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SUSTAINABLE CONSTRUCTION TAKING INTO ACCOUNT THE BUILDING IMPACT ON THE ENVIRONMENT

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Abstract. The paper describes a construction impact on the environment, people and their health, taking into account its subsequence. The authors offer an optimal way of building construction in order to satisfy the environmental control standards and impact on the environment. There are a few criteria of ecological materials compared with conventional materials. The aim of this investigation is to develop approach of building project ranking. The paper deals with analysis of the construction alternatives of one-flat dwelling houses. A few alternatives are given about how to choose an optimal project. The impact of construction on the environment is discussed. Analysis is performed taking into account building life-cycle impact on the environment, its financial and social conditions. The investigation includes pollution of building material production, construction processes, taking into account building longevity, price, running cost and utilization input of energy. Multicriteria assessment of the alternatives is made, considering impact not only on humans, but also on the environment. According to the described environmental, financial and qualitative criteria and by the assistance of newly-developed multicriteria method SAW-G, it was calculated, that a blockhouse, made mostly of wood-based materials with the result of 0.303 is by 6.6% a better alternative than a wood-frame building with the result of 0.286, made from wood-based and mineral-based materials, and the worst result of 0.280 was in a building from traditional bricks (a wood-based house is by 7.5% better than a brick house). AHP approach and SAW-G method are useful tools to help support a decision in convention site selection.

Keywords: construction, materials, building, environment, resource consumption, multicriteria assessment, impact on environment, SAW, SAW-G, AHP method.

1. Introduction

The progress of a national economy and society is impossible without construction because the result of construction – real estate for various purposes – is necessary for people to live, work and satisfy their social and other needs. Globally, the Lithuanian construction sector contributes averagely with one tenth of the total (annual) production of goods and services (Urbanavičienė *et al.* 2009). Construction products are very expensive, buildings and structures make the biggest share of assets both at the level of households, companies and the entire country; therefore, the percentage of the bargained amount may not be big, but it would amount to a considerable sum of money. Therefore, construction, services, management and maintenance on real estate sales must be efficient (Urbanavičienė *et al.* 2009). Institutional investors and practitioners are always immersed in managing their investment portfolios, not only to optimize returns, but more importantly to minimize potential risks (Hui *et al.* 2009).

Construction companies, just like many others, operate on the market and can go bankrupt (Kapliński 2008).

Cities are complex ecosystems affected by social, economic, environmental, and cultural factors. Cities are the source of global environmental pollution and ecological damage, and serve as major sinks for materials, energy, information, capital and population. The problem of attaining urban sustainable development is thus an important challenge. The development of evaluation indicators and a method for assessing the status of urban sustainable development will be required to support ecological urban planning, construction, and management (Li *et al.* 2009).

An increasing number of studies have identified the importance of sustainability in construction projects. With a focus on different aspects of sustainability, various sets of critical success factors have been suggested in literature (Yang *et al.* 2009). Decision-making or "problem-solving", as a broader term, is the process of selecting one or a few alternatives that should be the most favorable one(s) to objective(s). In this respect, the choice of alternatives can be handled as a multiple-criteria decision-making problem. In order to reach an optimum decision, well-defined criteria and superb solution techniques are required (Ulubeyli and Kazaz 2009). The environmental impact made by a number of industrial sectors has been studied more extensively. Sustainability assessment is a general term that encompasses a range of processes that broadly aim to integrate sustainability concepts into decision-making. A simple distinction can be drawn between "external" sustainability assessments that may be

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conducted by regulators as a part of the project approval process, and "internal" sustainability assessment conducted by companies themselves as a part of their business planning and decision-making processes (Stasiškienė and Šliogerienė 2009). The general consensus in literature is that the traditional method of valuation is inadequate in the valuation of environmentally contaminated property (Bello, V. and Bello, M. 2009).

The aim of this paper is to analyse the tendency of construction impact and impact of building materials on environment as well as to chose the best alternative from the presented buildings, assessing the environmental, financial and social aspects.

1.1. Impact of constructional materials

Different hierarchical levels of materials used are shown in Table 1, from the study scope down to the indicators, from criteria down to subcriteria (Lombera and Aprea 2010).

Table 1. Breakdown of "Materials used" study scope at its different hierarchical levels (Lombera and Aprea 2010)

Study Scope	Criterion	Subcriterion	Indicator
Materials used	Environmental impact derived from materials used	Damage to natural resources	Use of fossil fuels
			Use of minerals
		Damage to eco-system	Land uses
			Acidification
			Eutrophication
			Ecotoxicity
		Damage to human health	Climate change
			Ozone layer
			Cancerous substances
			Breathing effects due to organic substances
			Breathing effects due to inorganic substances
			Ionising radiation

In recent years, cheaper alternatives to traditional building materials have been increasingly used as a way of lowering building costs. For example, instead of natural woods, pressed-wood products and fiberboard are used. While cheaper is definitely good economically, it can be bad for human health. These synthetic materials emit volatile organic compounds (VOCs) or other hazardous air pollutants that may cause the nausea, dizziness, headaches, skin rashes, lethargy and skin and nose irritation (James and Yang 2005).

Selecting inappropriate materials can be expensive, but more importantly, it may preclude the achievement of the desired environmental goals (Castro-Lacouture *et al.* 2009).

1.2. Impact of the construction process

Most pollutant emissions result from construction and refurbishment. However, only two of the 24 recorded emissions are problematic (Zimmermann 2005):

a) sulphur dioxide: mainly due to fossil – fuel power generation;
b) fine particulates: mainly caused by the degradation of mineral construction materials.

General aspects of construction impact on the environment (EMAS 2001):

a) emissions into the air;
b) releases to water;
c) avoidance, recycling, reuse, transportation and disposal of solid and other wastes, particularly hazardous wastes;
d) use and contamination of land;
e) use of natural resources and raw materials (including energy);
f) local issues (noise, vibration, odour, dust, visual appearance, etc.);
g) transport issues;
h) risks of environmental accidents and effects arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations;
i) effects on biodiversity of atmospheric emissions.

The construction process is especially harmful to fully urbanized territories. It includes numerous sources of pollution: the entire traffic-related pollution and noise, dust, etc. (Mitkus and Shostak 2009). According to dispersity, dust is classified into 5 classes. The most hazardous of them are hard particles of the 5-th class. These hard particles are not stopped by human upper airway; therefore, they may lay low with airway diseases. Depositing on mucous membrane of nose, trachea, bronchi, they arouse inflammatory reactions, eventually they develop chronic hypertrophic and atrophic catarrhs. Later people get sick with such airway diseases as bronchitis, tracheitis, pneumonia, (diffusive sclerosis of the lungs) (Baltrėnas *et al.* 2007). One of the main methods for the air quality assessment and forecast is mathematical simulation of pollutants (Baltrėnas *et al.* 2008a). In order to simulate the dispersion of solid particles (SP) in the air, there can be applied the "Phoenics" software in which the proximity methods of equation solution are used, because an accurate analytic solution of movement equations is not possible to be applied (Baltrėnas *et al.* 2008b).

There are five aspects of environmental impact (Low *et al.* 2009):

a) energy efficiency which focuses on the approach that can be used in the building design and system selection to optimize the energy efficiency of buildings;
b) water efficiency which focuses on the selection of water use efficiency during construction and building operations;
c) environmental protection which focuses on the design, practices and selection of materials that would reduce the environmental impacts of built structures;

d) indoor environmental quality (IEQ) which focuses on the design strategies that would enhance the IEQ which includes air quality, thermal comfort, acoustic control and day-lighting;
e) other green features which focuse on the adoption of green practices and new technologies that are innovative and have potential environmental benefits.

There are a number of different frameworks for characterizing green buildings, including USGBC's LEED Green Building Rating System (www.usgbc.org), the Green Building Initiative's Green Globes System (www.greenglobes.com), Earth Advantage (www.earth-advantage.org), the U.S. Department of Energy's High Performance Building Standards (www.eere. energy. gov/buildings/highperformance/), the BRE Environmental Assessment Method (www.bream.org), and Building for Environmental and Economic Sustainability (http://www. bfrl.nist.gov/oae/software/bees/), among others (Allen and Potiowsky 2008).

In Europe general criteria for obtaining environmental information and selecting the indicators are laid down in the ISO standard on Environmental management (ISO 14031:1999). Lithuania has two standards, which are responsible for the environmental impact in this purview. It is EN ISO 14031:1999 Environmental Management – Environmental performance evaluation – Guidelines (ISO 14031:1999) and EN ISO 14040:1997 Environmental management. Life cycle assessment. Principles and framework (ISO 14040:1997). But the main purpose of this institution is to certificate the companies, not exactly building. That's why the assessment of environmental impact in the construction industry remains of low importance in Lithuania. There is no environmental certification, applicable to new constructions and improvements.

Environmental progress in the building design and construction industry will continue to stall if the significant social and psychological barriers that remain are not addressed (Hoffman and Henn 2008).

The McGraw Hill, Green Homeowner, made a very interesting survey, describing the profile of the green homebuyer as follows (Bernstein 2007):

a) Seventy one percent are female, outranking men significantly.
b) Two thirds have an income over US$50,000.
c) Average age is 45. However, the age distribution is widespread, indicating that there is a wide variation in the age of the green homeowner.
d) More green homeowners are married and highly educated.

Marketing professionals dub this demographic group LOHAS, signifying Lifestyles of Health and Sustainability (Hoffman and Henn 2008).

A range of design features, which commonly include the following, typify green projects (Shiers 2000):

a) maximum use of natural day-lighting for offices, enhanced air-quality and individual environmental control;
b) low energy consumption achieved by a range of techniques including the use of natural ventilation rather than air-conditioning, heat recovery systems and the use of thermal mass, careful orientation and low-energy lighting design, etc.;
c) minimizing site impact through sensitivity to site ecology and by careful landscaping;
d) use of grey-water re-cycling for landscape irrigation and WCs;
e) use of existing transport networks and a clear transport policy, e.g. car-sharing schemes, for building users;
f) re-use of existing buildings; and careful specification for building materials of lower environmental impact.

2. Methods and case study

Methods of multicriteria analysis were developed in the 1960's to meet the increasing requirements of human society and the environment (Zavadskas *et al.* 2009b). Multiple criteria decision aid provides several powerful solution tools for confronting sorting problems (Hwang and Yoon 1981; Figueira *et al.* 2005; Ginevičius *et al.* 2008a, b; Liaudanskiene *et al*. 2009; Zavadskas *et al*. 2008b). There can be used very simplified techniques for the evaluation such as the SAW – *Simple Additive Weighting* (MacCrimon 1968); TOPSIS – *Technique for Order Preference by Similarity to Ideal Solution* (Hwang and Yoon 1981).

The analysis of the purpose is to be achieved by using criteria of effectiveness, which have different dimensions, different significances as well as different directions of optimization (Ehrgott 2005). The discrete criteria values can be normalized by applying different normalization methods (Zavadskas and Turskis 2008; Peldschus 2009). The purpose of analysis can also be different (Bregar *et al.* 2008). Multiple criteria decision aid analysed by Hwang and Yoon (1981) provides several powerful and effective tools for confronting sorting problems analysed by Figueira *et al*. (2005).

There is a wide range of methods based on multicriteria utility theory: SAW (MacCrimon 1968; Ginevičius *et al.* 2008a, b); MOORA – Multi-Objective Optimization on the basis of Ratio Analysis (Brauers and Zavadskas 2006; Brauers *et al*. 2008a, 2008b; Kalibatas and Turskis 2008); TOPSIS (Hwang and Yoon 1981); VIKOR – compromise ranking method (Opricovic 1998; Opricovic and Tzeng 2004); COPRAS (Zavadskas *et al*. 2008a, 2009a); and other methods (Turskis 2008; Turskis *et al.* 2009; Zavadskas *et al.* 2010a).

Decision-makers in their activities deal with uncertain future. The multicriteria decision-making could be applied to assess different alternatives of future activities. Hui *et al.* (2009) incorporated the fuzzy concept in linear programming to obtain the best possible outcome in portfolios when direct real estate investment is included.

The best strategy could be selected from available scenarios, and information. In strategic decisions, dealing with uncertainty, the values of criteria could be determined in intervals – from pessimistic value to optimistic value.

The limits of criterion value could also be determined by an expert. In this case determination of limits depends on the qualification and experience of expert. Therefore it is better to gather the objective data.

Deng (1982) developed the Grey system theory and described operations with grey numbers. Grey relational analysis possesses advantages Deng (1988a, 1988b).

2.1. Investigation methodology

MacCrimon (1968) developed SAW method and it was applied for multicriteria decision-making in different fields (Ginevičius and Podvezko 2008; Ginevičius *et al.* 2008a, b): for simulation and comparison of selected methods (Zanakis *et al.* 1998); for solving fuzzy MADM problems (Hui *et al.* 2009); for facility location selection with objective/subjective criteria by applying a fuzzy simple additive weighting system under group decision-making (Chou *et al.* 2008); e-commerce performance assessment model in the retail sector of China (Huang *et al.* 2009); for contractors ranking (Darvish *et al.* 2009); for evaluation of transportation zones in Vilnius City analysis and ranking (Jakimavičius and Burinskienė 2009a, b).

The *Simple Additive Weighting* method can be described as fallows:

- selecting the set of the most important criteria x_j, describing the feasible alternatives;
- constructing the decision-making matrix X:

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; i=\overline{1,m}; j=\overline{1,n}, \quad (1)$$

where m is the number of alternatives; n – is the number of criteria; x_{ij} is value of j criterion in alternative i.

The normalized $\bar{x}_{ij}$ values of the j criterion for i alternative are calculated as follows:

$$\bar{x}_{ij}=\frac{x_{ij}}{\max_i x_{ij}}, \text{ if preferable is maximum;} \quad (2)$$

$$\bar{x}_{ij}=\frac{\min_i x_{ij}}{x_{ij}}, \text{ if preferable is minimum.} \quad (3)$$

The optimality criterion L_i of alternative equals to the sum of the weighted criteria values:

$$L_i=\sum_{j=1}^{n}\left(\bar{x}_{ij}q_j\right), \quad (4)$$

where q_j is the weight of j criterion.

Simple Additive Weighting method with grey number (SAW-G) method was selected for the problem solution (Zavadskas *et al.* 2010b).

The *Simple Additive Weighting* method with grey numbers can be described as a stepwise procedure:

Step 1: selecting the set of the most important criteria, describing the alternatives;

Step 2: constructing the grey decision-making matrix $\otimes X$:

$$\otimes X=\begin{bmatrix} \otimes x_{11} & \otimes x_{12} & \cdots & \otimes x_{1n} \\ \otimes x_{21} & \otimes x_{22} & \cdots & \otimes x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes x_{m1} & \otimes x_{m2} & \cdots & \otimes x_{mn} \end{bmatrix}=$$

$$\begin{bmatrix} [w_{11}; b_{11}] & [w_{12}; b_{12}] & \cdots & [w_{1m}; b_{1m}] \\ [w_{21}; b_{21}] & [w_{22}; b_{22}] & \cdots & [w_{2m}; b_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [w_{n1}; b_{n1}] & [w_{n2}; b_{n2}] & \cdots & [w_{nm}; b_{nm}] \end{bmatrix}; i=\overline{1,m}; j=\overline{1,n}, \quad (5)$$

where $\otimes x_{ij}$ is the grey value of grey criterion determined in interval $[w_{ij}; b_{ij}]$; w_{ij} is the lower bond of j criterion in alternative i, and b_{ij} is the upper bond of j grey criterion in alternative i; m is the number of alternatives, and n is the number of criteria.

Step 3: normalization procedure at obtaining comparable scales. The normalized values are calculated as follows:

$$\bar{w}_{ij}=\frac{w_{ij}}{\max_i w_{ij}}; \ \bar{b}_{ij}=\frac{b_{ij}}{\max_i b_{ij}}; \ \textit{if } \max_i x_{ij} \textit{ is preferable}; \quad (6)$$

$$\bar{w}_{ij}=\frac{\min_i w_{ij}}{w_{ij}}; \ \bar{b}_{ij}=\frac{\min_i b_{ij}}{b_{ij}}; \ \textit{if } \min_i x_{ij} \textit{ is preferable}, \quad (7)$$

where $\max_i x_{ij}$ is maximum value in j column;

$\min_i x_{ij}$ is minimum value in j column.

In *Step 3* grey normalized decision-making matrix $\otimes \bar{X}$ is prepared:

$$\otimes \bar{X}=\begin{bmatrix} \otimes \bar{x}_{11} & \otimes \bar{x}_{12} & \cdots & \otimes \bar{x}_{1n} \\ \otimes \bar{x}_{21} & \otimes \bar{x}_{22} & \cdots & \otimes \bar{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \bar{x}_{m1} & \otimes \bar{x}_{m2} & \cdots & \otimes \bar{x}_{mn} \end{bmatrix}=$$

$$\begin{bmatrix} [\bar{w}_{11}; \bar{b}_{11}] & [\bar{w}_{12}; \bar{b}_{12}] & \cdots & [\bar{w}_{1m}; \bar{b}_{1m}] \\ [\bar{w}_{21}; \bar{b}_{21}] & [\bar{w}_{22}; \bar{b}_{22}] & \cdots & [\bar{w}_{2m}; \bar{b}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\bar{w}_{n1}; \bar{b}_{n1}] & [\bar{w}_{n2}; \bar{b}_{n2}] & \cdots & [\bar{w}_{nm}; \bar{b}_{nm}] \end{bmatrix}; i=\overline{1,m}; j=\overline{1,n}. \quad (8)$$

Step 4: determining weights of the criteria q_j (full account in Chapter 2.2.).

Step 5: Weighted-normalized decision-making matrix $\otimes \hat{X}$ is obtained as follows:

$$\otimes \hat{x}_{ij}=\otimes \bar{x}_{ij}\cdot q_j; \ \hat{w}_{ij}=\bar{w}_{ij}\cdot q_j; \ \hat{b}_{ij}=\bar{b}_{ij}\cdot q_j. \quad (9)$$

In formula (9), q_j is the weight of the j criterion.

$$\otimes \hat{X} = \begin{bmatrix} \otimes \hat{x}_{11} & \otimes \hat{x}_{12} & \cdots & \otimes \hat{x}_{1n} \\ \otimes \hat{x}_{21} & \otimes \hat{x}_{22} & \cdots & \otimes \hat{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \hat{x}_{m1} & \otimes \hat{x}_{m2} & \cdots & \otimes \hat{x}_{mn} \end{bmatrix} = \tag{10}$$

$$\begin{bmatrix} [\hat{w}_{11};\ \hat{b}_{11}] & [\hat{w}_{12};\ \hat{b}_{12}] & \cdots & [\hat{w}_{1m};\ \hat{b}_{1m}] \\ [\hat{w}_{21};\ \hat{b}_{21}] & [\hat{w}_{22};\ \hat{b}_{22}] & \cdots & [\hat{w}_{2m};\ \hat{b}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\hat{w}_{n1};\ \hat{b}_{n1}] & [\hat{w}_{n2};\ \hat{b}_{n2}] & \cdots & [\hat{w}_{nm};\ \hat{b}_{nm}] \end{bmatrix};$$

Step 6: The next step is to calculate optimality criterion L_i to each alternative:

$$L_i = \frac{1}{m}\sum_{j=1}^{n}\frac{\hat{w}_{ij} + \hat{b}_{ij}}{2}. \tag{11}$$

Step 7: Optimal alternative is determined as maximal value of L_i.

2.2. Weights of criteria

The SAW-G method needs criteria weights. Weights of the criteria were determined weights by applying AHP method (Tables 2 and 3) (Saaty and Erdener 1979; Podvezko 2009).

The Analytic Hierarchy Process (AHP) is often referred to as the Saaty (Saaty and Erdener 1979; Saaty 1980, 1982, 1994) method. Thomas Saaty introduced the AHP theory in the mid-70s. AHP provides a proven, effective means to deal with complex decision-making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process.

Essence of the method is to construct a matrix expressing the relative values of a set of criteria. A relative scale is used to compare two objects at a time.

The AHP involves four main steps:

a) The first step is for the team to decompose the goal into its constituent parts, progressing from the general to the specific, and to develop a hierarchy of interrelated decision elements describing the problem (the hierarchy consists of the alternative management options).
b) Pair-wise comparisons on the decision elements are performed using a weighting scale, to generate the input data. It has been shown in comparative studies that a 9-point scale of comparison (Table 3) most closely simulates human decision-making when comparing objects. Carrying out *Pair by Pair* comparisons for all the criteria to be considered, and the matrix is completed.
c) Calculation is performed concerning a list of the relative weights, importance, or value of the criteria which are relevant to the problem in question (technically, this list is called an eigenvector).
d) The relative weights of the decision elements are aggregated to calculate ratings for the alternative decision possibilities. The final stage is to calculate a Consistency Ratio (***CR***) to measure how consistent the judgements have been relative to large samples of purely random judgements. If the ***CR*** is much in excess of 0.1 the judgements are untrustworthy. It is easy to make a minimum number of judgements after which the rest can be calculated to enforce perhaps an unrealistically perfect consistency.

Table 2. Pair-wise comparison matrix

	x_1	x_2	x_3	$x_{4\text{-}7}$	x_8	x_9
x_1		2	1/5	1/3	1/3	2
x_2	1/2		1/7	1/5	1/7	1/2
x_3	5	7		2	3	6
$x_{4\text{-}7}$	3	5	1/2		1/2	4
x_8	3	7	1/3	2		6
x_9	1/2	2	1/6	¼	1/6	
	q_1	q_2	q_3	$q_{4\text{-}7}$	q_8	q_9
	0.078	0.038	0.390	0.188	0.252	0.053
CR	0.031					

Table 3. The Saaty's Judgment Scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other
5	Much more important	Experience and judgement strongly favour one over the other
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

An advantage of the AHP is that it can be used to develop importance structures between criteria and/or as a complete decision-making framework for the analysis of management problems. It allows managers to make use of their professional judgements and, in the field of natural resource management, may include some interest group interaction as well.

Weights of 4–7 criteria are determined as follows:

$$q_j = q_{4-7} g_j. \tag{12}$$

2.3. Case study

Three alternatives of the most widely used dwelling-house construction alternatives were selected. The first alternative is a traditional brick house, built from standard materials, the second house is a blockhouse, made mostly of wood-based materials and the third one is built of wood frame, using a wood-based and mineral-based materials. The purpose of the assessment is to choose an optimal variant, taking into account an environmental impact, financial and qualitative aspects. The optimal alternative will be chosen applying SAW-G method. The main alternatives and criteria data are compiled on the basis of data from the Foresty Department (2007), market prices and statistics (Table 4).

3. Results and discussion

A thorough analysis of the initial values of possible alternatives could evidently show that there are no alternatives which are the best or worst according to the all criteria values.

The decision-making matrix (Table 5) was compiled according to Table 2 and 4. Table 5 shows the initial description matrix of the problem. All the meanings of criteria and alternatives are described in Table 4.

The normalized values are calculated according to equations (6) and (7). Then normalized decision-making matrix is presented in Table 6.

In the normalized matrix all the values are in the interval [0; 1]. In this case the criteria could be compared. But before comparison, it is necessary to calculate the weighted-normalized values of the matrix.

The weighted-normalized values of the criteria (Table 7) are calculated according to formula (9).

The weighted-normalized matrix enables to calculate the optimal criteria of all the alternatives.
Optimal criteria are calculated by formula (11) and presented in Table 7. Optimal criteria enable to rank the alternatives.

According to the calculation results, alternative ranking is as follows:

$$A_2 \succ A_3 \succ A_1 .$$

This means that the second alternative (wood-based building) is the best solution with the result of 0.303, and the first alternative (brick house) is the worst with the result of 0.280. The result of the third alternative (wood-frame building with mineral-based materials) is 0.286.

According to the results, it can be stated that the second alternative is by 7.5% better than the first alternative and by 6.6% better than the third alternative.

The investigation shows that according to the selected criteria, namely, by the price, construction term, longevity, CO_2 emission, SO_2 emission, phosphate emission, C_2H_4 ethene emission, running costs and utilization input of energy, the best alternative is a blockhouse, made mostly of wood-based materials. There is no significant difference between a traditional brick house, built from standard materials and a wood-frame building with mineral-based materials.

Table 4. Initial matrix of the problem description

Name of criteria	Criteria		Dimension	Optimization direction	Marking in formulas	Criterion weight	Alternative		
							(A_1)	(A_2)	(A_3)
						q_j	Brick house	Wood-based house	Wood-frame house
$\otimes x_1$	Building price		€/100m^2	Min	$w_1 = b_1$	0.078	46400	43500	40600
$\otimes x_2$	Construction term		month	Min	w_2	0.038	6	6	3
					b_2		8	8	6
$\otimes x_3$	Long-term		year	Max	w_3	0.390	70	70	60
					b_3		80	80	80
$\otimes x_4$	CO_2 equivalent (impact g_4= 0.76)	Production	kg/100m^2	Min	$w_4 = b_4$	0.143	62600	42100	51500
		Construction	kg/100m^2				21800	14600	18200
		Total	kg/100m^2				84400	56600	69600
$\otimes x_5$	SO_2 equivalent (impact g_5= 0.12)	Production	kg/100m^2	Min	$w_5 = b_5$	0.022	140	94	115
		Construction	kg/100m^2				48.7	32.5	40.5
		Total	kg/100m^2				188	126	155
$\otimes x_6$	Phosphete equivalent (impact g_6= 0.08)	Production	kg/100m^2	Min	$w_6 = b_6$	0.015	11.9	7.99	9.78
		Construction	kg/100m^2				4.14	2.76	3.45
		Total	kg/100m^2				16.04	10.76	13.23
$\otimes x_7$	C_2H_4 equivalent (impact g_7= 0.04)	Production	kg/100m^2	Min	$w_7 = b_7$	0.008	3.61	2.42	2.96
		Construction	kg/100m^2				1.26	0.84	1.03
		Total	kg/100m^2				4.86	3.26	3.99
$\otimes x_8$	Maintenance cost		€/100m^2	Min	w_8	0.252	58000	63800	58000
					b_8		78300	75400	74500
$\otimes x_9$	Utilization input of energy		MJ	Min	$w_9 = b_9$	0.053	6810	5680	9340

Table 5. Initial description matrix of the problem

Alter-native	Criteria											
	$\otimes x_1$	$\otimes x_2$		$\otimes x_3$		$\otimes x_4$	$\otimes x_5$	$\otimes x_6$	$\otimes x_7$	$\otimes x_8$		$\otimes x_9$
	$w_1 = b_1$	w_2	b_2	w_3	b_3	$w_4 = b_4$	$w_5 = b_5$	$w_6 = b_6$	$w_7 = b_7$	b_8	w_8	$w_9 = b_9$
Optimal	min	min		max		min	min	min	min	min		min
q	0.078	0.038		0.390		0.143	0.022	0.015	0.008	0.252		0.053
$\boldsymbol{A_1}$	46400	6	8	70	80	84400	188	16.04	4.86	58000	78300	6810
$\boldsymbol{A_2}$	43500	6	8	70	80	56600	126	10.76	3.26	63800	75400	5680
$\boldsymbol{A_3}$	40600	3	6	60	80	69600	155	13.23	3.99	58000	74500	9340

Table 6. Normalized decision-making matrix

Alter-native	Criteria											
	$\otimes \bar{x}_1$	$\otimes \bar{x}_2$		$\otimes \bar{x}_3$		$\otimes \bar{x}_4$	$\otimes \bar{x}_5$	$\otimes \bar{x}_6$	$\otimes \bar{x}_7$	$\otimes \bar{x}_8$		$\otimes \bar{x}_9$
	$\bar{w}_1 = \bar{b}_1$	$\bar{w}_2$	$\bar{b}_2$	$\bar{w}_3$	$\bar{b}_3$	$\bar{w}_4 = \bar{b}_4$	$\bar{w}_5 = \bar{b}_5$	$\bar{w}_6 = \bar{b}_6$	$\bar{w}_7 = \bar{b}_7$	$\bar{w}_8$	$\bar{b}_8$	$\bar{w}_9 = \bar{b}_9$
Opt.	min	min		max		min	min	min	min	min		min
q	0.078	0.038		0.390		0.143	0.022	0.015	0.008	0.252		0.053
$\boldsymbol{A_1}$	0.875	0.500	0.375	0.875	1.000	0.671	0.670	0.671	0.671	1.000	0.741	0.834
$\boldsymbol{A_2}$	0.933	0.500	0.375	0.875	1.000	1.000	1.000	1.000	1.000	0.909	0.769	1.000
$\boldsymbol{A_3}$	1.000	1.000	0.500	0.750	1.000	0.813	0.813	0.813	0.817	1.000	0.779	0.608

Table 7. Weighted- normalized decision-making matrix and optimall criteria

	Criteria												$\boldsymbol{L_i}$
	$\otimes \hat{x}_1$	$\otimes \hat{x}_2$		$\otimes \hat{x}_3$		$\otimes \hat{x}_4$	$\otimes \hat{x}_5$	$\otimes \hat{x}_6$	$\otimes \hat{x}_7$	$\otimes \hat{x}_8$		$\otimes \hat{x}_9$	
	$\hat{w}_1 = \hat{b}_1$	$\hat{w}_2$	$\hat{b}_2$	$\hat{w}_3$	$\hat{b}_3$	$\hat{w}_4 = \hat{b}_4$	$\hat{w}_5 = \hat{b}_5$	$\hat{w}_6 = \hat{b}_6$	$\hat{w}_7 = \hat{b}_7$	$\hat{w}_8$	$\hat{b}_8$	$\hat{w}_9 = \hat{b}_9$	
$\boldsymbol{A_1}$	0.069	0.019	0.014	0.341	0.390	0.096	0.015	0.010	0.005	0.252	0.187	0.045	0.280
$\boldsymbol{A_2}$	0.073	0.019	0.014	0.341	0.390	0.143	0.023	0.015	0.008	0.229	0.194	0.053	0.303
$\boldsymbol{A_3}$	0.078	0.038	0.019	0.293	0.390	0.116	0.018	0.012	0.006	0.252	0.196	0.032	0.286

4. Conclusions

1. The project life cycle 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. In strategic decisions, dealing with uncertainty, the values of criteria could be determined in intervals – from pessimistic value to optimistic value.

2. According to the criteria, which were described above, and by the assistance of newly-developed multicriteria method SAW-G, it was calculated that a blockhouse, made mostly of wood-based materials with the result of 0.303 is by 6.6% a better alternative than a wood-frame building with the result of 0.286, made from wood-based and mineral-based materials, and the worst results were obtained for a building from traditional bricks with the result of 0.280 (wood-based house is by 7.5% better than brick house).

3. Investigation shows that, however, the use of renewable materials in building construction is useful. And it is useful for the environment and people considering finance and quality.

4. The use of SAW-G and AHP method is suitable for the solution of this and similar problems because it is useful in decision-making, when it is necessary to compare criteria with different dimensions and purposes.

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TVARIOJI STATYBA, VERTINANT STATYBOS POVEIKĮ APLINKAI

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S a n t r a u k a

Aprašomas statybos darbų padarinių poveikis aplinkai, žmonėms ir jų sveikatai. Autoriai siūlo optimalų variantą iš pateiktų statybos projektų, atitinkančių aplinkos apsaugos reikalavimus. Pateikti ekologiškų statybinių medžiagų kriterijai, palyginti su tradicinių medžiagų kriterijais. Šio tyrimo tikslas yra sukurti statybos proceso klasifikavimo eilę, atsižvelgiant į ekonominius ir aplinkos apsaugos aspektus. Nagrinėjamos vienbučio gyvenamojo namo statybos alternatyvos. Pateiktos kelios alternatyvos, kaip parinkti optimalų projekto variantą. Aptartas gamybos darbų ir statybos poveikis aplinkai. Analizė atliekama atsižvelgiant į statybos gyvavimo ciklo poveikį aplinkai, finansines bei socialines aplinkybes. Tyrimas apima taršą statybinių medžiagų gamybos procese bei vykstant statybos procesui. Vertinama pastato ilgaamžiškumas, kaina, eksploatavimo išlaidos bei utilizacijos procesui suvartojama energija. Atliktas šių alternatyvų daugiakriterinis įvertinimas, apibrėžiant jų naudą ne tik žmonėms, bet ir aplinkai. Remiantis straipsnyje aprašytais aplinkos apsaugos, finansiniais ir kokybiniais kriterijais, nauju daugiakriteriniu *SAW-G* metodu buvo apskaičiuota, kad blokinis namas, pastatytas naudojant daugiausia medienos medžiagas (rezultatas 0,303), yra 6,6 % geresnis už namą (rezultatas 0,2860), pastatytą iš medinio karkaso ir naudojant mineralines bei medienos medžiagas, o blogiausias rezultatas – tai namas iš tradicinio plytų mūro (rezultatas 0,280) (medinis namas yra 7,5 % geresnis už mūrinį). *AHP* ir *SAW-G* metodai yra tinkami tokiems uždaviniams spręsti.

Reikšminiai žodžiai: statyba, medžiagos, pastatas, aplinka, išteklių eikvojimas, daugiakriterinis vertinimas, poveikis aplinkai, *SAW*, *SAW-G*, *AHP* metodas.

ОБЕРЕГАЮЩЕЕ ПРИРОДУ СТРОИТЕЛЬСТВО С УЧЕТОМ ВОЗДЕЙСТВИЯ СТРОЙКИ НА ОКРУЖАЮЩУЮ СРЕДУ

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Р е з ю м е

Описано влияние последствий строительства на окружающую среду, человека и его здоровье. Из приведенных строительных проектов, соответствующих экологическим стандартам, авторами статьи выбран оптимальный вариант. Приведены критерии экологичных строительных материалов и сравнены с традиционными материалами. Целью настоящего исследования было разработать очередность классификации строительного процесса с учетом экономических и экологических аспектов. Проанализированы альтернативы строительства одноквартирного жилого дома с целью выбора оптимального проекта. Обсуждено влияние строительства на окружающую среду. Анализ проведен с учетом воздействия жизненного цикла здания на окружающую среду, а также финансовых и социальных аспектов. Исследовалось загрязнение от производства строительных материалов, от процесса строительства с учетом долголетия дома, цены, расходов на эксплуатацию, а также энергии, расходуемой при утилизации. Произведен многокритериальный анализ вышеупомянутых альтернатив, оценена польза, приносимая как человеку, так и окружающей среде. На основании критериев охраны окружающей среды, финансов и качества работ с помощью нового многокритериального метода SAW-G было установлено, что блочный дом, построенный из деревянных материалов с результатом 0,303, на 6.6% лучше, чем дом из деревянного каркаса с минеральными и деревянными материалами с результатом 0,286. Наихудшим вариантом оказался дом, построенный из традиционной кирпичной кладки с результатом 0,280 (деревянный дом лучше кирпичного на 7,5%). Для решения задач такого типа оказались приемлемыми методы AHP и SAW-G.

Ключевые слова: строительство, материалы, дом, окружающая среда, истощение ресурсов, многокритериальная оценка, воздействие на окружающую среду, методы SAW, SAW-G, AHP.

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