0; 1] → [0; 0.333] ∪ [0.333; 0.666] ∪ [0.666; 1]. The first value is defined considering the arithmetic average of the first interval:

   (1) $= \frac{(0+0.333)}{2} = 0.1665$

   Similarly, this proceeds for the second value, considering obviously the second interval:

   (2) $= \frac{(0.333+0.666)}{2} = 0.5$

   For the third interval, the procedure is the same:

   (3) $= \frac{(0.666+1)}{2} = 0.8325$

6. Normalization of the alternatives matrix, as shown in Table 2. The aim of this process is to compile a matrix in which the numbers in the range [0; 1] appear. In this phase, it is necessary to pay attention to the identification of the minimum and maximum value for each column of the alternatives matrix. These values will then be used to normalize the criteria according to whether they are a cost or a benefit. Particular attention must be paid to the subdivision of the criteria into two distinct types based on "cost" or "benefit" parameters. In fact, in case a criterion is qualified as a cost to be sustained, this receives a negative connotation, and it is necessary to make sure that its value is minimized, reducing it according to the Formula (1):

$$Mij^* = Mj,min/Mij, \quad (1)$$

where Mj,min = min(i) Mij. Instead, when using a criterion capable of making a benefit, a positive contribution, it will tend to maximize its effects by adopting the Formula (2):

$$Mij^{*} = Mij/Mj,max, \tag{2}$$

where Mj,max = max(i) Mij.

7. Assigning weights to criteria.
8. Resolution of the alternatives matrix, which consists of the application of the Simple Additive Weighing method. This procedure makes it possible to evaluate the product between each element of the alternatives matrix and the respective weight column.
9. Determination of the index of preference, I_p, obtained as the sum of the values traceable in each line of the alternatives matrix.
10. Finding the solution to the problem by reading the highest I_p.

Table 1. Representation of the alternatives matrix.

Interventions/Criteria	C_1	C_2	C_3	C_4	...	C_n
A_1	C_1 (A_1)	C_2 (A_1)	C_3 (A_1)	C_4 (A_1)	...	C_n (A_1)
A_2	C_1 (A_2)	C_2 (A_2)	C_3 (A_2)	C_4 (A_2)	...	C_n (A_2)
A_3	C_1 (A_3)	C_2 (A_3)	C_3 (A_3)	C_4 (A_3)	...	C_n (A_3)
...	...	...	...	...	...	...
A_n	C_1 (A_n)	C_2 (A_n)	C_3 (A_n)	C_4 (A_n)	...	C_n (A_n)

Table 2. Representation of the normalized alternatives matrix.

Interventions/Criteria	C_1	C_2	C_3	C_4	...	C_n
A_1	M_{11}	M_{12}	M_{13}	M_{14}	...	M_{1m}
A_2	M_{21}	M_{22}	M_{23}	M_{24}	...	M_{2m}
A_3	M_{31}	M_{32}	M_{33}	M_{34}	...	M_{3m}
...	...	...	...	...	...	...
A_n	M_{n1}	M_{n2}	M_{n3}	M_{n4}	...	M_{nm}

The AHP method allows us to obtain a solution that is a function of the determined criteria for investigating parameters of the problem. Consequently, the choice of criteria is a fundamental step in the whole process. The criteria need to be defined according to the goal to be achieved. The method used is not of immediate application. A first problem is related to the matrix compilation, and it can be identified in the translation of qualitative judgments into quantitative ones. A second difficulty can be found in the definition of the criteria weights, then in the compilation of the weight vector. This vector allows us to establish the criteria classification according to the importance that the decision-maker assigns to them. Depending on the vector elements, some characteristics of the alternatives will be valorized over those that are functions of the criteria to which the decision-maker attributes less importance [36]. The final alternative ranking may vary in correspondence to the weight value. It is necessary to look for an easy tool that allows the decision-maker to express his will. To resolve these uncertainties, the most widely applied method is to use the Saaty eigenvalue scale [37]. On the contrary, this method presents a series of advantages such as the speeding up of the decisional process, the uncertainty reduction, the possibility of choosing the judgment criteria according to the goals, the transparency of the operative process, and the possibility of implementing the procedure in an iterative way to vary the input data according to the results obtained in the previous step.

3. Definition of Evaluation Criteria and Indicators

The present work concerns the definition of a methodology of useful and easy application in order to make possible the identification of a suitable project alternative within the organization of recovery interventions, energy requalification, and the improvement of seismic safety in existing school buildings. The proposed method represents a useful tool for the stakeholder who needs to undertake a convenience evaluation within a wider decision making process. It was decided to use the AHP method since the multi-criteria analysis is a procedure that is well suited to investigate a set of project choices correctly outlined. In this Paragraph will be provided a review of the proposed methodology through the description of the evaluation criteria identified for the comparison between recovery alternatives and/or the demolition/reconstruction of existing school buildings that are not of historical/architectural relevance.

The decision-making process should use well-calibrated and objectively evaluated criteria to lead the decision-maker to a clear and acceptable choice. It has been decided to refer to the following criteria:

- **ζ—SEISMIC SAFETY LEVEL:** this criterion is intended to investigate the structural response of the building being examined;
- **E_P—ENERGY PERFORMANCE:** this criterion has the task of making a comparison between the indices of non-renewable primary energy consumption related to the different project alternatives;
- **C_T—INTERVENTION COST:** the criterion considers the total costs necessary for the realization of the intervention in exam; within this item are also included the costs necessary for extraordinary maintenance;
- **E_{IMP}—ENVIRONMENTAL IMPACT:** this criterion considers the quantity of waste produced and the percentage of recovered material that can be obtained from it;
- **T_R—REALIZATION TIME:** the criterion weighs the time necessary to the realization of the proposed intervention;
- **D—DISTURBANCE:** this criterion measures the disturbance level caused to the different activities that take place inside the building, evidently in contrast with the planned interventions.

In order to guarantee the transparency of the decision-making process, the criteria designated for the evaluation operations, shown in Table 3, are presented.

Table 3. Schematization of the criteria and their respective properties.

Criterion	Indicator	Unit of Measurement	Objective Function
Seismic safety level	Ratio between capacity and seismic demand	adim.	maximize
Energy performance	Energy class	kWh/m^2 per year	maximize
Intervention cost	Total costs	€	minimize
Environmental impact	Waste production and recycling	t	minimize
Realization time	Estimated working time	Working days	minimize
Disturbance	Interactions with school activities	adim.	minimize

The analysis of an existing building's seismic performance cannot disregard the knowledge of the structure's characteristics. Unlike a newly designed building, it is not always possible to achieve adequate knowledge of the materials' resistance characteristics or the correct construction details. In addition, it is very complicated to estimate the nodes' plastic capacity or the whole structure's ductile capacity. These deficiencies can be partly overcome through careful investigations in situ.

In order to carry out interventions on the existing building heritage, it is necessary to interface with the design and implementation uncertainties that can be found in an existing building. Particular attention must be paid to certain characteristics, such as:

- The project is the result of the knowledge gained at the time of its construction;

- The original project could already contain technical or conceptual setting errors, even not directly visible;
- The building under study may have been the subject of accidental events, the effects of which are not apparent;
- It is possible to find faults in the construction and packaging of structural materials;
- The materials' quality and characteristics are not reliable;
- There may be degradation and deterioration of materials that are not always evident;
- There are some uncertainties regarding the foundation system;
- Structural changes may have occurred that are not always properly documented.

The definition of an indicator that takes into account the seismic safety level of the school building analyzed responds to the need to fully assess the seismic vulnerability. This expression indicates the building's susceptibility to damage caused by an earthquake of assigned characteristics [38,39]. This study considers the concept of induced vulnerability, which defines the possibility of whether a given physical element of the structure subjected to a seismic event of known characteristics may or may not be damaged.

In order to investigate the structural elements' responses to the design earthquake, it was decided to use the ratio between the resistant PGA and the stressing PGA, which, in the case of linearity between forces and displacements, is comparable to a similar indicator defined as the minimum ratio between the generic resistant and stressing characteristic, as highlighted in the Formula (3):

$$\zeta_E = \frac{PGA_r}{PGA_s} \cong \zeta = \frac{R}{E}. \tag{3}$$

The level of knowledge obtained implies the use of a linear static analysis, which is configured as a simplification of the linear dynamic analysis and is concretized in the application to the structure of static forces equivalent to those of inertia produced by seismic action, dynamic by nature.

The energy performance criterion is assessed by estimating the energy class of the building and the annual energy consumption expressed in kWh/m^2 per year. It is aimed to focus the attention on the practical aspects linked to the quantification of an indicator capable of providing reliable information in relation to energy efficiency works. In order to hypothesize interventions that can contribute to the energy class improvement of the generic building under investigation, it is necessary to start from the indicator evaluated in relation to the actual state of the school. Table 4 shows the building elements analyzed for the energy performance evaluation of the building under analysis.

The indicator is measured on the basis of the national standards required to draw up a building performance certificate [40]. The energy components that contribute to the definition of the building's energy class are summarized in the Formula (4):

$$\mathrm{EP}_{gl,\ nren} = \mathrm{EPH}_{nren} + \mathrm{EPC}_{nren} + \mathrm{EPW}_{nren} + \mathrm{EPV}_{nren} + \mathrm{EPL}_{nren} + \mathrm{EPT}_{nren}, \tag{4}$$

where:

$\mathrm{EP}_{gl,nren}$= global non-renewable primary energy, or "Consumption Index", useful to establish the relationship between the energy needed to bring an environment to the comfort temperature and its usable surface;
EPH_{nren} = non-renewable primary energy for winter air conditioning;
EPC_{nren}= non-renewable primary energy for summer air conditioning;
EPW_{nren} = non-renewable primary energy for the production of domestic hot water;
EPV_{nren} = non-renewable primary energy for ventilation;
EPL_{nren}= non-renewable primary energy for artificial lighting;
EPT_{nren}= non-renewable primary energy for the transport of people or things.

Table 4. Energy performance evaluation.

Building Element	Investigated Characteristic
Heating system	Typology Fuel Performance Energy vector
Lighting	Illuminating elements Elements number
Renewable Sources	Typology Use Accumulation Presence Power Energy vector
Opaque vertical outward facing structures	Typology Material Maintenance status Thermal transmittance U [W/m^{2}K]
Horizontal opaque roof structures	Typology Material Maintenance status Thermal transmittance U [W/m^{2}K]
Opaque horizontal floor structures towards the outside	Typology Material Maintenance status Thermal transmittance U [W/m^{2}K]
Transparent and opaque technical closures	Typology Material Maintenance status Thermal transmittance U [W/m^{2}K]

The reference parameters for the definition of the building's primary energy needs have been determined in accordance with the guidelines established by regulation UNI/TS 11300 [41]. Instead, for the determination of the energy performance for building classification, reference was made to the CTI 14:2013 recommendation [42].

The intervention cost indicator consists of two items relating to the direct quantification of the expenses necessary to carry out the proposed interventions and maintenance processes. Fixed costs, technical costs for the project execution, and those for the disposal of non-recyclable waste in landfills were taken into account. Variable costs related to aspects concerning the return over the years of investments in the energy sector, consumption savings, or possible financing have not been taken into account. The interventions costs are estimated through the metric estimate computation that takes into examination the items related to the different design solutions. Instead, the cost associated with the maintenance works is evaluated on the basis of the parametric costs related to the single component taken into consideration. For the determination of the single architectural components maintenance status it has been used evaluation sheets (an example is shown in Figure 1) that provide the necessary information for the examination of the analyzed element and the definition of the maintenance interventions necessary to guarantee its operation. This preventive operation allows the quantification of economic indicators by projecting the maintenance activities in a time horizon of 50 years. With such a wide time frame application, the costs need an updating operation. This operation is carried out through a simplified formulation that makes it possible to evaluate, in an indicative way, the current value of an amount available at a future date using a certain discount rate. The amounts analyzed belong to a type of costs that are registered a single time at the end of a given year, *t*. These expenses occur more frequently than once a year. The presented method allows us to calculate the Present Value, PV, after a certain number of years, *n*, according to a fixed interest rate, *r*. The function used is shown below (5):

$$PV = C_t \times \frac{1}{(1+r)^n}, \quad (5)$$

where:

Ct represents the value at current prices of the initial costs to be reconstructed after *n* years;
r is the discount rate in cents;
n is the number of years that pass from the analysis date to the cost occurrence.

PLASTER TYPOLOGY
Special plastic "scratched" plaster
MATERIALS
Water, Inert (marble granules or sands, quartz, silicates, possible clay flours, kaolin), Binder (acrylic or vinyl resins), Colored pigments, Additives
USE ENVIRONMENT
external
THICKNESS
0.1–0.4 cm
NUMBER OF LAYERS
≥ 1
WEIGHT
0.028 kN/m^2
CHARACTERISTICS
It represents the final layer of the plaster, which needs to be laid on a substrate consisting of ordinary mineral plaster. These plasters are designed for outdoor.
REFERENCE STANDARD
EN ISO 7783-2, EN 1062-3, EN 13687-3
REQUIREMENTS
Plastic plasters are special because the application process, the tools, the workers, the materials used, the final appearance have uncommon characteristics, suitable for specialized applications. These products realize only the finishing layer with the aim of playing a sealing-finishing role on already levelled substrates.
DURABILITY
The continuous plastic coating represents an inefficient solution since it creates a water-proof surface, but it is poorly breathable and therefore subject to swelling. The duration, in optimal conditions of the support and in external environment, reaches on average about ten years.

DEGRADATION FACTORS
Presence of humidity (descending, rising or condensation) in the substrate that develops steam under pressure between the substrate and the plaster.
Injury formation in the plaster with subsequent water penetration.
Reduction of elasticity due to solar radiation.
SERIOUS FAULTS
Micro cracks: capillary lesions and superficial cracks.
DIAGNOSIS AND INTERVENTION CRITERIA
Verification of the extent and cause of the defect. Laying of an additional layer or scraping and remaking of the external state.
SEVERE FAULTS
Humidity penetration: formation of moisture stains.
Swellings: localized detachment and lifting of the plaster surface.
DIAGNOSIS AND INTERVENTION CRITERIA
Analysis of the origin of infiltration. Demolition of the damaged plaster, removal of the cause, remaking with possible desalinating treatment of the substrate if the presence of salts is found.
Analysis of the causes that determined the swellings. Total refurbishment or localized patching after cleaning and treatment of the substrate and subsequent chromatic recovery of the finish.

MAINTENANCE STATUS: POOR		
MAINTENANCE INTERVENTIONS		
TIME	DESCRIPTIONS	SPECIFICATIONS
2–4 years	**Washing** Surface water washing	The washing must be carried out with techniques and any detergents suitable for the type of plaster. The cleaning is carried out by hand dusting or with arm suction.
3–5 years	**Shooting** Replacement of parts most subject to wear and tear or other forms of degradation	Removal of the areas to be replaced, cleaning of the substrate with a wire brush, preparation of the substrate, washing of the substrate, execution of the restoration with the same stratigraphy and the same materials as the original plaster.
5–10 years	**Painting** Restoring the finish	Cleaning and possible preparation of the substrate with consolidating agents, primers or primers suitable for the chemical composition of the paint to be used. Application of two or more coats of paint
5–10 years	**Polishing** Restoration of surface gloss	Polishing after removal with techniques adapted to the type of plaster of the most superficial patina of the previous treatment.
10–15 years	**Partial Reset** Renovation of the outer layer	Laying an additional thin layer of finishing or scraping and remaking of the outer layer
25–40 years	**Total Recovery** Complete replacement	Removal of the existing plaster and remaking after adequate preparation of the substrate

Figure 1. Example of analysis sheet (technological component: plaster).

The determination of costs attributable to extraordinary maintenance works has been carried out on the basis of processing items estimated by reference to parametric prices and standard costs [43–45]. The standardized costs are expressed as a percentage of the entire expenditure incurred for the construction of a new school building. A similar approach is also used for the economic evaluation of the measures inherent in the conservation of reinforced concrete structures. The monetary quantification of a monitoring program requires a different kind of economic analysis. In this case, it is necessary to apply a formulation (6) that allows us to obtain a final accumulation for limited postponed constant annuities [46]:

$$A_n = \left(a \times q^{n-1}\right) + \left(a \times q^{n-2}\right) + \left(a \times q^{n-3}\right) + \cdots + \left(a \times q^{n-(n-1)}\right) + \left(a \times q^{n-n}\right), \quad (6)$$

which corresponds to a geometric progression that can be expressed in the Equation (7):

$$A_n = a \times \frac{q^{n-1}}{r}, \quad (7)$$

where:

A_n represents the final accumulation—i.e., the total sum needed for a given extraordinary maintenance work;
a indicates the single annuity to be supported according to the need of the analyzed component;
q is the unitary amount, the sum of the capital and the interests accrued in a certain time unit;
n is the number of annuities that are added together;
r is the interest rate set at 4%.

The definition of an indicator containing information on environmental impact specifications is of fundamental importance within the building panorama. Just think that the inert waste recycling sector, started in Italy in the 1980s, has undergone exponential growth, leading to the birth of a real autonomous industrial sector. In addition, the European Directive 2008/98 CE, "Waste Framework Directive" [47] has introduced two substantial concepts in the field of construction and demolition waste recycling, C&D, in the following:

- Definition of a target for the inert waste recovery of 70% to be reached by 2020;
- Introduction of the end of waste concept.

This directive has determined a stance by the institutions that have been led to deepen the knowledge of the recycled aggregates sector and to investigate, at the same time, the quality of the product in order to allow its widespread use on the territory [48].

From this perspective, the intention is to implement an indicator that is capable of translating into numbers both the environmental and economic benefits resulting from the proper reuse of discarded materials.

The criterion regarding the environmental impact is defined so as to take into account the amount of produced waste and the percentage of waste that can be recovered and reused. The amount of waste produced, Q_{tot}, is evaluated in tons and estimated on the basis of the actual suggested interventions. Instead, the amount of C&D waste recovered is indicated by Q_{rec} and quantified by determining an indicative percentage of recyclable material. Additionally, in this case the unit of measurement used for the data quantification is expressed in tons. For the correct definition of the minimum percentage of recyclable uncontaminated special waste, in relation to each single material available for the suggested intervention, it has been established to take into reference the management and monitoring plan of the waste quantities coming from C&D [49]. The minimum percentage of construction and demolition to be used for recovery is set at 15%.

The Environmental Impact Indicator, E_{imp}, is estimated by giving equal importance to the two components represented by the total amount of waste produced and the percentage of waste recovered. The two indices are therefore weighted equally in the Formula (8):

$$E_{IMP} = 0.50 * Q_{tot} + 0.50 * Q_{rec}. \quad (8)$$

The realization times related to the different construction processes are useful to give greater value to alternatives capable of reducing operating times, so as to subtract the work use to the community for shorter time fractions. The construction site duration is calculated through the time schedule of works in order to establish the time in natural and consecutive days necessary to complete the planned operations.

The criterion connected to the disturbance indicator has the specific function of providing information on the obstacle level caused to conventional school activities by the processes and workings foreseen by the project interventions. The disturbance level cannot be estimated quantitatively, as well as the other criteria, but rather a scale of easily interpretable values will be used.

The qualitative judgments associated with the criterion need to be transformed into quantities in order to obtain the correct compilation of the alternatives matrix. The disturbance level associated with the single intervention is divided into four categories based on an increasing interference of work activities on the services provided by the school. Table 5 shows a simple representation of the above concept.

Table 5. Disturbance: definition of disturbance levels to school activities.

Disturbance Level	Description	Score
Low	Intervention that does not require the occupation of premises and does not involve the activities' interruption. The interventions, given their type and entity, can be carried out outside the activities' hours and/or with techniques that have a minimal impact in terms of space occupation.	0.125
Medium	Intervention that requires the occupation of premises and involves the temporary suspension of activities or their reorganization (e.g., alternating morning/afternoon classes). The user is, however, received by the facility during the intervention.	0.375
Medium-high	Intervention that requires the occupation of premises and involves the temporary interruption of activities or their reorganization (e.g., alternating morning/afternoon classes). Part of the user must be relocated to another suitable facility.	0.625
High	Intervention that requires the total occupation of the facility and does not allow any activity. The whole user must be relocated to another suitable facility.	0.875

The summary scheme presented in Figure 2 summarizes the operational steps of the proposed method.

1. → PLANNING STAGE	a. → Goal definition
	b. → Criteria selection
	c. → Criteria weighing
	d. → Indicators definition
2. → DATA ANALISYS	a. → Preliminary data collection
	b. → Current condition evaluation
	c. → Alternatives determination
	d. → Indicators evaluation
	e. → Matrix of alternatives filling
3. → RESULTS DISCUSSION	a. → Matrix of alternatives resolution
	b. → Alteratives prioritization
	c. → Best alternative choice

Figure 2. The method's overview scheme.

4. Implementation of the Methodology to a Case Study

The validity of the proposed method has been tested through direct application to a case study. It was decided to evaluate the improvement interventions on the Comprehensive Institute "Abate F. Galiani" of Montoro Superiore (AV) in Campania, Italy (Figure 3).

Figure 3. Photo of the current state of the Istituto Comprensivo "F. Galiani". Photo taken by the Authors.

The first step of the process consists of the examination of the school building in question in order to get information related to the construction period and the building's seismic and energy characteristics. These aspects are fundamental to identifying intervention strategies. The examined informations are schematically collected in Table 6.

Table 6. School building data.

Investigated Characteristic	Method	Results
Construction year	documental analysis	1960–67 Structural consolidation: 1980–85
Structural typology	documental analysis, survey	Elevating structure: beams, pillars, reinforced concrete stiffening baffles. Foundations: reinforced concrete plinths connected by grade beams
Structural safety	survey, pacometric analysis, thermographic analysis, simulated design, linear static analysis	Safety factor $\zeta = 0.499$.
Building elements status	analysis sheets	Widespread degradation state
Energy performance	energy performance certificate	Class "G"
Surface/volume	documental analysis, survey	$S = 1865\ m^2$ $V = 7120\ m^3$
Destination	survey	18 classrooms

The method's core consists of comparing project hypotheses related to the school building recovery or to its demolition and reconstruction. The considered project alternatives are seismic improvement and energy efficiency interventions. Each hypothesis taken into consideration is screened according to the criteria set.

The alternatives to be compared are listed below:

(a) Alternative 1—(A_1): provides for a seismic improvement of the structure and energy requalification of the building in accordance with current regulations [40]. Specifically, the following technical measures are envisaged:

- Structural consolidation through Carbon Fiber Reinforced Polymer (CFRP) systems for seismic improvement;
- Installation of PVC windows with thermal break, equipped with double low-emissivity glass and double glazing;
- Exterior insulation finishing system for the entire external surface of the building by using a high-performance insulating panel made of 80 mm-thick rock wool;
- Application of thermal insulation in correspondence of the roof slabs consisting of mineral insulating panels, water-repellent, treated with thermosetting resin based on organic and vegetable components, 100 mm thick;
- Installation of new classroom doors in accordance with the dimensions determined by the current regulations [50];
- Replacing lights with modern energy-saving LED lamps;
- Replacement of the existing boiler with a new condensing model of equal power.

(b) Alternative 2—(A_2): the hypothesis of seismic improvement is again taken into account, however, it was decided to upgrade the energy efficiency in order to give higher energy performance than the previous alternative. Specifically, the following technical measures are foreseen:

- Structural consolidation through CFRP systems for seismic improvement;
- Installation of new thermal break PVC window frames, equipped with double low-emissivity glass and double glazing filled with argon;
- Exterior insulation finishing system for the entire external surface of the building by using a high-performance insulating panel made of 80 mm-thick rock wool;
- Application of thermal insulation in correspondence of the roofing slabs consisting of very high-density mineral insulation panels, water-repellent, treated with thermosetting resin based on organic and vegetable components, 100 mm thick;

- Installation of new classroom doors in accordance with the dimensions established by the current regulations [51];
- Replacing lights with modern energy-saving LED lamps;
- Replacement of the existing boiler with a new condensing model of equal power;
- Installation of a new crawl space with a ventilated cavity in correspondence of the first floor;
- Demolition of the partition walls in order to replace them with similar structures built dry and equipped with acoustic insulation in compliance with current standards [52].

(c) Alternative 3—(A_3): consists of the complete demolition of the building and its reconstruction through a reinforced concrete framed structure. The demolition technique adopted will be the classic one.

(d) Alternative 4—(A_4): provides for the total demolition of the building and its complete reconstruction through a reinforced concrete framed structure. This alternative differs from the previous one since, in this case, a selective demolition intervention will be arranged.

The A_3 and A_4 project hypotheses are based on the following technical expedients:

- The realization of a crawl space for the correct thermal insulation of the building.
- Thermal insulation in mineralized wood fiber panels bonded with 80 mm-thick Portland concrete with special expedients for the thermal bridge removal.
- Flat roof with a ventilated cavity. The insulating layer is made of natural toasted cork panels with a thickness of 120 mm. A surface finishing layer made with a thermo-reflective aerogel paint.
- The transparent closures are replaced with PVC thermal break windows with double low-emissivity glass and argon-filled glazing.
- With regard to the technological systems, some technical hypotheses have been adopted aimed at reducing the energy needs of the school facility. For this purpose, the installation of the following components is considered: a photovoltaic system consisting of amorphous panels integrated in the roof covering, equipped with storage batteries or direct connection for energy feed into the grid; a rainwater recovery system with a collection and storage plant for irrigation and sanitary facilities; an electric heat pump generator with compression and high COP; a heating/cooling system with fan coils, divided into zones, with an integrated system of temperature, humidity, and radiation control; an integrated system of automatic management of the indoor natural ventilation with energy recovery and incoming air pre-treatment; an LED lighting system with presence and brightness sensors.

Once the project alternatives and evaluation criteria have been defined, as shown in Section 2, the method provides for the assignment of weights to the considered criteria. The phase of assigning weights to the criteria was based on a scale similar to that one of Saaty [52,53]. In the case of application, the weights were assigned to the criteria through the administration of an evaluation sheet to 20 experts in the sector, with the aim of drawing up a ranking of the criteria's importance. The task of each expert was to place all six criteria on a decreasing scale of preference. The next step made it possible to estimate the relative weights of the criteria using the pair comparison technique. The sum of the weights attributed to the criteria must return a unit value. In Figure 4, the criteria and the weights related to them are highlighted.

In the next step, the alternatives matrix is filled in and resolved. The matrix, shown in Table 7, is compiled by inserting in each cell the value assumed by the indicator corresponding to the considered criterion. In this way, each project alternative acquires six values linked to the six evaluation criteria.

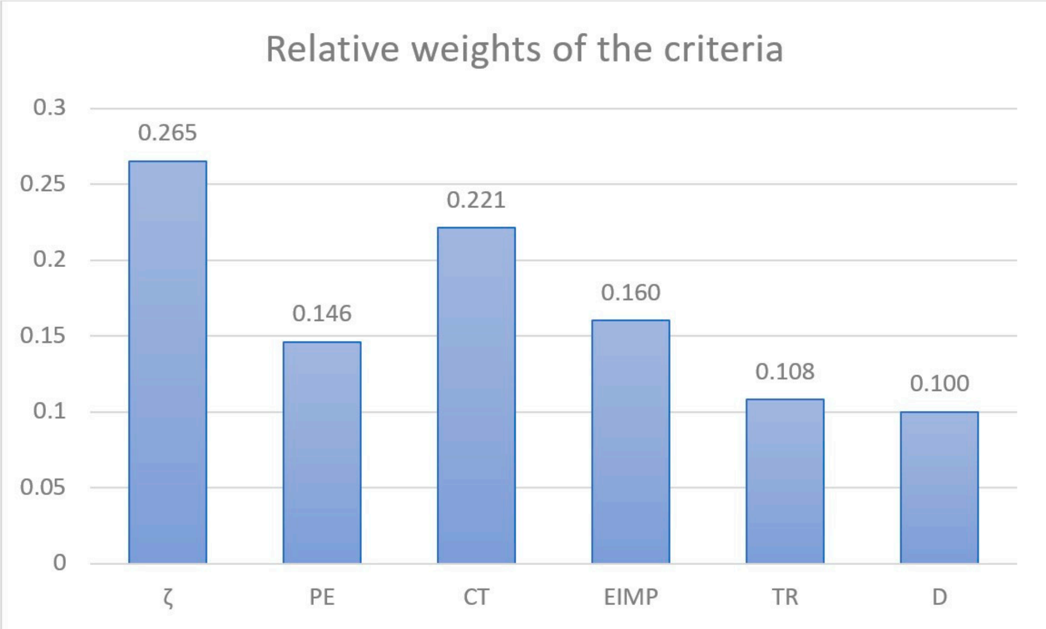

Figure 4. Relative weights of the criteria.

Table 7. Compilation of the alternatives matrix.

Interventions/Criteria	ζ	E_P	C_T	E_{IMP}	T_R	D
	R/E	**kWh/m² per Year**	**€**	**adim.**	**Days**	**Score**
A_1	1.01	119,872	2.765.56621	0.504	57	0.625
A_2	1.01	60,383	2.851.75793	0.136	90	0.625
A_3	1.28	16,687	3.068.04700	0.156	290	0.875
A_4	1.28	16,687	3.504.49900	0.511	300	0.875

The next step consists of the normalization of the alternatives matrix, as described in paragraph 2. This makes it possible to compare the different values of the indicators, which are uneven qualitative or quantitative variables. After normalization, it is possible to obtain, for each alternative, a global index of preference, I_p, which can be deduced from Table 8, expressing the "optimal" alternative in relation to the used criteria.

Table 8. Resolution of the alternatives matrix.

Interventions/Criteria	ζ	E_P	C_T	E_{IMP}	T_R	D
	R/E	**kWh/m² per Year**	**€**	**adim.**	**Days**	**Score**
Weight (w)	0.265	0.146	0.221	0.160	0.108	0.100
A_1	1.01	119,872	2.765.56621	0.504	57	0.625
A_2	1.01	60,383	2.851.75793	0.136	90	0.625
A_3	1.28	16,687	3.068.04700	0.156	290	0.875
A_4	1.28	16,687	3.504.49900	0.511	300	0.875

Figure 5 shows the project alternatives with the relative preference indexes. In relation to the different design solutions, the A_4 alternative is characterized by the highest index of preference, which is synonymous with the ability to achieve the best compromise between the set criteria and goals.

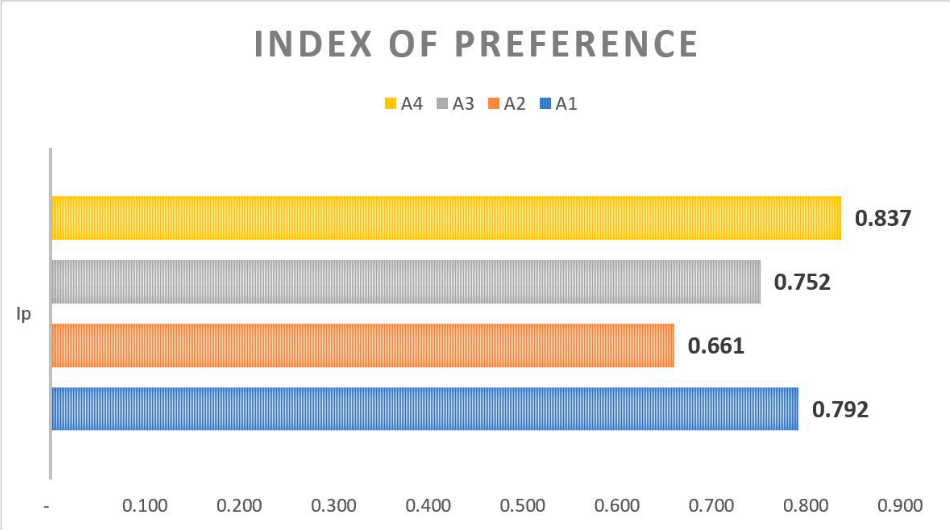

Figure 5. Indexes of preference graphic comparison.

The intervention involves the demolition and reconstruction of the building by adopting selective demolition techniques in order to reduce the contribution of waste material to the landfill, new reinforced concrete structures in compliance with current regulations, and highly energy-efficient plants.

5. Discussion

In light of the results obtained from the application of the method to the case study, some considerations can be made:

- The seismic safety level favors those project alternatives that provide for a new construction, as they are made according to current criteria and standards. Moreover, the presence of upwind walls built as part of a structural intervention following the 1980 seismic event in Irpinia greatly alters the seismic response of the existing structure. This makes the evaluation of the structure's post-elastic reserves very complex. This criticality leads to an understanding of the complexity in the definition of the indicators associated with the criteria, since the first must be able to catch the nature of problems very often articulated.
- One of the criteria that pushes more towards the choice of the optimal project hypothesis is the environmental impact indicator. This information is closely linked to the amount of waste produced and the amount of waste removed from the landfill and then recovered. This kind of process requires the precise and accurate knowledge of the waste recovery cycles. In this study, the general characteristics of the demolition phases have been examined, not entering into the specific costs, but only parametric, linked to the recovery process or environmental impact.
- It is clear that the ordering of alternatives is influenced by the distribution of relative weights and depends on the experts' discretion in relation to the specific case. This, at the same time, gives, however, extreme flexibility to the method, which does not claim to return the univocal solution of a problem but to orient in a structured and rational way towards those solutions that best satisfy specific goals.
- In addition, the method is "open", i.e., it can be implemented with additional evaluation criteria and the introduction of different needs and objectives.

6. Conclusions

The proposed methodology aims to support public administrations in planning the most appropriate interventions for the performance adjustment interventions of existing school buildings. The topic is extremely interesting, given the large number of schools in need of requalification.

The choice of the most appropriate intervention is linked to the contextual evaluation of many factors, and the use of multi-criteria methods allows us to rationally support the decision-making process, orienting towards the strategies that best meet the demand and performance framework.

Six evaluation criteria have been identified: (1) Seismic Safety Level, (2) Energy Performance. (3) Intervention Cost, (4) Environmental Impact, (5) Lead Time, (6) Disturbance. The next step after the criteria definition phase was the determination of the relative weights, based on the administration of a questionnaire to a panel of sector experts. It should be noted that the weights vector gives flexibility to the methodology, as it can also be differently calibrated in relation to the different needs of decision-makers and the specific goal of the problem in question. Although the weights attribution is discretionary, through sensitivity analysis it is possible to verify the influence of the variability of the weights themselves on the final results.

In particular, the methodology was applied to a case study in order to compare different hypotheses of structural and energy requalification with respect to the alternatives of school building demolition and reconstruction, with ordinary or selective demolition. Through the illustrated example, it is possible to highlight the potential of the proposed method as a tool to compare several intervention alternatives, both for single criteria and globally, in order to govern the choice process rationally and on the basis of quantitative evaluations.

Finally, it is intended to emphasize the possibilities of implementing the method. A first innovation could concern the number of criteria used to evaluate the best project alternative. Indeed, a greater specificity in the phases of alternatives analysis and evaluation would allow us to deepen the knowledge of the alternative compared characteristics. More knowledge, in this case, means more security in the choice phase. A second aspect to be implemented could concern the deepening of the analysis of the cost variability over time, taking into account the management expenses and those related to routine maintenance works.

Ultimately, it should be stressed that the proposed method is not structured to take into consideration school buildings of historical-architectural interest. In this case, the alternative of demolition and reconstruction is generally not feasible. Therefore, in order to deal with this kind of case, it is necessary to implement the method by making it capable, through further and appropriate indicator criteria, to compare project hypotheses that are based on the recovery of the building of historical/architectural value.

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