APPLICATION OF THE ANALYTIC HIERARCHY PROCESS (AHP) FOR ENERGETIC REHABILITATION OF HISTORICAL BUILDINGS

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ABSTRACT

Is it possible to integrate energy saving technologies and renewable energy in today's society with respect to the cultural and architectural aspects of historical buildings using tools to aid decision-making on how to integrate new functions, materials and techniques?

The aim of this paper is to analyze the link between utilization and conservation of monuments and describe a new approach for developing evaluation models of the potential sustainable energy rehabilitation of historical buildings. The experimental model is based on a multi-criteria approach—the Analytic Hierarchy Process (AHP) which introduces the use of expert opinions, complementary skills and expertise from different disciplines in conjunction with quantitative traditional analysis.

The main criteria used are: assess the impact of the proposed intervention in the light of international conventions on conservation (Restoration Charts); assess energy efficiency; assess environmental compatibility; and assess economic feasibility.

Keywords: Energetic rehabilitation, historical building.

Introduction

The sustainable recovery and structural adjustment of historical buildings are very complex processes, through which old spaces that were functionally designed for the past are adapted to modern standards of hygiene and well-being without compromising their historical character and artistic quality. Appropriate actions to save energy in buildings with high value must also ensure that changes can be easily removed without irreversible damage and that the materials and solutions proposed are compatible with the existing fabric.

In this context, a research process initiated in 2005 by the Built Heritage Lab of the Institute for Technologies Applied to Cultural Heritage (ITABC) of the National Research Council (CNR) has been involved since 2008 with the Sustainable Energy Communities in Historical Urban Areas (SECHURBA) project, whose objectives have been to promote sustainable energy interventions in very old historical urban areas, respecting culture,

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heritage and local character. Within the project, our group has played the role of Italian coordinator for four partners and leader of a major Work Package with which we have developed various activities. Among the tasks of the project, the most important for ITABC has concerned the proposal for and development of an instrument, the Intelligent Application Tool, designed to assess the compatibility of energy improvement interventions in monumental buildings. The tool uses a methodology for decision-making support and multi-criteria analysis to verify whether a particular technical solution, material or intervention procedure can complement and be compatible not only with the historical characteristics of a building but also with criteria of energy efficiency, affordability and environmental sustainability. The system takes into account the complexity of economic, physical, social, cultural and environmental factors, most of which belong to the realm of the immeasurable. The Analytic Hierarchy Process (AHP) method applied to our case study, was developed over a decade by T.L. Saaty, and is a technique structured to deal with complex decisions.
The tool makes the mechanism of the choices facing a set of decision-makers more rational and transparent. In our case, the decision-makers are experts with many skills: technicians (architects, systems engineers, restoration experts, energy consultants, engineers), owners of public and private property, politicians (local and national authorities, cultural organizations, international agencies), organisations in the climate and energy sectors (energy agencies, national Sechurba project leaders), market companies (producers, businesses, energy providers) and local communities and citizens.
The tool makes use of *"Superdecision"* open source software for matrix calculation, that is for calculation of the various weights of the alternatives according to the weights of various criteria. We will see some interesting results of this process applied to the Sechurba project case study.
The research team selected a case study in Italy, Zena Castle in the province of Piacenza, and, through a thorough fact-finding phase accompanied by detailed diagnostic surveys, identified the main issues, especially those related to its functional and energy behaviour and related needs, indicating those which could be proposals for improving performances and returns. The tool was used for the evaluation of the alternatives proposed by experts in two cases: one for the choice of photovoltaic modules for the roof and one for choosing the best thermal insulation for walls. The method was also tested on two other buildings of special architectural and historical significance: the Municipality of Copenhagen (Denmark) and the Chapel of the Souls in Santiago de Compostela in Spain.

Multicriteria decision model for the evaluation of the compatibility of energy projects in historical buildings

The process that was developed integrates the AHP method with an expert-based approach (that is, with the use of expert opinions, with the whole forming a complex tool based on a multidisciplinary approach).
The expert-based approach requires that the design group undertakes an integrated evaluation of all building components as well as typological and functional parameters of the architectural complex, performs energy audits and assesses needs in order to end up with a framework of the critical features of the building and priorities for action. The experts identify strategies and propose possible solutions or alternatives and the tool helps choose the best solution to meet the energy shortages that emerged after diagnosis, according to different criteria with respect to the old material, in terms of better living comfort and energy efficiency, cost effectiveness (in terms of short-term return on intervention costs and of energy saving) and environmental sustainability.
To choose among the alternatives, which make up a set of factors that by their nature are not quantifiable, the method uses a particular technique of paired comparisons that each expert uses to calculate the value of the "weights". The result of the matrix of paired comparison is a coefficient, which represents an estimate of the dominance of the first element over the second (or vice versa).
We developed survey record cards of the project's case studies, through which information was obtained both on the environmental and microclimatic characteristics of the site and on the building, accompanied by a thorough analysis of requirements and of energy performance and possible shortcomings or critical issues, useful for the definition of design solutions. Using standardised survey record cards, research was also carried out into energy-saving solutions, which brought to light some interesting national and international examples of rational use of energy conservation and applications of renewable energy, a sort of showcase for demonstrating the existence of possible and viable solutions.

On the whole, the tool presents itself as a process of integrated assessment broadly divided into 4 phases:

- Definition of the main objective and criteria (and related sub-criteria) of evaluation to assess the compatibility of measures for energy recovery in historic buildings;
- Construction of a model of analysis and evaluation of energy efficiency and of identified solutions;
- Identification of energy saving strategies;
- Construction of the AHP hierarchy, definition of the evaluation process, identification of a final hierarchy - with the objectives defined above - of the various solutions identified.

In order to define the criteria on which to base the assessment method, our research group conducted a preliminary analysis based on a critical study of international law and documentation on restoration, and of the energy efficiency of buildings. This research provided support for the definition of the four main base criteria for assessment as follows:

- Adherence to principles and international conventions on conservation: reversibility (ability to undo changes made); compatibility between old and new; minimal intervention; legibility of new interventions.
- Energy effectiveness and efficiency in order to maximize performance and ensure energy savings in buildings.
- Environmental sustainability in order to minimize the impact of environmental pollution and the maximum possible use of renewable resources.
- Economic viability, in order to recoup intervention and building management costs and also ensure savings in relation to the costs of structural management.

The criteria are then divided into 12 sub-criteria, grouped under a hierarchical tree.

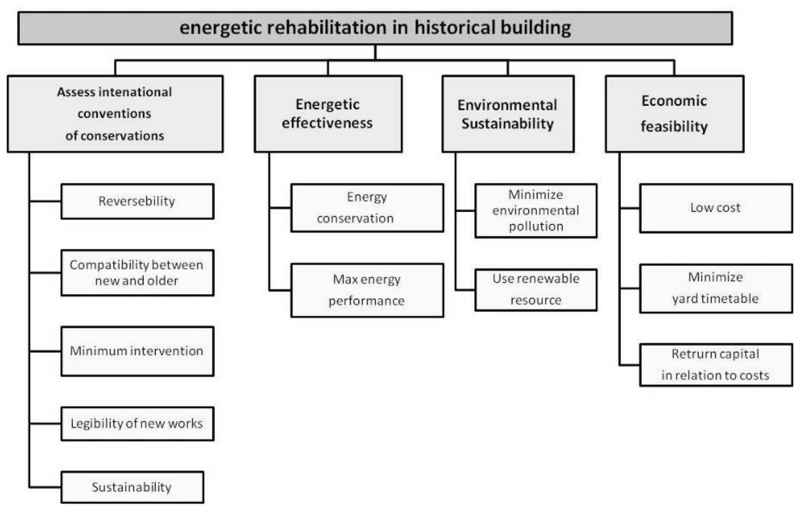

Figure 1. Tree illustrating the hierarchy of criteria and sub-criteria identified in the process.

Once the evaluation criteria had been defined, the next step was to organise them as a hierarchy. This process was carried out using an expert-based approach, with a comparison in pairs. Based on this assessment, the primary outcome criterion (46%) was related to compliance with international conventions on restoration, followed by the criterion related to the efficiency of the intervention (24%), and then, all at the same level (15%), criteria related to environmental sustainability and the economic feasibility of the intervention.

Identification of project alternatives and their evaluation

In recent years, a number of technologies have been developed for energetic rehabilitation. In addition, depending on building conditions, a wide variety of alternatives is available. Due to this wide range of alternatives, it is

necessary to use a method for screening out some alternatives (prior to performing a detailed analysis using decision support systems).
During this step, according to the objectives of the SECHURBA project, partners outline a programme to exchange knowledge about energetic rehabilitation alternatives in historical buildings.
To foster the organization of common knowledge, the research group prepared a draft check list for use by each SECHURBA partner to suggest new rehabilitation techniques and/or strategies. This draft proposal was organised in different sections containing information regarding energetic rehabilitation technologies and strategies and building element class.
A large database was then developed of technological solution best practices selected by experts from the vast market landscape, including those considered compatible with historical artefacts. Solutions, divided between RES (renewable energy) and RUE (energy saving), were classified and systematized on record cards by type of intervention and type of application, and are currently available online at the Sechurba site (http://www.database.sechurba.eu/).
In particular, these record cards indicating possible solutions were structured into two main sections:

1. The first, "RES/RUE – technical description" permitted the systematic collection of information regarding proposals to improve energy efficiency in historic buildings, building materials, building components (walls, windows and door frames, roof, floors), building performance (heating, cooling, lighting, hot water, heating water, electricity). Of particular importance is a section dedicated to the identification of energy efficiency class.
2. The second section, "Building Performance Rating", facilitated evaluation by experts of proposal suggested on the basis of the four criteria mentioned above. The rating scale is based on a qualitative assessment, using a 5-level scale of preferences (very strong, strong, medium, low, none).

In addition to the identification of different design solutions, the building energy audit, carried out through the use of appropriate protocols for assessing efficiency, has played a key role. For this analysis, the CNR has prepared a multicriteria investigation record card, which has facilitated the collection of information on historical and architectural, typological and structural characteristics, but also a detailed energy audit that has enabled the identification of needs, of critical points and of the possible failure of the building itself, in terms of energy efficiency.
Once the diagnosis and identification of intervention strategies and their design solutions had been carried out, the next step involved the assessment phase, carried out by identifying a hierarchy of preferences of the different alternatives suggested. At this stage, the alternatives were compared, two by two, by a team of reviewers with multiple skills: technical (architects, systems engineers, restoration experts, energy consultants, engineers), politicians (local and national authorities, cultural organisations, international bodies), organisations in the climate and energy sectors (energy agencies, national SECHURBA leaders), market companies (producers, businesses, energy providers) and local communities and citizens.
Use of the AHP method permitted definition of a hierarchy in which the alternatives were ranked according to their compliance with the criteria and then selected in the hierarchical classification, leading to identification of an integrated programme of action for energy recovery in building complexes. The method was successfully applied for energy recovery at Zena Castle, Piacenza. A careful analysis and energy audit of the castle complex identified the following critical points:

1. Water infiltration, thermal bridges;
2. Lack of insulation of windows and doors;
3. Heat loss;
4. Presence of mould;
5. Lack of insulation in enclosure walls (exterior walls, roofs and ground floors, shutters, doors and windows);
6. Need for an innovative energy production system for the architectural complex, including through the use of renewable sources to reduce energy consumption.

Through an expert-based approach, it was possible to define the following intervention strategies:

1. Increase the sealing and insulation of the building envelope (exterior walls, roofs and ground floors, shutters, doors and windows), thereby reducing heating requirements.
2. Reuse of some of the attic areas that met the necessary sanitary and hygienic requirements for occupancy as living quarters, for optimum recovery of space.
3. Restoration of the accessibility, functionality and structural reinforcement of the eastern wing that had been abandoned after collapse of the intermediate floors.
4. Recovery of the basement areas from both a conservation and a functional standpoint.
5. Design of an innovative energy production system for the entire architectural complex, supported by the use of renewable sources. In addition, reduction of energy consumption for cooling during the summer and heating during the winter and improvement of the hot water system and lighting of indoor and outdoor areas.

For each of these strategies, the team of experts identified a number of alternative solutions to resolve them. Then, through the application of AHP, they were compared according to the criteria listed above and n hierarchy of possible solutions was established. This operation was carried out for each of the strategies identified. In order to facilitate the process of benchmarking, Superdecision, an open source software, was used as a decision-making aid and to support the calculation and return of information.
Through this procedure, it became possible to define an integrated energy recovery programme for the castle, selecting alternative solutions for each of the strategies identified that were better suited to the sustainability criteria that had been set.

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