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: Restoration, Energetic rehabilitation, Historical buildings, Multicriteria Analysis.

Introduction

The potential of energy saving measures in historic buildings is of great interest, due to the increased building stock in European level, the particularities in their architectural form, typology and antiqueness of construction, the energy efficient initial design and their specific use and operation.

But the sustainable restoration, plant adaptation and technological reuse of historical buildings are very complex processes, whereby old spaces designed to function in the past are renovated to accommodate modern standards of hygiene and well-being, without compromising their historical character or artistic quality. Appropriate energy saving interventions in listed buildings must also ensure that such changes can be easily carried out without irreversible damage and that the material and solutions proposed are compatible with the existing material and structure.

In this context the Built Heritage Lab of the Institute for Technologies Applied to Cultural Heritage (ITABC) of the CNR (National Research Council) has promoted an European project (under the

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framework of the Intelligent Energy Europe Programme) titled SECHURBA, whose objectives have been to encourage sustainable energy interventions in historical urban areas, respecting culture, heritage and local character. The project has involved historic communities and buildings in 10 case studies to demonstrate how by addressing barriers, they can contribute to cultural, social, economic and environmental objectives and enable governments to exceed their statutory climate change requirements. Sechurba project was implemented in 7 European countries and project activities were carried out by 13 organizations.

But the energetic renovation of monuments involves a great number of variables, so a Multicriteria Analysis technique have been utilized in order to help the identification of different solutions and the definition of the priorities. Among the different methods of Multicriterial analysis used in urban and architectonic design the “Analytic Hierarchy Process” (AHP) was chosen as a technique structured to deal with complex decisions, developed over a decade ago by T.L. Saaty. The system takes into account the complexity of economic, physical, social, cultural and environmental factors, most of which are extremely difficult to determine.

In the framework of the project, the main task of our team was the development of a new, highly innovative and comprehensive Intelligent Application Tool, to identify appropriate sustainable energy solutions and achieve best practice in complex situations such as historic buildings.

Some interesting results of this process applied to the Sechurba project case studies will be presented. The Italian case study selected was the Zena Castle located in the Emilia Romagna Region, were a preliminary phase of integrated surveys and a systematic study of the historical, physical and architectural characteristics of the monument were carried out. Zena Castle is made up of six historical buildings with different origins and used over time for different purposes. The main building, the castle itself, is the oldest and most imposing. Almost all the buildings and surrounding areas are under restrictions because of their historic and architectural value and the main building – the castle – is adorned by many frescoes. The tool was used for the evaluation of the alternatives proposed by experts in two cases: one for testing the possibility of application of renewable energy technique and one for choosing thermal insulation for external walls. Detailed trials of the tool were also carried out in Denmark using Copenhagen City Hall as case study and examining the interventions regarding increased ventilation and PV potential. Also in Spain the tool was used to assess potential interventions with regards issue of dampness, and high electricity installation in the Capela Xeral das Ánimas in Santiago de Compostela.

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

The process developed, integrates the AHP method with an expert-based approach, that means the help of expert opinions and a multidisciplinary approach.

The expert-based approach requires that the design group undertakes an integrated evaluation of all building components as well as the typological and functional parameters of the architectural complex, performs energy audits and assesses needs in order de fine a general framework of the critical aspects and of the priorities.

The tool is organized in a process of integrated assessment divided into 4 phases:

1. Definition of the main objective and criteria (and the related sub-criteria) of evaluation to assess the compatibility of energy saving measures in historic buildings;
2. Construction of a model of analysis and evaluation of energy efficiency;
3. Identification of the energy saving strategies;
4. Construction of the AHP hierarchy, definition of the evaluation process, identification of a final hierarchy of the different solutions identified.

The first step concern the evaluation of the criteria of compatibility of energy projects in historical context, proposed by our expert team. On this stage we defined the comparison criteria for evaluating different proposals for energetic rehabilitation in the built heritage. Our research group conducted a
preliminary analysis based on critical studies of international laws and documentation on restoration, and of the energy efficiency of buildings. The main criteria that we have identified are the follows:

1. The Assess to the international Conventions of Conservations (that means to take under consideration the main principles of the European Charters of Restoration on which there is widest consensus, that are: a) reversibility (that means: the possibility to undo work and bring the fabric back to its original state); b) compatibility between new and old; c) minimum intervention, Legibility of new works against the existing.

2. Energetic Effectiveness (in order to maximize the energetic performance of the building saving energy).

3. Environmental Sustainability (in order to Minimize environmental pollution, and to use renewable resource).

4. Economic feasibility (in order to achieve low cost, to minimize yard timetable and to return capital in relation to costs).

The evaluation criteria have not the same weight, they may change according to the different typology of building or to different cultural contexts.

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

Once the evaluation criteria have been distinct, they have been to organised in a hierarchy. This process was carried out using an expert-based approach and the pairwise comparisons. 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 energy efficiency (24%), and then, all at the same level (15%), criteria related to environmental sustainability and the economic feasibility.

Identification of project alternatives and their evaluation
To develop a decision model for energetic retrofitting of historical building, a great amount of information is necessary.
To assist the process of analyzing building and site, survey cards of the project’s case studies were made, organized in different sections, containing information regarding the building and all its relative data, where information on the environmental and microclimatic characteristics of sites and buildings could be recorded. The check lists were also used to synthesized the energy performance analysis, useful for to define design solutions.
An important section of the work was the energetic diagnosis of the building. For Zena Castle we used different methods and software in order to calculate its energy efficiency and develop a thermal analysis. The method used was based on a direct survey of the building, supported by the calculation of transmittance of all single constructive elements, combined with the analysis of weak points, climatic, geometrical, typology and installation data. The result indicates that the building belongs to the “G Class”, with poor energy efficiency.

In the test carried out on the castle of Zena, after the building analysis and energetic diagnosis, the expert team identified the following problems as most critical and urgent:

1. The architectural complex needs new energetic production systems;
2. The building envelope has a very poor level of insulation, that produces high thermal losses;
3. The energy consumption for heating and cooling are very high and the existing plants are obsolete.

Then, to solve these problems, the expert team suggests the following main strategies, or goals:

1. New energy supply systems, also using renewable energy;
2. Improvement of the envelope performance through wall insulation improving;
3. Improvement of the efficiency of heating and cooling existing plants.

In order to provide possible solutions for the strategies identified, a huge database of best practices and of technological solutions was then developed, analyzing the vast market landscape and considering only those compatible with historical constructions. The database of new products and materials, providing information on types of innovative interventions that can be made to reduce carbon emission, is available online in the Sechurba website (http://www.database.sechurba.eu/).

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 experts 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.

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Figure 2 The database of new products and materials available online in the Sechurba website (http://www.database.sechurba.eu/)
From this database, the expert team proposed a set of alternative options for each strategy. Regarding the problem of the “Needs of energetic production systems”, raised out from building analysis and energetic audit, the strategy individuated by the expert team was to find “New systems of energy supply using “renewables”. To achieve this goal, after a deep evaluation of the products suitable for this purpose from the database, the experts suggested 4 alternatives: “Solé Power” an integrated system of tiles that can be installed like traditional clay tiles; “Kalzip”, an amorphous module of thin photovoltaic film; “Techtile energy”, were tile contains a photovoltaic cell, installed like normal roof tiles, and “Fornacefonti”, mounted on a clay tile with low visual impact. After have identified the different alternatives they have been compared using the pairwise comparison, respecting the different criteria previously determined. The tool use "Superdecision", an open source software involved in calculating various weights of the alternatives according to the weights of the various criteria. All the different alternatives were first ordered partially (for each criterion) and then globally, considering all the criteria, and the solution on the top of the ranking should be the best from all points of view. The aims was to guarantee the respect of the integrity and authenticity of the monument, as well as its sustainability, comfort and ‘livability’ with the use of these technological solutions.

Figure 3 The judgement the alternatives with respect to each of the criteria

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

1. Increasing of the insulation of the building envelope (exterior walls, roofs and ground floors, shutters, doors and windows)
2. Reuse of some of the attic areas for the optimisation of these abandoned spaces.
3. Restoration of the accessibility, functionality and structural reinforcement of the eastern wing, compromised by the collapse of the intermediate floors.
4. Conservative and functional restoration of all the basement areas.
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 experts identified a number of alternative solutions that, through the application of AHP, have been compared according to the criteria listed above.
Conclusions
With the establishment of this scientific path, a theoretical, methodological and technological approach was developed. The process uses innovative principles to design interventions of conservation and functional restoration for buildings with significant historical and architectural value. This path represents an essential guide for performing a kind of restoration that is compatible with the contemporary needs to reuse this heritage. It is oriented to establish a design methodology that can represent a “model for sustainable energy rehabilitation interventions”.

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