Multi-criteria Assessment Model of Technologies

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Abstract: Construction is a sector that accepts innovations slowly. Selection of effective technological systems in construction is a complex multi-criteria task. Many decision-makers refuse innovations once faced with similar difficulties. The article presents an original approach towards a development of multi-criteria assessment and ranking technique for alternatives of technology in construction. The problem was solved using different well-known MCDM methods ELECTRE IV and MULTIMOORA. Three hybrid methods SWARA-TOPSIS, SWARA-ELECTRE III, SWARA-VIKOR were used to solve the same problem. Priority of considered alternatives was determined based on the average of alternatives performance rank. The article presents a practical case study on evaluation of different alternatives for public buildings refurbishment using typical and novel thermal insulation technologies for facades. Research results demonstrate that novel facades thermal insulation alternatives for facades have a higher performance level than commonly used ones.

Keywords: MCDM, model, ELECTRE IV, MULTIMOORA, SWARA-TOPSIS, SWARA-ELECTRE III, SWARA-VIKOR, facades, thermal insulation

1. Introduction

Market participants avoid investing in novel and advanced technologies as usually such decisions are associated with staff training, higher initial costs and uncertainty regarding the possible benefits. For this reason, complex model for the assessment of technological solutions should be developed to facilitate the generation and development of commercially viable products. Technology selection is a complex and intricate problem. A decision-maker is not always able to adequately assess conflicting criteria and find the most preferable solution [1, 2]. A multi-criteria model and different techniques provide means to resolve the problem as follows:

- selection and analysis of alternatives related to the objective;
- selection and analysis of criteria that describe the alternatives;
- selection of the most important criteria;
- setting weights for each criterion (significance or priority);
- gathering of criteria values;
- testing of criteria values;
- application of multi-criteria methods;
- selection of the preferred (optimal) alternative.

The model could be applied for ranking and assessment of technologies as well as evaluation of products, processes and innovative solutions. Refurbishment and renovation of buildings is a world-wide problem of crucial importance. In this article, performance of the model is investigated by solving the renovation problem: undertaking a comparative assessment of alternatives of typical and novel facade insulation technologies for refurbishment of public buildings. Potentially, the market for new high efficient technologies in the insulation sector is unlimited. Even when taking into account the diversity of insulation needs across Europe (depending, for instance, on climate specificities), all individual homes, buildings and industries could be the target of these technologies [3]. However, innovative technologies represent a small share of the total turnover of the insulation market in the European Union (around 5%). With policy makers and civil society increasingly focusing on energy efficiency and the environmental impact of construction products, more innovative products are entering the market [4], [5]. With energy efficiency being a European flagship action in the EU 2020 strategy, awareness among producers and end users should rise, and drive the market to further take into account the environmental–related performance of the products [6]. Most of the electricity, which is generated in Europe, is consumed in buildings. Residential buildings consume about 2/3 of energy per whole building sector [7], [8]. Old apartment buildings use the largest share of energy in post-Soviet countries. This situation was caused by Soviet construction norms. Nowadays, these buildings do not meet the requirements of modern world development and construction norms. These buildings should to be retrofitted (renovated). Research findings and examples of implemented projects show the existence of a huge energy efficiency potential in post-Soviet buildings. Assessment of thermal insulation technologies for buildings is a MCDM problem. Such point of view to the problem supports the development of innovative technological solutions that comply with needs and requirements of the market and enable their effective industrial implementation.

Technology selection is a complex MCDM problem. The process includes different criteria, determination of criteria weights and most importantly to choose the right technique. Zavadskas and Turskis [9] stated that the major criticism issued in the address of MCDM methods is related to the different techniques. Sometimes, different results are obtained when applied to the same problem.

The main reasons of this are:

- Using weights differently;
- Different selection of the best solution;
- Attempt to scale objectives;
- Introducing additional parameters that affect the solution.

2. Assessment Model

A research model for feasibility assessment of existing and novel construction technologies for refurbishment of public buildings is presented below. The main stages of the model (Figure 1) are as follow:

- Identification of feasible alternatives, which are related to the purpose of problem solution.
- Implementation. Determining the criteria set and their values.
- Assessment. Describing the initial decision-making matrix, determining weights of criteria, selecting relevant MCDM methods and, finally, solving the problem.
- Decision. Analysis of results and the final decision on implementation of the most relevant alternative.

The model aims at selecting the best construction alternative from all those investigated.

Many MCDM methods are available [9]. Several well-known and widely used MCDM methods were applied in this research. Five different well-known MCDM methods were selected to solve the problem: SWARA-TOPSIS, SWARA-ELECTRE III, ELECTRE IV, SWARA-VIKOR and MULTIMOORA. The efficiency of those methods is substantiated by well-known scientists and MCDM experts.

SWARA. Only well-founded weighting factors should be used because weighting factors are always subjective and influence the solution. The main feature of SWARA (Step-wise Weight Assessment Ratio Analysis) method allows estimating opinions of experts or interest groups on significance ratio of the criteria in the process of their weight determination [10].

Based on the experience and literature overview, five different MCDM problem solution methods were selected:

- *MULTI-MOORA*. Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadskas [11]. MULTIMOORA method was chosen because it is not only relatively efficient and easily understood but also based on logic in selection of the most appropriate alternative or ranking from available alternatives [12]. This method was developed and became MULTI-MOORA [13] (MOORA plus the full multiplicative form). Brauers et al. [14] evaluated the economy of regions and tested regional development considering multiple objectives. Some more recent applications can be mentioned, as a ranking panel building refurbishment elements effective selection [15], Lithuanian case study on masonry buildings [16] or calculations for heating losses in a building [17].
- *ELECTRE III.* This is a well-established MCDM method that has a history of successful real-world applications. ELECTRE III requires an input of criteria evaluations for the alternatives (decision-making matrix), preference information, expressed as weights, thresholds, and other parameters. Performance of alternatives can usually be determined with “certain accuracy”, and the imperfect knowledge about the evaluations can be taken into

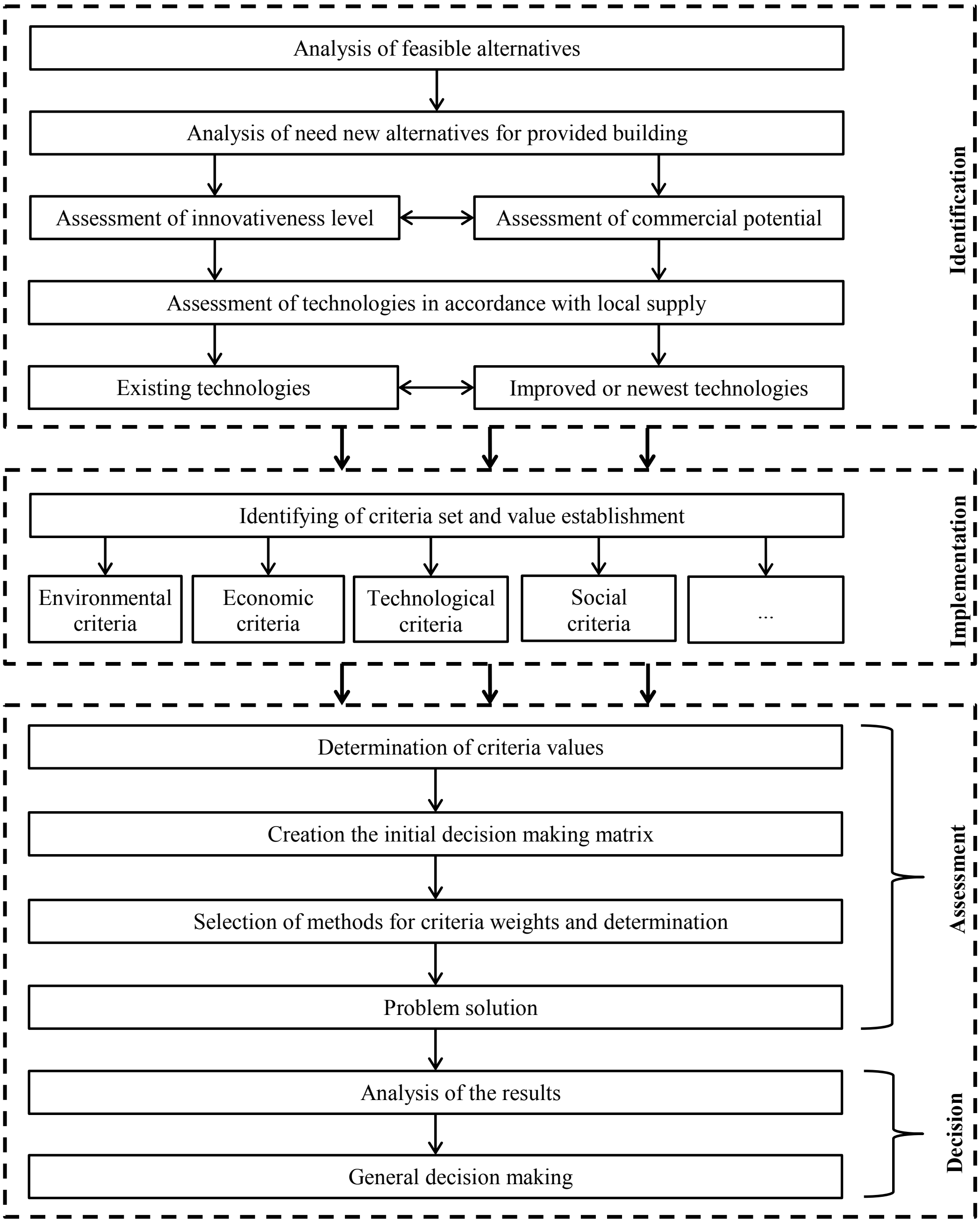

Figure 1. Assessment model for rational technology system

account when defining the thresholds for the model. For preference information the situation is even worse: if DMs cannot provide precise and complete weight information or there are multiple DMs with conflicting preferences, ELECTRE methods cannot be used for decision aiding without some external method for transforming the preferences to deterministic weight values. The ELECTRE III method is based on two phases. First, the outranking relation between pairs of actions is formed. This results in an outranking matrix. The second phase consists of exploiting this relation, producing a partial pre-order [18].

– *ELECTRE IV*. Roy and Bouyssou [19] proposed ELECTRE IV to simplify the procedure of ELECTRE III. The basic difference between ELECTRE III and ELECTR IV is that ELECTRE IV does not introduce any weight expressing the weights of the criteria, which may be hard to measure in practice. However, this does not mean that weights of criteria are assumed to be equal. Therefore, the pseudo criteria are used, as in ELECTRE III [20].

- Decision-makers in construction problems-solving applied ELECTRE III method for assessing the optimal location of a construction and demolition waste management facility [21] as well as multi-criteria aided design of integrated heating–cooling energy systems in buildings [22] and selecting the best partner construction enterprise in terms of partnering relations [23]. Aguilera et al. [24] applied ELECTRE III/IV method for planning process of an integrated urban transportation system. Stevovic et al. [25] used ELECTRE IV for applying sustainable development concept, which includes finding the optimal technical solutions that would enable exploitation of the resources of energy with minimal environmental damage.
- *TOPSIS*. The technique for order performance by similarity to ideal solution (TOPSIS) is one of known classical MCDM methods. It was first developed by Hwang and Yoon [26] for solving MCDM problems. The basic idea of TOPSIS is simple and intuitive: measure the distance of alternatives to predefined ideal and anti-ideal points first and, then, aggregates the separate distance information to reach the overall evaluation results. TOPSIS is attractive as limited subjective input is needed from decision-makers. Many authors argue that TOPSIS is an easy and useful method helping a decision-maker select the best choice according to both the minimal distance from the positive-ideal solution and the maximal distance from the negative-ideal solution.
- *VIKOR*. The VIKOR algorithm was proposed by Opricovic [27]. It is a MCDM method for complex systems based on ideal point method. VIKOR helps to determine the positive-ideal solution and the negative-ideal solution in the first place. The positive-ideal solution is the best value of alternatives under assessment criteria, and the negative-ideal solution is the worst value of alternatives under assessment criteria. The principle of VIKOR algorithm is based on the ideal point method. It is easy to understand, has less factors to consider and a simpler calculation. The main advantages of the VIKOR method are that it can solve discrete decision problems with conflicting and non-commensurable (different units) criteria [28] and provide a solution that is the closest to the ideal.

3. Case Study

Public buildings refurbished in in the period of 2010-2013 were investigated (Region of Vilnius, Lithuania). Different characteristics of buildings were determined [3]: physical deterioration of buildings, absorption of facades, outdoor air temperature, indoor air temperature, relative humidity, floor temperature, surface (ceiling) temperature, carbon dioxide concentration, U-value. Thermovision was performed and economic calculations were made. One of the most important tasks for refurbishment is thermal insulation of external walls. The case study presents comparison of typical thermal insulation technologies for external walls improved thermal insulation alternatives that were recently proposed by manufacturers.

Typical two-story kindergarten buildings with reinforced concrete framework were selected for case study. The walls were built from 240 mm thick aerated concrete slabs. Investigations shows that U-value of walls equals to 0.58 W/(m^2·K).

Six feasible alternatives $A_1 - A_6$ for thermal insulation of external walls of buildings were selected (Table 1):

- A_1 – thermally insulated with 150 mm thick mineral wool boards using an external plastered composite thermal insulation system.
- A_2 – thermally insulated with 150 mm thick polystyrene foam boards using an external plastered composite thermal insulation system.
- A_3 – thermally insulated with 150 mm thick mineral wool panels using ventilated external thermal insulation system with decorative facades panels.
- A_4 – thermally insulated with 150 mm thickness polystyrene foam with seam panels using composite external plastered thermal insulation system (e.g., Tex-Therm WDSS). All polystyrene foam boards are equipped with a special hook-shaped seam,

which pins to the ground in the flat zone connection. The approval of rebate cards can sink into each other and merge with each other. The key benefits of these technologies are: studs are "hidden" in the layer of insulation, so they do not show through the plaster, a stud does not heat bridges, special serrated flat profile provides a larger surface connection and tightness of all rebate cards have the same thickness (≈ 40 mm), shorter studs can be used (≈ 95-110 mm), which is independent of the length of the material thickness, and better clamping of plates at the base is ensured with less studs [29].

- A_5 – thermally insulated with 150 mm thickness milled grey polystyrene foam (neopor) panels using external thermal ventilated insulation system (e.g. Swisspor LAMBDA Vento). The exclusivity of this technology is in the bracket shell, which is mounted with non-metallic profiles but rather spacer screws using a wooden frame. The main benefits of these systems are: increases tightness of milled neopor plates (which sink into each other and connect with each other), neopor thermal resistance is higher than plain polystyrene foam using spacer screws, thus avoiding large heat losses through ventilation for heat insulation system frame [30].
- A_6 – thermally insulated with 150 mm thickness rock wool panels with a layer of wind protection from and the sealing strips using an external ventilated thermal insulation system (e.g. Paroc Cortex One). The exclusivity of this technology is in stone wool panels, which are coated with flame-resistant, water vapour permeable but air insulating film. This system uses additional sealing strips that are glued to flat junctions and corners (external wall angles). The key benefits of these technologies are: increased tightness of stone wool slab with a special film coating and sealing tapes does not require additional wind insulation layer using the diffusion film and a special air insulating layer of wool, suitable for use in high rise buildings [31].

Nominal group technique Delfi [32] was selected to determine criteria set for evaluation of alternatives, 25 highly experienced civil engineers and HVAC specialists were involved to the process. They selected five main criteria $c_1 – c_5$ (Table 1):

- c_1 – Price including VAT, (€/100 m^2). The cost of thermal insulation alternatives (including VAT) for back external wall of the building, which has no opening, was calculated in each case. This criterion is

Table 1. Initial decision-making matrix for retrofitting of facades

Alternatives for thermal insulation of external walls	Criteria				
	Price including VAT, (€/100 m^2)	U-value, (W/(m^2·K))	Duration of works, (m. d./100 m^2)	Payback period, (years)	Water vapour diffusion, (score)
Typical thermal insulation technologies (systems) for external walls					
A_1	5683.49	0.20	38.34	15.43	3
A_2	4772.48	0.20	34.24	12.95	3
A_3	8979.56	0.25	48.02	28.07	4
Modernised typical thermal insulation technologies (systems) for external walls					
A_4	4838.11	0.19	31.90	12.80	3
A_5	9732.34	0.18	39.81	25.10	4
A_6	9624.07	0.23	45.96	28.36	4
Optimality direction	min.	min.	min.	min.	max.

expressed by the amount of money, needed to install 100 m^2 of thermal insulation system (€/100 m^2).

- c_2 – U-value, (W/(m^2·K)). Heat transfer coefficient of external walls was determined based on in-kind research conducted in buildings and the theoretical calculations according to the manufacturer's thermal properties of materials.
- c_3 – Duration of works, (m. d./100 m^2). The duration of works is calculated using normative labour inputs. This criterion is expressed by the amount of working days, during which one professional worker installs 100 m^2 of the thermal insulation system.
- c_4 – Payback period, (years). A simple payback period of external wall modernization is calculated dividing the initial investments by annual thermal energy savings through external walls.
- c_5 – Water vapour diffusion (score). External thermal insulation composite systems (ETICS) and external thermal ventilated systems maintain different levels of water vapour diffusion. The values of this criterion are expressed by scoring [33].

Five important criteria were selected to solve the problem. Next, a survey of 25 experts was carried out and these criteria were rated and listed from the most important to the least important as follows: $c_4 \succ c_1 \succ c_2 \succ c_5 \succ c_3$.

After determining the ranks of criteria, the authors of the article made individual rankings comparing criteria between each other using SWARA method (Figure 2) and parameters that determine the extent by which one criterion is better than another (s_j).

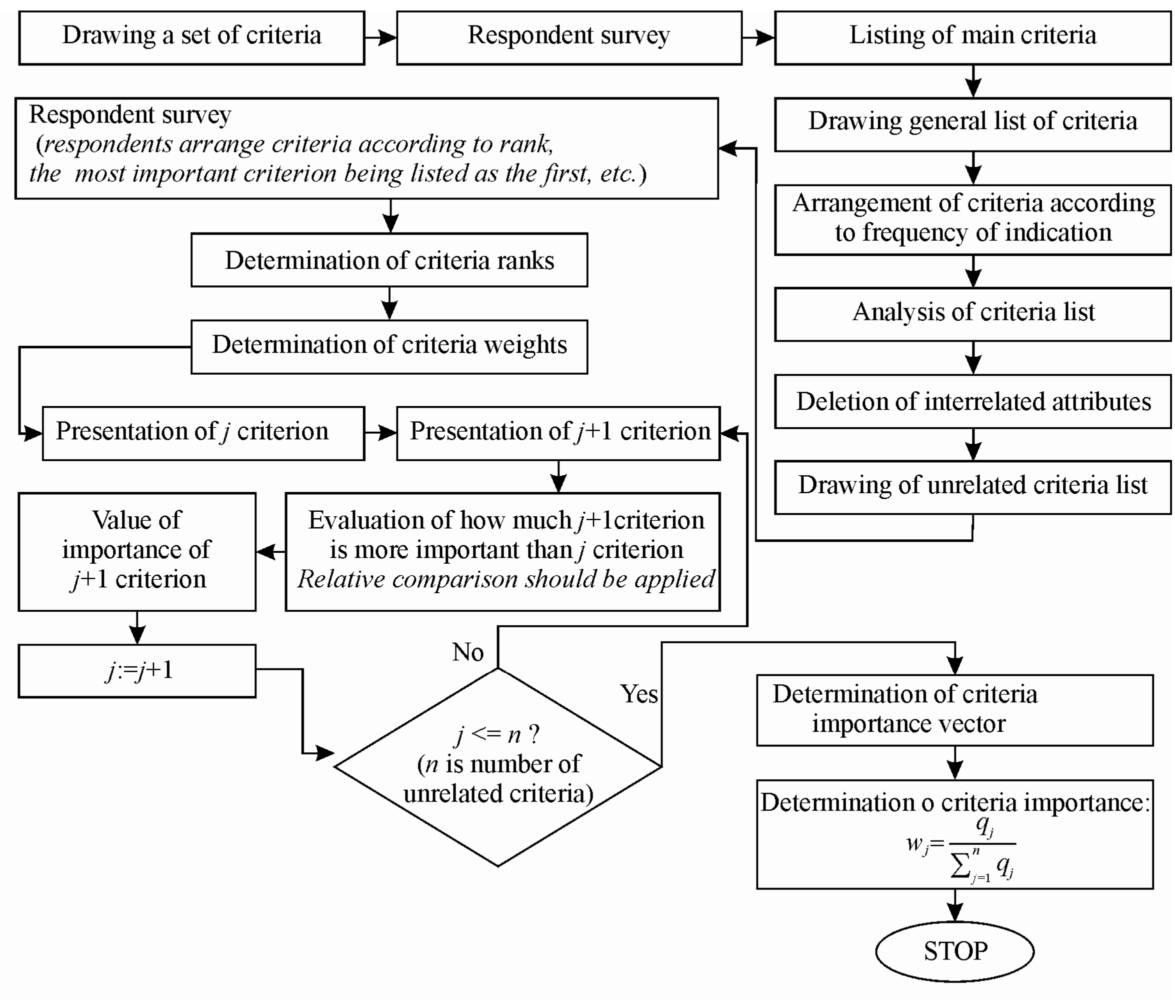

Figure 2. Determining criteria weights [34]

Finally, data were processed (the arithmetical mean was derived) and further calculations of the SWARA method were performed. Results are given in Table 2.

Table 2. Criteria parameters by SWARA method

Criterion	Comparative importance of average value, s_j	Coefficient, k_j	Recalculated weight, q_j	Weight, w_j
c_4	—	1.000	1.000	0.294
	0.350			
c_1		1.350	0.741	0.218
	0.100			
c_2		1.100	0.674	0.198
	0.250			
c_5		1.250	0.539	0.158
	0.200			
c_3	—	1.200	0.449	0.132

According to different solution methods alternative ranks were not in the same sequence (Table 3). The final ranking of alternatives was made based on average of ranks for each alternative. The calculated standard deviation shows the existing variation or dispersion from the average. A low standard deviation indicates that data points tend to be very close to the mean, a high standard deviation indicates that data points are spread out over a large range of values.

Table 3. Criteria parameters by SWARA method

Alternatives	SWARA-TOPSIS	SWARA-ELECTRE III	ELECTRE IV	SWARA-VIKOR	MULTI-MOORA	Average	Standard deviation
A_1	3	3	6	3	3	3.6	1.200
A_2	2	1	3	2	2	2.0	0.632
A_3	5	4	4	6	6	5.0	0.894
A_4	1	1	1	1	1	1.0	0.000
A_5	4	2	2	4	4	3.2	0.979
A_6	6	3	5	5	5	4.8	0.979

Alternatives rank as follows:

$A_4 \succ A_2 \succ A_5 \succ A_1 \succ A_6 \succ A_3$.

The results show that the best alternative according to all MCDM methods is: external rendering thermal insulation system with polystyrene foam and seam panels. That is the improved typical external wall insulation technology, which is difficult to find on Lithuanian market (only few buildings were renovated using this technology).

4. Conclusions

This paper developed a novel assessment model for a rational technology system. A complex technology assessment model is a tool supporting the assessment of marketability opportunities of an innovative technological solution. Model performance is tested through solving the problem for assessment of traditional and available on the market thermal insulation technologies for facades in comparison to improved solutions. The problem was solved using different MCDM methods (ELECTRE IV, MULTIMOORA and proposed hybrid methods SWARA-TOPSIS, SWARA-ELECTRE III, and SWARA-VIKOR) and establishing ranks of the investigated alternatives. Based on the developed algorithm and determined criteria set for the problem solution, it is determined that novel alternatives should be applied to modernise public buildings.

The proposed model could be modernised and applied to solve different problems related to assessment of innovations and comparative analysis.

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