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INTEGRATED MULTI-CRITERIA EVALUATION OF HOUSE'S PLAN SHAPE BASED ON THE EDAS AND SWARA METHODS

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Abstract. With this article we strive to create a theoretical valuation model based on multiple criteria mathematical methods by selecting a basic shape of single-family residential house's plan. Most of the researches and analysis discuss the interfaces of architectural shapes of the buildings with sustainability only in the buildings with unique design. Meanwhile, the model comprising a selection of a basic shape of the single-family house was not implemented. Our study evaluated the individual parameters associated with selection of the house shape: compactness, safety, material input, variability of premises and spaces. The SWARA (Step-Wise Weight Assessment Ratio Analysis) method is applied in the calculation of the relative importance of the criteria and the EDAS (The Method of Evaluation Based on Distance from Average Solution) method was used to prioritize the alternatives.

Keywords: single-family residential house, house's plan shape, sustainability, SWARA, EDAS.

Introduction

Over the past decade, a growing part of people already can afford themselves to have a single-family house. This is due to people's desire to separate the work area from the private one (Alfa.lt 2010), the desire to be closer to nature and the national governments' strategy in the issues of housing development (Rid *et al.* 2017). Demand for individual housing is growing rapidly in all countries, including the EU (Eurostat 2014). With development of a loan systems and growth of consumption needs, a growing number of economy-class customers purchase the standard plots, in which they are building (typical) single-family houses with repeatable design. Single-family residential houses are using

more and more energy resources, so their sustainability is as important as all the buildings.

In today's extremely fast changing world, the sustainable development became one of the most important factors in defining the quality buildings (Yang *et al.* 2017), which create a healthy environment for humans and reduce the negative impact on the environment. John Elkington (1997) was one of the first who named the concept of sustainability TLB (Triple bottom line) as a long term perspective of production effects. And already in 2005, the World Summit on Social Development presented and outlined the definition of sustainability as the three anchors of sustainability: social,

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environmental and economic (Fig. 1) (SP 2014). The three anchors of sustainability fully define the sustainability problem, satisfying the present needs and causing no threat to meeting the opportunities of future needs. In other words, the sustainability is a setting of high living standards for present and future people generations. The construction industry is one of the areas, covering all three anchors of sustainability: social (Kamali, Hewage 2017), economic (Lizana *et al.* 2016) and environment protection (Holmstedt *et al.* 2017).

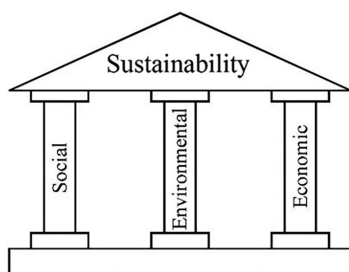


Fig. 1. The Three Pillars of Sustainability (according to SP 2014)

The European Union taking into account the global energy and environmental situation has set a certificate system, regulating the building energy efficiency (Rodriguez-Ubinas *et al.* 2014). To this end, different countries have developed certification systems, among which the main is BREEM (Building Research Establishment Environmental Assessment Methodology) and LEED (Leadership in Energy and Environmental Design). These and other systems evaluate buildings of the different purpose and/or their environmental and technical aspects (Vilutienė *et al.* 2015). These methods are not widely used in setting the sustainability of single-family residential houses. Therefore, new systems are being created next to the most famous certification systems, which focus on aspects of the specific type or purpose buildings.

In the scientific literature, interfaces of sustainability of the buildings with spatial shape are examined quite widely, but not much attention is given to the shape of single-family houses. Gou and Xie (2017) in their research have seen the influence of new architectural shapes on sustainability. Caruso and Kampf (2015) with the help of an algorithm intended to increase the use of solar energy, investigated the reduction of energy costs associated with building shapes under the different climatic conditions. Mooneghi and Kargarmoakhar (2016) after the comparison of high-rise and low-rise buildings of older and newer

construction have reasoned the interdependence of external shapes and functional space constraints of the buildings. Qi and Wang (2014) have reasoned the use of the shape factor in determining the energy efficiency of the buildings. However, various scientific studies have presented the different conclusions after the evaluation of energy consumption costs in various shapes of the buildings. Some scientific works (Zhang *et al.* 2016; Jin, Jeong 2014) have presented the reasoning of reduction of the consumed energy costs in comparison with simple and unique shape of the buildings in prejudice of the latter ones. Other scientific works have reasoned the shape interfaces of building types with specific regions of the countries. Krarti and Ihm (2016) have thought that the optimal design of the building, based on the compact solution of architecture can reduce the energy consumption even at 32–60% in the MENA (Middle East and North Africa) regions. To this end, repeatable designs of the houses created for different climatic regions could solve at least some of the problems associated with energy consumption. Importance of compactness of the panel houses has been denied by the study (Premrov *et al.* 2016) carried out in three different European cities: Ljubljana, Munich and Helsinki. Average temperature, solar potential, characteristics of unique (free) shape of the buildings (optimum glazing, orientations and so on) has been measured. It was found that climate inclemency has the greatest impact on the energy consumption (it means the annual temperature of the region).

It was found that the shapes of residential buildings influence the sustainability of buildings along with the other parameters after the review of mentioned scientific articles. Soflaei *et al.* (2017) have identified the additional sustainability criteria of single-family houses: the comfort, privacy and security. And Kang *et al.* (2014) have evaluated the quality of houses under the psychological, physical, social and even managerial aspects. Bolis *et al.* (2017) have presented the decision-making process model, which is dominated by the importance of individual needs. Therefore, the selection issues of the main constructions and materials of given house, selection of the design of structural elements and the shape of house itself became important. The selection of spatial single-family house's shape is influenced by different restrictions (Micallef *et al.* 2016), natural conditions, increasing energy consumption requirements, priorities of customers, available resources and other aspects.

These aforementioned quite complicated decision problems can be effectively solved within multi-criteria decision making (MCDM) framework (Si *et al.* 2016; Jalaei *et al.* 2015; Kabak *et al.* 2014).

Multi-criteria decision-making approach is very useful in many problems such as project selection, supplier selection, risk assessment, contractor evaluation, etc. Many studies have been made on MCDM methods and applications (Ruzgys *et al.* 2014; Lu *et al.* 2014; Alimardani *et al.* 2013).

1. Problem formulation for the selection of single-family house’s plan shape

This chapter proposes a theoretical shape selection model of the typical single-family house using MCDM system. We assume that the house with a total area of about 150 m² is made for 2–4 persons of young family, where children age is up to 16 years. We also do not link the selected model shapes with the unique shapes of the building. Basic typical shapes of the single-family houses are chosen for designed buildings (Fig. 2): rectangular, square, L-shaped and cross-shaped. The total area has been evaluated adequately: it was decided that total area of one- and two-story buildings of all kinds is the same. All roofs of single-family houses (alternatives) are pitched, regardless of the number of floors. Stairway area is eliminated from the general area because of the uniformity of total area evaluation.

We should discuss and analyze the criteria relating to assessment of buildings’ sustainability and relevance to individual houses while developing a theoretical model of selection of base scheme for the single-family residential house. Typical selection stages are presented in Figure 3.

7 independent experts (5 architects and 2 constructors) related to home designing and construction participated in an expert evaluation of shape selection of the typical single-family house. There was no discussion on the importance of the four major criteria. The proposal to include the “aesthetics” criterion was rejected as too subjective. There were selected four major criteria with common expert consensus which have been most relevant in selecting basic shape of typical single-family house. The problem can be solved with MCDM method because it has the structure of several criteria. Experts arranged together the criteria in accordance with importance: material costs of the main structural elements, safety, layout variability of the



Fig. 2. Basic shapes of single-family house’s plan

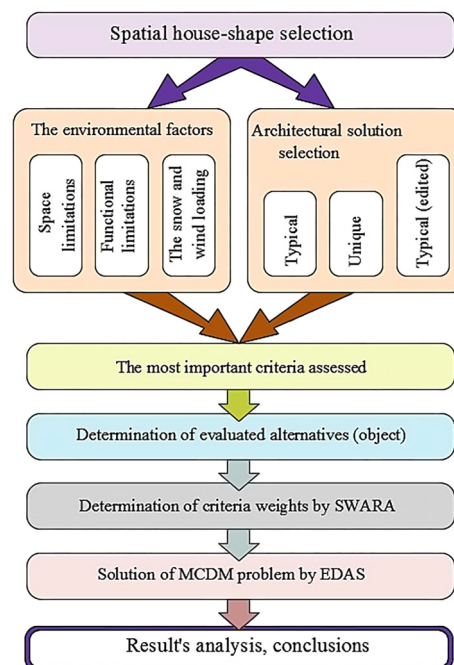


Fig. 3. Spatial house-shape selection scheme

premises and spaces and shape compactness. Criteria and their descriptions sorted by relevance are presented in Table 1.

Costs of materials (c_1) of the structural elements (walls, foundations, spans and roof) are selected because of price relevance. Since the price for economy-class customers is one of the most important aspects, experts gave precedence to this criterion. While comparing a perimeter of square and L-shaped buildings’ walls and foundations, the length of the latter ones is bigger by 25 percent. In all cases, the roof area is evaluated only as a two-pitched. It is assumed that the span is constructed only in cases of 2-story houses, and attics in all cases are made warm.

Table 1. Criteria (c_1-c_5) sorted by relevance

c_1-c_5	min/max	Criteria titles
c_1	min	Costs of materials of the main structural elements, m ²
c_2	max	Safety, scores
c_3	max	Layout variability of the premises and spaces, scores
c_4	max	Shape compactness

Stairway space in scientific studies is identified as one of the most dangerous spaces of the building (Raina *et al.* 2015). The analyzed scientific articles focus on the most important aspects of stairway safety – this is inclination angle (step width to height ratio) (Asai *et al.* 2014; Madehkhaksar, Egges 2016; Turskis, Juodagalviene 2016). It is clear that not only sizes of stairs affect the large number of accidents. This is also due to the lack of appropriate attention, behavioral adequacy, people age problems, stairway coverings, lighting and so on. Elder people or children suffer the most severe disasters on the stairs. According to the studies carried out by Startzell *et al.* in 2000 even 41% of accidents that occurred on the stairs are related to the lack of attention. Not all opinions of experts were concurring on the importance of safety in assessing the safety criteria (c_2): most of the designers think that the aesthetic aspect is more important.

Even after selection of a typical project, the customers have their own vision about space zoning issue. The higher the total area of the house, the more space is left for imagination. This layout criterion of premises and spaces (c_3) is relevant when the plot orientation is the poorest in respect of cardinal directions. This is related to the possibilities of the contextuality (in the plot of buildings' zoning).

Criterion of shape compactness (c_4) was selected due to lower energy consumption costs after the review of scientific literature. Energy saving is relevant to both types of buildings: currently designed as well as currently renovated. In all cases, the major percentage of energy savings falls on the rational insulation of exterior partitions and their efficient renewal (Aviža *et al.* 2015). Authors mentioned in the literature review (Premrov *et al.* 2016; Krarti, Ihm 2016) have not

denied compactness affect on the energy consumption, but they have reasoned more important significance of the other criteria.

2. Alternatives of the single family residential house

Factors influencing the designing of single-family residential houses are very different. Therefore, different plots, houses with different designs (unique or typical), structures and materials are selected. However, the main aspects that determine the quality of life in a house are safety and sustainability. Sustainability is determined not only by materials selected according to A or A+ energy efficiency class, but also by other aspects. For example, in unique building case, after the selection of a high house with small area (with second light), it is very hard to reach energy efficiency requirements of class A. After all, energy consumption depends on the area of the house, so in this case, insulation and recuperation system would be too expensive.

A review of typical individual projects presented by Lithuanian architects has been performed before addressing the selection task of the most rational shape for single-family house. Trends of single-family houses shapes have been established after a review of 313 projects created in the last 2–3 years period (Namų projektai 2017; Namų planai 2017; ekspertai.lt 2017) in Lithuania. The vast majority of typical single-family houses' projects offered by Lithuanian architects are from 80 to 250 m² of the total area, 1- or 2-story, and their target shape is similar to shapes showed in Figure 2. The review found that 43.5% houses are of rectangular shape, 18.2% – of square shape, 16.2% – L-shaped and 22.1% – cross-shaped.

We have chosen eight options (Table 2) according to these shapes, i.e. all the shapes presented in Figure 2 for 1- and 2-storey building cases.

Table 2. Main shapes for single flat dwelling houses

A ₁	A ₂	A ₃	A ₄
A ₅	A ₆	A ₇	A ₈

3. The SWARA method

In this method (Kersulienė *et al.* 2010), expert has an important role in evaluations and calculating weights. Also, each expert has chosen the importance of each criterion. Next, each expert ranks all the criteria from the first to the last one (Stanujkic *et al.* 2015; Nakhaei *et al.* 2016). An expert uses his or her own implicit knowledge, information and experiences. Based on this method, the most significant criterion is given rank 1, and the least significant criterion is given rank last. The overall ranks of the group of experts are determined according to the mediocre value of ranks.

The process of determining the relative weights of criteria using SWARA method can accurately be shown by using the following steps:

Step 1. The criteria are sorted in descending order based on their expected significances.

Step 2. Starting from the second criterion, the respondent expresses the relative importance of criterion j in relation to the previous ($j-1$) criterion, for each particular criterion. According to Kersulienė *et al.* (2010), this ratio is called the Comparative importance of average value, s_j :

$$s_{j \leftrightarrow j+1} = \frac{\sum_{h=1}^r c_{j \leftrightarrow j+1}}{r}, j = \overline{1, n}. \tag{1}$$

Step 3. Determine the coefficient k_j as follows:

$$k_j = s_{j \leftrightarrow j+1} + 1, j = \overline{1, n}. \tag{2}$$

Step 4. Determine the recalculated weight w_j as follows:

$$w_j = \frac{w_{j-1}}{k_j}, j = \overline{1, n}, \tag{3}$$

Step 5. The relative weights of the evaluation criteria are determined as follows:

$$q_j = \frac{w_j}{\sum_{j=1}^n w_j}, j = \overline{1, n}, \tag{4}$$

where q_j denotes the relative weight of criterion j .

Table 3 represents results of pairwise comparison made by experts.

Table 4 presents calculation results by SWARA method: the average values of indicators' relative comparative importance, coefficients of indicators' relative comparative importance, converted (intermediate) indicator weights and final indicators' weights.

4. The EDAS method

The Evaluation Based on Distance from Average Solution (EDAS) method is introduced by Keshavarz Ghorabae *et al.* (2015), and therefore it can be stated as a newly-proposed method. The basic ideas of the EDAS method are the use of two distance measures, namely the Positive Distance from Average (PDA) and the Negative Distance from Average (NDA); and that the evaluation of the alternatives is done according to higher values of the PDA and lower values of the NDA.

Table 3. Relative importance assessment in indicators' pairs

Expert	Pairwise comparison of criteria relative importance		
	$c_{1 \leftrightarrow 2}$	$c_{2 \leftrightarrow 3}$	$c_{3 \leftrightarrow 4}$
1	0.3	0.6	0.2
2	0	0.8	0.4
3	0.2	0.6	0.8
4	0.4	0.3	0.6
5	0.1	0.7	0.5
6	0	0.8	0.1
7	0.3	0.5	0

Table 4. Criteria Weighting by SWARA method

Indicator	Average values of comparative importance indicators, $s_{j \leftrightarrow j+1}$	Coefficients of comparative importance indicators, k_j	Recalculated (intermediate) indicators weights, w_j	Final indicators weights, q_j
c_1	–	1.000	1.000	0.3344
c_2	0.130	1.130	0.880	0.2943
c_3	0.430	1.430	0.620	0.2074
c_4	0.260	1.260	0.490	0.1639
	–		2.990	

The computational procedure of the EDAS method, for a decision-making problem with m criteria and n alternatives, can be precisely presented as follows.

Step 1. Select the available alternatives, the most important criteria that describe the alternatives, and construct the decision-making matrix X , shown as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{12} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix}, \quad (5)$$

where x_{ij} denotes the performance rating of the alternative i on the criterion j .

Step 2. Determine the average solution according to all criteria, shown as follows:

$$x_j^* = (x_1, x_2, \dots, x_n), \quad (6)$$

where

$$x_j^* = \frac{\sum_{i=1}^m x_{ij}}{m}. \quad (7)$$

Step 3. Calculate the positive distance from average d_{ij}^+ and the negative distance from average d_{ij}^- , according to the type of criteria (benefit and cost), shown as follows:

$$d_{ij}^+ = \begin{cases} \frac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\max} \\ \frac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (8)$$

$$d_{ij}^- = \begin{cases} \frac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\max} \\ \frac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (9)$$

where Ω_{\max} and Ω_{\min} denotes the set of the benefit criteria and the cost criteria, respectively.

Step 4. Determine the weighted sum of PDA, Q_i^+ , and the weighted sum of NDS, Q_i^- , for all alternatives,

as follows:

$$Q_i^+ = \sum_{j=1}^n w_j d_{ij}^+; \quad (10)$$

$$Q_i^- = \sum_{j=1}^n w_j d_{ij}^-. \quad (11)$$

Step 5. Normalize the values of the weighted sum of the PDA and the weighted sum of the NDA for all alternatives, shown as follows:

$$S_i^+ = \frac{Q_i^+}{\max_i Q_i^+}; \quad (12)$$

$$S_i^- = 1 - \frac{Q_i^-}{\max_i Q_i^-}, \quad (13)$$

where S_i^+ and S_i^- denote the normalized weighted sum of the PDA and the NDA, respectively.

Step 6. Calculate the appraisal score S_i for all alternatives, as follows:

$$S_i = \frac{1}{2}(S_i^+ + S_i^-). \quad (14)$$

Step 7. Rank the alternatives according to the decreasing values of appraisal score. The alternative with the highest S_i is the best choice among the candidate alternatives.

This paper presents an extension of the EDAS method based on the use of interval grey numbers. On the basis of the proposed extension, the EDAS method can be used most efficiently for solving a larger number of complex real-world decision-making problems, especially those associated with an uncertainty, and so it can be applied in many fields for the purpose of analysis, modeling and forecasting. Finally, the usability and effectiveness of the proposed approach are checked on a known MCDM example. The obtained results confirm the usability of the proposed approach.

In the Table 5 one can find Initial decision making matrix with criteria significance by alternatives.

Calculation process and calculation results by applying EDAS method are presented in Table 6 below.

Table 5. Initial decision making matrix with criteria significance by alternatives

			Weights	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇	A ₈	A*
c ₁	min	m ²	0.334	404.1	418.4	418.3	413.1	467.6	478.5	451.3	455.5	438.350
c ₂	max	scores	0.294	2	1	2	1	2	1	2	1	1.500
c ₃	max	scores	0.208	5	6	6	7	5	5	3	4	5.125
c ₄	min	-	0.164	16	6.5	17.7	6.7	20.7	7.8	19	7.3	12.713

Table 6. Ranking of alternatives by applying EDAS method

	d_{ij}^+									
	A^*	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	
c_1	438.350	0.078	0.046	0.046	0.058	-0.067	-0.092	-0.030	-0.039	
c_2	1.500	0.333	-0.333	0.333	-0.333	0.333	-0.333	0.333	-0.333	
c_3	5.125	-0.024	0.171	0.171	0.366	-0.024	-0.024	-0.415	-0.220	
c_4	12.713	-0.259	0.489	-0.392	0.473	-0.628	0.386	-0.495	0.426	$\max Q_i^+$
Q_i^+		0.077	0.033	0.085	0.075	-0.032	-0.070	-0.079	-0.087	0.085
	d_{ij}^-									
		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	
c_1		-0.078	-0.046	-0.046	-0.058	0.067	0.092	0.030	0.039	
c_2		-0.333	0.333	-0.333	0.333	-0.333	0.333	-0.333	0.333	
c_3		0.024	-0.171	-0.171	-0.366	0.024	0.024	0.415	0.220	
c_4		0.259	-0.489	0.392	-0.473	0.628	-0.386	0.495	-0.426	$\max Q_i^-$
Q_i^-		-0.077	-0.033	-0.085	-0.075	0.032	0.070	0.079	0.087	0.087
S_i^+		0.909	0.386	1.000	0.882	-0.382	-0.834	-0.933	-1.029	
S_i^-		1.883	1.375	1.972	1.858	0.629	0.190	0.093	0.000	
S_i		1.396	0.881	1.486	1.370	0.124	-0.322	-0.420	-0.514	
Rank		2	4	1	3	5	6	7	8	

Conclusions

The EDAS calculation method provides the best option: a square shape one-storey house (A_3). Despite a much more compact shape of 2-storey houses, the selection of the best alternatives was determined by a safety factor, i.e. elimination of internal stairway. According to the results obtained, the advantage of the first four options (rectangular and square shapes) is obvious. The results confirmed the suitability of selected shapes of the typical single-family houses’ projects created by Lithuanian architects for economy-class customers.

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