

# Using Multicriteria Analysis in Issues Concerning Adaptation of Historic Facilities for the Needs of Public Utility Buildings with a Function of a Theatre

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**Abstract.** Implementations concerning adaptation of historic facilities for public utility objects are associated with the necessity of solving many complex, often conflicting expectations of future users. This mainly concerns the function that includes construction, technology and aesthetic issues. The list of issues is completed with proper protection of historic values, different in each case. The procedure leading to obtaining the expected solution is a multicriteria procedure, usually difficult to accurately define and requiring designer's large experience. An innovative approach has been used for the analysis, namely - the modified EA FAHP (Extent Analysis Fuzzy Analytic Hierarchy Process) Chang's method of a multicriteria analysis for the assessment of complex functional and spatial issues. Selection of optimal spatial form of an adapted historic building intended for the multi-functional public utility facility was analysed. The assumed functional flexibility was determined in the scope of: education, conference, and chamber spectacles, such as drama, concerts, in different stage-audience layouts.

## 1. Introduction

The existing central and suburban foundations that have become useless as a result of technical, social and economic progress, are waiting for their new functions. Emerging new buildings, often erected against urban rules, do not necessarily create new, usable quality expected by local communities. Thus, the in-depth analysis of existing resources of residential/commercial/industrial buildings is the most important step to make already at the stage of development plan. The leading idea of a new functional complex should be maintaining the existing structures and including them in usage, their possible spatial development and skilful aesthetic "harmonisation" with the newly designed structures. This issue is highly complex. One needs to start from the macro-scale, go to the "architectural" scale in order to finally go back to the urban scale. Such "path" needs to be repeated multiple times, each time enriching the solution by the aspects that will emerge during the process. This should be a multilateral and in-depth study analysis using all the available methods, starting from graphical methods and concluding with scientific methods, based on mathematics. Such activity can be called a multi-branch transition from the general view to details, in result of which the final solution will be close to optimum. Of course, the more complex function is, the more difficult the problem is.



The internal function is connected to the external function which includes availability for pedestrians and vehicles, insolation. These basic criteria that need to be met are accompanied by the necessity of obtaining landscape value and by environmental protection issues. That is how the complexity of the issues presents itself.

Every design issue concerning multi-functional space will be multiplying difficulties resulting from different users' needs. In an auditorium for lectures and conferences, placing subsequent rows of seats does not require taking into account full visibility of the podium. Thus, the logarithmic curve of the distance between the head tops and the line of vision can be relatively flat if assuming the visibility of people is from the knees to the head. Only exceptional types of lectures requires full visibility, close or even extended in comparison to a theatre.

Area and cubature are next parameters that are contradictory when taking into consideration different users' point of view. In the most general terms, area and cubature of stage and audience, bandstand or conference podium, and the width of the adjacent 1<sup>st</sup> row, are, as a rule, different. This results in the need for universal solution of light and acoustics. This last factor comprises separate issue. In the rooms for the "spoken word", where no artificial sound system is installed, reverberation time should be about 1.4 seconds. In the case of chamber music (e.g. a choir, string quartet or nonet), the required reverberation time increases to 1,6 - 1,7 seconds. This small increase already requires specialist acoustic design procedures, as well as execution procedures. Therefore, difficulties not necessarily increase in direct proportion to the extending functional requirements but more in an increase reaching geometric.

Accepting those extended criteria necessary to solve and included in one object, is highly difficult without using accurate, mathematical methods. With proper selection of criteria, including relatively wide range of the building usage technologies, the proposed, multicriteria analysis can ideally help in complex designing process.

In Polish conditions one more criterion was added in the 1990's. It is connected to social and political problems, resulting with often complicated changes in ownership happening in the area of economic and spatial as well as mental terms. Finding the best solution for the often complex ownership situation is sometimes impossible. This mental factor can turn out impossible to go through. A compromise will be required. It is not possible to include it in criteria of the analysis but making the analysis significantly more difficult.

These issues also require presentation from a different point of view. The surrounding space is constantly changing as a result of continuous civilizational development that generates new needs. This also concerns buildings being the heritage of previous generations. Very large group of structures, such as fortifications, palaces or post-industrial buildings, was build intended for functions that nowadays became useless. Only the most valuable structures adopted functions of museums and are financed with public funds. Separate group comprise sacral structures, which type of use have not changed until today. Economic balance is decisive concerning the remaining objects' fate. Not taken over by private owners and adjusted to new functions, they will gradually deteriorate. The highest chances have structures located in areas attractive for investors: in the city centres and districts of high touristic potential. The scope of adaptation depends on many factors that cannot be arranged hierarchically. It can be the building's age and its technical condition, material solutions and original and assumed function. This scope can be limited to the existing structures or it can assume adding new facilities that in the case of structures partially preserved often has a character of reconstruction. It is always connected to the necessity of introducing new technical equipment to completely modify the whole range of buildings. That is why adaptation of historical objects is an especially complex issue requiring maintaining its historical tissue with a complex function of public utility buildings. This leads to the necessity of not only modelling the building's shape adequate for its architectural detail but also viewing the wider context of the surrounding space based on the network of communication and installation connections comprising a large-space scale. It can include the assigned part of the urban layout, or wider, the entire urban organism.

Therefore, it is a process that requires meeting many variable criteria concerning different branches. The decisions made will be connected to responsibility for the people's needs. Moreover, profitability

of the investment is included which is seen as fulfilment of social needs, and, not necessarily at equal level of importance, the economic balance. Thus, the designing requirements are often contradictory and require making compromise decisions by the designer.

Lack of repeatability of designing and implementation conditions that every time require individual or even entirely unique approach to the issues of designing is characteristic for the construction undertakings. The decisions that were made, are significantly influenced by different degree of experience and preferences of designers, translating into different assessment and selection of design solutions. Thus, one needs to reach for equipment and methods exceeding conventional approach, logic at first, and mathematics at more advanced stage. This gives enables including complex nature of decision-making process on one hand, and, on the other hand, of imitating not always strict interrelations.

Despite high significance and potential of currently available tools of the multicriteria analysis, this method is not widely reflected in the literature. Sparse papers [1, 2, 3, 4] describe this subject selectively. The most interesting depiction of the issue was shown in the paper [5] in which authors used the Multicriteria Decision-Making Analysis in the assessment of adaptation possibilities of historical post-industrial buildings in Turin. However, the paper lacks a comprehensive approach taking into consideration the complexity of this issue. Moreover, using the AHP method in part of the above-mentioned papers today seems insufficient.

## **2. Subject-matter of the analysis**

The subject matter of the analysis is located in Zabrze at the Roosvelta Street 3c, on the south side, in a complex creating a horseshoe shape. From the east, the structure is limited by the gable of the 3-floor residential building. Two structures, on the north and the south side, before 1989 were owed by the military unit. Along with the courtyard it created a space closed in a physical sense and in a sense of availability (figure 1). The historical aspect need to be, in particular, seen as maintaining the form of the system and human scale of the building itself. The entire complex, as originating from the turn of the 19<sup>th</sup> and 20<sup>th</sup> century, is subjected to the conservator's protection, thus all the changes in the plan and character of the elevation required agreement with the Voivodeship Conservator of Monuments.

After political changes in Poland, the "military" complex was transferred to the city. In 1998-2000, complex designing works aiming at revalorization of both buildings along with the adjacent area, including adaptation for the educational and cultural purposes. From the north side, the structure was re-designed for the educational and administrative purposes for the Faculty of Organization and Management of the Silesian University of Technology. Six audio-visual rooms were placed there (120 participants each) as well as 12 laboratories, a library, dean's office, and student service office. The building on the south side was supposed to "supplement" education, with a room assumed as multifunctional, remote from the busy street. But the superior aim was serving the academic cultural entities, mainly the theatre for the students Gliwice STG, and the Academic Choir of the Silesian University of Technology. During the designing works, through negotiations with the Silesian Operetta House, its "light" repertoire was taken into consideration. On a daily basis, the educational classes are held in the mobile, acoustically separated spaces, which are divided into 2, 3, or 4 independent rooms

During the designing process it was necessary to extend the building by a hall directly adjacent to the building from the north side in order to meet conditions of such vast mobility. The hall interchangeably serves as a wardrobe for the artists. In the elongated part of the complex, a second, representation entrance was designed. To meet the conservator's requirements, the expansion was executed maintaining formal and aesthetic character of the existing building, limiting the cubature to the required minimum. Moreover, it was managed to restore the construction of the roof truss, keeping the originally found arrangement of beams and regional style. The entire investment was completed in 2003 (execution of the buildings along with interiors).

The space closed in the entertainment building should combine subjectivity of connections between the function, form and construction, and also artistic vision of the concept of a theatre, taking into

account formal and legal as well as economic requirements. The adapted spatial solutions should be a result of an in-depth analysis of relations of specific features of theatrical area, taking into account high complexity of the issue and all the aspects often contradictory or even mutually exclusive [6].

The entertainment building program, its cubature and functional layout can be considered in the objective range with *a priori* assignment of the type of the spectacle. It is thus possible to determine the average functional and spatial requirements when taking into account technology of the spectacle operation. Going deeper into the artistic formula of the theatre spectacle, the area connected to its functional and spatial elements becomes non-measurable and indefinable. However, the multicriteria assessment used in the work allows approximation of the most flexible option and in such way the issues undergoing the assessment were directed.

The stage-audience room was designed in a way giving larger *spectrum* of the space possible usage as a theatre, while maintaining its educational function.



**Figure. 1.** Site plan and view from the western side of the executed multi-functional building. Author of the design: architect P. Obracaj

For the designer, the solutions' core was:

- indication of spatial assumptions of stage and audience changeable function allowing to obtain wide *spectrum* of creative possibilities with fixed area and cubic volume,
- completion of the stage and audience changeable function with flexible solution of back-up facilities of technical function, serving in relation to the multifunctional room (in the design it was executed in a form of cubature at the side of the theatrical room as well as adapted for these purposes adjacent part of the building),
- and maintaining historical values.

In the conducted analysis, besides the executed variant, also its modifications were assumed comprising of modelling the placement and size of the technological part of the theatrical building, concerning part comprising of technical rooms on the level of the stage (side scene docks) and mezzanine (the underground floor). The stage and audience variants possible for implementation in the designed building were shown in figure 2 [6]. For their proper verification, the selected method of multicriteria decision making was used.

### 3. Classification of spatial solutions and evaluation criteria

In the simulation analysis, the following assumptions were made, conditioned by legal requirements and buildings existing on the plot:

- fixed area of the theatre room basic variant,
- changing usable area and development of theatre's technological part,
- lack of developing variants concerning construction of the building,
- the level of financing meeting the needs of each spatial variant (financing: the EU "FARE" fund),
- meeting formal and legal requirements including fire protection regulations and conversational conditions,
- enough plot area for additional structure area.

Chosen functional and spatial solutions subjected to the analysis and graphical interpretation of the evolutionary analysis of preparing variants of functional layouts are presented in table 1 and figure 2. Classification of the assumed assessment criteria are presented in table 2.

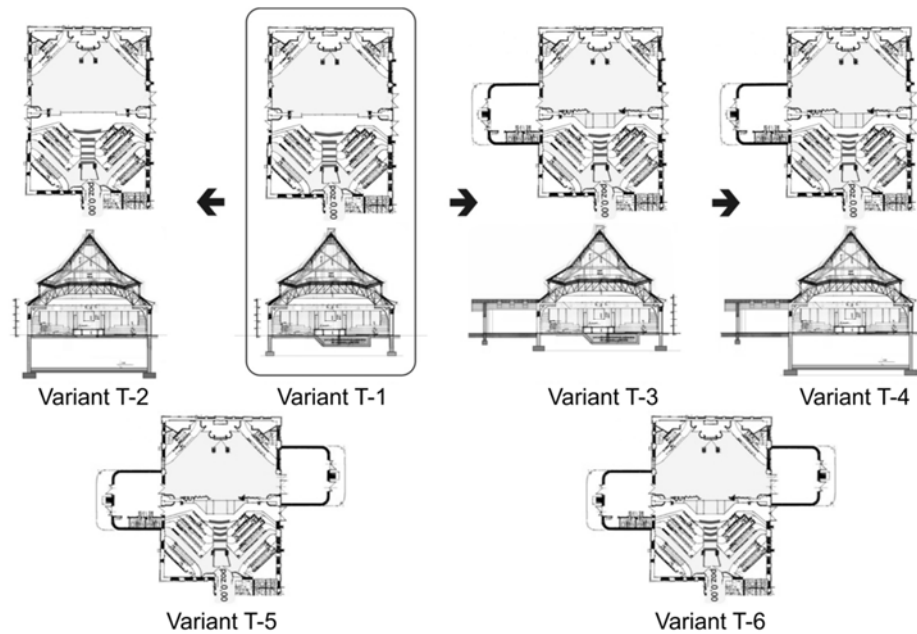
**Table 1.** Chosen functional and spatial solutions subjected to the analysis:

<b>Solution variant</b>	<b>Description of the subject matter</b>
<b>T-1</b>	Basic variant: theatre room with a stage and audience without technological back-up facilities
<b>T-2</b>	Variant with technological back-up facilities on the underground floor (mezzanine)
<b>T-3</b>	Variant with technological back-up facilities on the level of stage (side scene dock)
<b>T-4</b>	Variant with extended back-up facilities located on the underground floor (mezzanine) and on the level of the stage (side scene dock)
<b>T-5</b>	Theatre variant with the extended double technological back-up facilities on the level of stage (two side scene docks)
<b>T-6</b>	Variant with extended back-up facilities located on the underground floor (mezzanine) and on the level of the stage (two side scene docks)

**Table 2.** Classification of the assessment criteria

<b>Criteria/ subcriteria</b>	<b>Description of the subject matter</b>
<b>A</b>	Criterion of meeting the conservator's requirements
A1	Assessment of composition of the spatial form (at the angle of reference to the existing form as well as fitting in the existing landscape)
A2	Maintaining historical and cultural values
<b>B</b>	Adaptation to the usage requirements
B1	The scope of possibilities of using the building (artistic activities - repertoire scope: theatre, opera, concert hall, non-artistic activities: lecture hall, events for the for the faculty and outside organisers)
B2	Conditions of labour in implementation of artistic activities
B3	Relationship stage - audience with the technical back-up facilities with the social area
<b>C</b>	Security criterion
C1	The degree of complexity of the building construction
C2	The degree of difficulty of meeting the requirements of fire protection, including the permissible loads of the fire zones and required time of evacuation
C3	Accessibility for the rescue teams
<b>D</b>	Economic criterion
D1	The cost of construction of 1m <sup>2</sup> of area estimated based on the national average of the cost of constructing theatre buildings
D2	The estimated cost of exploitation assumed based on the arithmetical mean resulting from the average annual cost of maintenance of theatre structures in Poland (partially convergent with the B1 criterion)
<b>E</b>	Criterion of technical relation of the building with the surroundings
E1	Communication connection with the existing routes for pedestrian and motor traffic
E2	Possibility of introducing convenient parking space
E3	Connection to the existing technical infrastructure (water and sewage system, electric power, telecommunication networks)





**Figure 2.** Chosen functional and spatial solutions subjected to the analysis [6].

#### 4. Application of modified EA FAHP modelling

The Chang's method is currently one of the most popular methods of the extent analysis (Extent Analysis FAHP –EA FAHP), due to relatively simple course of calculations. [7]. The disadvantage of the Chang's method is the possibility of obtaining, as a result of calculations, zero partial values of weight vectors occurring in the case of significant differences in scores. They decide on the rank of the assessed elements (criteria, subcriteria, variants). That is why the occurrence of zero values leads to incorrect results. Elimination of zeros requires extending the scale by the fuzzy values of modal values in the range from 1 to max. 7. For the criteria expressed normatively it seems enough [8] but in the case of criteria containing the aspect, for instance, of aesthetic assessment or not liable to accurate rules it definitely is not enough. Modification of the EA FAHP method was proposed by Wang and Elhag reporting different way of calculating the synthetic measure index of the scores eliminating occurrence of zero values [9].

The analysis of the decision-making process using the EA FAHP method with retaining the original recording of the Saaty's AHP method proceeds in the following way (“~” the amounts expressed using fuzzy values):

**Step 1.** Hierarchization of the decision-making process in result of its decomposition, in which the objective function is preferential arrangement of the variants (figure 3).

**Step 2.** Assessment through comparing criteria of the same level (subcriteria, variants) in pairs in the presence of a criterion of higher level. The comparison is made using the relative scale of dominance assessments obtained as a result of transformation of the original Saaty's scale through fuzzification of crisp values (table 3).

As a result of comparison in pairs we obtain square matrix of scores:

$$\tilde{A} = \left( \tilde{a}_{ij} \right)_{n \times n} = \begin{bmatrix} \tilde{a}_{11} = (1, 1, 1) & \tilde{a}_{12} = (l_{12}, m_{12}, u_{12}) & \dots & \tilde{a}_{1n} = (l_{1n}, m_{1n}, u_{1n}) \\ \tilde{a}_{21} = (l_{21}, m_{21}, u_{21}) & \tilde{a}_{22} = (1, 1, 1) & \dots & \tilde{a}_{2n} = (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} = (l_{n1}, m_{n1}, u_{n1}) & \tilde{a}_{n2} = (l_{n2}, m_{n2}, u_{n2}) & \dots & \tilde{a}_{nn} = (1, 1, 1) \end{bmatrix} \quad (1)$$

while:

$$\tilde{a}_{ji} = \left[ \tilde{a}_{ij} \right]^{-1} = (l_{ij}, m_{ij}, u_{ij})^{-1} = \left( \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}} \right) \quad (2)$$

**Step 3.** Classification of the decision variants. Due to the lack of fuzzy values equivalents, in order to perform approximate verification of scores allocation accuracy, the consistency ratio CR was used, calculated for modal values of fuzzy values used as scores in the matrices of comparisons in pairs. Then the CR is calculated as in the classic AHP method:

$$CR = \frac{\lambda_{\max} - n}{(n-1) \cdot RI} < 0,1 \quad (3)$$

where:

$\lambda_{\max}$  - maximum value of the matrix A own vector, created from the modal values of fuzzy values,

n - matrix A rank,

RI - random index of inconsistency of grading, according to table 4.

The obtained value of the consistency ratio CR ranged from 0 to 0.089.

**Step 4.** Calculation of the synthetic measure index  $\tilde{S}_i$  according to the interchangeable formula proposed by Wang and Elhag [9]:

$$\tilde{S}_i = \frac{\tilde{RS}_i}{\sum_{j=1}^n \tilde{RS}_j} = \left( \frac{\sum_{j=1}^n l_{ij}}{\sum_{j=1}^n l_{ij} + \sum_{k=1, k \neq i}^n \sum_{j=1}^n u_{kj}}, \frac{\sum_{j=1}^n m_{ij}}{\sum_{k=1, k \neq i}^n \sum_{j=1}^n m_{kj}}, \frac{\sum_{j=1}^n u_{ij}}{\sum_{j=1}^n u_{ij} + \sum_{k=1, k \neq i}^n \sum_{j=1}^n l_{kj}} \right) \quad (4)$$

where:

$\tilde{RS}_i$  - sum of values of the  $i^{\text{th}}$  line of the partial scores matrix.

**Step 5.** Components of weight vector expressed using non-fuzzy values (in a form of crisp values) are obtained according to the formula:

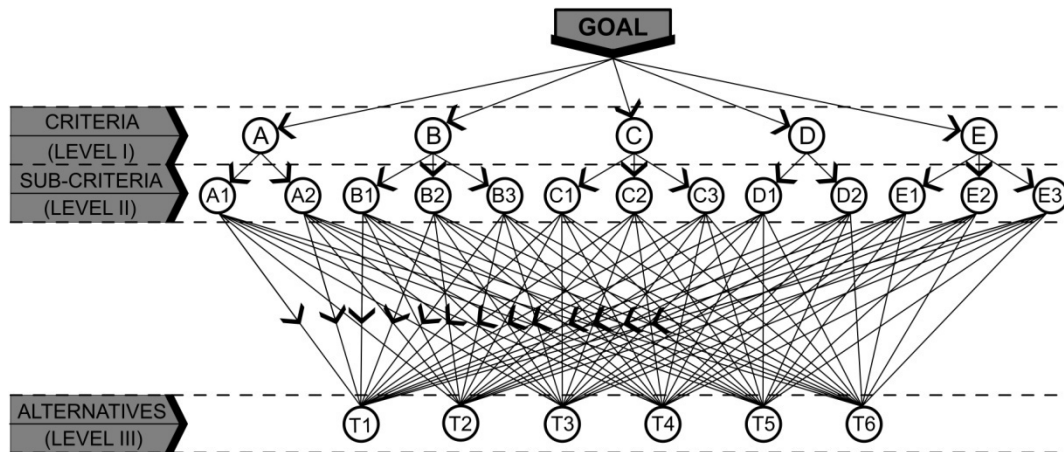
$$W_i = S_i \left( \tilde{S}_i \right) = \frac{l_i + m_i + u_i}{3} \quad (5)$$

finally, after normalization:

$$W'_i = \frac{S_i}{\sum_{i=1}^n S_i} \quad (6)$$

Partial priorities vectors comprise local values (in the range of the level of the score) of criteria, subcriteria and variants. The value of the global vector for the variants is calculated through multiplication of local values of variants with local values of subcriteria for certain criterion (from the

level III to I) and then adding them up. The conduct is analogical to the one in the AHP method. Values of global scores were presented in table 5.



**Figure 3.** Hierarchic model of the analysed decision-making process

**Table 3.** The original Saaty's scale of the dominance assessments with the corresponding fuzzy values

Dominance scale / linguistic assessment	Corresponding fuzzy value	The opposite	The opposite of the fuzzy value
1 / equivalence	(1, 1, 1) for those that are equivalent	1/1	(1, 1, 1)
2	(1, 2, 4)	1/2	(1/4, 1/2, 1)
3 / minor dominance	(1, 3, 5)	1/3	(1/5, 1/3, 1)
4	(2, 4, 6)	1/4	(1/6, 1/4, 1/2)
5 / strong dominance	(3, 5, 7)	1/5	(1/7, 1/5, 1/3)
6	(4, 6, 8)	1/6	(1/8, 1/6, 1/4)
7 / very strong dominance	(5, 7, 9)	1/7	(1/9, 1/7, 1/5)
8	(6, 8, 9)	1/8	(1/9, 1/8, 1/6)
9 / absolute dominance	(7, 9, 9)	1/9	(1/9, 1/9, 1/7)

2, 4, 6, 8 with the corresponding fuzzy values they comprise the intermediate values

**Table 4.** Values of the RI index depending on n [10].

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

## 5. Summary and conclusions

The presented algorithm of solving complex decision-making processes using the modified EA FAHP method enabled assessment and selection of the most flexible functional and spatial variant of a multi-functional building in an adapted space. After analysing the main criteria and subcriteria, the B criterion proved to be decisive (0.436), assigned to the range of adaptation to building usage requirements. Whereas, the lowest score obtained the D criterion (0.051) that is responsible for the economic aspect of the entire undertaking (table 5). The ratio of weights of criteria B and D reflects the majority of such structures implementations, which most important is the space for artistic activities, while the cost of execution can be considered a secondary issue.

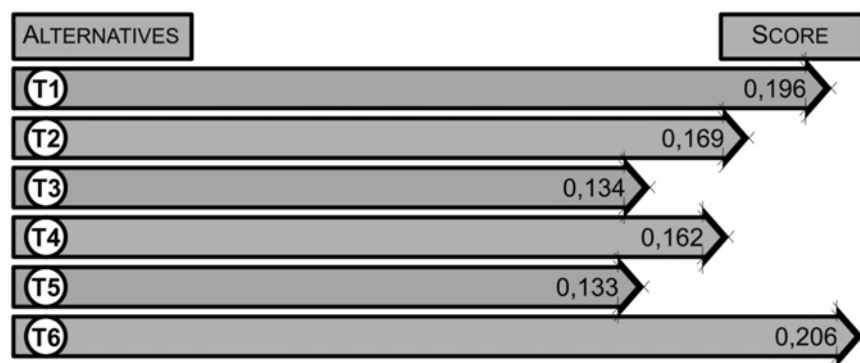
Out of the variants of functional and spatial solutions (T1 – T6), the highest score obtained variant T6(0.206) – building with extended back-up facilities placed on underground floor (mezzanine) and double on the level of the stage (two side scene docks) (figure 4). Such high score results from the possibility of wide spectrum of implementation of artistic undertakings.



**Table 5.** The end form of the ranking of variants (values of partial priorities vectors and global vector W were rounded to three decimal places).

Variant	Value of partial priorities vectors of the criteria / subcriteria / variants assessment														Global value of variants
	A		B			C			D		E				
	0.196		0.436			0.230			0.051		0.088				
	A1 0.857	A2 0.143	B1 0.649	B2 0.234	B3 0.117	C1 0.418	C2 0.418	C3 0.165	D1 0.143	D2 0.875	E1 0.311	E2 0.076	E3 0.613		
T1	0.313	0.073	0.042	0.032	0.127	0.077	0.413	0.405	0.451	0.451	0.389	0.400	0.400	0.196	
T2	0.313	0.095	0.086	0.050	0.063	0.268	0.195	0.268	0.258	0.258	0.267	0.092	0.092	0.169	
T3	0.182	0.256	0.086	0.069	0.062	0.100	0.193	0.156	0.127	0.127	0.183	0.269	0.269	0.134	
T4	0.066	0.473	0.190	0.170	0.031	0.447	0.104	0.080	0.068	0.068	0.085	0.051	0.051	0.162	
T5	0.063	0.052	0.190	0.233	0.344	0.054	0.058	0.044	0.049	0.049	0.046	0.156	0.156	0.133	
T6	0.063	0.052	0.405	0.447	0.373	0.054	0.037	0.029	0.046	0.046	0.031	0.033	0.033	0.206	

Variants T5 (0.133) and T3 (0.134) obtained the lowest scores. Low score of variant T5, especially in comparison to variant T6, results from the lack of underground floor (criterion B), while in comparison to other variants, from low score in the safety C criteria and economic D criterion (what was not compensated fully with the high score according to the B criterion (possibility of adapting to usage conditions), like in the case of variant T6. Whereas, the T3 variant owes its low position mainly to the low score in the B criterion. The obtained results confirm assumptions adopted by the designer focusing on such creation of space that would allow the best possible conditions for organising spectacles.

**Figure 4.** Graphic interpretation of variants ranking (values of the global priorities vector).

The results obtained with the analysis using the modified EA FAHP method led to the following conclusions:

- the results indicate efficacy and full usefulness of the method,

- the method allows broader representation of the decision-making process through its transposition into a readable hierarchic structure, it also introduces simple comparison in pairs and approximate verification of scores accuracy,
- using fuzzy values allows to include the hard-to-measure factors, the uncertainty in the precision of making comparisons in pairs, and group assessments,
- using the modified method allows to use full score scale what is especially important in the case of criteria that are not normatively expressed and that depend on subjective perception of a decision-maker (e.g. aesthetics),
- the results enable quantitative ranking and allow determination of differences in preferences of individual variants by means of numbers,
- the method comprises an excellent and innovative tool, especially when deciding is connected to high financial risk and responsibility for human life and health,
- however, it requires high input of labour (elaboration at least in the construction range of designs for all the assessed variants), thus, it is necessary to search for simplified solutions (indicator) that would, however, allow to take into consideration individual character (lack of repeatability) of each investment.

These advantages allow full usage of designer's or designing team's knowledge and enable solving issues of high degree of complexity.

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