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SELECTION OF FACADE'S ALTERNATIVES OF COMMERCIAL AND PUBLIC BUILDINGS BASED ON MULTIPLE CRITERIA

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ABSTRACT. An appropriate mechanism for supporting design management practices at an early stage of project is crucial in terms of adding value over scope, time and total investment strategic decisions. The clients are not only interested in value for money in relation to the investment in project development but costs associated in operation and maintenance over project life cycle as well. These criteria make possible to evaluate design solutions which can be characterized by quantitative and qualitative criteria which possibly have different weight, dimension and direction of optimization (maximisation or minimization). The purpose of this article – is to compare different designs of building or its structure and to select the best alternative using criteria of optimality. Case study is demonstrated by selecting the best facade system to cover the building. For this purpose four alternatives of building facades are under consideration. Two criteria (out of three) indicate that for the case study the most preferable facade's alternative is gas silicate masonry, covered by Rockwool and "Minerit" facade plates.

KEYWORDS: Building life cycle; Alternatives; Decision making; Utility theory; Entropy weights

1. INTRODUCTION

Poor design strategic decision-making practice often leads to confusions and conflicts in complex engineering projects. Generally, life cycle management refers to management of systems, products, or projects throughout their useful economical lives (Venckus et al., 2010). Projects pass through a succession of phases throughout their lives, each with their own characteristics and requiring different types of strategic decisions and management. Usually the lifecycle of every building covers the following stages (see Figure 1): generation of idea (predesigned proposals), design, construction, maintenance, reconstruction (if possible) and demolition (disposal). In order to design and implement a high-quality house project, it is necessary to take care of its efficiency from the brief stage to the end of its life's service

(Kaklauskas et al., 2009, 2011; Zavadskas et al., 2011). Buildings demand energy in their life cycle right from its construction to demolition (Ramesh et al., 2010). Results over the entire building life cycle indicate that construction, while not as significant as the use phase, is as important as other life-cycle stages (Bilec et al., 2010). Many criteria, such as apartment's size and layout, age, size and location of the building, proximity to community and transport services affect the quality of life of the residents (Šijanec Zavrl et al., 2009). Some authors (O'Sullivan et al., 2004; Liu et al., 2010; Chau et al., 2007; Banaitienė et al., 2008) distinguished life-cycle elements otherwise but nevertheless one of the most important stages remains the building design preparation. Increasing complexity and sophistications in construction create new challenges in design strategic management practices. Several design features can affect the energy efficiency of building envelopes, including the shape of the building, wall and roof construction, foundation type, insulation levels, window type and area, thermal mass, and shading. For a given floor area, determining the envelope configuration that results in minimum annual energy consumption can be a challenging task, but ultimately not very useful, since economic considerations must play a role in the construction of any real building (Tuhus-Dubrow and Krarti, 2010). The prediction of the performance or service life of a building system and their components is a very complex task (Kumar et al., 2010). The use of dwellings contributes significantly to human-induced environmental burden in a number of ways, including energy consumption and the maintenance and replacement of building components., extending the service life of building components decreases the input of material resources, production processes and the waste processing of building components during the service life of a dwelling, which is beneficial to the environment (Blom et al., 2010). Lowering energy intensity and environmental impacts of buildings is increasingly becoming a priority in energy and environmental policies in European countries (Blengini and Di Carlo, 2010). According to the philosophy of environmental protection, a building design should take into consideration its entire life cycle, and its structure and utilities should allow the supplies of energy needed for heating to be eliminated while using the building (Sobotka and Rolak, 2009). Frenette et al. (2010) presented a case study comparing five wall assemblies for the exterior wall of a residential building in Quebec City (Canada). The clients are not only interested in value for money in relation to the investment in project development but costs associated in operation and maintenance over project life cycle as well. In the evaluation process, selection of design configuration must enable meeting the target associated with business and strategic objectives of the organisation. On building design depends forthcoming: construction technology, terms and price of construction, aesthetical view and performance of building (usage term, lifecycle costs and quality of life level), environmental impact during building demolition, market value, attractiveness, and also other features.

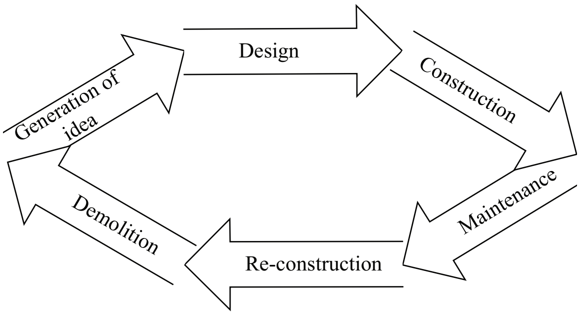


Figure 1. Lifecycle of a building

Simulation based project life cycle evaluation and decision analysis adds significant value in evaluating such alternatives by reducing uncertainties in design, implementation and operations with a greater confidence.

Ultimately, the best solution in reaching the goal of project life cycle is an outcome of the integration between analysis and tradeoff phases.

Wen (2001) analysed structural failures in recent earthquakes and hurricanes. The author has exposed the weakness of current design procedures and shown the need for new concepts and methodologies for building performance evaluation and design. A reliability-based framework for design is proposed for this purpose. Performance check of the structures is emphasized at two levels corresponding to incipient damage and incipient collapse. Minimum lifecycle cost criteria are proposed to arrive at optimal target reliability for performance-based design under multiple natural hazards.

Use of process simulation technique assists in analysing feasible design solutions based on technical, functional and operational aspects of projects. Building evacuation simulation provides designers with an efficient way of testing the safety of a building before in design stage. Pelechano and Malkawi (2008) presented a review of crowd simulation models and selected commercial software tools for high rise building evacuation simulation. The commercial tools selected (STEPS and EXODUS) are grid-based simulations, which allow for efficient implementation but introduce artefacts in the final results. The authors focus on describing the main challenges and limitation of these tools, in addition to explaining the importance of incorporating human psychological and physiological factors into the models.

Al-ajmi and Hanby (2008) explored reduction of energy consumption in buildings in desert climate Kuwait. Authors used building and plant simulation programs as a design tool for carrying out the performance of proposed building designs and to evaluate the effects of varying design parameters. A building model representative of a typical Kuwaiti dwelling has been implemented and encoded within the TRNSYS-IISIBAT environment. A typical meteorological year for Kuwait was prepared and used to predict the cooling loads of the air-conditioned dwelling. Several parametric studies were conducted to enable sensitivity analyses of energy-efficient domestic buildings to be carried out, namely relating to building envelope, window type, size and direction, infiltration and ventilation.

Vakili-Ardebili and Boussabaine (2007) analysed a complex process – Sustainable building design dynamism. Authors emphasize that consideration of different aspects such as environment, economy and society in addition to design characteristics makes the process of design even more complex. Also the subjectivity in design decisions makes the process of ecological assessment quite vague and difficult. Fuzzy logic techniques could help to compensate for the lack of full knowledge and subjectivity of design parameters. Hence, a fuzzy methodology is proposed in this paper for modelling and representing eco- building design criteria. The model is based on three linguistic variables. The developed model is able to indicate the low eco-efficient and high eco-efficient bands of a particular building design based on a set of eco-design criteria.

McDermott et al. (2007) in their research examined the interaction between user activity and dwelling design and how this might affect health and safety. It aimed to identify how people use features within new homes and how this may limit the protection afforded by building design, codes and regulations. Forty, home-based, semi-structured, in-depth interviews and home inspections were conducted with individuals recently inhabiting a new home. The accounts suggest that designers and builders need to give greater consideration to how occupier behaviour interacts with building features so that improvements in both design and occupier education can lead to improved health and safety.

Da Graça et al. (2007) tried to present a method for evaluating and optimising environmental comfort parameters of school buildings during the preliminary stages of design. In order to test the method, 39 existing public school building designs in the State of São Paulo, Brazil, had their plans analysed and characterised in relation to their influence on environmental comfort. Four aspects of comfort were considered: thermal, acoustic, natural lighting and functionality. Maximisation of various aspects of comfort simultaneously was shown to be impossible, but compromise solutions could be found.

De Almeida and de Oliveira (2007) presented a case-study of a public building as an example of the adequacy of timely analyses of building performance, based on a preliminary architectural design. The options were created and analysed with the help of the VisualDOE™ building simulation tool, aiming at a comfortable and energy efficient building. Several parameters were used for enabling the sensitivity analyses, namely relating to wall structure and materials, window frames, HVAC system, etc.

Luck and McDonnell (2006) performed an investigation of the exchange of ideas and information between an architect and building users in the early stages of the building design process before the design brief or any drawings have been produced. The purpose of their research is to gain insight into the type of information users exchange with architects in early design conversations and to better understand the influence the format of design interactions and interactional behaviours have on the exchange of information. Recommendations are made on the format and structure of pre-briefing conversations and on designers' strategies for raising the level of information provided by the user beyond the functional or structural attributes of space.

Rounce (1998) emphasised the need to reduce waste and improve efficiency of the design process. Author states that quality management and its application to the building design process is still a relatively new technique as are the concepts of waste, quality and efficiency. Factors contributing to waste in building design are examined and appear to be mainly management problems. The authors recommend reducing wastage and improving quality and profitability in architectural design.

Turskis et al. (2009) proposed multi-criteria optimization system for decision making in construction design and management.

In spite of the progress in developing methods and tools to support sustainable building design, there is still a lack of a formal approach to bridge the "no man's land" gap between the traditional building engineering disciplines, and between these and the architecture, to achieve the level of building integration required for sustainability (Mora et al., 2011).

How to take the right design solution? In many cases it is not possible to do that from the first time. Therefore, one has to look through many alternatives. Just after analysis of all advantages and disadvantages of different design solutions and their magnitude it is possible to say which solution of building (or its part) design is the best. Procedure mentioned seems very simple in this regard, however very contradictory information should be taken into account.

The goals to be achieved in this contribution are as following:

- to carry out a survey on building design processes;
- to survey previous attempts assessing building design alternatives;
- to suggest and describe assessment methodology to compare alternative building's facades;
- to gain qualitative and quantitative information on some alternative building's facades design options;

– to perform calculations comparing alternative building's facades of particular building structure;
– to present conclusions about suitability of methodology suggested.

2. MODEL FOR SELECTING ALTERNATIVES BASED ON THE HIGHEST EFFICIENCY CRITERIA OF A SUCCESS

In the scientific researches one can find various methodologies, models or algorithms to evaluate alternatives. Multi-Criteria Analysis (MCA) is a decision-making tool developed for complex problems. In a situation where multiple criteria are involved confusion can arise if a logical, well-structured decision-making process is not followed. Another difficulty in decision making is that reaching a general consensus in a multidisciplinary team can be very difficult to achieve. By using MCA the members don't have to agree on the relative importance of the Criteria or the rankings of the alternatives. Each member enters his or her own judgements, and makes a distinct, identifiable contribution to a jointly reached conclusion.

Multiple criteria decision aid provides several powerful solution tools (Hwang and Yoon, 1981; Figueira et al., 2005) for confronting sorting the problems. There can be used very simplified techniques for the evaluation such as the Simple Additive Weighting – SAW; TOPSIS – Technique for Order Preference by Similarity to Ideal Solution (Hwang and Yoon, 1981). A more detailed survey of multi-attribute decision making methods in the construction context is presented by many authors (Zavadskas et al., 2010a). The project life cycle (Medineckienė et al., 2010), must be evaluated according to multiple criteria taking in to account the general aspects of construction impact on environment. The best strategy could be selected from available scenarios and information.

Wang et al. (2007) proposed a method to assess cost-effectiveness of insulated exterior walls of residential buildings in cold climate. By considering energy savings, increased usable floor area, construction costs, insulation replacement and salvage values, the method calculated the main cost or benefit difference of using insulated exterior walls throughout a building lifecycle compared with the typical non-insulated solid clay brick walls, and subsequently defined a cost-effectiveness criterion (CEI) for measuring the overall cost efficiency of insulated exterior walls.

Peldschus et al. (2010) investigated the theory of the two-person zero-sum games with an application to construction site selection.

Kalibatas and Turskis (2008) focussed on the multiple criteria analysis of inner climate, its influence on human beings and problems caused by the parameters of inner climate not meeting the standards. Zavadskas et al. (2009) analysed indoor environment before and after refurbishment of buildings.

Tupenaite et al. (2010) performed assessment of alternatives for built and human environment renovation by using the widely known multiple criteria assessment methods SAW, TOPSIS, COPRAS and applied newly developed method ARAS (Zavadskas and Turskis, 2010; Zavadskas et al., 2010c; Turskis and Zavadskas, 2010a,b).

Methods of multiple criteria evaluation were used in selecting the most economical thermal insulation for the main building of Vilnius Gediminas Technical University (Ginevicius et al., 2008). The calculations were performed by 6 multiple criteria evaluation methods.

The main objectives of Ding's research (2008) were to examine the development, role and limitations of current environmental building assessment methods in ascertaining building sustainability used in different countries which leads to discuss the concept of developing a sustainability model for project appraisal based on a multi-dimensional approach, which will allow alternatives to be ranked.

One of the best known criteria of a success is the criterion of a mean-weighted success of the decision made according to the formula (1) (Zavadskas, 1987; Turskis et al., 2009).

Multiplicative exponential generalized optimality criterion of a success avoids some deficiencies of typical form linear criterion (2) (Zavadskas, 1987).

On the basis of the expressions (1) and (2) (Zavadskas et al., 2009) there can be formulated a joint criterion of a mean-weighted success in the decision making which is a weighted aggregation of additive and multiplicative methods for constructing the generalized criterion (3) (Zavadskas, 1987). At $\lambda = 1$ this criterion is transformed into additive criterion, and when $\lambda = 0$ – into multiplicative one. The formulation of a aggregated utility criterion allows by changing the coefficient λ to approximate it either to an additive or multiplicative criterion of optimality and through this it approximates to the expression to the greatest extend reflecting the actual state of things.

$$K_{1i} = a_i = \left\{ a_i / A_i \in A_i \cap \max_i \frac{1}{n}\left(\sum_{j=1}^{n} w_j \bar{x}_{ij}\right) \cap \sum_{j=1}^{n} w_j = 1 \right\}; \quad \forall ij;\ i = \overline{1,m};\ j = \overline{1,n}; \tag{1}$$

$$K_{2i} = a_i = \left\{ a_i / A_i \in A_i \cap \max_i \left(\prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}\right) \cap \sum_{j=1}^{n} w_j = 1 \right\}; \quad \forall ij;\ i = \overline{1,m};\ j = \overline{1,n} \tag{2}$$

$$K_{3i} = a_i = \begin{cases} a_i / A_i \in A_i \cap \max_i \left\{ a_i / A_i \in A_i \cap \max_i \left(\lambda \left(\sum_{i=1}^{n} \hat{x}_{ij} w_j \right) + (1-\lambda) \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \right) \cap \sum_{j=1}^{n} w_j = 1 \right\}; \\ \forall ij;\ i = \overline{1,m};\ j = \overline{1,n}, \end{cases} \tag{3}$$

where: $\bar{x}_{ij}$ – value of the j-th criterion for the i-th alternative; $\hat{x}_{ij}$ – normalised-weighted values; w_j – weight of j-th criterion; λ – coefficient of confidence; n – quantity of criteria; m – quantity of alternatives.

For a more detail survey of Multi criteria decision making methods see for applications in the construction context Zavadskas (1987).

3. DETERMINING OF CRITERIA WEIGHTS BY MEANS OF AN ENTROPY

There are possible different methods, which could to be applied to determine criteria weights (Zavadskas et al., 2010b; Keršulienė et al., 2010). Shannon (1948), was the first who introduced the concept of entropy into theory of information. Entropy is considered as a measure of indeterminate from a random value. The aspects of application of entropy for selecting solutions have been presented in works (Jeynes, 1957; Paelnik, 1976). The Entropy may be used for criteria weights determination (Ye, 2010; Taheriyoun et al., 2010; Liu and Zhang, 2011).

The criteria weights determination begins from normalization of initial decision-making matrix.

The initial decision-making matrix X can be described as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{mn} \end{bmatrix}; i = \overline{1,m},\ j = \overline{1,n}, \quad (4)$$

where: $i = \overline{1,m}$ are the compared solutions' alternatives; $x_1, x_2, \dots, x_n$ – multiple criteria, and $x_{11}, x_{12}, \dots, x_{mn}$ – the multiple criteria values.

Under simultaneous presence of both criteria with minimal and maximal preferable optimal values, the normalization of the matrix X into normalized decision-making matrix $\overline{X}$ according to the expressions (5) and (6) is necessary:

$$\overline{x}_{ij} = \frac{x_{ij}}{\max\limits_i x_{ij}},$$

$$\textit{if } \max_i x_{ij} \text{ value is preferable , and} \quad (5)$$

$$\overline{x}_{ij} = \frac{\min\limits_i x_{ij}}{x_{ij}},$$

$$\textit{if } \min_i x_{ij} \text{ value is preferable}, \quad (6)$$

where: $\overline{x}_{ij}$ – are the dimensionless criteria values. All maximal normalized values of criteria are preferable. If all maximal values or all minimal values of all criteria are preferable, the normalization is not necessarily to be performed, i.e. it is assumed $X = \overline{X}$.

Subsequently, the level of entropy E_j of each criterion is determined as follows:

$$E_j = -k \sum_{i=1}^{m} \overline{x}_{ij} \ln(\overline{x}_{ij}), (i = \overline{1,m};\ j = \overline{1,n});$$
$$j = \overline{1,n});\ k = \frac{1}{\ln m}. \quad (7)$$

As there is known, the criterion of entropy changes in the interval [0; 1], therefore:

$$0 \le E_j \le 1;\ j = 1, n \quad (8)$$

The variability level of j-th criterion within limits of the solvable problem, which is on the set of alternatives, is determined by d_j:

$$d_j = 1 - E_j;\ j = 1, n \quad (9)$$

If all criteria are equally important, or to put it in other words, there are no subjective or expert estimates of their weight, the weights of the criteria are determined according to the formula:

$$w_j = \frac{d_j}{\sum\limits_{j=1}^{n} d_j}. \quad (10)$$

4. CASE STUDY: EVALUATION OF BUILDING FACADES ALTERNATIVES

Working principle of alternatives' evaluation technique is demonstrated by selecting the best facade system to cover commercial or public building. For this purpose four building facades alternatives is under consideration : a) cellular concrete masonry, covered by Rockwool plates and decorative plaster surface; b) "sandwich" facade panels; c) gas silicate masonry, covered by Rockwool and "Minerit" facade plates; d) aluminium-glazing facade (Povilavičius, 2007; Šaparauskas et al., 2010). Criteria to be used for comparison are presented in Table 1.

Decision-making matrix of the problem is presented in Table 2.

Table 1. Criterion system for comparison of façade alternatives

Criteria	Units	Optimum	Facade alternatives			
			1	2	3	4
I. Economy						
1) Installation cost – x_1	Lt/m^2	min	370	314	480	850
2) Labour intensivity by assembling – x_2	Days	min	11.0	7.00	10.0	16.0
II. Performance parameters						
3) User friendliness – x_3	Points	max	2.69	3.37	3.09	3.17
4) Durability – x_4	Points	max	2.75	3.27	3.67	4.10
5) Warranty – x_5	Points	max	5.00	35.0	30.0	50.0
III. Environmental impact						
6) Environmental friendliness – x_6	Points	max	1.63	1.72	1.87	1.91
7) Recovery (utilization) – x_7	Points	max	1.47	2.07	1.38	2.22
8) Aesthetics – x_8	Points	max	7.11	5.60	7.82	8.25
IV. Structural properties						
9) Weight of structure – x_9	Kg/m^2	min	88.0	12.6	94.0	23.0
10) Thickness of structure – x_{10}	mm	min	410	100	410	65.0
V. Physical properties						
11) Sound isolation – x_{11}	Points	max	2.93	2.13	2.87	1.10
12) Fire resistance – x_{12}	Points	max	1.98	3.21	2.94	4.37

Table 2. Initial decision-making matrix

Criteria													
Optimal		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
		min	min	max	max	max	max	max	max	min	min	max	max
Alternatives	a_1	370	11.0	2.69	2.75	5.00	1.63	1.47	7.11	88.0	410	2.93	1.98
	a_2	314	7.00	3.37	3.27	35.0	1.72	2.07	5.60	12.6	100	2.13	3.21
	a_3	480	10.0	3.09	3.67	30.0	1.87	1.38	7.82	94.0	410	2.87	2.94
	a_4	850	16.0	3.17	4.10	50.0	1.91	2.22	8.25	23.0	65.0	1.10	4.37

Table 3. Determining of criteria weights by means of an Entropy (calculating process)

Initial decision-making matrix													
Criteria													
Optimal		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
		min	min	max	max	max	max	max	max	min	min	max	max
Alternatives	a_1	370	11.0	2.69	2.75	5.00	1.63	1.47	7.11	88.0	410	2.93	1.98
	a_2	314	7.00	3.37	3.27	35.0	1.72	2.07	5.60	12.6	100	2.13	3.21
	a_3	480	10.0	3.09	3.67	30.0	1.87	1.38	7.82	94.0	410	2.87	2.94
	a_4	850	16.0	3.17	4.10	50.0	1.91	2.22	8.25	23.0	65.0	1.10	4.37
Optimal values		314	7	3.37	4.1	50	1.91	2.22	8.25	12.6	100	2.93	4.37
Normalised decision-making matrix													
Alternatives	a_1	0.8486	0.6364	0.7982	0.6707	0.1000	0.8534	0.6622	0.8618	0.1432	0.2439	1.0000	0.4531
	a_2	1.0000	1.0000	1.0000	0.7976	0.7000	0.9005	0.9324	0.6788	1.0000	1.0000	0.7270	0.7346
	a_3	0.6542	0.7000	0.9169	0.8951	0.6000	0.9791	0.6216	0.9479	0.1340	0.2439	0.9795	0.6728
	a_4	0.3694	0.4375	0.9407	1.0000	1.0000	1.0000	1.0000	1.0000	0.5478	1.5385	0.3754	1.0000
Level of entropy		E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_j		0.5661	0.6485	0.2287	0.3949	0.5673	0.1806	0.4571	0.3188	0.6329	0.0184	0.4472	0.6146
Variability level		d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}
d_j		0.4339	0.3515	0.7713	0.6051	0.4327	0.8194	0.5429	0.6812	0.3671	0.9816	0.5528	0.3854
Criteria weights		w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}
w_j		0.0627	0.0508	0.1114	0.0874	0.0625	0.1183	0.0784	0.0984	0.0530	0.1417	0.0798	0.0557

Table 4. Ranking of alternatives by applying the criterion of a mean-weighted success

Initial decision-making matrix													
Criteria													
Optimal		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
		min	min	max	max	max	max	max	max	min	min	max	max
Alternatives	a_1	370	11.0	2.69	2.75	5.00	1.63	1.47	7.11	88.0	410	2.93	1.98
	a_2	314	7.00	3.37	3.27	35.0	1.72	2.07	5.60	12.6	100	2.13	3.21
	a_3	480	10.0	3.09	3.67	30.0	1.87	1.38	7.82	94.0	410	2.87	2.94
	a_4	850	16.0	3.17	4.10	50.0	1.91	2.22	8.25	23.0	65.0	1.10	4.37
Optimal values		314	7	3.37	4.1	50	1.91	2.22	8.25	12.6	100	2.93	4.37

(Continued)

(Continued)

Normalised decision-making matrix														
		$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	$\bar{x}_5$	$\bar{x}_6$	$\bar{x}_7$	$\bar{x}_8$	$\bar{x}_9$	$\bar{x}_{10}$	$\bar{x}_{11}$	$\bar{x}_{12}$	
Alternatives	a_1	0.8486	0.6364	0.7982	0.6707	0.1000	0.8534	0.6622	0.8618	0.1432	0.2439	1.0000	0.4531	
	a_2	1.0000	1.0000	1.0000	0.7976	0.7000	0.9005	0.9324	0.6788	1.0000	1.0000	0.7270	0.7346	
	a_3	0.6542	0.7000	0.9169	0.8951	0.6000	0.9791	0.6216	0.9479	0.1340	0.2439	0.9795	0.6728	
	a_4	0.3694	0.4375	0.9407	1.0000	1.0000	1.0000	1.0000	1.0000	0.5478	1.5385	0.3754	1.0000	
Normalised-weighted decision-making matrix														
w_j		0.5661	0.6485	0.2287	0.3949	0.5673	0.1806	0.4571	0.3188	0.6329	0.0184	0.4472	0.6146	1.0000
		$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{x}_7$	$\hat{x}_8$	$\hat{x}_9$	$\hat{x}_{10}$	$\hat{x}_{11}$	$\hat{x}_{12}$	K_1
Alternatives	a_1	0.0532	0.0323	0.0889	0.0586	0.0062	0.1010	0.0519	0.0848	0.0076	0.0225	0.0798	0.0252	0.0510
	a_2	0.0627	0.0508	0.1114	0.0697	0.0437	0.1066	0.0731	0.0668	0.0530	0.0921	0.0580	0.0409	0.0691
	a_3	0.0410	0.0355	0.1021	0.0782	0.0375	0.1158	0.0487	0.0932	0.0071	0.0225	0.0782	0.0374	0.0581
	a_4	0.0231	0.0222	0.1048	0.0874	0.0625	0.1183	0.0784	0.0984	0.0290	0.1417	0.0300	0.0557	0.0710

Table 5. Ranking of alternatives by applying the multiplicative exponential generalized optimality criterion of a success

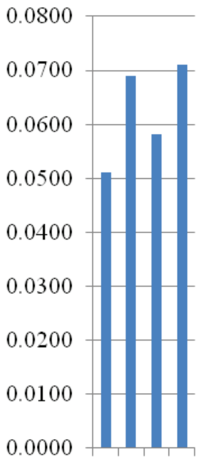
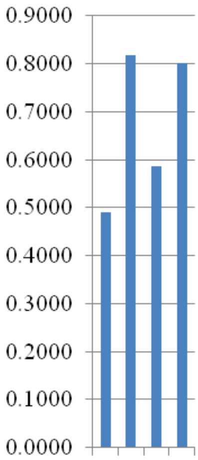
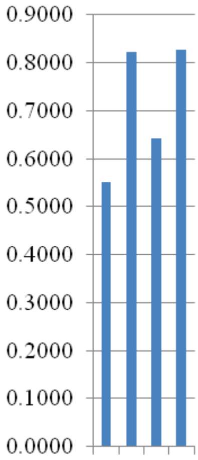
Initial decision-making matrix													
Criteria													
Optimal		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
		min	min	max	max	max	max	max	max	min	min	max	max
Alternatives	a_1	370	11.0	2.69	2.75	5.00	1.63	1.47	7.11	88.0	410	2.93	1.98
	a_2	314	7.00	3.37	3.27	35.0	1.72	2.07	5.60	12.6	100	2.13	3.21
	a_3	480	10.0	3.09	3.67	30.0	1.87	1.38	7.82	94.0	410	2.87	2.94
	a_4	850	16.0	3.17	4.10	50.0	1.91	2.22	8.25	23.0	65.0	1.10	4.37
Optimal values		314	7	3.37	4.1	50	1.91	2.22	8.25	12.6	100	2.93	4.37
Normalised decision-making matrix													
		$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	$\bar{x}_5$	$\bar{x}_6$	$\bar{x}_7$	$\bar{x}_8$	$\bar{x}_9$	$\bar{x}_{10}$	$\bar{x}_{11}$	$\bar{x}_{12}$
Alternatives	a_1	0.8486	0.6364	0.7982	0.6707	0.1000	0.8534	0.6622	0.8618	0.1432	0.2439	1.0000	0.4531
	a_2	1.0000	1.0000	1.0000	0.7976	0.7000	0.9005	0.9324	0.6788	1.0000	1.0000	0.7270	0.7346
	a_3	0.6542	0.7000	0.9169	0.8951	0.6000	0.9791	0.6216	0.9479	0.1340	0.2439	0.9795	0.6728
	a_4	0.3694	0.4375	0.9407	1.0000	1.0000	1.0000	1.0000	1.0000	0.5478	1.5385	0.3754	1.0000

(Continued)

(Continued)

Normalised-weighted decision-making matrix														
w_j		0.5661	0.6485	0.2287	0.3949	0.5673	0.1806	0.4571	0.3188	0.6329	0.0184	0.4472	0.6146	1.0000
		$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{x}_7$	$\hat{x}_8$	$\hat{x}_9$	$\hat{x}_{10}$	$\hat{x}_{11}$	$\hat{x}_{12}$	K_2
Alternatives	a_1	0.9898	0.9773	0.9752	0.9657	0.8660	0.9814	0.9682	0.9855	0.9021	0.7702	1.0000	0.9569	0.4912
	a_2	1.0000	1.0000	1.0000	0.9804	0.9780	0.9877	0.9945	0.9626	1.0000	0.9408	0.9749	0.9830	0.8173
	a_3	0.9738	0.9821	0.9904	0.9904	0.9686	0.9975	0.9634	0.9947	0.8989	0.7702	0.9983	0.9782	0.5873
	a_4	0.9395	0.9589	0.9932	1.0000	1.0000	1.0000	1.0000	1.0000	0.9686	1.0000	0.9248	1.0000	0.8015

Table 6. Determined optimality criteria by applying weighted aggregation of additive and multiplicative methods

	$\frac{1}{n}\sum_{j=1}^{n} w_j \bar{x}_{ij}$	$\prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}$	$\lambda\left(\sum_{i=1}^{n} \hat{x}_{ij} w_j\right) + (1-\lambda)\prod_{j=1}^{n} (\bar{x}_{ij})^{w_j}$ $\lambda = 0.5$
a_1	0.0510	0.4912	0.5516
a_2	0.0691	0.8173	0.8230
a_3	0.0581	0.5873	0.6423
a_4	0.0710	0.8015	0.8265
Graphic view of alternatives performance			

Weights of the criteria were determined by applying entropy method (formulas 5–10). Decision-making matrix was normalised by applying formulas (5 and 6). The assessment results of alternatives are presented in Table 3. Ranking of alternatives by applying the criterion of a mean-weighted success and by applying the multiplicative exponential generalized optimality criterion of a success are presented in Tables 4 and 5.

5. CONCLUSIONS

Results over the entire building life cycle indicate that construction, while not as significant as the use phase, is as important as other life-cycle stages. A case study of the assessment of buildings' facades ability was used to demonstrate the applicability and the effectiveness of the proposed approach.

Increasing complexity and sophistications in construction create new challenges in design strategic management practices. Several design features can affect the energy efficiency of building envelopes, including the shape of the building, wall and roof construction, foundation type, insulation levels, window type and area, thermal mass, and shading.

The research revealed that building design stage is extremely important by solving technical, economical, social and environmental problems of building project developers, inhabitants and other interest parties.

For evaluation of alternatives Entropy and three Efficiency criteria of a success technique are selected.

Methods mentioned are applied by evaluating different building facades. Results indicate that in case under consideration designers prefer "gas silicate masonry, covered by Rockwool and "Minerit" facade plate.

According to results of calculation the alternatives ranks as follows (see Table 6):

- $a_4 \succ a_2 \succ a_3 \succ a_1$, according to additive criterion of optimality;
- $a_2 \succ a_4 \succ a_3 \succ a_1$, according to multiplicative criterion of optimality;
- $a_4 \succ a_2 \succ a_3 \succ a_1$, according to weighted aggregation of additive and multiplicative optimality criterion's values;

According to the case study the best alternative is the fourth alternative, and the first alternative is ranked as the worst alternative.

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SANTRAUKA

KOMERCINĖS IR VIEŠOSIOS PASKIRTIES PASTATŲ FASADO ALTERNATYVŲ DAUGIAKRITERINĖ ATRANKA

Jonas ŠAPARAUSKAS, Edmundas Kazimieras ZAVADSKAS, Zenonas TURSKIS

Tinkamas sprendimų priėmimo mechanizmas projektuojant pastatą yra labai svarbus priimant strateginius investicijų sprendimus. Klientus yra suinteresuotas ne tik projekto įgyvendinimo kaina, bet ir eksploatavimo išlaidomis. Šio straipsnio tikslas – palyginti skirtingus pastato projektus arba konstrukcijas ir pagal tris optimalumo kriterijus parinkti geriausią alternatyvą. Šie trys kriterijai leidžia įvertinti projektinius sprendinius, kurie gali būti apibūdinami kiekybiniais ir kokybiniais rodikliais, turinčiais skirtingas dimensijas ir optimizavimo kryptį (maksimizavimas arba minimizavimas). Skaitiniame pavyzdyje demonstruojamas geriausios fasado sistemos parinkimas pastatui. Jame svarstomos keturios alternatyvos. Du kriterijai (iš trijų) rodo, kad šiam konkrečiam atvejui tinkamiausias yra fasadas, sumūrytas iš dujų silikato blokelių, aptaisytų „Rockwool" mineraline vata ir „Minerit" fasado plokštėmis.