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ROLE OF DECISION MODELS IN THE EVALUATION OF SPATIAL DESIGN SOLUTIONS

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ABSTRACT

Decision making in architectural and urbanistic spatial design is a process, where the set of solutions to the spatial problem, which matches the objectives and the requests best, is selected. The research goals are to present the possibility of using multiple-criteria models of evaluation in selection of spatial solutions, to implement (realise) the model in Rhino 3D environment, to test the model on the example of an actual architectural competition and to test and compare three methods of multiple-criteria evaluation for suggested spatial solutions. To check the hypothesis and the research questions, documentation from a closed, public, project, open, anonymous, single--stage architectural competition was selected. The selected solutions were evaluated by three methods. For all the selected multiple-criteria methods we can establish that they are highly subjective, not too accurate and as such inappropriate for the evaluation of solutions to the spatial problem. According to certain criteria, the PMI ("plus/minus/implications") method of multiple-criteria decision making has proven to be the best or the most useful method among the analysed ones.

Keywords: decision-making in architecture, architectural competitions, decision-making systems, multiple-criteria decision-making modelling

IL RUOLO DI MODELLI DECISIONALI NELLA VALUTAZIONE DI SOLUZIONI DI PROGETTAZIONE DELLO SPAZIO

SINTESI

Il processo decisionale nella progettazione architettonica e urbanistica dello spazio è un processo alla fine del quale viene scelta la soluzione che meglio soddisfa gli obiettivi e requisiti stabiliti. Gli scopi della presente ricerca sono: presentazione della possibilità di utilizzo di modelli di valutazione multicriterio nella scelta tra soluzioni spaziali; implementazione (realizzazione) del modello nel programma Rhino 3D; verifica del modello sull'esempio di un concorso di architettura reale; sperimentazione e confronto di tre metodi di valutazione multicriterio sulle soluzioni spaziali proposte. Per verificare l'ipotesi e gli interrogativi di ricerca è stato scelto il materiale di un concorso pubblico di architettura di realizzazione, aperto, monofase, anonimo e già terminato. Le soluzioni selezionate sono state valutate mediante i tre metodi. Possiamo costatare che tutti e tre i metodi multicriterio selezionati sono fortemente soggettivi, troppo imprecisi e, in quanto tali, inadatti alla valutazione delle soluzioni del problema spaziale. Tuttavia, limitatamente ad alcuni determinati parametri, il metodo del processo decisionale multicriterio PMI («plus/minus/implications») risulta il migliore, ossia il più utile.

Parole chiave: processo decisionale in architettura, concorsi di architettura, sistemi di assistenza nella decisione, modelli decisionali multicriterio

INTRODUCTION

Decision making in architectural and urbanistic spatial design is a process, where the set of solutions to the spatial problem, which matches the objectives and the requests best, is selected (Čok, 2014). This process of spatial planning is based on creating a multitude of solutions, which are arranged in the process, analysed and finally selected, rejected or evaluated in relation to other solutions. In order to obtain the best architectural and urbanistic designs, the standard procedure is to organise a competition, which is usually done by the Chamber of Architecture and Spatial Planning of Slovenia (ZAPS) in Slovenia, however, private investors can also publish calls for internal competitions. The selection of the best solutions is based on the consensus of the jury. Quality work of the latter depends on co-operation of architects, urbanists, professionals from various fields, investors and other participants. It is important to take into consideration interdisciplinary knowledge in order to obtain a comprehensive assessment and to evaluate architectural and urbanistic solutions. At the same time, design criteria are becoming increasingly more demanding, while the legal limits are becoming increasingly more extensive. With that, the multitude of data, which the members of the jury must excel in during the process of selection, is increasing. Therefore, architects and urbanists need new tools, the so-called architectural devices" (Negroponte, 1970), which enable effective and computerised analyses of spatial solutions based on various criteria and measures.

Procedure of evaluating spatial solutions: architectural and urbanistic competitions

Architectural and urbanistic competition is a selection procedure of a comprehensive solution, which presents the best solution to the set problem. The selection of solutions is prepared by the jury, which consists of members of a professional association (chamber), investor, civil society, etc. The selection is based on previously defined criteria of the competition. Various professionals have their own opinions about the competition and competitions are carried out in different manner in different countries. The modern architectural competition in Europe reaches 150 years into the past with its rules and tradition (Rönn et al., 2013). The competition can be seen as an institution, which follows a system of rules and enables and keeps the social order (Andersson et al., 2016). Some professionals are convinced that members of juries are facing competitions with regular methods and limitations of the vision, which originates from their rigid assessment period (Cucuzzella, 2016).

In the key phase of the evaluation by the jury, the process of estimation and decision making, is usually redirected. Pre-determined competition criteria are rearranged at this step according to the newly determined and interpreted criteria of members of the selection board. In an extreme case, a new group of criteria is formed. Usually, the competitors are not familiar with this process, however, this process is the reason for many polemics and issues, connected to the process of decision-making in architectural competitions (Al-Qaysi, et. al. 2016). Within the profession, there are different explanations of BIM (Building Information Modelling) models (in similar parametric tools) in architectural competitions. This is the precise reason why BIM models and other tools are still not generally established in the creation of competition solutions and are part of negotiation (Sørensen et. al, 2015). However, it is precisely these models and tools that enable analysis of spatial solutions also on the basis of newly determined common criteria, which have not been defined already by the invitation to the competition.

Selection of the best solutions of architectural and urbanistic competitions consists of two essential steps. The first one is *the selection of criteria*, which will be later on used to decide about the selection, and the second one is *the consistency of the procedure* of choosing the best solution, which is carried out on the basis of previously selected criteria.

Decision support systems

Decision support systems are part of informatisation of the decision-making process. They are computer programmes, which are intended for the improvement of the success of professionals, professional and scientific organisations by using information technology. Users of decision support systems are professionals: managers, analysts and all those who are required to handle any form of data at their work (Sharda et al., 2014). Decision support systems can be divided into areas, which they cover, and based on that what they deal with: data, models, processes or communications (Power, 2013).

The moment of decision is key in decision making. Most often, we decide between versions which are similar to each other in terms of characteristics. At the beginning of the process of decision making, goals are set, which we want to achieve by making the correct choice: we therefore select the version, which comes closest to the fulfilment of goals. Usually we do not want to achieve just one goal, but several goals at the same time, therefore this procedure is also known as multiple goal decision making.

In evaluation of different solutions to the spatial problem, there is generally not just one characteristic because of which an individual solution would be more suitable or better than another. The choice is usually based on combination of the best elements of the spatial solution. Poor characteristics of the solution are also important and need to be considered too before the final decision. In decision models (Bohanec, 2012) the characteristics of solutions are described by parameters or criteria; therefore, we talk about multiple-parameter or multiple-criteria decision making. It is characteristic of this approach that we are simultaneously evaluating several characteristics of spatial solutions. Individual spatial solutions can then be evaluated in such manner that evaluations based on individual characteristics are combined into the final evaluation. This evaluation can be taken as the basis for classification of solutions from the best to the worst.

There are several methods of multiple-criteria decision making, and in practice they are used for various purposes (Greco et al., 2015). Some of them are simpler and suitable for a small number of criteria, others are more complex and suitable for selection of decision making problems with a larger number of solutions and criteria. For example, we know the method of analysing advantages and disadvantages, the PMI method, the Abacon method, the Kepner – Trengue method, which connects simple and complex multiple-parameter methods, the MAUT method (Multi Attribute Utility Theory) and others.

Determination of criteria for evaluation of spatial solutions

Evaluation systems, which are created in the same social space with the same cultural values, differ from each other (Musek, 1993). Some methods are of general importance. In addition to values of individuals (education, professional and life experience, age, etc.) a lot of other factors have influence on evaluation, such as social system, cultural awareness, economic development, etc.

In evaluation of planned interventions into space, we always face questions about objective and subjective criteria (Table 1). The goal is to choose such that have a decisive influence on the solution of the set problem. All of the determined criteria are not equal, some of them are more important than others. By taking various criteria into consideration it is possible to evaluate individual solutions to the spatial problem and arrange (rank) them from the best to the worst.

The criteria in architectural and urbanistic competitions are divided into quantitative and qualitative (Table 1). The first cover those areas which can be measured and calculated, while others refer to those areas, where informed assessment is necessary in order to obtain an evaluation (Strong, 2013). In interviews about architectural competitions, experienced members of juries have emphasised that technical and aesthetic measures are important to assess the spatial solutions, however quality comprehensive spatial solution is worth a lot more than a sum of its individual parts (Svensson, 2013; Verovšek & Čavić, 2017).

Criteria are determined based on architectural and urbanistic professional starting points, and usually also because of priority objectives of clients. In documentation for the call to the competition, value points have been attributed to the criteria. They facilitate evaluation, carried out by the members of the jury.

Table 1: Some quantitative and qualitative criteria which have influence on evaluation of architecture and urbanism (Dimitrovska, Andrews, 2011).

QUANTITATIVE CRITERIA		QUALITATIVE CRITERIA	
ARCHITECTURE	**URBANISM**	**ARCHITECTURE**	**URBANISM**
location	floor area ratio (FAR)	architectural design	accessibility
surface area	site coverage ratio	floor plan	adaptability
sunlight and illumination	plot volume space index	cross-section	the importance of the room
façade openings	density	façade	
economic efficiency	planned use	details	
	sunlight and illumination	material	
	economic efficiency	sustainability	

Use of multiple-criteria model for evaluation of the best spatial solutions

The goal of the research is to present the possibility of using multiple-criteria models of evaluation in selection of spatial solutions, to implement (realise) the model in Rhino 3D environment, to test the model on the example of selected solutions of an actual architectural competition and to test and compare three methods of multiple-criteria evaluation for suggested spatial solutions.

We assume that some of the multiple-criteria models can be included in the process of evaluation of spatial solutions. Here we expect to be able to answer additional research questions, such as:

- Does the use of decision making systems change or confirm the decision, which was the
- consequence of another procedure?

- Which decision making model from the chosen three is the most suitable for evaluating
- architectural and urbanistic solutions?
- To what extent is it possible to translate the decision making model to the visual
- programming environment (VPE) Rhino 3D?

MATERIALS AND METHODS

To check the hypothesis and the research questions, documentation from a closed, public, project, open, anonymous, single-stage architectural competition was selected. The architectural competition was organised by ZAPS for an apartment building with external arrangement on location Polje III in Ljubljana. The subject of the invitation to the competition was arrangement of a neighbourhood of non-profit rental apartments while arranging a certain number of covered and external parking lots, on a plot sized 9167 m2. The area within the regulation line (surface of the plots of land for construction) is 8487.50 m2 big.

The competition for Polje III, Ljubljana 6 (ZAPS, 2018), has the following starting points for design listed in the documentation of the call for competition:

- The solutions must take the prescribed site coverage ratio (SCR) into consideration, which is at 30 % (for the area within the regulation line). SCR is the ratio between the ground plan projection of the most exposed parts of the building on the terrain and the surface of lots, intended for construction. Balconies and overhangs are not taken into consideration in the ground plan projection of external dimensions of the most exposed parts of the building on the terrain. On the other hand, surfaces of floor plan projections of the biggest external dimensions of all simple and undemanding buildings on the terrain are taken into consideration, as well as the surface of the driveway into and out of the basement.
- The assembly of building masses, the height gauges and open space arrangements must be adapted and harmonised with the surrounding buildings and regulations.
- The solutions must comply with the fact that there is an intention to construct an apartment, which is entirely intended for rent to the rightful claimants in the following shares:
  - 2/3 of apartments should be unprofitable;
  - 1/3 of apartments should be residential units;
  - an underground garage is planned, intended for parking personal vehicles for the housing programme of the building complex.
- The solutions must provide the following number of parking lots (PM):
  - 2 parking lots for apartments, which includes a parking lot for visitors (i.e. 1 parking lot in the garage + 1 parking lot at the level);
  - 1 parking lot per 3 residential units + 10% for visitors (out of which 1 parking lot per 3 residential units is guaranteed in the garage, while the remaining 10% are at a level).

To check the hypothesis and research questions, the material about those solutions, which received the first three awards, was chosen. 3D-images of individual solutions were prepared on the basis of competition reports in PDF (ZAPS, 2018) and transferred to the virtual spatial environment in Rhino 3D programme (Rhino3d.com, 2018) (Figure 1). The presentation panels of competition solutions are of high enough quality for reproduction. If BIM or digital models of some other type would be available, the entire procedure could be faster and more reliable.

Data about chosen spatial solutions were transferred into virtual 3D environment of the Rhino 3D programme, in which it is possible to start the VPE plugin Grasshopper (GH). With individual components of VPE the Rhino3D/Grasshopper (RG) definition to check spatial solutions was determined. It consists of several smaller parts – modules, which represent the chosen criteria. Individual models are made of even more basic components. The set of individual models of RG definition therefore gives measured results (Table 2) for each and every solution.

For the analysis of the definition of the algorithm for evaluation of 3D-models of competition solutions, the selection and the adaptation of evaluation criteria, which were stated in the competition conditions, were prepared. The evaluation criteria were selected according to the usefulness of criteria in the work method. Evaluation criteria of the competition were divided into three categories. The first two criteria categories (*Functional criteria* and *Programme criteria and economic justification*) can be measured. For the values of qualitative category *Design criteria***,** we assume that they can be rated subjectively according to the rating scale from 0 to 3.

Quantitative criteria, which were selected for evaluation, are the following:

1. Functional criteria:
   - floor area ratio (FAR);
   - gross surface/plot;
   - site coverage ratio 30%;
   - plot volume space index (volume depending on the lot);
   - density.

2. Programme criteria and economic justification:
   - number of residential units;
   - price (in EUR);
   - relationship between the price of the investment and the number of residential units* (in EUR/per unit);
   - garage price** (in EUR);
   - price of external arrangement** (in EUR);
   - price of apartments** (in EUR);
   - number of parking lots;

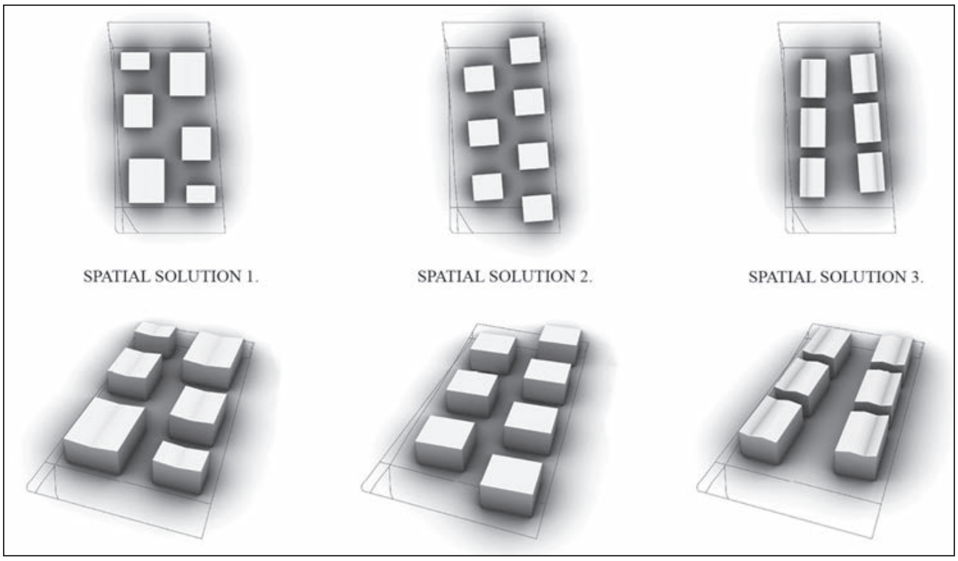

Figure 1: The first three competition solutions for apartment buildings with external arrangement of the Polje III location in Ljubljana: preparation of a 3D-model in the Rhino 3D environment for urban simulation, where the first, the second and the third solution follow one another from left to right; floor plan of all three solutions in the row above; spatial view of all three solutions in the row below.

- relationship between the number of parking lots and the residential units* (parking lots/unit);
- number of covered PM**;
- number of open PM**;
- number of buildings**.

Qualitative criteria which were selected for the evaluation, are the following:

1. Design criteria:
   - design of external surfaces;
   - design of external residential surfaces;
   - floor plan diversity;
   - façade design;
   - compliance with the surroundings*;
   - long views;
   - accessibility/transition.

(* - is not taken into consideration in all models, ** is not taken into consideration in any decision-making models)

Calculation of the Value of Quantitative Criteria with RG modules

In the Rhino 3D with GH environment individual criteria from components were defined in such manner that RG definitions are measuring the desired or requested target values, based on the criteria, translated into modules.

Floor area ratio (Figure 3) is one of the conventional ratios – modules in checking the spatial solutions and is defined as the ratio between the entire useful surface of the building (gross floor surface) and the surface of the plot.

The procedure of the definition of the module in the Rhino 3D/GH environment (Figure 3): Silhouettes of buildings were changed into surfaces. The building surface was moved along the axis z for the height of the storey and was multiplied by the number of floors. The sum of surfaces was divided by the surface area of the building land.

Site coverage ratio (Figure 4) expresses the ratio between the covered surface of the structure (building plot) and the surface of the plot.

The procedure of the definition of the module in the Rhino 3D/GH environment: Using an algorithm, the surface of the building plot was calculated, which was divided by the surface of the building land (figure 4).

Surface area to volume ratio (of the building mass) (Figure 5) expresses the ratio between the volume of the building mass and the surface of the plot (building plot).

The procedure of the definition of the module in the Rhino 3D/GH environment: The sum of the building volumes, which was prepared in the initial phase, was divided by the surface of the building land (Figure 5).

Definition for the calculation of ***density*** (Figure 6) is usually expressed by the number of persons per hectare or number of residential units per hectare, which is the most efficient in the project phase (Dimitrovska Andrews, 2011).

The procedure of the definition of the module in the Rhino 3D/GH environment: In the initial phase, a layer was prepared, which is part of urban simulation and re-

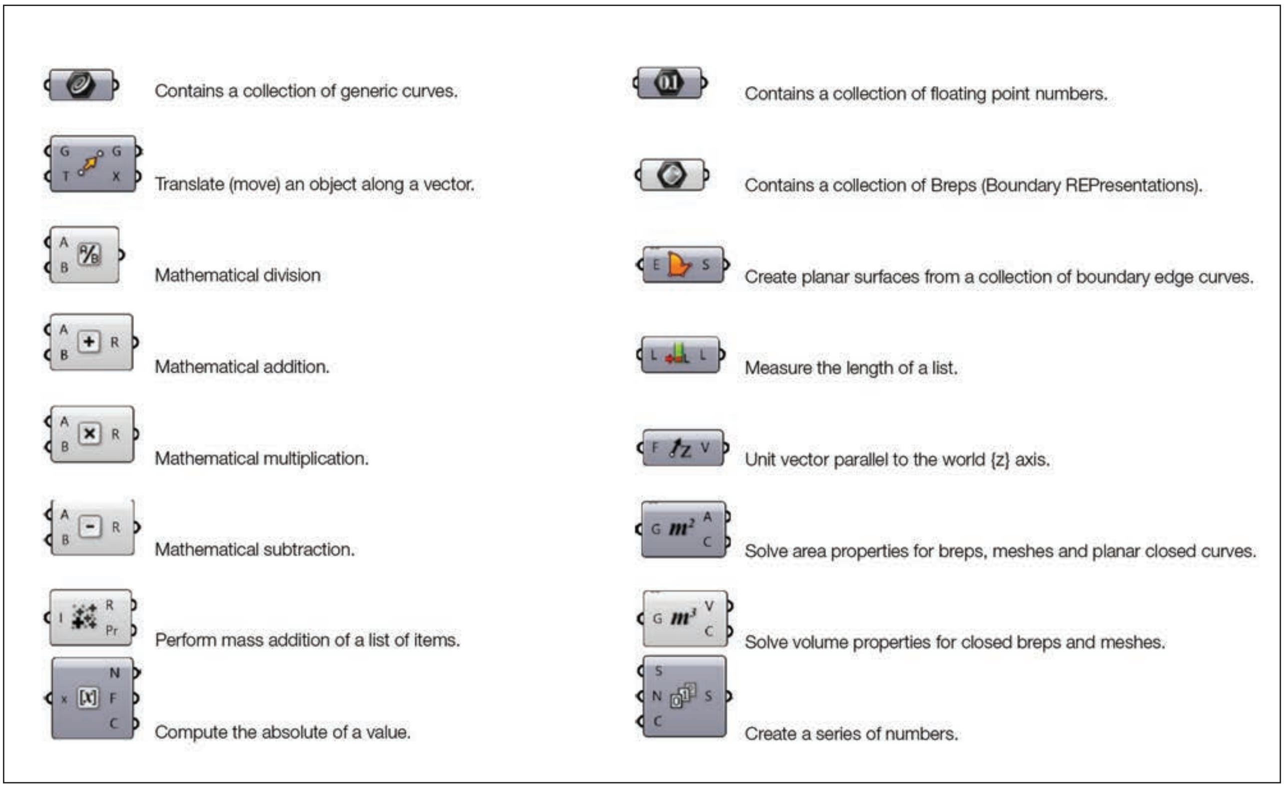

Figure 2: Legend of Components in Grasshopper Modules Definitions.

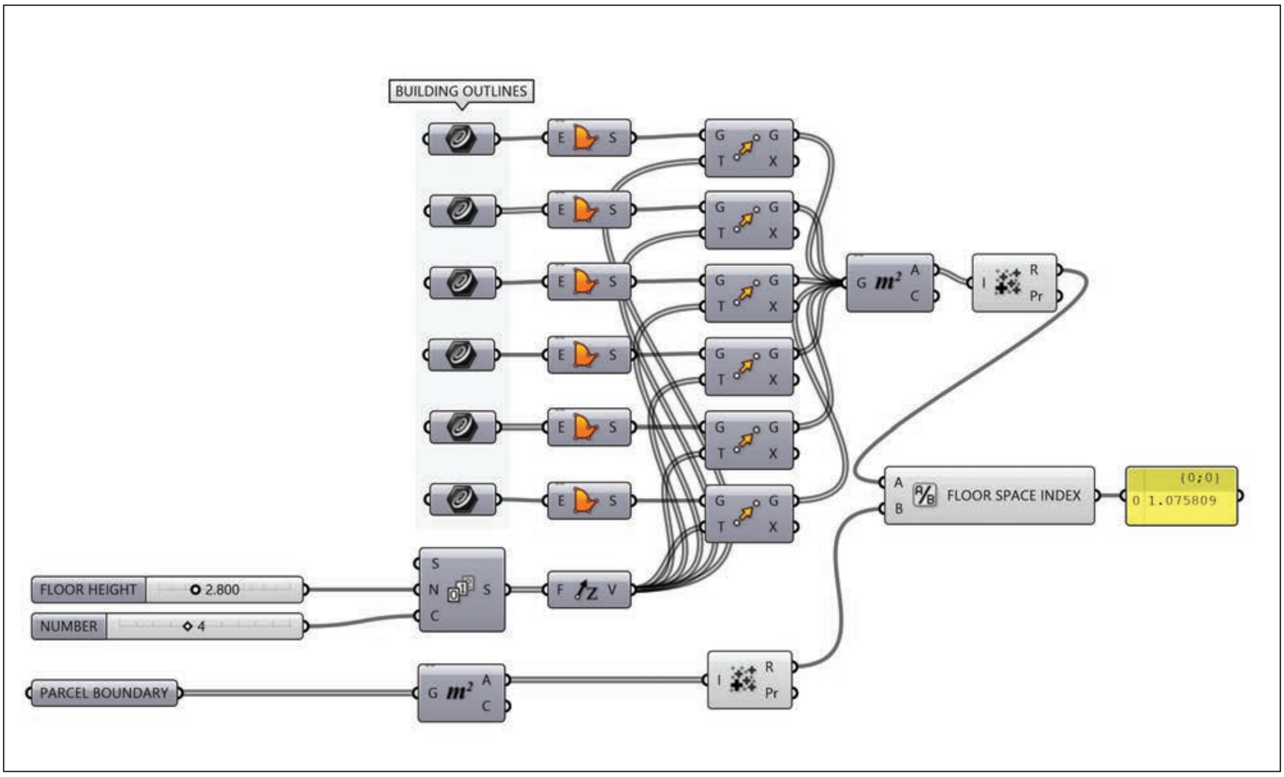

Figure 3: Definition of the floor area ratio model (FI) in Grasshopper.

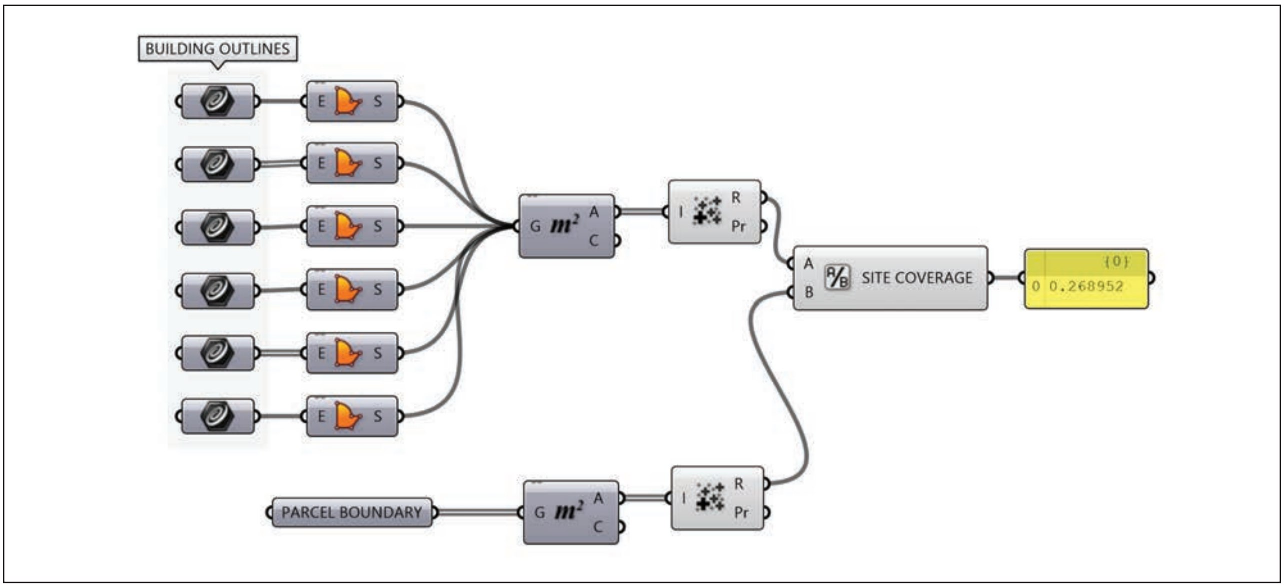

Figure 4: Definition of the site coverage ratio module in Grasshopper.

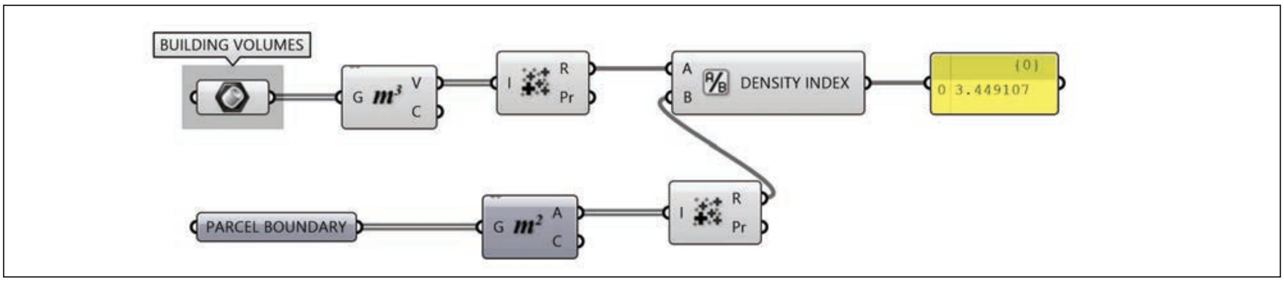

Figure 5: Definition of the surface area to volume ratio module in Grasshopper.

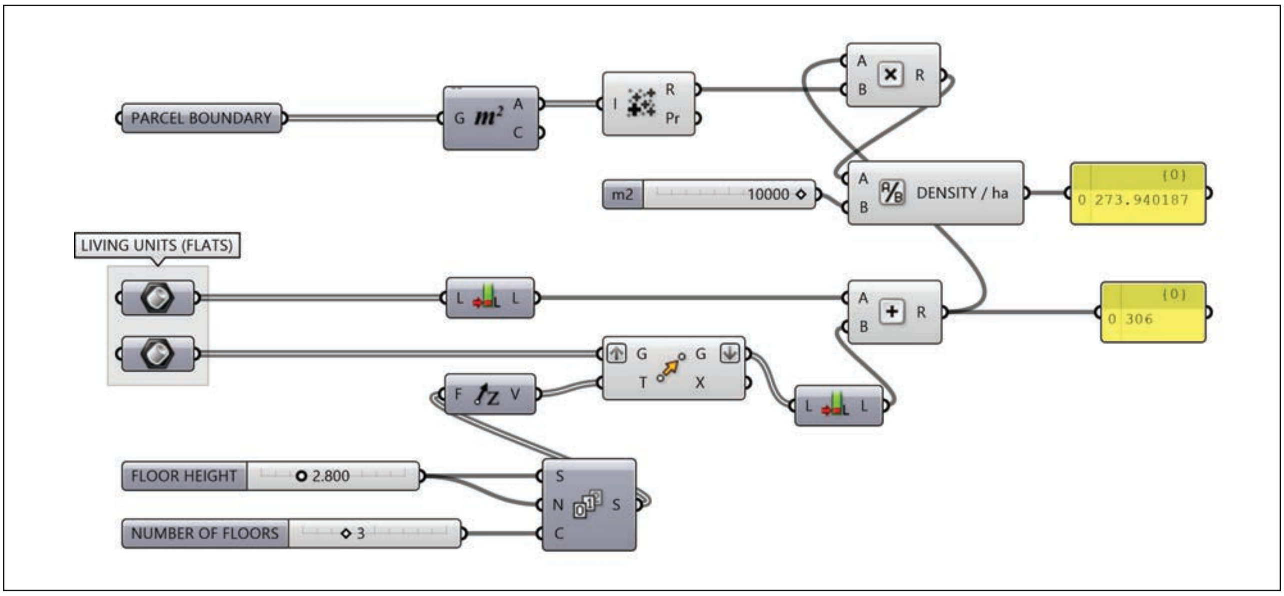

Figure 6: Definition of the density module in Grasshopper.

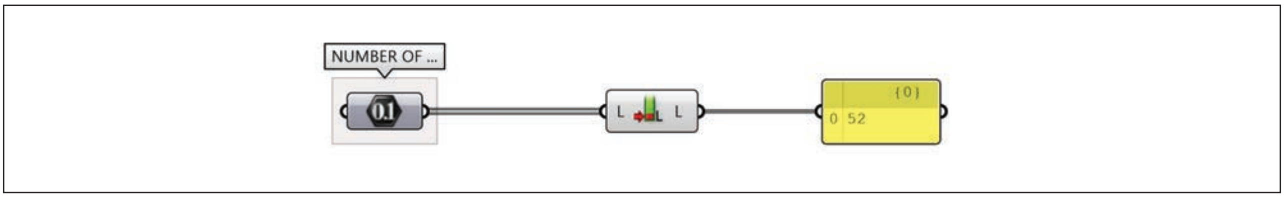

Figure 7: Definition of the module for counting individual elements of urban simulation, such as residential units, parking lots, rooms, etc. in Grasshopper.

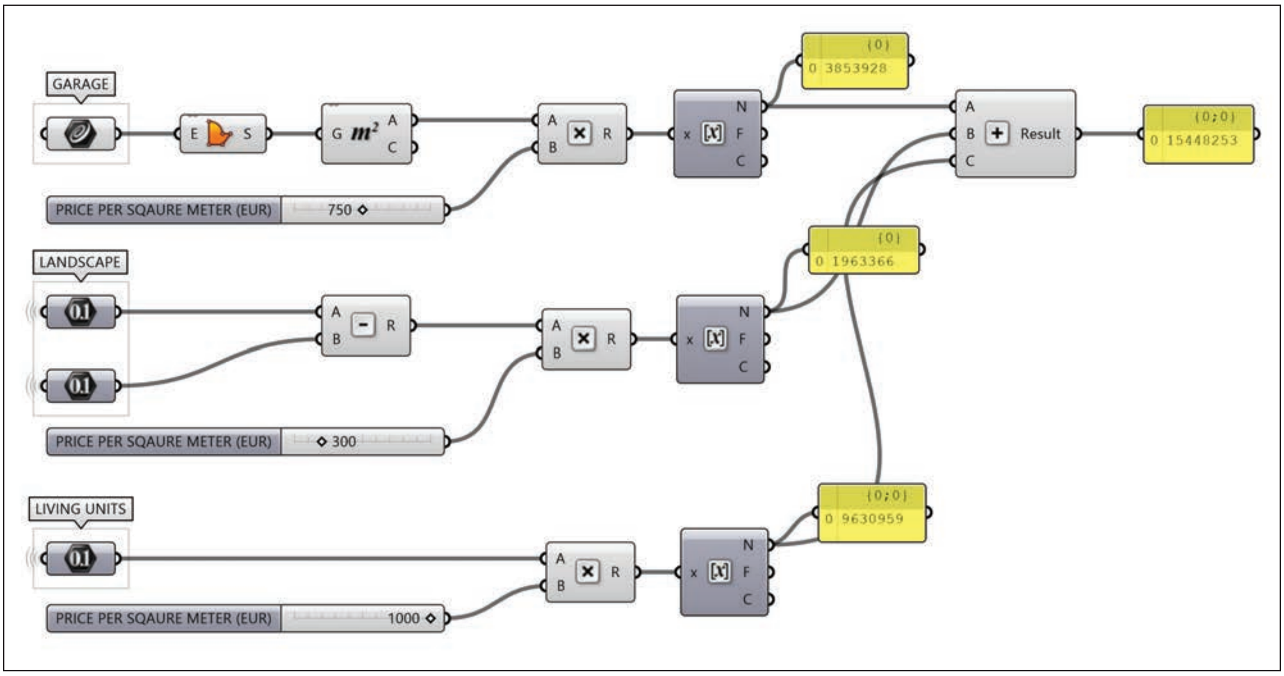

Figure 8: Definition of the module of common evaluation of the investment, based on assumptions of the evaluation for the performance of construction works in relation to the square metre of individual parts of the investment, in Grasshopper.

presents the number of residential units. The latter were counted and divided by the surface of the building plot. In the following step, the value obtained was converted into residential units per hectare (Figure 6).

To calculate ***programme criteria and economic justification*** various parts of the 3D-model had to be counted first, such as parking lots and residential units. The 3D-model must be prepared in advance in such manner that objects, which are counted, are present in the 3D-model.

The procedure of the definition of the module in the Rhino 3D/GH environment: The module, which counts the number of residential units, external parking lots and the number of parking lots in the garage (Figure 7).

For various investment calculations the counted objects were used and by using calculation operations they were combined into the investment evaluation in EUR, the ratio between the investment evaluation and the number of residential units (EUR per unit), investment evaluation for garages (EUR), evaluation of the exterior arrangement (EUR), evaluation of the investment into the apartments or residential units (in EUR), the number of parking lots, the ratio between the number of parking lots and residential units (parking lots/unit) (Figure 8).

Qualitative results of criteria used in the multiple-criteria methods

Evaluation of individual qualitative measures and criteria is based on interviewing three independent experts in architecture. An individual evaluation of each solution for an individual criteria was evaluated according to the scale from 0 to 3. With average rate of each evaluation of every criterion we get an individual qualitative evaluation which we use in the decision making model.

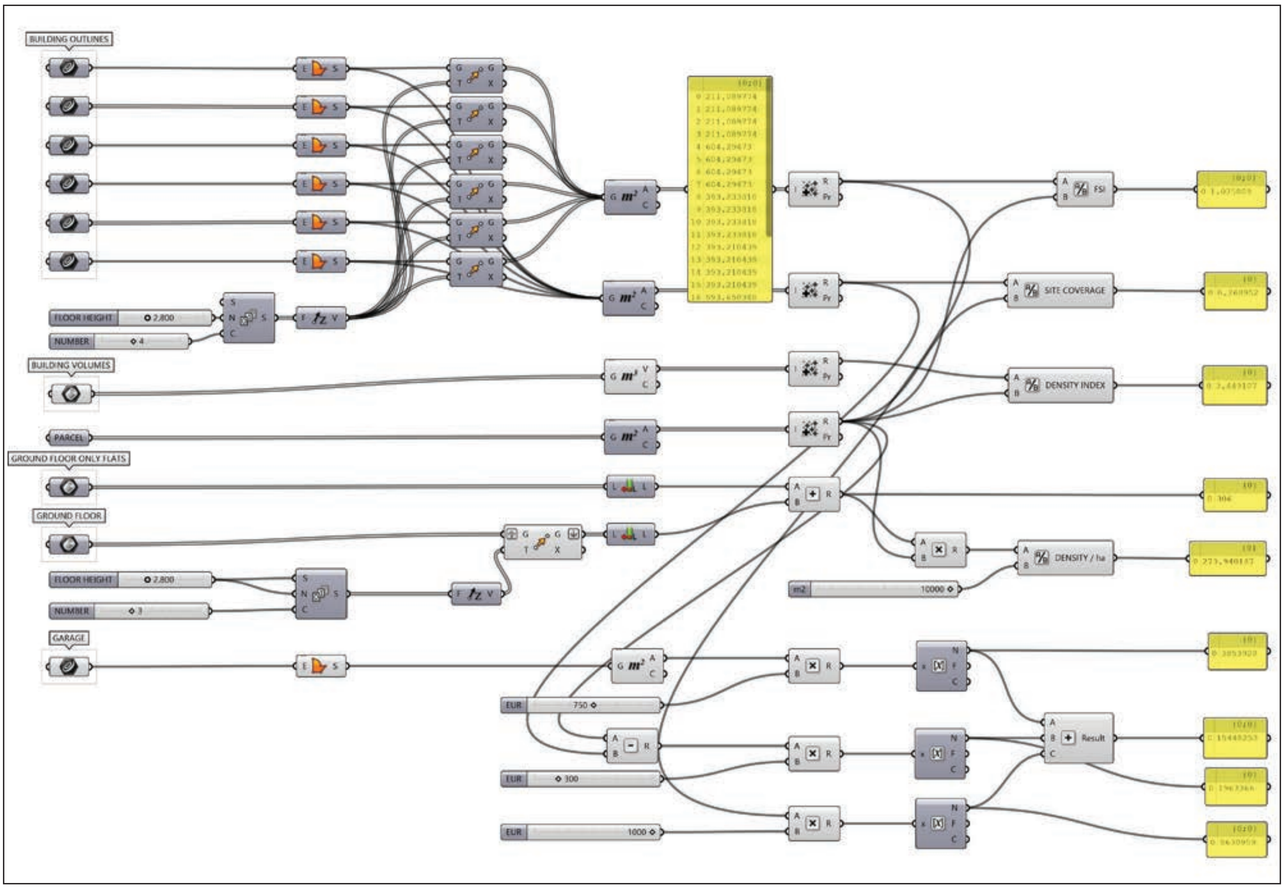

Figure 9: Definition (consisting of modules) of the 3D-model analysis based on functional and programme criteria and economic justification for one of the solutions in Grasshopper.

Combination of modules

By combining individual modules (Figure 9), selected quantitative functional criteria, programme criteria and economic justification (Table 2) were calculated.

Qualitative criteria were added to quantitative criteria (measured with RG) (Table 3).

Selection of multiple-criteria methods for the evaluation of spatial solutions

For the research, we have selected three rather simple multiple-criteria methods (Bohanec, 2012):

- **The analysis of advantages and disadvantages**, which enables findings about the greatest advantages and the disadvantages for each and every solution compared to other versions.
- **PMI method** (»plus/minus/implications«), which is the upgraded method of the analysis of advantages and disadvantages. Assessment with positive and negative points is added to the advantages and characteristics of the solution.
- **Abacon method,** with which we determined the criteria, which influence the selection of the best solution. The criteria are arranged from the most to the least significant and prepared in such manner that the most important criteria are listed on the top of the table.

To select the best multiple-criteria decision making method the decision, in this case spatial problem needs to be identified first. To determine the best solution to the spatial problem, the following needs to be evaluated in relation to one another. The decision problem is therefore broken down in such way that objective and subjective criteria for its evaluation can be determined. The results of the criteria for individual solutions to the spatial problem are additionally evaluated with the selected multiple-criteria method. Each evaluation method ranks spatial solutions differently according to its characteristics and procedures. In accordance with the selected criteria for the evaluation of the methods of evaluation (Table 7), we will choose the most suitable method of multiple-criteria decision making for the selection of the best solution to the spatial problem. The

Table 2: Overview of the results by considering the evaluation criteria of the competition jury (* – is not taken into consideration in all models, ** – is not taken into consideration in any decision-making model).

	SOLUTION 1	SOLUTION 2	SOLUTION 3
FUNCTIONAL CRITERIA			
Floor area ratio (FAR) Gross surface/plot	floor area ratio (FAR)	architectural design	accessibility
Site coverage ratio (max 0.3)	site coverage ratio	floor plan	adaptability
Plot volume space index (volume depending on the lot)	plot volume space index	cross-section	the importance of the room
Density	density	façade	
PROGRAMME CRITERIA AND ECONOMIC JUSTIFICATION			
Number of residential units	98	119	138
Price (in EUR);	15,448,253	14,590,272	16,230,830
Relationship between the price of the investment and the number of residential units* (in EUR/per unit)	157,635	122,607	117,614
Garage price** (in EUR)	3,853,928	3,779,410	3,921,885
Price of external arrangement** (in EUR)	1,963,366	2,026,890	1,905,424
Price of apartments** (in EUR)	9,603,959	8,783,972	10,403,521
Number of parking lots	212	206	194
Relationship between the number of parking lots and the residential units* (parking lots/unit)	2.16	1.73	1.4
Number of covered**	114	107	113
Number of open**	98	99	81
Number of buildings**	6	7	6

selected method of evaluation, along with determined objective and subjective criteria, ranks the solutions in question.

RESULTS

Comparison of evaluation of results of various decision making models

Analysis of Advantages and Disadvantages

For all three selected competition solutions their greatest advantages and disadvantages (PS) were discovered. The methodology of the decision making model is based on the procedure that quantitative results from Table 2 and qualitative results from Table 3 are converted into uniform descriptive assessments in accordance with the selected criteria. Individual ratings are divided into three categories (Table 4): ADVANTAGES, where individual criteria are usually positive, DISADVANTAGES, where individual criteria are usually negative and NEUTRAL, where results from Table 2 and Table 3 are usually neither positive nor negative. If we only consider the largest number of positive ratings in evaluation of solutions, the best solution is solution number 1 and the worst one is solution number 3.

PMI Method (“plus/minus/implications”) is the upgraded advantages and disadvantages method. This time, advantages and disadvantages are evaluated with positive and negative points between -5 and 5 (Table 5). The method enables evaluation of not only the extreme (very good or very bad) characteristics, but also medium characteristics. The question which arises while using this method is the manner of weighting individual criteria, which are equal or independent from each other. This is at the same time the greatest weakness of the PMI method. The results of the method show that solutions 1 and 2 are equal, while solution 3 is substantially worse than the other two.

For the **Abacon** method those parameters were selected that influence the decision about good or bad solution, so it is important that the calculation includes all the important parameters. In decision-making all parameters are equally important or the importance changes according to the relationships between them (Table 6). The weaknesses of the method are the arbitrary division of parameters from the most important to the least important and the complexity of the graphical result. The only advantage of this method is the simplification of weighting. For every solution we obtain a visual profile,

Table 3: Overview of the results by considering the evaluation criteria of the competition jury.

DESIGN CRITERIA (0–3)	R1	R2	R3
Design of external surfaces	3	1	2
Design of external residential surfaces	3	2	1
Floor plan diversity	3	2	1
Façade	3	2	1
Compliance with the surroundings	2	2	2
Long views, cityscapes	2	3	1
Accessibility/transition	3	2	3

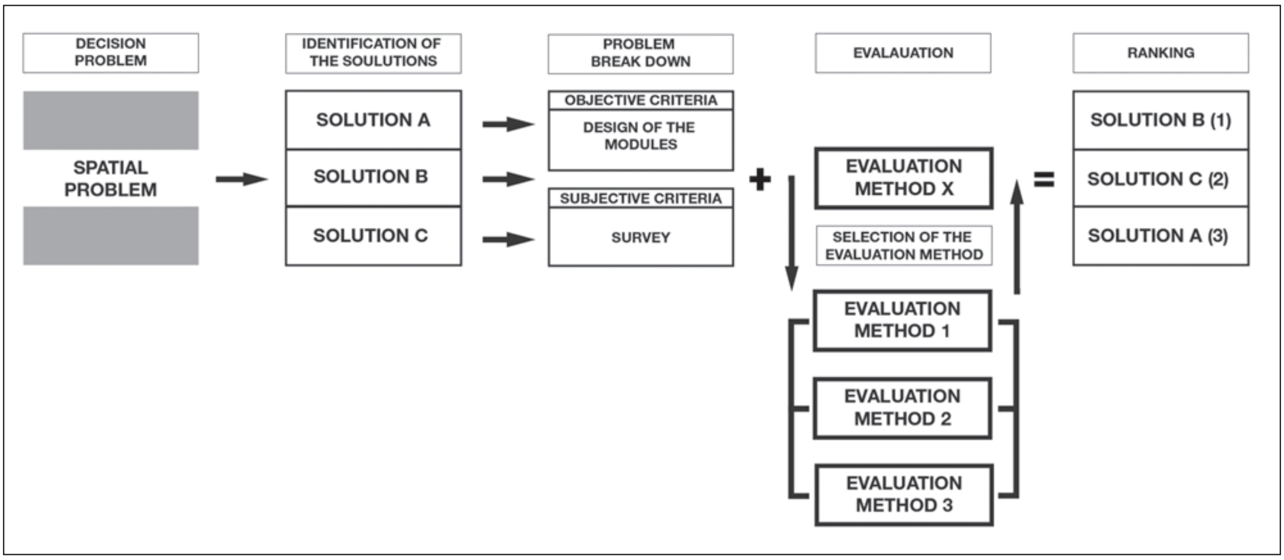

Figure 10: The course of the task model.

which can be compared between individual solutions: the greater the surface on the left side of the profile, the better solution.

DISCUSSION

The results of the multiple-criteria model of advantages and disadvantages confirm the results of the selection of the competition jury, however this multiple-criteria model is the most unsuitable model for selection of spatial solutions due to its subjective approach. Already with the PMI method, two solutions reach the best result. However, it is impossible to choose the best solution with the Abacon method: we can only see that the solution which received the first award, prevails in terms of quality of design solutions, and the other two solutions in terms of quality functional solutions and the economic justification rating.

We did not get an adequate answer to the question, which decision making model from the chosen three is the most suitable for evaluating architectural and urbanistic solutions. The advantages and disadvantages method is one of the simplest methods. For each criterion the greatest advantages and weaknesses of the solution to the decision problem are defined. The findings have been arranged in the table and the best solution is the one that gets the largest number of advantages. Significant weakness of this method is that it does not allow adding numerical rating to the descriptive ratings of solutions. We also cannot define the relationship between data using this method. All results are equal. The question is, how to treat the mean values, where the solution is neither bad nor good. From the methodological perspective, the method is very subjective and non-systematic (Bohanec, 2012). The method is useful as the basis for understanding the problem, for the collection of criteria and is the basis to continue evaluation with more complex methods.

PMI method is the upgraded method of the analysis of advantages and disadvantages. Using the PMI method we can evaluate characteristics, which are neither bad nor

Table 4: Results of the analysis of solutions according to the advantages and disadvantages method: the largest number of advantages equals the best result.

SOLUTION 1	SOLUTION 2	SOLUTION 3
ADVANTAGES		
floor plan diversity	orderliness of external residential surfaces	suitable floor area ratio
quality designed façade	low price of apartments	suitable site coverage ratio
suitable number of parking lots	the lowest investment	the lowest price of apartments
good accessibility and transition	maintaining cityscapes, long views	
orderliness of external residential surfaces		
design of external surfaces		
DISADVANTAGES		
unsuitable density	unsuitable floor area ratio	unsuitable site coverage ratio
unsuitable site coverage ratio	unsuitable site coverage ratio	unsuitable building density
unsuitable number of residential units	unsuitable building density	large number of residential units
high price of apartments	unsuitable number of parking lots	the most expensive investment
	unsuitable design of external surfaces	unsuitable number of parking lots
	too small floor plan diversity	unsuitable design of external surfaces
		too small floor plan diversity
		poorly designed façade
		unsuitable emphasis of long views
NEUTRAL		
satisfactory floor area ratio	satisfactory coverage of the lot	satisfactory design of external surfaces
satisfactory site coverage ratio	satisfactory number of residential units	satisfactory accessibility and transition of the settlement
satisfactory price of investment	satisfactory design of façade	
satisfactory maintenance of city-scapes, long views	satisfactory accessibility and transition of the settlement	

good, and that way somehow lose the categories of bad and good. Here, weighting individual criteria, which are equal and independent from each other is problematic. Despite the possibility of weighting individual criteria, which are used to evaluate solutions, and the possibility to numerically evaluate the best or the worst solution, a very small difference in ratings can cause changes to the order. It is the problem of value relation between the criteria. The method is still very subjective and inaccurate, however it provides good guidance for the development of more complex models of multiple-criteria decision making.

The weakness of the Abacon method is the condition that no crucial criterion is overlooked. The weaknesses of the method are present particularly in the methodology of division into the most and the least important, which can be very hard to determine, since parameters (criteria) are not equal to each other. The graphic result "solution profile" is visually very interesting, however it is hard to imagine when results of different solutions are compared. In practice, this method is not used for evaluation and ranking of solutions, but for the comparison between them. We cannot calculate anything from the profiles, we can only notice emphasised trends.

Table 7 shows that considering the set criteria, the PMI method is the best or the most useful multiple-criteria decision making method.

It has been proven that it is possible to translate individual modules to VPE, which can calculate individual quantitative criteria (Table 2). Transfer of decision models under consideration to VPE due to the distinct qualitative nature of results is not practical and will be the subject of the next research.

CONCLUSION

All methods included in the research can be marked as inadequate for the purpose of evaluation of spatial so-

Table 5: The results of the analysis of solutions according to the PMI method with added assessments in the range from – 5 (very bad) to 5 (very good).

SOLUTION 1		**SOLUTION 2**		**SOLUTION 3**	
ADVANTAGES					
satisfactory floor area ratio (FAR)	**2**	the lowest investment	**5**	suitable floor area ratio (FAR)	**5**
satisfactory site coverage ratio	**2**	satisfactory number of residential units	**3**	suitable site coverage ratio	**5**
suitable number of parking lots	**4**	satisfactory filled plot	**2**	satisfactory design of external surfaces	**3**
suitable external residential surfac-es	**3**	suitable external residential surfaces	**3**		
suitable design of external surfaces	**3**	satisfactory design of the façade	**2**		
floor plan diversity	**4**	suitable emphasis of long views	**5**		
suitable design of façade	**3**				
suitable emphasis on long views	**3**				
DISADVANTAGES					
unsuitable density	**0**	unsuitable floor area ratio (FAR)	**-1**	unsuitable building density	**-2**
unsuitably filled plot	**-3**	unsuitable site coverage ratio	**0**	unsuitable number of residential units	**0**
low number of residential units	**-4**	unsuitable building density	**-3**	unsuitably filled plot	**-3**
satisfactory price of investment	**0**	unsuitable number of parking lots	**-3**	unsuitable number of parking lots	**-5**
		unsuitable external surfaces	**-3**	the most expensive investment	**-3**
		too small floor plan diversity	**0**	unsuitably designed external residential surfaces	**-2**
				unsuitable floor plan diversity	**0**
				unsuitably developed façade	**0**
				unsuitable emphasis of long views	**-1**
CONSEQUENCES					
expensive apartments	**-3**	cheaper apartments	**5**	the cheapest apartments	**5**
accessibility and transition of the settlement	**3**	accessibility and transition of the settlement	**2**	accessibility and transition of the settlement	**3**
TOTAL NUMBER 1 SOLUTIONS	**17**	**TOTAL NUMBER 2 SOLUTIONS**	**17**	**TOTAL NUMBER 3 SOLUTIONS**	**5**

lutions. It is characteristic of all three selected methods that they are distinctly subjective and too inaccurate for the discussed use. All methods lack the hierarchic relationship between the results of various criteria and the determination of the relationship between them. The first two methods can act as the start to discover the problems and the development of more complex models. The Abacon method however has the hierarchic scale of criteria, however the implementation is completely unsuitable for evaluation of spatial solutions.

The research serves as a good foundation for continuation of including multiple-parameter models into the decision-making systems and evaluation of spatial solutions. Due to increased extent of works and details, which are expected from project leaders, it is possible to see from the basic multiple-criteria decision making methods that multiple-criteria tool would be beneficial both to project leaders and to the consistency of the procedure during the evaluation of competition solutions, because it enables quick check up of the spatial solution in accordance with the pre-determined criteria. To continue the study, more complex hierarchic models of multiple-criteria decision making will have to be checked, such as Kepner-Tregoe, which, in addition to mutual comparison of solutions, enables their evaluation, and MAUT, which is based on the theory of multi-parameter usefulness, where the structure of the decision problem is defined by tree or hierarchy of parameters, and the DEX method, which is based on qualitative (symbolic) parameters.

Table 6: Results of the analysis of solutions according to the Abacon method.

		POOR RATING				**R1**	**R2**	**R3**				**GOOD RATING**
Functional criteria	floor area ratio (FAR)	Unsuitable		2					1		3	Suitable
	site coverage ratio at max 30%	Unsuitable	1	2							3	Suitable
	plot volume space index (volume depending on the lot)	Unsuitable	1		3					2		Suitable
	density	Unsuitable		2	3				1			Suitable
Achievement of the programme and economic justification	number of residential units	Unsuitable	1							2	3	Suitable
	number of parking lots	Unsuitable		2	3				1			Suitable
	ratio	Unsuitable	1							2	3	Suitable
	price	Unsuitable	1		3					2		Suitable
	ratio	Unsuitable	1							2	3	Suitable
Design criteria	external surfaces	Unsuitable		2	3				1			Suitable
	external residential surfaces	Unsuitable		2	3				1			Suitable
	floor plan diversity	Unsuitable		2	3				1			Suitable
	façade	Unsuitable		2	3				1			Suitable
	compliance with the surroundings	Unsuitable										Suitable
	long views	Unsuitable	1	2	3							Suitable
	accessibility/transition	Unsuitable		2					1		3	Suitable

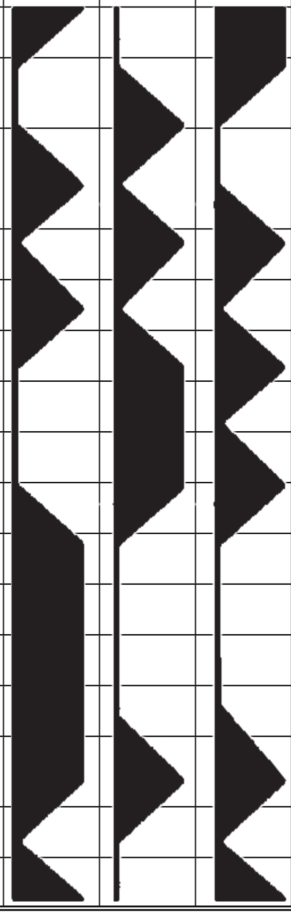

Table 7: Results of the analysis of suitability of selected multiple-criteria models, ratings on the interval from 0 (bad rating) to 3 (good rating).

	Advantages and disadvantages	**PMI method**	**Abacon**
Adding numeric rating	0	1	1
Transparency of the method	1	3	2
Simplicity of use	1	3	2
Use in model/translation to mathematic model	0	2	2
Graphic presentation	1	1	3
Importance of the order	2	2	1
Clarity of result	3	3	1
Graphic presentation	0	1	2
Total	**8**	**16**	**14**

VLOGA ODLOČITVENIH MODELOV PRI VREDNOTENJU PROSTORSKIH REŠITEV

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IZVLEČEK

Odločanje v arhitekturnem in urbanističnem oblikovanju prostora je proces, v katerem je izbrana tista različica rešitev prostorskega problema, ki najbolj ustreza zastavljenim ciljem in zahtevam. Tudi proces načrtovanja v prostoru temelji na oblikovanju množice rešitev, ki so v procesu razvrščene, analizirane in na koncu izbrane, zavržene ali ovrednotene v odnosu do drugih rešitev. Cilji raziskave so prikazati možnost uporabe večkriterijskih modelov vrednotenja pri izbiranju prostorskih rešitev, implementirati (realizirati) model v okolju Rhino 3D, preizkusiti model na primeru konkretnega arhitekturnega natečaja in preizkusiti ter primerjati tri metode večkriterijskega vrednotenja za predlagane prostorske rešitve. Za preveritev hipoteze in raziskovalnih vprašanj je bilo izbrano gradivo zaključenega, javnega, projektnega, odprtega, anonimnega, enostopenjskega arhitekturnega natečaja, ki ga je razpisala Zbornica za arhitekturo in prostor Slovenije (ZAPS) za večstanovanjske stavbe z zunanjo ureditvijo na lokaciji Polje III v Ljubljani. Izbrane rešitve so bile ovrednotene s tremi metodami. Za vse tri izbrane večkriterijske metode lahko ugotovimo, da so izrazito subjektivne, preveč nenatančne in kot take neprimerne za vrednotenje rešitev prostorskega problema. Med analiziranimi metodami je sicer glede na določene kriterije metoda večkriterijskega odločanja PMI (»plus/minus/implications«) najboljša oz. najuporabnejša.

Ključne besede: odločanje v arhitekturi, arhitekturni natečaji, sistemi za pomoč pri odločanju, večkriterijsko odločitveno modeliranje

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