# EVALUATION OF ALTERNATIVE BUILDING DESIGNES ACCORDING TO THE THREE CRITERIA OF OPTIMALITY

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Abstract. The purpose of this article – is compare different designs of building or its structure and to select the best alternative using criteria of optimality. These three 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 (maximization or minimization). 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 Roockwool and "Minerit" facade plates.

Keywords: criterion of optimality, Entropy, weights, matrix, alternatives of building façade.

## 1. Introduction

Usually the lifecycle of every building covers the following stages: generation of idea (pre-design proposals), design, construction, maintenance, reconstruction (if possible) and demolition (disposal). Some authors (O'Sullivan *et al.* 2004) distinguished life-cycle elements otherwise but nevertheless one of the most important stages remains the building design preparation. On building design depends forthcoming: construction technology, terms and price of construction, aesthetical view and performance of building (usage term, lifecycle costs, quality of life level), environmental impact during building demolition, and also other features.

How to take the right design solution? In many cases it is not possible to do that from the first time. Therefore, one have 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 building design alternatives;
– to gain qualitative and quantitative information on some building design options;
– to perform calculations comparing different building design alternatives of particular building structure;
– to present conclusions about suitability of suggested methodology.

## 2. Importance of building design process

Globally, scientists-engineers are trying to solve many different problems in building design stage.

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.

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 artifacts 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 modeling 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.

## 3. 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.

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.

The main objectives of Ding (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. Similar problem investigated Ginevicius *et al.* (2008).

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

where $\overline{x}_{ij}$ - value of the *j*-th criterion for the *i*-th alternative.

Multiplicative generalized optimality criterion of a success avoids some deficiencies of typical form linear criterion:

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

On the basis of the expressions (1) and (2) there can be formulated a joint criterion of a mean-weighted success in the decision making which is a weighted combination of additive and multiplicative methods for constructing the generalized criterion:

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

At $\lambda = 1$ this criterion is transformed into additive criterion, and when $\lambda = 0$ – into multiplicative one. The formulation of a joint criterion allows by changing the coefficient $\lambda$ 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.

## 4. Determining of criteria weights by means of an Entropy

Shanon 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.

The criteria weights determination begins from normalization of initial decision-making matrix (Zavadskas *et al.* 2008a,b).

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

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

where $i = \overline{1,m}$ are the compared solutions' alternatives, $x_1, x_2, ..., x_n$ - multiple criteria, and $x_{11}, x_{12}, ..., x_{mn}$ – 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 (Zavadskas and Turskis 2008):

$$\overline{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \ if \ \max_i x_{ij} \ value \ is \ preferable \qquad (5)$$

$$\overline{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \ if \ \min_i x_{ij} \ value \ is \ preferable \qquad (6)$$

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:

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

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

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

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

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

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:

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

## 5. Case study: evaluation of alternative building facades

Working principle of Alternatives' evaluation technique is demonstrated by selecting the best facade system to cover the building. For this purpose four building facades alternatives is under consideration (see Table 1): cellular concrete masonry, covered by roockwool plates and decorative plaster surface; "sandwich" facade panels; gas silicate masonry, covered by roockwool and "Minerit" facade plates; aluminium glazing facade (Povilavičius 2007).

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

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.

**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

| Optimal | | Criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $x_8$ | $x_9$ | $x_{10}$ | $x_{11}$ | $x_{12}$ |
| | | 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.** Determined optimality criteria – weighted combination of additive and multiplicative methods

| | $\dfrac{1}{n}\sum_{j=1}^{n} w_j \overline{x}_{ij}$ | $\prod_{j=1}^{n} \left(\overline{x}_{ij}\right)^{w_j}$ | $\lambda\left(\sum_{i=1}^{n} \hat{x}_{ij} w_j\right) + (1-\lambda)\prod_{j=1}^{n}\left(\overline{x}_{ij}\right)^{w_j}$ |
|---|---|---|---|
| $a_1$ | 0.6235 | 0.5225 | 0.3392 |
| $a_2$ | 6.3060 | 0.8690 | 1.2228 |
| $a_3$ | 7.0939 | 0.6241 | 1.1988 |
| $a_4$ | 6.9431 | 0.8515 | 1.2936 |

## Conclusions

1. 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.
2. For evaluation of alternatives Entropy and Efficiency criteria of a success technique are selected.
3. Methods mentioned are applied by evaluating different building facades. Results indicate that in case under consideration designers prefer "gas silicate masonry, covered by roockwool and "Minerit" facade plate.
4. According to results of calculation the alternatives ranks as follows:
   - $a_3 \succ a_4 \succ a_2 \succ a_1$, according to additive criterion of optimality;,
   - $a_2 \succ a_4 \succ a_3 \succ a_1$, according to multiplicative criterion of optimality;
   - $a_3 \succ a_4 \succ a_2 \succ a_1$, according to weighted combination of additive and multiplicative optimality criterion's values.

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