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The choice of variant technologies and materials supported by multicriteria methods and an assessment of variants with graphic profiles of criteria*

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Abstract

On many occasions, while executing construction projects, we must solve dilemmas regarding the use of specific technologies and materials. Depending on the purpose and future functions of a building, as well as expectations of its occupants and users, different solutions might prove to be superior. Numerous factors influence the final decision, hence effective tools which support the decision-making process are needed. When many parameters must be taken into consideration, multi-criteria analysis methods appear to be the best choice.

Having analyzed many such cases, the author has developed her own approach, which includes a graphic template corresponding to the importance of criteria assigned to a planned building project, to which profiles of the variants submitted to an assessment are compared. The discussed case is the roof structure over a machine shop, in which – due to the intended production – harsh ambient conditions are expected. An analysis was made to evaluate three variants of the roof cover, i.e. based on timber, steel or prestressed ferroconcrete girders.

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Keywords: building materials, variants of a development project, multi-criteria methods, graphic method

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1. Introduction

For making an assessment of a building project, it is crucial to prepare and analyze several variants of its execution. These variants are reviewed with respect to technical and technological possibilities, economic aspects, conditions in which a planned structure will function and other project- or site-specific circumstances. While developing a plan of a new building, it is necessary to take into account the relevant standards and directives, regulations governing technical aspects of the building craft, work safety and hygiene, fire protection, and many other norms, regulations, technical approvals, technical documentation, administrative decisions, etc. All structural elements of buildings must be designed in compliance with the above regulations. The total costs of a building enterprise are composed of the site-specific costs of the construction, costs of transport, costs of hiring qualified employees and specialist equipment and others. The future maintenance expenses, on the other hand, can be affected by the necessary conservation works [1].

Making a decision about the shape of a construction project in such a complicated situation calls for an efficient decision-making support method, which will take into account all significant aspects and, on the other hand, which will allow the analyst to identify the variant that will ensure the best fulfillment of all important criteria. A great number of available methods and techniques serving for analysis of variant solutions make it difficult to choose the one that will guarantee the expected effect. When selecting a decision-making support method, one should pay attention to such features as the method's readability, quality and ability to provide verifiable results as well as the mathematical apparatus involved. Subjectivity of an assessment is another aspect that should be considered because many of the broadly used methods are based on opinions provided by experts and persons engaged in the performance of a given project. Hence, their assessment and the final evaluation can be burdened by some error, which should be kept in mind. Subjectivity is most often encountered in methods which deal with non-measurable quality factors [2].

2. Methodology of computational methods

An analysis of criteria carried out in order to evaluate variant solutions includes events and processes of diverse nature. They can belong to so-called measurable factors, the assessment of which according to a given criterion is quite obvious. In turn, two approaches can be taken to obtain an objective evaluation of non-measurable factors. One is a descriptive method, while the other one requires a numerical measurement scale. The two approaches can be included in any of a number of multi-criteria methods, e.g. MCE analysis, AHP, Indicator Methods. It is, however, difficult to determine to what extent the final outcome is laden with error. One can only assume that the final results are acceptable approximations, but they still need additional interpretation before a rational decision can be made. Each of the mentioned methods has unique characteristics, which have an impact on the final result [3, 4].

Let us see how computational methods are applied in practice, taking the simplest one, such as the MCE Analysis, as an example. The foundation for the MCE method is to determine weights and to assess the importance of criteria as well as the degree to which they said criteria are satisfied by subsequent variants of the project. These assessments are made based on field interviews as well as surveys completed by experts and persons engaged in the planning of a given project. Surveys must be designed in a way that allows one to order data and to determine a scale for the evaluated criteria [1, 2]. The MCE (Multi-Criterial Evaluation) analysis is applied to support a decision-making process when the number of analyzed criteria ranges from a few to over a dozen. The first step in any analysis is to define criteria which will lead to the achievement of the aim. The criteria occurring in the MCE analysis can be divided into two groups: hard criteria (so-called constraints, barriers, obstacles) and soft criteria (parameters, factors) [3, 5]. First, variants that do not fulfill the principal requirements (constraints) are discarded from our analysis, which therefore deals only with the criteria identified as having the character of factors. The suitability of the analyzed variants [2, 6] is derived from the following (1) formula:

$$S = \sum_{i=1}^{n} w_i x_i \tag{1}$$

where: S – suitability, w – weight of a criterion, x – value of a parameter, i – a criterion, n – number of criteria.
In the following section we will present an example of such calculations.

3. Description of variant solutions

An engineer who is working on a plan of a roof cover on girders must take into consideration several factors. To choose the optimal solution of a girder, both technical aspects must be considered and the construction work involved as well as the conditions in which the planned structure will function in the future. In our case, we will analyze three solutions: timber, pretensioned prestressed concrete and steel girders.

Timber girders (v1) are a known solution although they are not widely popular in engineering practice. Because of the heterogeneous structure of wood and limited dimensions of wooden elements, timber girders have not been adopted to building larger span roofs. An alternative is to use glued timber elements, which have superior properties. The solution considered as a possible one in the analyzed case is a girder made from glued timber. The manufacturing technology, whereby glued timber construction elements are made in specialized manufacturing plants, makes it possible to obtain a relatively homogenous structure of the material and good protection from external factors. Compared with solid timber, glued timber shows better strength characteristics and allows for construction of larger spans [7, 8, 9].

The second analyzed solution is a girder made of pretensioned prestressed concrete (v2). This is an element with very good strength properties and is able to transfer large loads. The specific technological and construction characteristics as well as the fact that such elements are manufactured in specialized pre-fabrication factories make pretension prestressed concrete girders one of the most resistant elements to environmental conditions [10, 11, 12].

The third analyzed solution is a steel girder (3). Steel structures compared with the ones made from other materials, i.e. timber, ferroconcrete, present significant homogeneity of mechanical and physical properties. Customized production of steel elements enables one to achieve a very high level of precision. Moreover, the light weight of steel constructions lowers the transportation costs, and the assembly does not require the use of cranes with high hoisting capacity [13, 14, 15].

The advantages and disadvantages of the discussed solutions could substantiate a decision of selecting one over the other two variants. However, a decision based on lists of pros and cons might not be a completely informed one. In many cases, the final decision can also depend on the ability of a structure of transfer loads, the ease of transport or a short assembly time. Other decisive factors could be the cost of raising the construction or the expense of future maintenance. Clearly, there are many factors involved in making a decision about which specific solution should be implemented, and frequently the decision-making process must be aided by appropriate techniques and tools. When facing such difficult decisions, help can be sought in mathematical methods, of which multi-criteria analyses are worth attention [16].

4. Methodology of the approach – a case analysis

When selecting a decision-making support method, one should pay attention to such features as the method's readability, quality and ability to provide verifiable results as well as the mathematical apparatus involved.

Adequate preparation of data for analysis is equally important. In the following case, the assessment criteria applied to analyze the available variants were as follows:

A. Construction criteria
   - A1. Easy transport and construction works,
   - A2. Ability to transfer large loads,
   - A3. Easy and quick assembly,
   - A4. Light weight of the structure,

B. Economic criteria
   - B1. Costs of manufacturing the element,
   - B2. Transportation costs,
   - B3. Costs of assembly and construction works,

C. Environmental criteria
   - C1. Resistance of the structure to variable humidity,
   - C2. Resistance to low temperatures,

C3. Resistance to biological corrosion factors,
C4. Fire resistance,
C5. Recyclability,

D. Exploitation criteria
D1. Resistance to shock impact,
D2. Easy repairs and reinforcement,
D3. Frequency of repairs and maintenance works,
D4. Treatments to protect the structure from external conditions,

E. Other criteria
E1. The machine floor accessible to large vehicles,
E2. Production operations possible at low temperatures,
E3. Response to vibrations.

Weights assigned to subsequent criteria were determined by taking into account the specific character of the planned building and the operating conditions for the girders. The importance of the main criteria as well as the meaning of the subcriteria was assessed. Their value is comprised in an interval of 0-1. For the assessment of how individual criteria were satisfied by the analyzed solutions, a 0 to 6 scale was adopted, where 0 meant a given criterion was not satisfied at all, while 6 stood for the maximum fulfillment of this criterion. The calculations are set in Table 1. Because the roof will cover a machine floor in an industrial plant, high value was assigned to the environmental conditions and the exploitation factors in which the elements will work.

Table 1 Specification of values of weights of the main criteria and subcriteria

Criteria	Subcriteria	Main weights	Weights	Value
A	a1	0,12	0,07	0,008
	a2	0,12	0,18	0,022
	a3	0,12	0,35	0,042
	a4	0,12	0,4	0,048
B	b1	0,14	0,22	0,031
	b2	0,14	0,36	0,050
	b3	0,14	0,42	0,059
C	c1	0,29	0,14	0,041
	c2	0,29	0,15	0,044
	c3	0,29	0,17	0,049
	c4	0,29	0,24	0,07
	c5	0,29	0,30	0,087
D	d1	0,4	0,11	0,044
	d2	0,4	0,27	**0,108**
	d3	0,4	0,29	**0,116**
	d4	0,4	0,33	**0,132**
E	e1	0,05	0,26	0,013
	e2	0,05	0,32	0,016
	e3	0,05	0,42	0,021

The calculations demonstrate that the most important subcriteria, which can be decisive in selecting the type of roof girders, are the following ones: repairs and the need to protect the structure against the environmental conditions which can affect it negatively (d2, d3, d4). Table 2 shows how the variant solutions satisfy these criteria.

Table 2 Assessment of the analyzed variants (v1, v2, v3)

Subcriteria			Assessment v1		Assessment v2		Assessment v3
	Weights	v1		v2		v3	
a1	0,008	2	0,016	0,5	0,004	3	0,024
a2	0,022	2,5	0,055	0,7	0,0154	3,5	0,077
a3	0,042	3	0,126	1	0,042	4	0,168
a4	0,048	3	0,144	2	0,096	4,5	0,216
b1	0,031	1	0,031	1	0,031	3	0,093
b2	0,050	3	0,15	2	0,1	4,5	0,225
b3	0,059	4	0,236	2,5	0,1475	5	0,295
c1	0,041	3	0,123	1,5	0,0615	1	0,041
c2	0,044	3	0,132	1,5	0,066	1	0,044
c3	0,049	4	0,196	2	0,098	1,5	0,0735
c4	0,07	5	0,35	2,5	0,175	2	0,14
c5	0,087	5	**0,435**	3	0,261	3	0,261
d1	0,044	2	0,088	2	0,088	1,5	0,066
d2	0,108	3	**0,324**	3	**0,324**	2,5	0,27
d3	0,116	3	**0,348**	4,5	**0,522**	3	**0,348**
d4	0,132	5	0,66	4,5	0,594	3	**0,396**
e1	0,013	1	0,013	0,5	0,0065	1	0,013
e2	0,016	2	0,032	1	0,016	1,5	0,024
e3	0,021	3	0,063	1,5	0,0315	1,5	0,0315
		sum	3,522		2,6794		2,806

The analysis performed as explained above proved that the highest sum of points was scored by the timber structure – v1. However, the result may not satisfy completely the investor’s expectations, because the final evaluation is affected by the points scored for other, less significant criteria. Moreover, the analysis of the assessment results can be a laborious task, which is made even more difficult due to a large number of generated data. An alternative approach proposed in this paper is the methodology elaborated by the author, which relies on a graphical assessment of the variants with the help of profiles.

4. The graphic analysis method

Multi-criteria analytical methods are mathematical methods. Irrespective of the method we choose, it is necessary to apply some mathematical apparatus, which entails more or less complicated calculations. Time-consuming and laborious computations often discourage persons interested in the support of decision-making processes. Having to analyze computation results in the form of a series of figures creates an obstacle to the implementation of these methods in real life. For this reason, while analyzing variants of different solutions associated with the execution of development projects in the building industry, I elaborated a method based on a comparison of the shape of graphic profiles of variants with a template of criteria determined for a given solution.

In order to obtain a template of criteria, we arrange the main criteria in the order of increasing value of weights. Within groups of main criteria, we arrange the subcriteria according to the same principle.

The order was arranged according to the assigned weights: A – 0.12, B – 0.14, C – 0.29; D – 0.4 and, finally, other criteria, specific for given plan and construction circumstances. The same applies to the sequence of subcriteria. Table 3 sets the analyzed types of roof girders arranged according to the above principle.

Table 3. Data for the preparation of a template of criteria

Criteria	Subcriteria	Weights
A	a1	0,008
	a2	0,022
	a3	0,042
	a4	0,048
B	b1	0,031
	b2	0,050
	b3	0,059
C	c1	0,041
	c2	0,044
	c3	0,049
	c4	0,070
	c5	0,087
D	d1	0,044
	d2	0,108
	d3	0,116
	d4	0,132
E	e1	0,013
	e2	0,016
	e3	0,021

The next step is to make an assessment of the variant solutions and to construct profiles for each of the analyzed variants. The data must be arranged according to the same order as adopted for the development of the template.

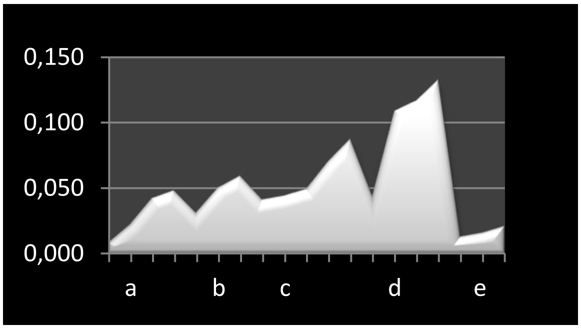

Fig. 1. Template of criteria

In our case, the task is to make an assessment of three solutions of the construction of a roof girder: timber (v1), pretensioned and prestressed concrete (2) and steel one (3). The assessment results are presented in table 4, while the templates are illustrated in Figs 2,3,4,5.

Table 4 Assessment of the analyzed criteria – data for the profiles

Criteria	v1	v2	v3
a1	0,016	0,004	0,024
a2	0,055	0,0154	0,077
a3	0,126	0,042	0,168
a4	0,144	0,096	0,216
b1	0,031	0,031	0,093
b2	0,150	0,100	0,225
b3	0,236	0,1475	0,295

c1	0,123	0,0615	0,041
c2	0,132	0,066	0,044
c3	0,196	0,098	0,0735
c4	0,35	0,175	0,14
c5	0,435	0,261	0,261
d1	0,088	0,088	0,066
d2	0,324	0,324	0,27
d3	0,348	0,522	0,348
d4	0,66	0,594	0,396
e1	0,013	0,0065	0,013
e2	0,032	0,016	0,024
e3	0,063	0,0315	0,0315

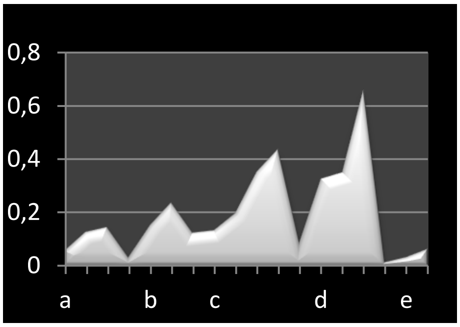

Fig. 2. Profile of variant 1

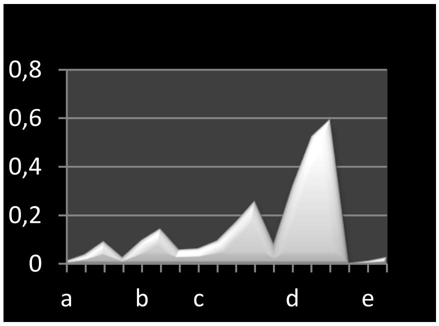

Fig.3. Profile of variant 2

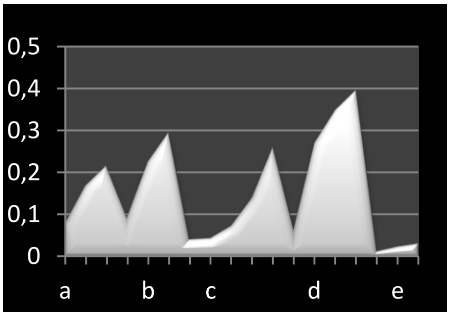

Fig.4. Profile of variant 3

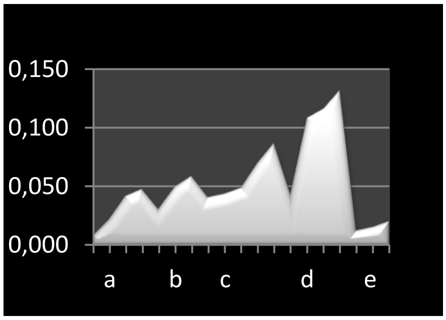

Fig.5. Template of criteria

By comparing the shapes of the graphs, it becomes evident that the profile of variant 1 is most closely congruent with the template of criteria. This comparison verifies the results obtained with the computational method. However, the graphic analysis method takes into account the specific nature of a given solution and evaluates the most important features of each variant owing to the comparison made at this stage. Also, an analysis of graphic profiles of solutions is simpler and more user-friendly, and its outcome seems more reliable.

5. Summary and conclusions

While preparing for an execution of a building project, it is extremely important to analyze thoroughly various aspects of the planned undertaking. One of the problems that a building engineer or architect must solve, in cooperation with the developer, is the choice of structural and material solutions. Analysis of available technologies should be carried out with the use of decision-making support methods.

The case approach presented in this article demonstrates the applicability of mathematical analytic methods to the assessment of variant construction solutions, and compares such methods to the one developed by the author and used for completing various types of construction projects. The application of the graphic interpretation of solutions prepared in the form of profiles of variants subsequently compared with the template of criteria is a more use-friendly method of interpretation of analytical results than other multi-criteria methods. The ready-made profiles can be used by architects, building engineers and developers, who increasingly appreciate this solution.

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