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MULTI-CRITERIA SELECTION OF THE ONE FLAT DWELLING HOUSE, TAKING INTO ACCOUNT THE CONSTRUCTION IMPACT ON ENVIRONMENT

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Abstract. The article describes a multi-criteria selection of the one flat dwelling house, taking into account the construction ecological aspects, their impact on environment and their economic and social condition. A problem of a global climate change is discussed, how construction industry determinate the CO_2 emission to an atmosphere, how a construction material manufacturing impacts to an environment. The best alternative selection of the one flat dwelling house is presented. The first house is masonry, built from standard materials, the second is the blockhouse, made mostly of wood-based materials, and the third is built of wood frame, using a wood-based materials and mineral-based materials. The weights of criteria are determined by applying AHP method. The best alternative is selected by applying the SAW (*Simple Additive Weight*), COPRAS (*COmplex PRoportion ASsessment*), and MEW (*Multiplicative Exponential Weighting*) methods.

Keywords: construction, material, environment, impact, MCDM, SAW, MEW, COPRAS, AHP.

Introduction

Global climate change is one of the most serious global environmental problems faced by humankind at present (Wu and Zhang 2008). The world is becoming an increasingly urban place. About 65 % of the world's population is expected to live in urban areas by the year 2025 (Schell and Ulijaszek 1999).

The civil construction industry is not only one of the biggest sectors in the economy but is also one of the greatest polluters (Ilha *et al*. 2009). The construction sector plays a major role in the development of society. It wields enormous influence over economic activity, employment and growth rates. However, it also has a substantial impact on the natural environment, the effects of which are evident across the world. Over recent decades, initiatives have proposed environmentally friendly buildings and sustainable construction has centered on residential and office buildings (Lombera and Aprea 2010). Buildings have a significant and continuously increasing impact on the environment because they are responsible for a large portion of carbon emissions and use a considerable number of resources and energy (Castro – Lacouture *et al.* 2009).

To meet the Kyoto target of reducing carbon dioxide emissions by 20 % by 2010 the UK government has introduced a number of measures to achieve energy conscious buildings and promote sustainability within the built environment. One of the devices through which to do this is the Building Regulations, which were originally introduced to ensure public health and safety, but are increasingly seen as a tool for limiting the environmental impact of the built environment on natural resources (Hamza and Greenwood 2009).

Construction industry, though quite specific, obeys the same laws of economy as other sectors (Kapliński 2008). To find and accept the right decision in construction industry is difficult problem. Decision maker usually has too little information and it is usually incomplete. The help for the decision making is application of the multi-criteria decision making (MCDM) techniques and their modifications.

Impact of construction materials on environment and ecoproducts' industry

Transformation of raw materials into construction materials generates roughly 50 % of all atmospheric emissions of CO_2. Therefore, there is an onus on the architectural and engineering professions to integrate environmental protection mechanisms into their work, so as to comply fully with environmental requirements (Kangas 2004).

Researches of U.S. boffins (Roodman *et al*. 1995; USGBC Research Committee 2008) revealed that buildings consume 40 % of the world's materials, use 55 % of the wood cut for nonfuel use, use 12.2 % of the total water consumed, consume 40 % of the world's energy and 71 % of U.S. electricity, produce 40 % of U.S. nonindustrial waste, and create 36 % of the carbon dioxide emissions that cause global warming.

Organic materials market is not as extensive as expected. Nevertheless, organic products are produced and supplied to the consumer in all over the world. For example, U.S. cement producers can reduce CO_2 emissions per ton of cement manufactured through the addition of mineral components such as fly ash or slag (waste products from coal burning and steel production) (Hoffman 2006). Bamboo and cork are the two most widely known rapidly renewable materials, though building materials made from agricultural-waste byproducts, including wheat straw and sugarcane bagasse, or fiber crops, like kenaf and hemp, are becoming more common (Stephens 2009). Canadian researchers writes about the aspects of lignocellulosic – fibre reinforced "green" materials (Baltazar-y-Jimenez 2009). Spain propose compressed earth blocks masonry and walls, made of "eco-concrete" consisting of a mixture of local soil and granulated cork, cement and water (Delgado and Guerrero 2006). Chine produces different products from organic recourses: wood mineralized boards, green magnesium oxide boards, green fibre cement boards, and even green fiber cement and calcium silicate boards (www.alibaba.com). Lithuanian manufacturers offer multi-purpose insulating panels from hemp and wood chips; blocks of wood, specialty minerals and portland; paints and oils from renewable natural resources; the flooring from a bamboo and large selection of products from wood.

Impact of construction process on environment

There are five main aspects of environmental impact. They are (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 focuses on the adoption of green practices and new technologies, which are innovative and have potential environmental benefits.

Multi-criteria decision making methods

Methods of multi-criteria 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).

There is a wide range of methods based on multi-criteria utility theory: SAW (MacCrimon 1968; Ginevičius *et al.* 2008a, b); MOORA – Multi-Objective Optimization on basis of Ratio Analysis (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); MEW (*Multiplicative Exponential Weighting*) (Zavadskas 1987); and other methods (Turskis 2008; Turskis *et al.* 2009).

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.

Methodology

Most of the methods need the criteria weights, determining by AHP (Analytic Hierarchy Process) method. The AHP is often referred as the Saaty (Saaty and Erdener 1979; Saaty 1980, 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. Podvezko (2009) presented the application of AHP technique.

Often all the methods criticized for the fact that in some cases using different methods, different results are obtained. Therefore assessment should be applied by a few methods. The optimal alternative will be chosen applying SAW (MacCrimon 1968; Ginevičius *et al.* 2008a, b), COPRAS (Zavadskas *et al*. 2008a, 2009a) and MEW (Zavadskas 1987) methods.

The normalised values of the criteria are calculated as follows:

a) For SAW and MEW methods:

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \text{ if preferable is maximum;} \quad (1)$$

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \text{ if preferable is minimum.} \quad (2)$$

b) For COPRAS method:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad (3)$$

where:

$i = \overline{1, m}$ – alternatives;

$j = \overline{1, n}$ – criteria.

Cas study

There are three alternatives of dwelling house investigated. The thirst alternative traditional brick house (A_1), built from standard materials and the second house is blockhouse (A_2), made mostly of wood-based materials, and the third one is built of wood frame (A_3), 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 main alternatives and criteria data are compiled on the data from the Foresty Department (2007), basis of market prices and statistics (Table 2).

Weights (q_j) of the criteria were determined by applying AHP method (Table 1) (Saaty and Erdener 1979; Podvezko 2009).

The decision – making matrix (Tables 2 and 3) was compiled according to the Table 1.

In Table 2 CR – consistency ratio.

Normalised decision-making matrix was calculated according to the equations (1), (2) and (3); and is presented in Tables 4 and 6.

Weighted-normalised values of the criteria are presented in Tables 5, 7 and 8. The results of all the methods are represented in Table 9.

Table 1. Pair-wise comparison matrix of criteria

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

Table 2. Initial matrix of the problem

Name of criteria	Criteria		Dimension	Opt. direction	Attribute Weight q_j	Alternative		
						Brick house	Wood-based house	Wood-frame house
x_1	Building price		€/100m^2	Min	0.078	46400	43500	40600
x_2	Construction term		month	Min	0.038	7	7	4.5
x_3	Long-term		year	Max	0.390	75	75	70
x_4	CO_2 equivalent (impact g_4=0.76)	Production	kg/100m^2	Min	0.143	62600	42100	51500
		Construction	kg/100m^2			21800	14600	18200
		Total	kg/100m^2			84400	56600	69600
x_5	SO_2 equivalent (impact g_5=0.12)	Production	kg/100m^2	Min	0.022	140	94	115
		Construction	kg/100m^2			48.7	32.5	40.5
		Total	kg/100m^2			188	126	155
x_6	Phosphate equivalent (impact g_6=0.08)	Production	kg/100m^2	Min	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
x_7	C_2H_4 equivalent (impact g_7=0.04)	Production	kg/100m^2	Min	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
x_8	Maintenance cost		€/100m^2	Min	0.252	68150	69600	66250
x_9	Utilization input of energy		MJ	Min	0.053	6810	5680	9340

Table 3. Initial decision- making matrix

Alternative	Criteria								
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Optimisation direction	min	min	max	min	min	min	min	min	min
q_j	0.078	0.038	0.390	0.143	0.022	0.015	0.008	0.252	0.053
A_1	46400	7	75	84400	188	16.04	4.86	68150	6810
A_2	43500	7	75	56600	126	10.76	3.26	69600	5680
A_3	40600	4.5	70	69600	155	13.23	3.99	66250	9340

Table 4. Normalised decision-making matrix (for SAW method) – $\overline{X}$

Alternative	Criteria								
	$\overline{x}_1$	$\overline{x}_2$	$\overline{x}_3$	$\overline{x}_4$	$\overline{x}_5$	$\overline{x}_6$	$\overline{x}_7$	$\overline{x}_8$	$\overline{x}_9$
A_1	0.8750	0.6429	1.0000	0.6706	0.6702	0.6708	0.6708	0.9721	0.8341
A_2	0.9333	0.6429	1.0000	1.0000	1.0000	1.0000	1.0000	0.9519	1.0000
A_3	1.0000	1.0000	0.9333	0.8132	0.8129	0.8133	0.8170	1.0000	0.6081

Table 5. Weighted- normalised decision-making matrix (SAW method) – $\hat{X}$

Alternative	Criteria									L
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{x}_7$	$\hat{x}_8$	$\hat{x}_9$	
A_1	0.0686	0.0246	0.3900	0.0958	0.0151	0.0101	0.0050	0.2451	0.0445	0.8988
A_2	0.0732	0.0246	0.3900	0.1429	0.0226	0.0150	0.0075	0.2400	0.0533	0.9690
A_3	0.0784	0.0382	0.3640	0.1162	0.0183	0.0122	0.0061	0.2521	0.0324	0.9180
Remarks: Alternative ranks as follows: $A_2 \succ A_3 \succ A_1$.										

Table 6. Normalised decision-making matrix (MEW method) – $\overline{X}$

Alternanative	Criteria								
	$\overline{x}_1$	$\overline{x}_2$	$\overline{x}_3$	$\overline{x}_4$	$\overline{x}_5$	$\overline{x}_6$	$\overline{x}_7$	$\overline{x}_8$	$\overline{x}_9$
A_1	0.8750	0.6429	1.0000	0.6706	0.6702	0.6708	0.6708	0.9721	0.8341
A_2	0.9333	0.6429	1.0000	1.0000	1.0000	1.0000	1.0000	0.9519	1.0000
A_3	1.0000	1.0000	0.9333	0.8132	0.8129	0.8133	0.8170	1.0000	0.6081

Table 7. Weighted- normalised decision-making matrix (MEW method) – $\hat{X}$

Alternative	Criteria									L
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{x}_7$	$\hat{x}_8$	$\hat{x}_9$	
A_1	0.9896	0.9833	1.0000	0.9445	0.9910	0.9940	0.9970	0.9929	0.9904	0.8876
A_2	0.9946	0.9833	1.0000	1.0000	1.0000	1.0000	1.0000	0.9876	1.0000	0.9659
A_3	1.0000	1.0000	0.9735	0.9709	0.9953	0.9969	0.9985	1.0000	0.9738	0.9119
Remarks: Alternative ranks as follows: $A_2 \succ A_3 \succ A_1$.										

Table 8. Weighted- normalised decision-making matrix (COPRAS method) – $\hat{X}$

Alternative	Criteria									S_{+j}	S_{-j}
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{x}_7$	$\hat{x}_8$	$\hat{x}_9$		
A_1	0.0279	0.0145	0.1330	0.0573	0.0090	0.0060	0.0030	0.0842	0.0166	0.1330	0.2185
A_2	0.0261	0.0145	0.1330	0.0384	0.0061	0.0040	0.0020	0.0860	0.0139	0.1330	0.1910
A_3	0.0244	0.0093	0.1241	0.0472	0.0075	0.0050	0.0025	0.0819	0.0228	0.1241	0.2005
Remarks: Q_1= 0.3216; Q_2= 0.3488; Q_3= 0.3297. Alternative ranks as follows: $A_2 \succ A_3 \succ A_1$.											

Table 9. The solution results

Alternatives	The results of SAW method	Ranks of SAW method	The results of MEW method	Ranks of MEW method	The results of COPRAS method	Ranks of COPRAS method
A_1	0.8988	3	0.8876	3	0.3216	3
A_2	0.9690	1	0.9659	1	0.3488	1
A_3	0.9180	2	0.9119	2	0.3297	2

This means that the second alternative is the best solution and the first alternative is the worst.

All of the methods show the same results. That means that the second alternative is clearly the best alternative.

Conclusions

The project's life cycle must be evaluated according to multiple criteria taking in to account 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.

There is determined set of criteria for problem solution and present multi-criteria problem solution model.

The calculation shows, that the second alternative (wood-based building) is the best solution and the first (brick house) is the worst, taking into account an environmental impact, financial and qualitative aspects.

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