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COMPUTER-AIDED DECISION-MAKING IN CONSTRUCTION PROJECT DEVELOPMENT

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Abstract. One of the most difficult problems in construction is taking objective decisions. A decision-making process is very complicated and time consuming (due to the complex nature of construction projects). Many experts with extensive knowledge of construction industry take subjective decisions related to verbal methods of decision-making. Difficulties are related mostly to the creation of a set of relevant criteria, providing answers to the decision-maker's questions. A set of proper criteria and mathematical tools (such as computer calculation algorithms with multi-criteria analysis) could significantly improve objective decision-making. The paper presents ESORD – an informatics tool allowing to establish a hierarchy (ranking) of different types of solutions on the basis of mathematical calculation. The authors present a comparison of different methods used for multi-criteria decision-making.

Keywords: informatics tool, construction projects, multi-criteria decision-making, investment variants.

Introduction

One of the main problems faced by every investor/project manager is selecting an implementation variant for an investment project. The difficulty related to this issue emerges as early as at the stage of investment preparation, once requirements and expectations of the investor are defined in the functional–utility program. At individual stages of the lifecycle of an undertaking, analysed phenomena are very complex, which is mainly due to specific traits, characteristics, complexity and nature of construction processes and relations between them. On the other hand, a description of these relations is based mainly on expert opinions and should take into account both measurable factors and those difficult to measure (Ustinovichius *et al.* 2006; Kildienė *et al.* 2014; Vodopivec *et al.* 2014); besides, its quality depends largely on expert knowledge and experience of decision-makers.

The issue of decision-making constitutes an integral part of every field of science and art. A decision-making process is an activity which results in taking a specific decision. The entity involved in a decision-making process is a decision-maker, expressing specific preferences, assessing possibilities and results, and choosing the final decision-making variant (Książek 2010a; Tyszka 1986; Brown 2012; Yazdani-Chamzini *et al.* 2013a; Ustinovichius *et al.* 2011; Ghosh *et al.* 2012). Analysis of the decision-making situation is the first task of a decision-maker. The decision-making situation is a set of all elements, dependent on and independent of an assessor, which exert impact on the decision to be made. In the process of formulation of the decision-making problem, factors independent of a decision-maker include a set of variants to be examined (the so-called conditions restricting the decision), while factors dependent upon the decision-maker include criteria for assessment of solutions, described by technical and economic indicators, most adequate for the given decision-making situation, expressed in specific units (Zavadskas *et al.* 2014b; Yazdani-Chamzini *et al.* 2013b; Zolfani *et al.* 2013).

Assessment of characteristics of a given variant may be both quantitative (objective) and qualitative (difficult to measure) (Ustinovichius 2004; Simanavičienė *et al.* 2014). The difficulty in decision-making is not only due to the level of complexity of a task as well as complexity and designation of variants, but also – expectations of the assessing person. On the other hand, preferences of the expert are largely dependent on the point of view of the decision-maker who has caused development of the given opinion or assessment. The authors believe that due to the above reasons, computer-based implementation of calculation algorithms of selected methods of assessment and ranking of solutions is an efficient tool that allows to obtain aggregated variant assessments and results in a more

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efficient decision-making process. Detailed information concerning the issues of valuation of criteria, as well as the psychological aspect of decision-making has been presented in Brauers *et al.* (2013), Hashemkhani *et al.* (2013), Ustinovichius *et al.* (2007), Tyszka (1986) and Zavadskas *et al.* (2012, 2014a).

1. Main assumptions of the methodology of assessment and ranking of solutions in the construction trade

According to the authors, the calculation algorithms of various types of methods of multi-criteria assessment and the theoretical apparatus – including sociology, psychological theory of decision-making and decision-making analysis – contribute to greater effectiveness of the decision-making process, and allows for avoidance of substantial mistakes that could interfere with the quality and reliability of the decision made. In practice, individual tools are often used selectively, which often garbles the assessment results. Experts are expected to make assessments in accordance with their professional knowledge and the construction art – reliable, objective and considering the specific character of the given decision-making situation. It would be difficult, however, to clearly define individual preferences, system of values, and motivations of an expert. Expert opinions are formulated on the basis of their knowledge and experience, and they depend upon such factors as availability of information and the level of complexity of the task, emotional state and mood, self-esteem and susceptibility to group influence, and the mode of perception of a given phenomenon (Ustinovichius 2007; Turskis *et al.* 2013; Zavadskas *et al.* 2014a).

Sometimes, difficulties associated with decision-making arise from an assessor's fear to assume responsibility, make a mistake or be rejected by the community. Therefore, in order to as much as possible eliminate the causes of interference with decisions made, an original survey of decision-maker preferences has been developed, as well as the decision-making variant ranking procedure, implemented as the ESORD calculation tool (Expert System for Assessment of Developer Solutions) (Tyszka 1986; Kozielecki 1977). In the opinion of the authors, the purpose of the survey developed within the framework of this research was – in the first place – to clearly and precisely define criteria for assessment of variants, referring to the problem of selecting the best investment (e.g. premises, building) from the perspective of expectations particular to potential recipients (users) (Peng, Tzeng 2013; Zalewska, Zalewski 2012).

2. IT tool to support decision-making in the construction industry

The ESORD IT tool contains groups, types and kinds of criteria entered into the system, which have been defined in accordance with the aspect of selection of the apartment (house) variant with reference to preferences of potential purchasers and users.

Figure 1 presents the overall block diagram of algorithms used by ESORD, using the variant ranking methods (Książek 2010b, 2011).

2.1. Algorithm solving the presented problem

As a result of conducted surveys, the basic group of criteria for the assessment of residential construction facilities (Table 1) was formed and separated, together with definition of the levels of importance of the features suggested in

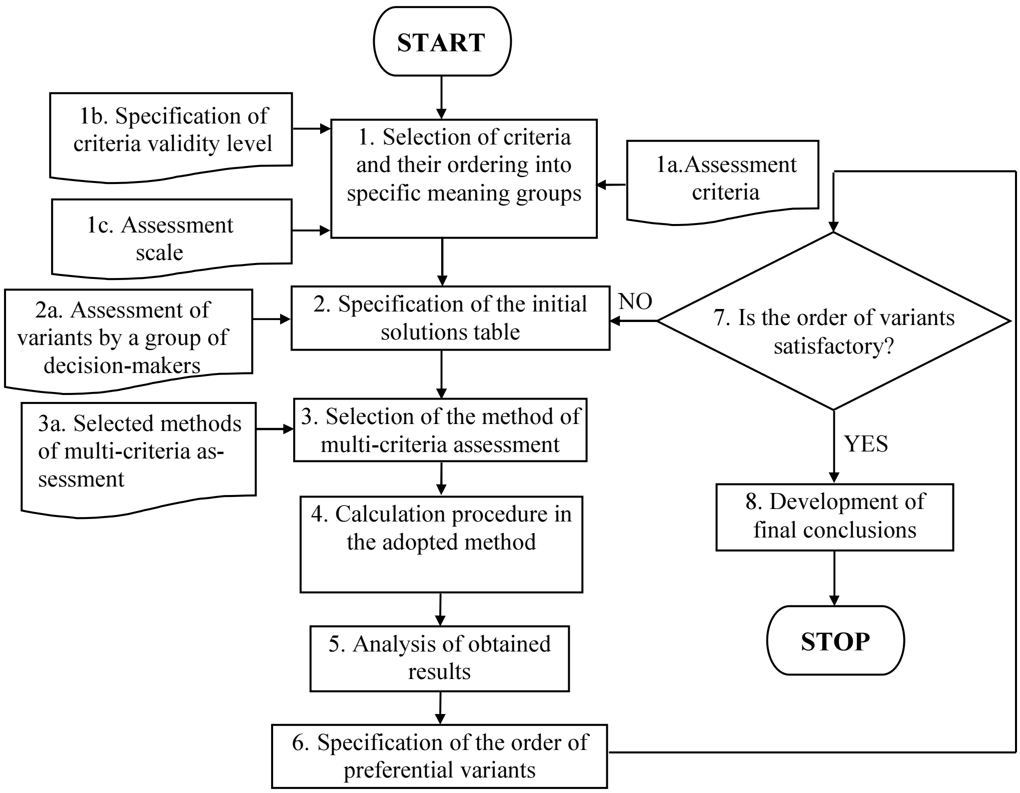
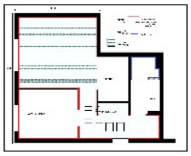
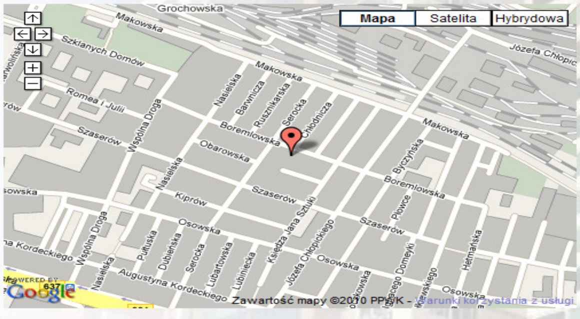
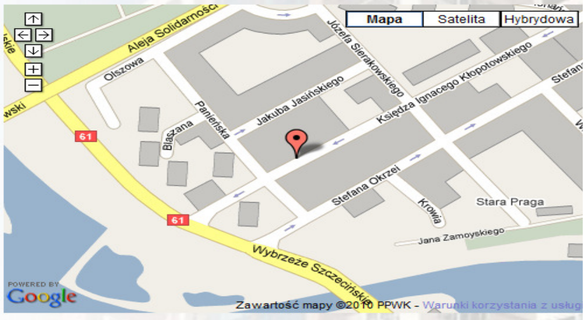
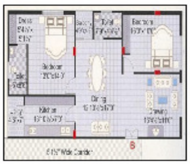
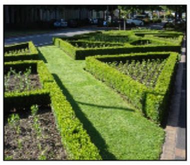
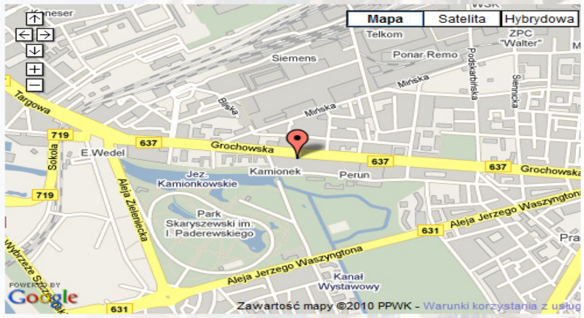
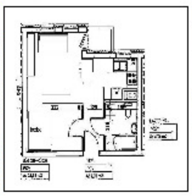
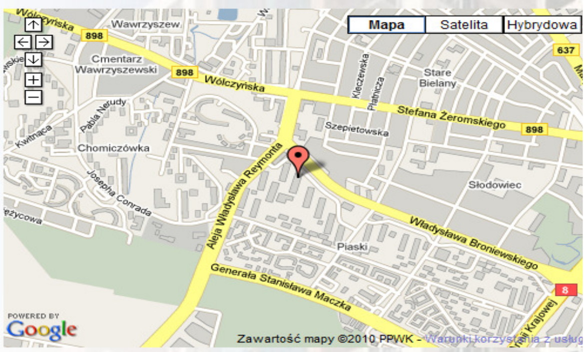


Fig. 1. General chart of activities during the assessment of decision variants

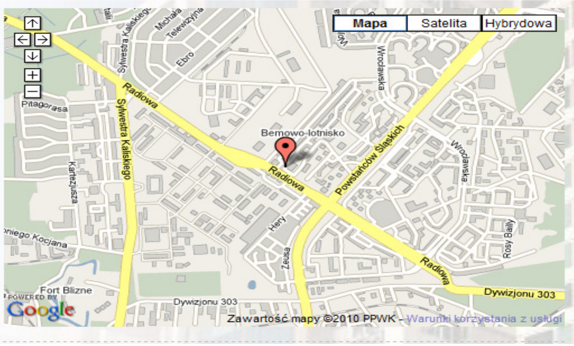
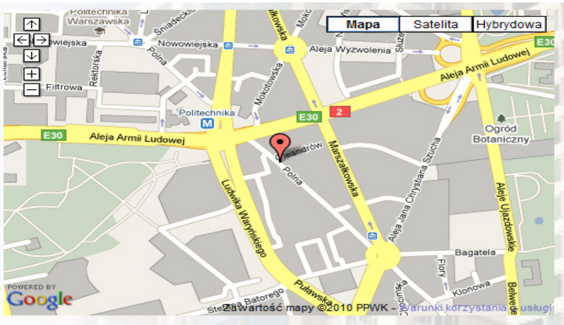
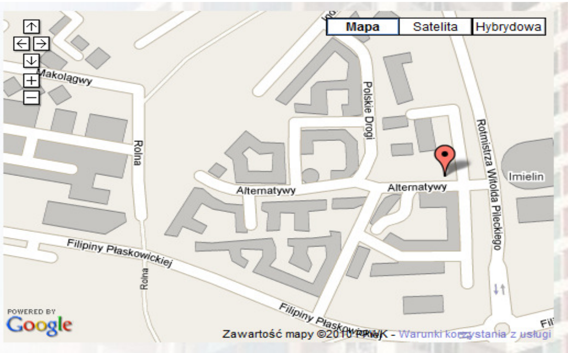
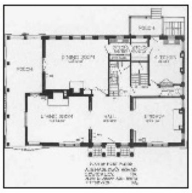
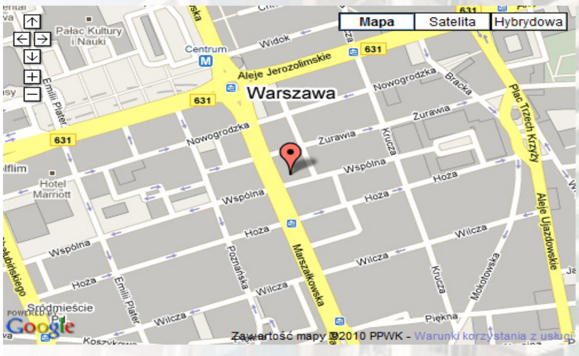
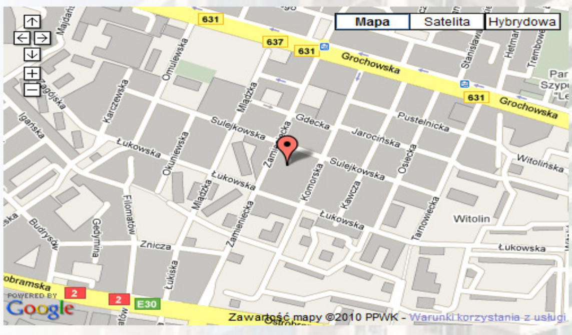
Table 1. Basic group of criteria used for assessment of residential construction facilities

A. Facility location	B. Technical infrastructure of the facility	C. Facility structure	D. Rooms functionality	E. Apartments finishing standard	*F. Safety*	*G. Cleanness and ecology of the facility*	H. Attitude towards the facility	*I. Costs*
A 1. City infrastructure (transport) **A 1.1. subway** (distance up to 1 km) **A 1.2.** city train (distance up to 1 km) **A 1.3.** tramways (distance up to 1 km) **A 1.4.** buses distance up to 1 km)	**B 1. Number of lifts in one stairway** **B 1.1.** Number of floors below 5 (except ground floor and underground) (1 lift) **B 1.2.** –//– (2 lifts), **B 1.3.** –//– (none) **B 1.4.** Number of floors below 5 (except ground floor and underground) (1 lift), **B 1.5.** –//– (2 lifts)	**C 1.** Wall	**D 1. Ergonomics of the rooms** **D 1.1.** shape of rooms similar to square – easy to arrange **D 1.2.** niche for a wardrobe in the hall **D 1.3.** niche for a refrigerator in the kitchen **D 1.4.** other facilities (wardrobe, utility room etc.) **D 1.5.** shape of rooms similar to a rectangle (long and narrow)	**E 1. Internal walls** **E 1.1.** plaster + paint **E 1.2.** plaster **E 1.3.** other solution	**F 1. Staircase** **F 1.1.** entry phone **F 1.2.** videophone	**G 1. Frequency of cleaning inside the facility** **G 1.1.** all working days **G 1.2.** three times a week **G 1.3.** two times a week **G 1.4.** other	**H 1. Aesthetics of the facility exteriors** **H 1.1.** plaster elevation **H 1.2.** glass elevation **H 1.3.** natural stone elevation **H 1.4.** other solution	**I 1. Purchase price and utilization price** **I 1.1.** sales price for 1 sq.m. of usable space of the building **I 1.2.** the expected costs of utilization of the facility for 1 sq.m. of usable space of the building **I 1.3.** other costs
A 2. Social infrastructure (service and education facilities) **A 2.1.** shopping and service facilities (food store, fair, market) up to 200 m **A 2.2.** education facilities (school, kindergarten, playground) up to 200 m	**B 2. Car park** **B 2.1.** by the building, **B 2.2.** guarded car park **B 2.3.** park place inside the facility /multi-level car park, **B 2.4.** other place	**C 2.** Backbone	**D 2. Height of the floors in residential premises** **D 2.1.** up to 2.70 m **D 2.2.** 2.71–2.90 m **D 2.3.** over 2.90 m	**E 2. Ceilings** **E 2.1.** plaster + paint **E 2.2.** plaster **E 2.3.** other solution	**F 2. Entry door to the apartment** **F 2.1.** ordinary **F 2.2.** antiburglary	**G 2. Ecology** **G 2.1.** waste selection **G 2.2.** electric energy saving devices in the facility (energy saving bulbs, movement sensors) **G 2.3.** water saving devices in the facility (meters) **G 2.4.** protection against noise **G 2.5.** water processing plant **G 2.6.** solar batteries **G 2.7.** other solutions	**H 2. Comfortable use of the premises** **H 2.1.** feeling of satisfaction and comfort **H 2.2.** feeling of safety **H 2.3.** other impressions	
A 3. Surrounding **A 3.1.** recreation areas (park, woods, lake etc.) distance up to 1 km **A 3.2.** highway – distance up to 1 km **A 3.3.** recreation and sports centres – distance up to 1 km **A 3.4.** production plant (e.g. factory) with certain nuisance degree – distance up to 1 km	**B 3. IT telecommunication connections** **B 3.1.** cable phone, **B 3.2.** Cable TV, **B 3.3.** Internet **B 3.4.** others	**C 3.** Mixed		**E 3. Floors** **E 3.1.** made of plastics **E 3.2.** made of wood **E 3.3.** made of ceramic materials **E 3.4.** made of stone materials **E 3.5.** no finishing	**F 3. Building security** **F 3.1.** receptionist inside the building **F 3.2.** guard at the entrance to the building **F 3.3.** 24 h patrols of local security **F 3.4.** closed housing estate **F 3.5.** police precinct (distance – 1 km)			
				E 4. Window sills **E 4.1.** made of plastics (for example conglomerate) **E 4.2.** made of stone materials (for example marble) **E 4.3.** metal **E 4.4.** wooden **E 4.5.** other				

Table 2. Apartment database

Var. no.	Variant description		
1	Name: Variant 1 Street: Boremlowska 51 Balcony area (m2): 12 No. of rooms: 2 Cost: PLN 391645 The apartment plan   	City: Warsaw Living area (m2): 46 Garden area (m2): 0 Floor: 3	
2	Name: Variant 2 Street: Kłopotowskiego 7 Balcony area (m2): 8 No. of rooms: 3 Cost: PLN 400000 The apartment plan    See enlarged pictures (3)	City: Warsaw Living area (m2): 78 Garden area (m2): 0 Floor: 4	
3	Name: Variant 3 Street: Grochowska 309 Balcony area (m2): 13 No. of rooms: 4 Cost: PLN 667000 The apartment plan   	City: Warsaw Living area (m2): 84 Garden area (m2): 0 Floor: 3	
4	Name: Variant 4 Street: Bernardyńska 8 Balcony area (m2): 6 No. of rooms: 3 Cost: PLN 405000 The apartment plan   	City: Warsaw Living area (m2): 56 Garden area (m2): 0 Floor: 1	
5	Name: Variant 5 Street: Broniewskiego 68 Balcony area (m2): 6 No. of rooms: 2 Cost: PLN 441100 The apartment plan   	City: Warsaw Living area (m2): 55 Garden area (m2): 0 Floor: 9	

Continued Table 2

6	Name: Variant 6 Street: Radiowa 16 Balcony area (m2): 8 No. of rooms: 3 Cost: PLN 600400 The apartment plan City: Warsaw Living area (m2): 76 Garden area (m2): 0 Floor: 3    See enlarged pictures (3)	
7	Name: Variant 7 Street: Polna 7 Balcony area (m2): 5 No. of rooms: 2 Cost: PLN 340200 The apartment plan City: Warsaw Living area (m2): 42 Garden area (m2): 0 Floor: 8   	
8	Name: Variant 8 Street: Alternatywy 4 Balcony area (m2): 10 No. of rooms: 3 Cost: PLN 526781 The apartment plan City: Warsaw Living area (m2): 69 Garden area (m2): 0 Floor: 3   	
9	Name: Variant 9 Street: Wspólna 41 Balcony area (m2): 10 No. of rooms: 3 Cost: PLN 510000 The apartment plan City: Warsaw Living area (m2): 65 Garden area (m2): 0 Floor: 4   	
10	Name: Variant 10 Street: Zamieniecka 8 Balcony area (m2): 10 No. of rooms: 4 Cost: PLN 550000 The apartment plan City: Warsaw Living area (m2): 82 Garden area (m2): 0 Floor: 6   	

the survey, using the preferences specified by respondents. The collection of criteria segregated into importance groups, their importance levels and preferences defined by decision-makers with respect to a residential construction facility constitute the starting point for the methodology of solution assessment suggested by the authors.

In the opinion of the authors, it will be possible to improve prioritisation of the solutions and select the best one using the obtained survey results, correlated using a supporting IT tool.

ESORD orders the variants using the entire group of implemented assessment method algorithms or using only those indicated by the user (decision-maker). As a result, one receives a table and a visual presentation of results in the form of aggregated assessments (resulting from the use of a given group of methods) and classification of the considered variants using each of the methods of multi-criteria assessment.

Figure 1 presents the general chart of activities during the assessment of decision variants within the framework of the suggested methodology.

In order to arrange the project variants, the following multi-criteria assessment methods were applied: *ELECTRE* (Roy 1991), ideal point (Hwang, Yoon 1981; Zalewski 2013), *AHP* (Saaty 1994; Gudienė *et al.* 2014), total, weighted total (MacCrimmon 1968), and the method using elements of fuzzy logic (Zadeh *et al.* 1975; Zadeh 1978; Corriere *et al.* 2013; Radziszewska-Zielina 2011; Kaya, Kahraman 2014). In order to implement the suggested methodology, the ESORD IT tool was developed (Expert System of Developer Solutions Assessment). The software uses algorithms of the above-listed methods and detailed results of surveys that constitute the basis to define the level of importance of specific criteria. This chapter presents performance of specific calculations leading to prioritisation of the considered variants, using numeric examples from the ESORD IT tool (Książek 2010c).

The above chart was expanded so that IT implementation of algorithms of specific methods of assessment to the ESORD software was possible.

2.2. Input data for all methods

Input data for all calculation methods constitute:

1. Calculation algorithms of methods (Książek 2010b, 2011; Książek, Nowak 2009).
2. List of criteria (described in Table 1) assessed by a group of respondents within the framework of surveys conducted by the authors (Krzemiński, Książek 2008).
3. Criteria importance levels (obtained on the basis of preferences specified by the respondents within the framework of surveys conducted by the authors and generated by ESORD).
4. A collection of decision variants implemented in the system, subject to assessment (the so-called apartment database presented in Table 2).
5. Survey of decision-maker's preferences concerning the examined residential construction facility (Książek 2010a).

ESORD calculates the so-called main weights vector for specific criteria in order to determine the level of their completion. In order to determine the vector, the following marks were adopted for the main criteria: K^L – assessment of Type 1 user for the *Facility location* criterion; K^{In} – assessment of Type 1 user for the *Technical infrastructure of the facility* criterion; K^{Ko} – assessment of Type 1 user for the *Facility structure* criterion; K^F – assessment of Type 1 user for the *Rooms functionality* criterion; K^S – assessment of Type 1 user for the *Apartments finishing standard* criterion; K^B – assessment of Type 1 user for the *Safety* criterion; K^C – assessment of Type 1 user for the *Cleanness and ecology of the facility* criterion; K^O – assessment of Type 1 user for *Attitude towards the facility* criterion; K^K – assessment of Type 1 user for the *Costs* criterion; W^L – the main weights vector index value for the *Facility Location* criterion.

The specific main weights indexes for the criteria are calculated using the following formula:

$$W^{NK} = \frac{K^{NK}}{\left(K^L + K^{In} + K^{Ko} + K^F + K^S + K^B + K^C + K^O + K^K\right)}, \tag{1}$$

where: NK – name (mark) of a given criterion.

Therefore, for example, the value of W_i^L index in relation to the *Facility location* criterion is calculated in the following way:

$$W^L = \frac{K^L}{\left(K^L + K^{In} + K^{Ko} + K^F + K^S + K^B + K^C + K^O + K^K\right)}. \tag{2}$$

It should be noted that while calculating the main weights vector, the system does not include the weights value for detailed criteria. For main criteria, the received results are presented in Table 3.

Table 3. Main criteria weights vector

Criterion	Weight	Criterion	Weight
Facility location	0.143	Safety	0.143
Technical infrastructure of the facility	0.107	Cleanness and ecology of the facility	0.107
Facility structure	0.036	Attitude towards the facility	0.107
Rooms functionality	0.143	Costs	0.107
Apartments finishing standard	0.107		

2.3. Calculations for the selected assessment methods

ESORD software has implemented calculation algorithms of the selected methods of multi-criteria assessment including the average (total) method, weighted average (weighted total) method, ELECTRE method, ideal point method, AHP method and the calculation method using fuzzy logic.

Assessment of each criterion is made in accordance with the following dependence:

$$k_{ij}^{NK} = \left(O_{ij}^{I}\right)_{NK}^{2} \cdot \left(O_{ij}^{II}\right)_{NK}^{2}, \tag{3}$$

where: k_{ij}^{NK} – assessment value for *NK* criterion, where the *ij* indexes mean specific sub-criteria presented on the examples below; $\left(O_{ij}^{I}\right)_{NK}$ – *NK* criterion assessment meeting the expectations of Type 1 user; $\left(O_{ij}^{II}\right)_{NK}$ – *NK* criterion assessment given by Type 2 user; *n* – means the *n* sub-criterion within a given *NK* criterion.

Raising the point assessment of a given criterion to a power was introduced to the system in order to enable more extensive differentiation of the final assessments of variants. In order to calculate values of the assessments of the considered decision variants for specific criteria, the system performs calculations in accordance with the dependence presented below:

$$W_w^{NK} = \frac{\sum_{n=1}^{r}\left(k_{ij}^{NK}\right)_n}{\sum_{n=1}^{r}\left(\max k_{ij}^{NK}\right)_n}; \quad w=(1,...,10), \quad n=1,2,\dots r, \tag{4}$$

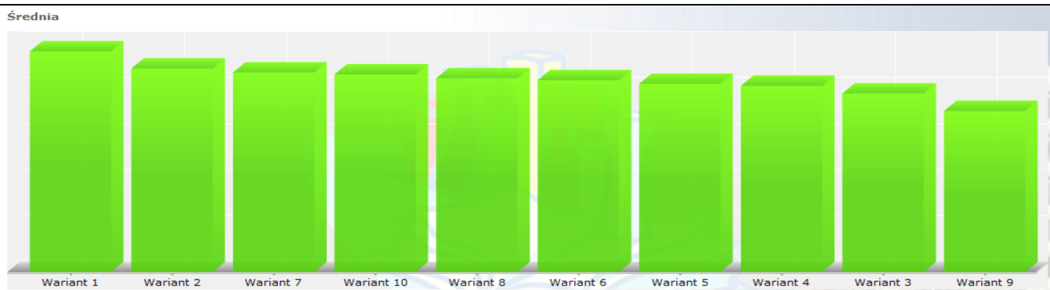
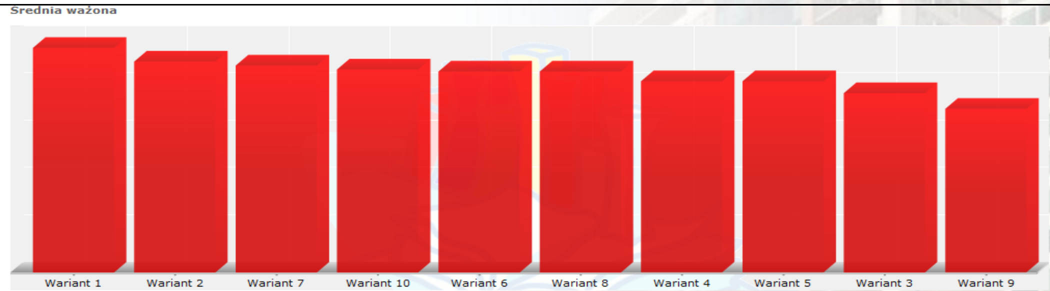
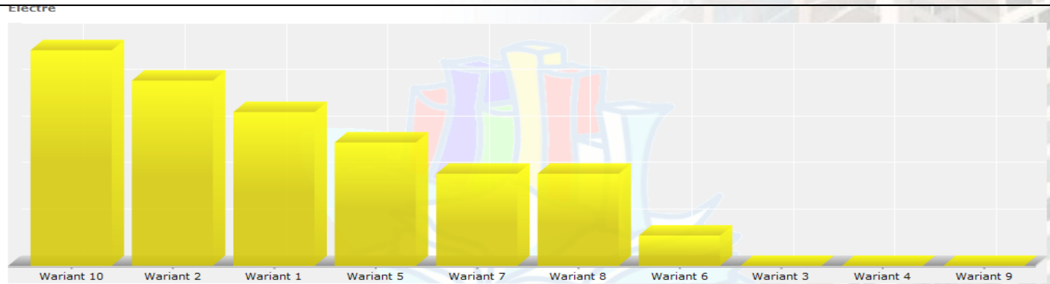
where: W_w^{NK} – assessment of "*w*" variant according to "*NK*" criterion.

Based on the conducted calculation procedure, the system generates the results of ordering specific decision variants subject to assessment. The final assessments for specific solutions received after using the methodology are presented in Table 4. Table 5 contains a visual presentation of the orders of preferential variants generated by ESORD for specific assessment methods.

Table 4. Collective presentation of final variant assessments for all methods

Variant\ method	Weighted average	Average	Ideal point	Electre	Fuzzy logic	AHP
Variant 1	0.114	0.115	0.123	0.172	0.120	0.121
Variant 2	0.107	0.106	0.116	0.207	0.112	0.104
Variant 3	0.091	0.093	0.092	0.0001	0.077	0.090
Variant 4	0.097	0.097	0.105	0.0001	0.104	0.095
Variant 5	0.097	0.098	0.074	0.138	0.084	0.096
Variant 6	0.102	0.100	0.099	0.034	0.096	0.102
Variant 7	0.105	0.104	0.115	0.103	0.118	0.101
Variant 8	0.102	0.101	0.102	0.103	0.113	0.104
Variant 9	0.083	0.084	0.063	0.0001	0.057	0.084
Variant 10	0.103	0.103	0.110	0.241	0.121	0.102

Table 5. Visualization of the order of preferential variants for applied methods

Methods	Visualization of the order of preferential variants
Average method	
Weighted average method	
ELECTRE method	

Continued Table 5

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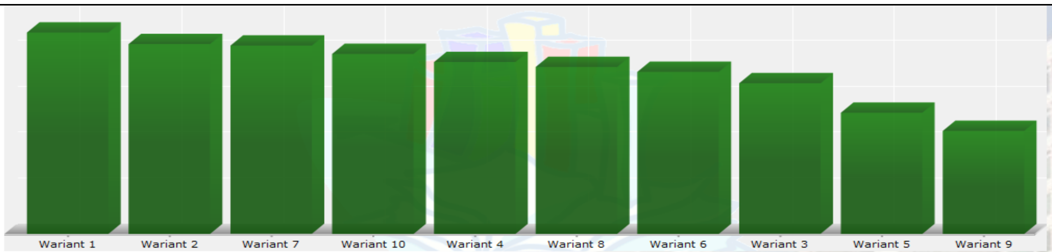
<tr><td>Ideal point method</td><td>
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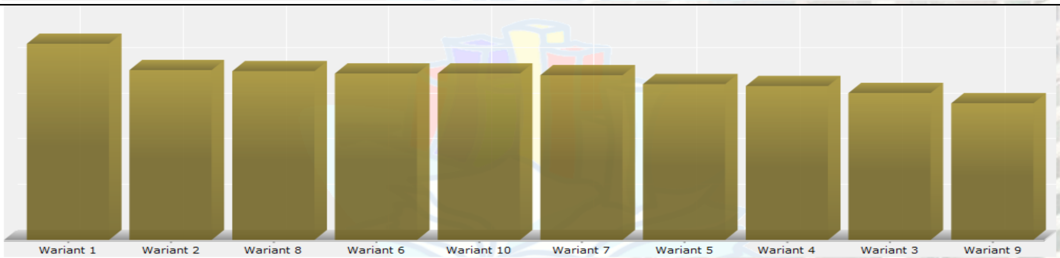
<tr><td>AHP method</td><td>
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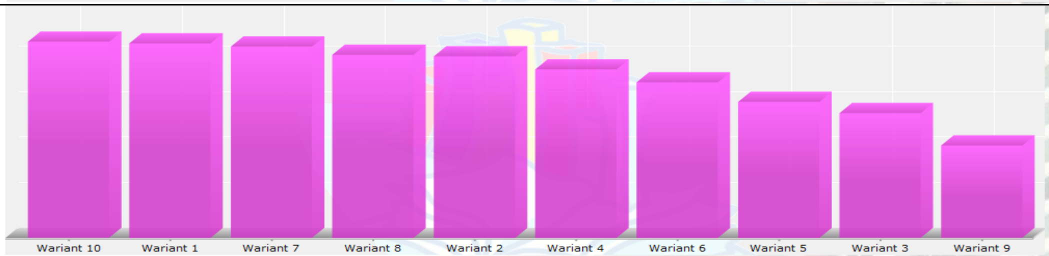
<tr><td>Calculation method using elements of fuzzy logic</td><td>
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Table 6. List of preferential variants ordered from the best to the worst (variant, city, street, price and assessment)

Variant	City	Address	Price	Assessment
Variant 1	Warsaw	Boremlowska 51	391 645	518
Variant 2	Warsaw	Klopotowskiego 7	400 000	409
Variant 3	Warsaw	Zamieniecka 8	550 000	320
Variant 4	Warsaw	Polna 7	340 200	286
Variant 5	Warsaw	Alternatywy 4	526 781	194
Variant 6	Warsaw	Radiowa 16	600 400	120
Variant 7	Warsaw	Bernardynska 8	405 000	71
Variant 8	Warsaw	Broniewskiego 68	441 100	67
Variant 9	Warsaw	Grochowska 309	667 000	10
Variant 10	Warsaw	Wspolna 41	510 000	0

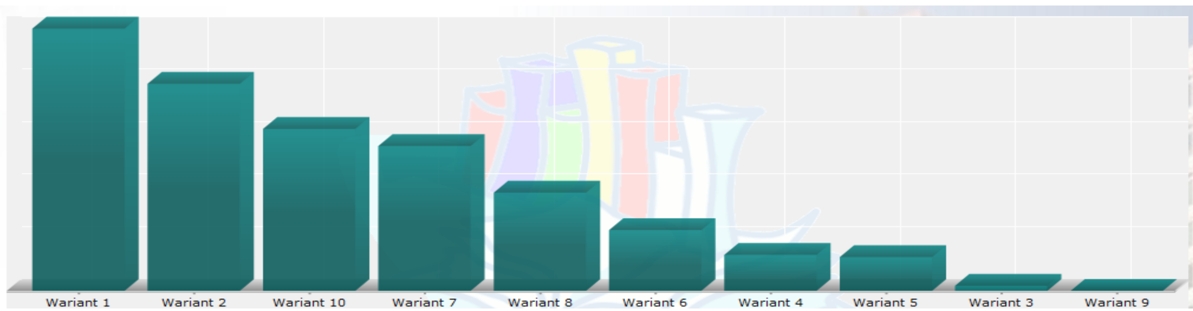

Fig. 2. Visualization of the obtained order of preferential variants

3. Comparative analysis of the obtained results of variant assessment

Expert assessment was applied to ten decision variants introduced to ESORD system. Their detailed description is included in Table 2. The analysis of the obtained results was conducted using the selected methods of multi-criteria analysis (average, weighted average, ELECTRE, ideal point, AHP and the calculation method using fuzzy logic).

Table 6 presents the obtained list of preferential variants ordered from the best to the worst. Figure 2 presents the obtained order of the analysed solutions.

Table 7. Assessment of the correlation level of the results pertaining to assessed examples of decision variants in the form of numerical values of cos θ

	Weighted average	Average	Ideal point	Electre	Fuzzy logic	AHP
Weighted average	1	0.998	0.896	0.892	0.81	0.931
Average	0.998	1	0.896	0.891	0.801	0.933
Ideal point	0.896	0.896	1	0.905	0.824	0.832
Electre	0.892	0.891	0.905	1	0.744	0.915
Fuzzy logic	0.810	0.818	0.824	0.744	1	0.738
AHP	0.931	0.933	0.832	0.915	0.738	1

Table 8. Assessment of the correlation level of the results pertaining to assessing examples of decision variants in linguistic form

	Weighted average	Average	Ideal point	Electre	Fuzzy logic	AHP
Weighted average	**Very high**	**Very high**	Medium	Medium	Low	High
Average	**Very high**	**Very high**	Medium	Medium	Low	High
Ideal point	Medium	Medium	**Very high**	High	Low	Low
Electre	Medium	Medium	High	**Very high**	Low	High
Fuzzy logic	Low	Low	Low	Low	**Very high**	Low
AHP	High	High	Low	High	Low	**Very high**

4. The comparison of results obtained by different methods

The results of ordering decision variants were subject to analysis using two selected methods – A and B. For example, specific A and B methods generate the obtained ranking of solutions in the following form:

- method A: [Variant 1, Variant 5, Variant 3, Variant 2, Variant 4];
- method B: [Variant 2, Variant 1, Variant 5, Variant 4, Variant 3].

A and B methods may be compared by calculating $\cos\theta$, namely, the angle between their vectors in accordance with the dependence:

$$\cos\theta := \frac{\mathbf{A}\cdot\mathbf{B}}{|\mathbf{A}||\mathbf{B}|}, \tag{5}$$

where: $|\mathbf{A}||\mathbf{B}|$ – lengths (norm, value) of vectors A and B; $\mathbf{A}\cdot\mathbf{B}$ – the scalar product of vectors A and B; $\cos\theta$ – the angle between vectors A and B.

Tables 7–8 present the assessment of the correlation level of the ordering results for variant examples for the selected multi-criteria assessment methods in the linguistic form, and the numerical values reflecting them – cos θ.

The analysis of correlation of the results pertaining to ordering examples of decision variants for the selected multi-criteria assessment methods (Table 9) shows that specific numerical values fall between 0.738 and 0.999. Therefore, in order to compare correlation levels of the results within the framework of the assessment methods used in the calculation procedure, the following thresholds were adopted:

- below 0.85 – low correlation of results;
- 0.85–0.94 – medium correlation;
- 0.95 – high correlation;
- over 0.95 – very high correlation.

The ESORD software generates assessments based on thresholds adopted by the authors. Order of specific variants obtained using each of the methods is presented in Table 9.

Table 9. Classification of variants within the framework of selected assessment methods

	Order of variants received within the framework of specific methods
Average method	$1 \succ 2 \succ 7 \succ 10 \succ 8 \succ 6 \succ 5 \succ 4 \succ 3 \succ 9$
Weighted average method	$1 \succ 2 \succ 7 \succ 10 \succ 6 \succ 8 \succ 4 \succ 5 \succ 3 \succ 9$
ELECTRE method	$10 \succ 2 \succ 1 \succ 5 \succ 7 \succ 8 \succ 6 \succ 3 \succ 4 \succ 9$
Ideal point method	$1 \succ 2 \succ 7 \succ 10 \succ 4 \succ 8 \succ 6 \succ 3 \succ 5 \succ 9$
AHP method	$1 \succ 2 \succ 8 \succ 6 \succ 10 \succ 7 \succ 5 \succ 4 \succ 3 \succ 9$
Fuzzy logic	$10 \succ 1 \succ 7 \succ 8 \succ 2 \succ 4 \succ 6 \succ 5 \succ 3 \succ 9$

Based on the conducted analysis of correlation of results for the specific methods, it was stated that:

- Very high correlation occurs between the results of average and weighted average method. In the case of those methods, the order of the first three variants is the same, namely: $1 \succ 2 \succ 7$.
- High correlation occurs between the results of ELECTRE, ideal point and AHP methods. For those methods, variant 2 was placed on the second place in the classification. In the ELECTRE method, variant 10 was on the first place, while for AHP and ideal point methods, variant 1 was the best. The specifics of ordering solutions in the ELECTRE method is that at the last stage of the calculation procedure, the calculations are made in a binary system, so the variants with slightly differentiated assessment may become equal (for example variant 7 and 8 or variants 3, 4 and 9). High correlation occurs also between the results of AHP, total and weighted total methods.
- Medium correlation occurs between the results of ELECTRE, entropy, total and weighted total meth-

ods. Although in the case of the above methods (apart from ELECTRE), the order of the three first variants is the same (namely $1 \succ 2 \succ 7$), the differences in their assessments are quite significant, presumably because of high differentiation of the calculation algorithms. In the ELECTRE method, the order of the three first variants is different only because variant 10 is in the first place, namely $10 \succ 2 \succ 1$.

– Low correlation occurs between the results of the method using the elements of fuzzy logic, ideal point, entropy, total, weighted total, ELECTRE and AHP. For the method using elements of fuzzy logic and ELECTRE, variant 10 is the best. For the remaining methods, variant 1 is the best. Further order of the objects is as follows: $2 \succ 1 \succ 5$ for ELECTRE method and $1 \succ 7 \succ 8$ for the method using fuzzy logic. In the case of average, weighted average and ideal point methods – the order of the first three preferential variants is the same, namely, $1 \succ 2 \succ 7$. For AHP method, the order of the first three preferential variants is as follows: $1 \succ 2 \succ 8$.

In the opinion of the authors, the approach of an average software user towards the obtained order of decision variants is important. Based on the above calculation example, it can be stated that among ten examples of apartments which were considered, variants with numbers 1, 2, 7 and 10 in all methods (apart from variant 7 in ELECTRE method and variant 2 in the method using fuzzy logic) were ordered (in various sequences) on the places from 1 to 4. For example, the variants with numbers 1 and 2 were the best for six of the considered methods. Variant 7 was placed on the third place of the preferential list for five methods. Variant 10 was on the fourth and fifth place, accordingly. Only in the case of the method using elements of fuzzy logic and the ELECTRE method, variant 10 obtained the highest position. In the opinion of the authors of this paper, none of the users is going to check all ten variants generated by the software, but only the first three or four, as the closest to meeting their expectations. Therefore, the calculation method applied to order the decision variants should be the least labour-consuming, which is very easy using the ESORD tool.

Conclusions

Based on the conduced research and analyses, the following conclusions may be drawn:

1. Expectations of an assessor towards a specific decision variant are significantly dependent on their approach in a given decision-making situation.
2. Because of the specifics of design solutions in residential construction, a universal method allowing complex approach to the problem is not possible. In a given decision-making situation, it is possible to obtain a reliable assessment result and select the variant, which is the most adequate in relation to expectations of the future user of an apartment, formed in a specific criteria system.
3. Estimation of decision solutions in accordance with the specific assessment methods for the assumed decision-making situation is different mainly on the farther places of the preferential order, while the order of the first three or four variants is usually the same. Accordingly, taking into account high subjectivity in assessment of initial criteria, it can be stated that the assumptions made in this work have been met successfully.
4. The integrated multi-criteria assessment of design solutions for residential facilities introduced by the authors is susceptible to algorithmization, which allowed designing the IT tool (ESORD software).

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