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A multi-criteria group decision-making method for the thermal renovation of masonry buildings: The case of Algeria

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ABSTRACT

The future of masonry buildings with heritage values is certain – the investments in making such buildings energy-efficient during renovations to meet the energy consumption requirements will increase over the next decade. However, decision makers fail to address the concerns of each project actor and give specific answers on how basic requirements on such historical buildings can be implemented. This paper proposes a new multi-criteria group decision-making method for the thermal renovation of masonry buildings. The aim of the proposed method is to rank different renovation solutions. The method uses; the structured group interaction method Delphi to define the evaluation criteria and the thermal renovations solutions, Swing method to facilitate the process of the determination of the criteria weights, the group decision support system (PROMETHEE GDSS) to reach a global ranking of the renovations solutions, PROMETHEE V to introduce additional constraints, as well as the Graphical Analysis for Interactive Aid (GAIA) analysis to get a better understanding of conflicts and similarities between the criteria and among the decision makers. We proceed to exemplify by means of a real-life case project in Algeria and offer suggestions on what front-ended stakeholders could do to reduce the energy consumption in masonry buildings.

1. Introduction

Residential and tertiary sectors in Algeria consume about 34% of the total energy production in the country. The government has launched in 2016 a thermal renovation program for existing buildings to reduce the energy consumption. This program is led by the national agency for the promotion and the rationalization of the energy use (APRUE). It aims to insulate 100.000 houses per year. The national fund for energy management (FNME) will provide 80 percent of the costs related to these interventions [1].

The existing building stock in Algeria has reached 6,500,000 dwellings in 2016, from those 1,050,000 consist of masonry dwellings built before 1945. The majority of masonry buildings were built during the French colonial period. These buildings represent a valuable architectural heritage. They were constructed using traditional techniques and materials (for e.g. load bearing walls of stone masonry, vaulted brick floor and metal beams) [2]. The masonry buildings are subject in Algeria to a wide preservation program, many buildings rehabilitations are undertaken across the country. In 2016, the government envisages the diagnostics of 300.000 dwellings. Rehabilitation operations will be launched following these diagnostics. These actions will be conducted and financed by the government. The buildings rehabilitation will concern only common parts of buildings (exterior facades, yards, cellars, entrance halls, stairwells, accessible and inaccessible terraces, and pitched roofs) [3].

The energy-saving program in the residential sector and the rehabilitation of masonry buildings program offer a great opportunity to perform the thermal renovation of masonry buildings. This will balance between the improvement of the thermal performance of the existing buildings stock and the perseveration of masonry buildings. However, the choice of improvement alternatives during their thermal renovation is a complex decision because:

- It involves different stakeholders (actor concerned with the preservation of buildings, actor concerned by the reduction of energy consumption, building users, and so on) that can express a multitude of criteria (economic, energy, cultural, historical, and so on).

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- The communication among the actors to obtain a consensus regarding the definition of evaluation criteria, and the potential thermal renovation solutions might be complicated due the differences in their respective backgrounds.
- The difficulty in assessing the importance of each criterion for each actor.

Due to the multi-decision makers and multi-criteria character of the thermal renovation of masonry buildings in Algeria, it is difficult to find solutions that can optimize all the criteria at once. Therefore, it would be more appropriate to find consensus solutions. The multiple-criteria decision analysis is a useful tool for this type of problem; it evaluates different solutions taking into account both the preferences of decision makers and the different criteria. Many research studied the application of multi-criteria decision methods in the renovation of masonry buildings [4–7]. Yet, only few works focused on the use of such methods in order to make masonry buildings energy-efficient [8–10]. This paper proposes a new group decision aid method that combines the Delphi method, the Swing method, and the Preference Ranking Organization Method for Enrichment Evaluation PROMETHEE methods [11] for the thermal renovation of masonry buildings with a heritage value. The aim of the proposed method is to rank different thermal renovation solutions using a multi-criteria and multi-decision makers approach. This paper is divided into six-parts, the following section presents a literature review concerning the application of multi-criteria decision aid methods in the field of thermal renovation, part 3 develops the method used in this paper, part 4 provides the results of the application of the method on a case study, Section 5 evaluates the proposed method, while Section 6 presents conclusions and directions for future research.

2. Literature review

Different methods were applied to support decisions for the thermal renovation of buildings [8–10,12,13–26]. These methodologies can be categorized into two main families as indicated in Zavadskas et al. [12]: the Multi-Criteria Decision Aid methods (MCDA), in which the numbers of alternatives to consider is finite and known, and the Multi-Objective Optimization methods (MOO), which enables the consideration of an infinite set of alternatives.

2.1. Multi-criteria decision aid (MCDA) methods

MCDA used for the thermal renovation of buildings can be ranked into two different approaches; the partial aggregation approach and the complete aggregations approach.

2.1.1. The partial aggregation approaches

The advantage of this approach is that it provides the opportunity to take into account both quantitative and qualitative criteria without having to do any coding. It does not allow compensation between criteria such as facing two actions “*a*” and “*b*”; it is based on the assumption that “*a*” outrank “*b*” if “*a*” is at least as good as “*b*” on a majority of criteria without being too much worse in other criteria. Rey [13] proposed an outranking MCDA with partial aggregation from the ELECTRE (Elimination and Choice Expressing the Reality) methods for the thermal renovation of office buildings. Outranking methods were also applied to study air conditioning systems [14]. Catalina et al. [15] applied MCDA method ELECTRE in order to select an appropriate multi-source energy system for residential houses. Avgelis and Papadopoulos [16] used ELECTRE in order to rank different HVAC (Heating, Ventilation, and Air Conditioning) systems in a university building regarding energy costs and inflation, as well as the economic and life cycle costs of acquiring a system.

2.1.2. The complete aggregation approach

The complete aggregation approach gives a note to all scenarios, whilst basing the score on the most important criteria. However, this approach presents several limitations. It allows the compensation of low score in criteria with good results on several other criteria. Also, it is necessary to carry out a coding while taking into account both quantitative and qualitative criteria. Roulet et al. [17] suggested a multi-criteria rating methodology based on a complete aggregation approach in order to assess the effectiveness of various thermal renovation scenarios.

Blondeau et al. [18] tested MAUT (Multi-Attribute Utility Theory) method in the study of summer ventilation strategies in an educational building. Their findings highlighted the limitations of this method. It is completely compensatory and it sometimes provides counter-intuitive results. Alanne [19] applied a multi-criteria decision aid model type “knapsack” to help designers to choose the most appropriate renovation actions during the design phase of a project. The advantage of this model is to treat a portfolio optimization case by introducing constraints. The disadvantage is the purely additive character of the model.

Medineckiene and Björk [20] applied the multi-criteria decision aid method SAW (Simple Additive Weighting), MEW (Multiplicative Exponential Weighting), and COPRAS (COmplex PRoportion ASsessment) to choose solutions for the thermal renovation of Swedish residential apartments. Kontu et al. [21] proposed the multi-criteria decision aid method SMAA (Stochastic Multi-criteria Acceptability Analysis) to assess which heating system would be best for new single-family homes. The advantage of both approaches cited in this paragraph is to take into account the preferences of the building users; they were involved in the decision process using interviews for the first method and questionnaire for the second in order to get their preferences regarding different evaluations criteria.

Šiožinytė et al. [22] applied the TOPSIS Grey (Technique for Order Preference by Similarity to Ideal Solution with grey numbers) and AHP (Analytic Hierarchy Process) methods to find the best compromise solution in order to make vernacular buildings energy efficient. Different criteria were considered, such as architectural heritage, requirements (norms), energy and comfort. Ruzgys et al. [23] applied an integrated SWARA (Step-wise Weight Assessment Ratio Analysis) – TODIM (an acronym in Portuguese of Interactive and Multi-criteria decision-making) multi-criteria decision-making method in order to rank the best alternatives of residential building modernization in Lithuania.

Terracciano et al. [9] have studied the analysis of vertical addition systems for energetic retrofitting of existing masonry buildings. The multi-criteria decision-making TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method have been used in order to compare the vertical addition systems with each other in terms of structural, environmental, and economic performance parameters. Zagorskas et al. [10] applied TOPSIS method to select the best insulation option for historic buildings among five internal insulation materials. This method takes into account five criteria: cost of the material, complexity of the installation, heat transfer coefficient, loss of space, and moisture properties of the material. The relevance of both methods presented by Terracciano et al. [9], and Zagorskas et al. [10] compared to all the other methods previously cited, is that they take into account the specificity of the thermal renovation of masonry buildings with a heritage value. However, they both have several limitations, such as the method proposed by Zagorskas et al. [10] can be applied only for the internal insulation of buildings, while the method suggested by Terracciano et al. [9] can be used only for the selection of vertical addition