Chapter 6

# Multiple Criteria Evaluation of Assembling Buildings from Steel Frame Structures

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79858

**Abstract**

Steel frame structures are often used in the construction of public and industrial buildings. They are used for all types of slope roofs; walls of newly built public and industrial buildings; load bearing structures; and roofs of renovated buildings. The process of assembling buildings from steel frame structures should be analysed as an integrated process influenced by factors such as construction materials and machinery used, the qualification level of construction workers, complexity of work, and available finance. It is necessary to find a rational technological design solution for assembling buildings from steel frame structures by conducting a multiple criteria analysis. The analysis provides a possibility to evaluate the engineering considerations and find unequivocal solutions. The rational alternative of a complex process of assembling buildings from steel frame structures was found through multiple criteria analysis and multiple criteria evaluation. In multiple criteria, evaluation of technological solutions for assembling buildings from steel frame structures by pairwise comparison method the criteria by significance are distributed as follows: durability is the most important criterion in the evaluation of alternatives; the price of a part of assembly process; construction workers' qualification level (category); mechanisation level of a part of assembling process; and complexity of assembling work are less important criteria.

**Keywords:** steel frame structure, technological solution, assembling work, network model, multiple criteria evaluation

## 1. Introduction

Modern construction industry is developing rapidly, thanks to new technologies. Steel frame structures are often used in the construction of public and industrial buildings. Buildings from insulated metal structures have the following advantages: excellent architectural look that meets the strictest requirements for modern buildings; simple and fast mounting enabling to

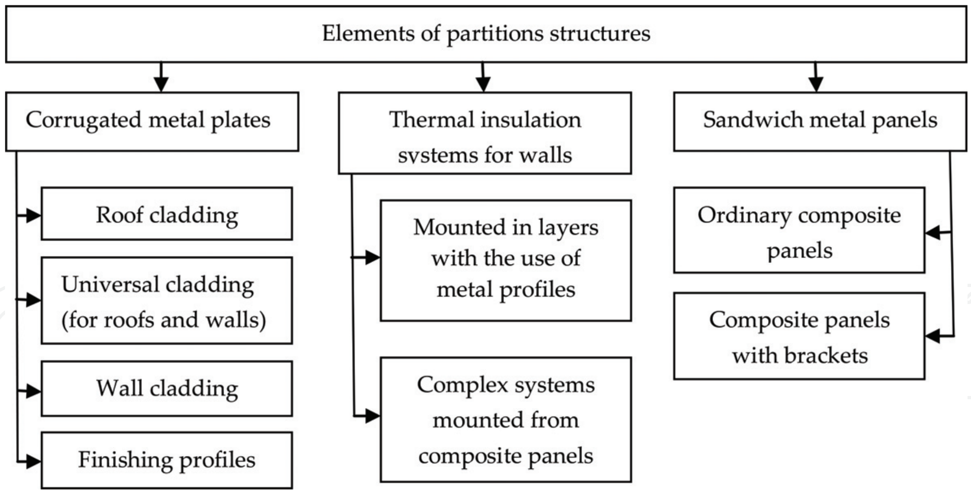


**Figure 1.** Elements of partition structures.

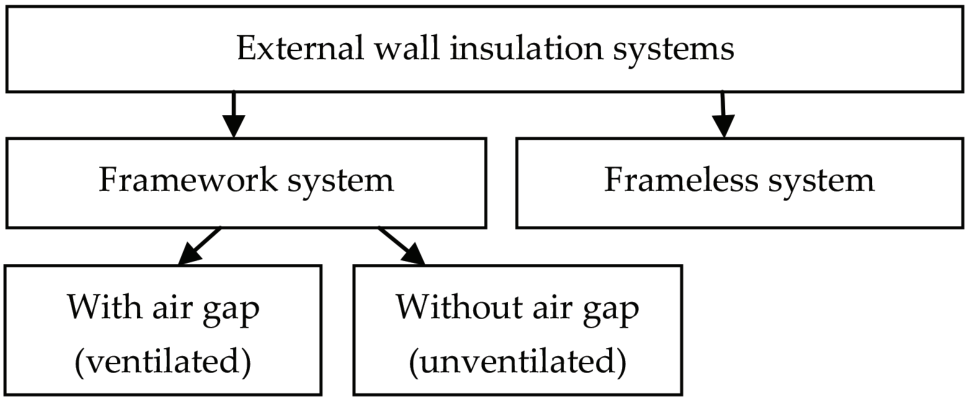


**Figure 2.** External wall insulation systems.

erect a big building in a very short time calculated in months or even in weeks; good thermal-technical characteristics as modern metal structures enable to avoid thermal bridging at connections, and the thickness of heat insulating layer is selected according to applicable standards; good operation characteristics as reliable elements ensure the required tightness of the building, and metal elements are protected from corrosion by more than one layer of coating.

Modern steel frames are made of the following components: bearing metal elements of the structural framework (partitions and load bearing elements); roof, roof-wall and wall cladding; partition insulation packages (thermal insulation, noise insulation, wind and vapour barriers). Elements of partitions structures and external wall insulation systems are presented in **Figures 1** and **2**.

Methods of insulating walls of existing industrial buildings:

- Thermal insulating layer is fixed directly to the façade that is afterward finished by reinforced (with mesh or fibre) plastering. It is a frameless insulation system.
- Wood or metal studs are fixed to the wall, thermal insulation is placed into the spaces between studs, and various finishing panels are fixed to the studwork. It is a framework system (ventilated).

- Finished elements made of joined thermal insulation, and finishing layers (composite panels) are fixed to the wall.

## 2. Designing the network model for alternative mounting solutions in steel frame building

### 2.1. Making combinations of complex processes

The main stages for designing network models for steel frame building are as follows:

- making combinations of complex processes used in steel frame building;
- finding possible alternatives of partial processes in steel frame building;
- finding technological links between the alternatives of partial processes in steel frame building;
- drawing networks for steel frame building technology.

In terms of system approach, steel frame building is a complex process made of various partial (work) processes that can be completed by different working methods, which are determined by work object characteristics, construction materials, work tools, equipment, number of workers and their qualification. Each of the above factors is described by certain technical and economic indicators [1–3].

The complex process of steel frame building can be divided into the following partial technological processes: F—steel frame mounting, B—mounting of bearing structures (beams and trusses); I—installing connections (**Figure 3**).

The complex process of wall and roof erection can be divided into the following partial technological processes: P—mounting of purlins, IL—inner layer mounting, S—sound insulation mounting, T—thermal insulation mounting, W—wind insulation mounting, and FL—finishing layer (**Figures 4** and **5**).

### 2.2. Alternatives of partial processes in steel frame building

The analysis of steel frame building reveals many technological systems of this complex process. Many alternative solutions can be found by changing work methods. Different work methods result from the change of building structures, work tolls and mechanisms used.

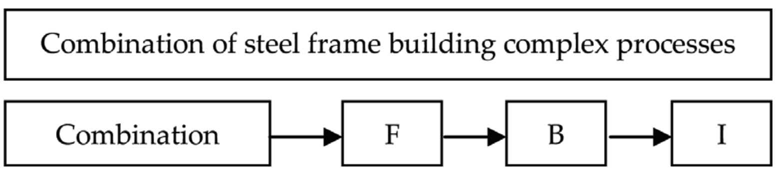


**Figure 3.** Diagram of steel frame building complex process combination.

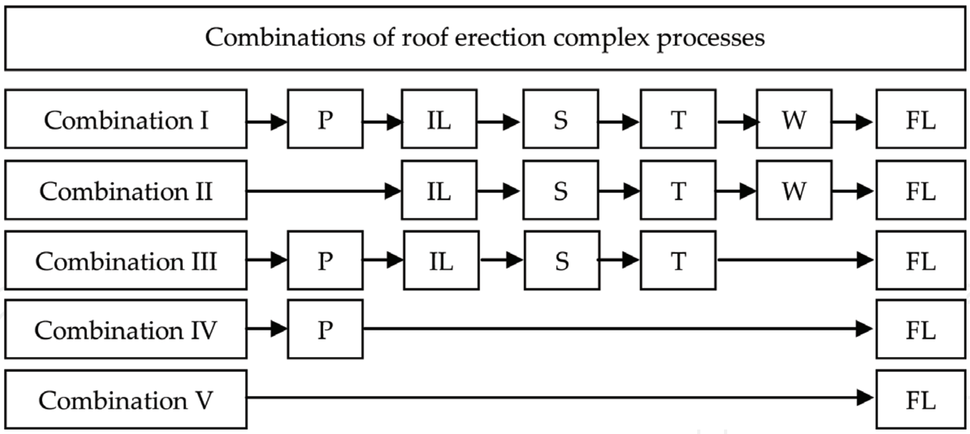


**Figure 4.** Diagram of wall erection complex process combination.

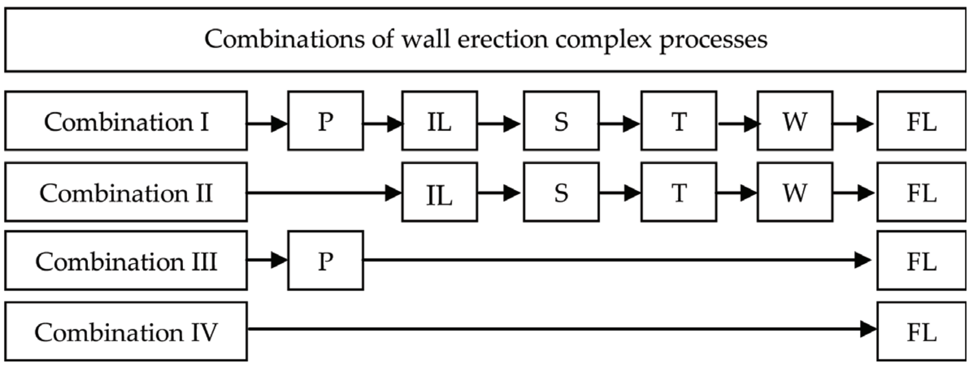


**Figure 5.** Diagram of roof erection complex process combination.

Available alternatives of work processes used for the building steel framework are presented in **Table 1**.

### 2.3. Technological links between partial processes in steel frame building and network model design

Network modelling of construction processes significantly improves operations management, work culture and efficiency, shortens the commissioning term, and reduces construction costs [4].

The method is beneficial only if the following conditions are met: well-organised data collection, transfer and processing; expedient system of decision-making and task delegation to operators supported by computerised network and specialists highly competent in network planning and control.

The graphical representation of the variety of works in a construction process with marked technological and organisational links is called a network model [5]. The network model with computed space, time, and technological parameters is called a network. Alternatives of separate (partial) technological processes and dependency relationship between them must be

| Partial process alternative code | Title of partial process in steel frame building: partial process alternatives (short description) |
|---|---|
| | Mounting of columns: |
| F1 | Manually, bolted connections |
| F2 | Manually, welding |
| F3 | Mechanically, crane lifting, bolted connections |
| F4 | Mechanically, crane lifting, welding |
| F5 | Mechanically, hoist lifting, bolted connections |
| F6 | Mechanically, hoist lifting, welding |
| | Mounting of bearing structures: |
| B1 | Mounting beams manually, bolted connections |
| B2 | Mounting beams manually, welding |
| B3 | Mounting beams, crane lifting, bolted connections |
| B4 | Mounting beams, crane lifting, welding |
| B5 | Mounting beams, hoist lifting, bolted connections |
| B6 | Mounting beams, hoist lifting, welding |
| B7 | Mounting trusses, hoist lifting, assembling on the ground |
| B8 | Mounting trusses at designated height, hoist lifting |
| B9 | Mounting trusses, assembling on the ground, crane lifting |
| B10 | Mounting trusses at designated height, crane lifting |
| | Making connections: |
| I1 | Making connections manually, welding |
| I2 | Making connections manually, bolting |
| I3 | Making connections, hoist lifting, bolting |
| I4 | Making connections, hoist lifting, bolting |
| I5 | Making connections, crane lifting, welding |
| I6 | Making connections, crane lifting, bolting |

**Table 1.** Alternatives of work processes used for the building a metal framework.

set in the design of network technological model. Technological links are made for three building alternatives: steel frame (**Figure 6**), roof (**Figure 7**), and wall (**Figure 8**).

Technological network model for the complex installation of steel frame is shown in **Figure 9**.

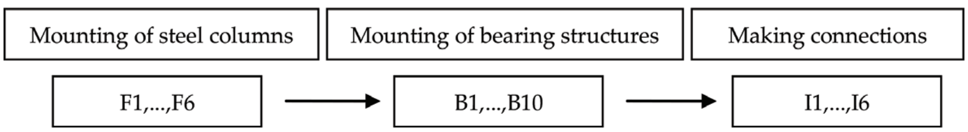


**Figure 6.** Technological links between partial processes in steel frame building.

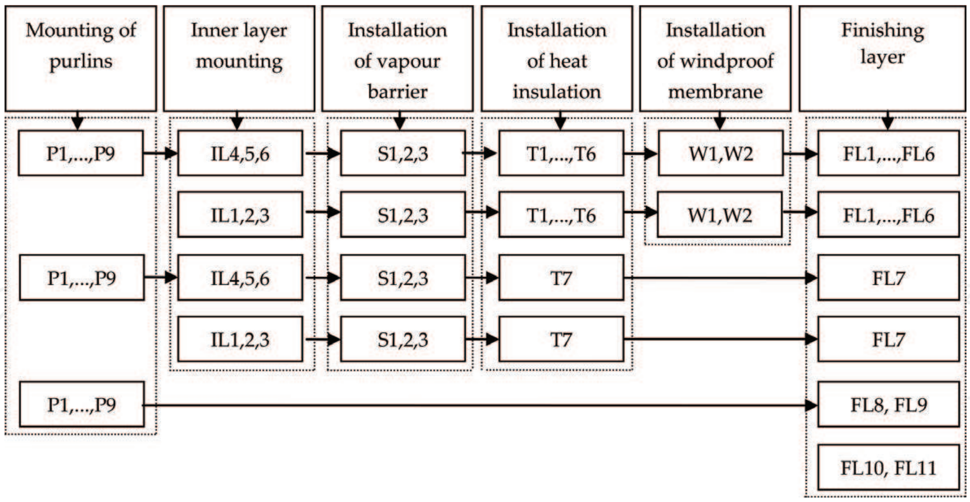


**Figure 7.** Technological links between partial processes in roof building.

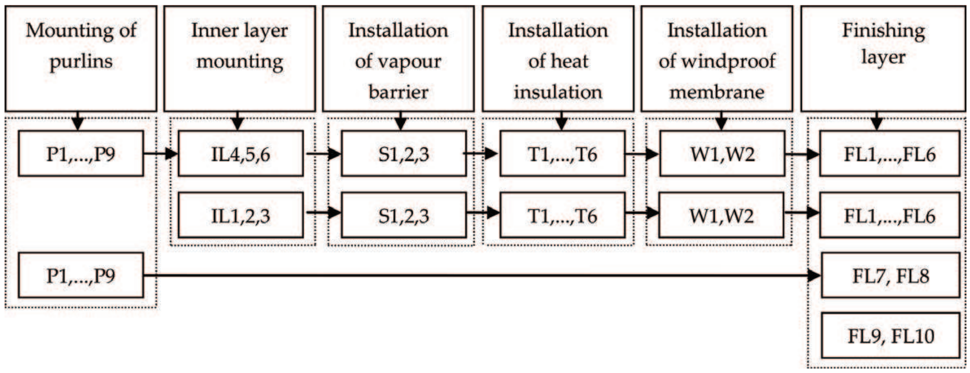


**Figure 8.** Technological links between partial processes in wall building.

## 3. Major principles of construction technological decision optimisation

Applicable technological and other project decision optimisation methods used in projection and construction processes could be divided into two major groups: applied mathematics and systemic-technical analysis methods. A great deal of construction organisation tasks could be solved by using mathematic statistics (correlation and regression analysis), theory of chances, mathematic programming, 'gambling' theory, multi-criteria optimisation and other methods.

The selection of optimisation method depends on the task character which is solved, the possessed source information and frequently it requires local interpretation. While solving practical construction optimisation tasks, most frequently only one (the most important) of several economic criteria is chosen (e.g. total construction price, object construction or separate pieces of construction per one solid metre (1 $m^3$) price, the revenue received, the greatest turnover, etc.). The significance of the criterion selected is very important. It shows that one of the criterions mentioned (e.g. revenue received), which is selected by the interested party, is

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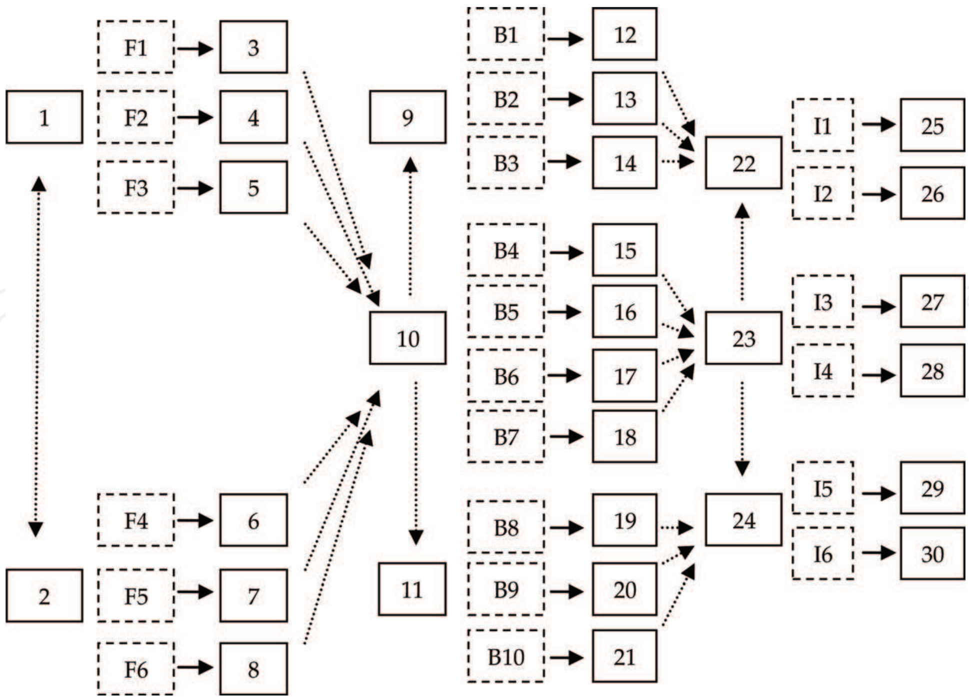


**Figure 9.** Technological network model for the complex installation of steel frame.

much more important than the other one, for example, total construction price. Therefore, to be concrete, it shows the significance of one criterion to the interested party in comparison with the rest, which are left as less significant or insignificant.

The significance of the criterion could be determined by employing statistical, expert opinion-based methods, even comparison, and entropy methods. These methods help to determine various theoretical, subjective, and complex values of great significance that are further used in the decision optimisation counting processes. By counting values, it is meant that the interested party could choose the criterion (they think) of the greatest significance.

Moreover, the client is frequently much more interested not in the price, but in other criteria such as construction duration, aesthetics, harmfulness to the health of the materials used, longevity, convenience to exploit, comfortability, and so on. So any construction technological decisions could be described and optimised according to the following system of criteria evaluation, where the criteria could be expressed by the indices of technological economy and quality characteristics. For this purpose, methods of multi-criteria decisions are used [1, 2].

It can be argued that each of the decision optimisation method mentioned has its own advantages and disadvantages. Moreover, each of them could be used to solve the tasks of specific constructions groups. They help to create various optimisation models of theoretical objects, technological or work processes like technological net models (alternative decisions, resources, dynamic, duration), mathematic models (shape of matrices, equation systems, various probability models), expert level systems, decision support systems and many others models.

Researches of modelling and optimisation were founded based on the applied mathematics method, economics, system theory, cybernetics, and in the sphere of counting technological science and its integration. While optimising technological construction processes, it is advisable to apply the theoretical principles of system methodology on the grounds that, nowadays, the technological projection methods which are used do not correspond to the requirements of effective decision-making. It could be noted that one of the major disadvantages are the decisions are accepted synonymically, without any preliminary examination and evaluation of the model of construction process technology and many the like multi-criteria evaluation [3]. While solving the any technological decision optimisation problem, it is necessary to perform three major steps of construction process systemic examination (**Figure 10**).

While modelling the construction composite process technological decisions, it is advisable to accept these main preconditions:

- all possible variations of complex process technologic decisions have to be constructed. Moreover, technological connections and partial variants of the processes (partial alternative decisions) have to be established;
- while forming the net model, consisting of partial process technological variants, it is necessary to take a precondition that only one of many other partial process technological variants will be implemented;
- every partial process has got its individual time duration, which is either technologically based or depends on the work expenditure.

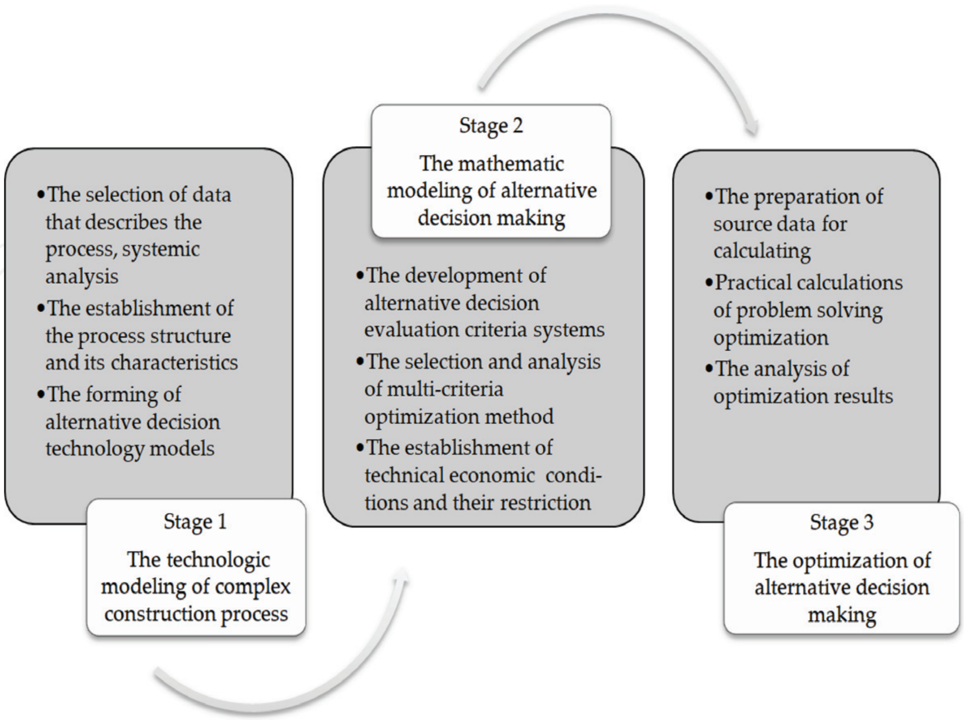


**Figure 10.** The steps of construction composite process systemic examination.

| Alternative decisions | Evaluation criteria | | | |
|---|---|---|---|---|
| | $K_1$ | $K_2$ | … | $K_n$ |
| $a_1$ | $x_{11}$ | $x_{12}$ | | $x_{1n}$ |
| $a_2$ | $x_{21}$ | $x_{22}$ | | $x_{2n}$ |
| … | … | … | … | … |
| $a_m$ | $x_{m1}$ | $x_{m2}$ | | $x_{mn}$ |

**Table 2.** The source data matrix *P*.

So while creating the mathematical model of alternative technological decision-making, it is advisable to define the set of the compared alternative decisions and their evaluation criteria. In that case, the source data matrix *P*, presented in **Table 2**, is prepared.

The source data matrix *P* most often consists of different units of measurement. For this reason, the matrix should be normalised, that is, it has to be transformed into the anti-dimensioned unit or sizes. Knowing the aims of the solution and applying the methods of normalisation, various normalised values of indices are obtained, which play the key role in other stages of solution in the field of multi-criteria optimisation.

The quantitative and qualitative characteristics are shown in **Table 3**.

| Criteria | Unit of measurement | Definition |
|---|---|---|
| The price of a part of assembly process | (EUR/unit of measurement) | Price (in EUR) per conventional unit of measure of the analysed partial process alternative |
| The qualification level of construction workers | Category | Evaluation criterion indicating the workers' ability to do the work of the relevant complexity |
| Mechanisation level of a part of assembling process | % | |
| Durability | In year | Life cycle of steel frames |
| Complexity of assembling work | In points | Complexity of work evaluation criterion |

**Table 3.** Alternatives of work processes used for the building a metal framework.

## 4. Major rudiments of applying the method of proximity to an ideal point used to evaluate the technology

The main essence of the multi-criteria evaluation method is the formation of generalised composed criterion. It is based on the comparison deviation of the criteria from so-called the ideal criteria, consisting of the best variant criteria being analysed. By applying the method and $K_{bit}$ criteria, it is advisable to consider that each variant of the task problem solving utility function has the tendency to monotonously increase or monotonously decrease, that is, the larger value of any indices, the better it is or worse for less of the same index value. It depends on the fact whether the utility function increases or decreases. Indices have to be either cardinal or ordinal. If there are ordinal (qualitative) indices, they should be quantified. Besides, significance values should be determined, otherwise, they all are accepted as being equals. The application algorithm of the method of proximity to an ideal point, estimating the significance of the criteria, is presented in **Figure 11**.

The matrix $P$ of alternative architectural decisions is created. There could also be criteria either grouped or ungrouped. The matrix normalisation is being done, according to the formula:

$$\overline{x_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \tag{1}$$

where $i = \overline{1, m}$; $j = \overline{1, n}$.

If the significance of the subjective or theoretical ($\overline{q}$ or $q_t$) criteria is known, then the vector column multiplied by the normalised matrix corresponding column.

$$\text{Weighed matrix is obtained } \overline{P^*} = \left[\overline{P}\right] \cdot [q] \tag{2}$$

If there are no values of significance, then $\overline{P} = \overline{P^*}$ ($\overline{P}$ matrix is compared to the weighed matrix), that is, we take the precondition that entire alternative solution criteria are equally important. The ideal positive variant is being established:

$$a^+ = \left\{ \left[ \left( \max_i f_{ij}/j \in I \right), \left( \min_j f_{ij}/j \in I' \atop j \right) \right] /i = \overline{1, m} \right\} = \{f_1^+, f_2^+, \dots, f_n^+\} \tag{3}$$

where $I$ is the indices of ratio (maximising), which possesses the highest values.

The ideal negative variant is being established:

$$a^- = \left\{ \left[ \left( \min_i f_{ij}/j \in I \right), \left( \max_j f_{ij}/j \in I' \atop j \right) \right] /i = \overline{1, m} \right\} = \{f_1^-, f_2^-, \dots, f_n^-\} \tag{4}$$

The difference (distance) between real and ideal positive variant is being found:

$$L_i^+ = \sqrt{\sum_{j=1}^{n} \left( f_{ij} - f_j^+ \right)^2} \tag{5}$$

where $a_i$ is the real variant, $a^+$ is the ideal positive variant, and $L_i^+$ is the positive distance.

The difference between real and ideal negative variant is being found:

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$$L_i^- = \sqrt{\sum_{j=1}^{n} \left(f_{ij} - f_j^-\right)^2} \tag{6}$$

$K_{bit,i}$ calculation of values (each alternative value is found):

$$K_{bit,\,i} = \frac{L_i^-}{L_i^+ + L_i^-}, \text{ when } \forall_i; \;\; i = \overline{1, m}. \tag{7}$$

$0 \leq K_{bit} \leq 1$, besides,

$$K_{bit,\,i} = \begin{Bmatrix} 1, jei & a_i = a^+ \\ 0, jei & a_i = a^- \end{Bmatrix} \tag{8}$$

The best (the most rational) architectural solution will become the one, which $K_{bit}$ value will be max ($K_{bit,i}$ = max). Using the values generates the priority sequence utility degree establishment. The value of the variant being tested is compared to the value of the ideal variant.

$$N_i = \frac{K_{bit,\,i}}{K_{bit,\,\max}} \cdot 100\% \tag{9}$$

The method of proximity to an ideal point can be applied to find the most effective engineering solution alternative.

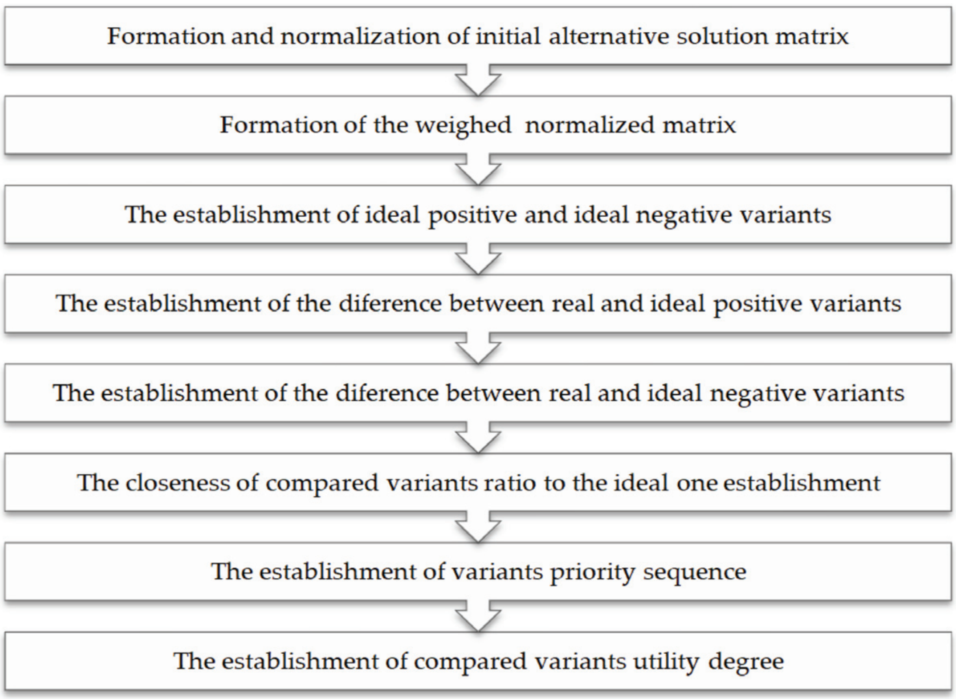


**Figure 11.** Application algorithm of the method of proximity to an ideal point.

## 5. Multi-criteria evaluation of alternative solutions in steel frame building

The rational alternative for steel frame building is found from the diagram presented in **Figure 12**.

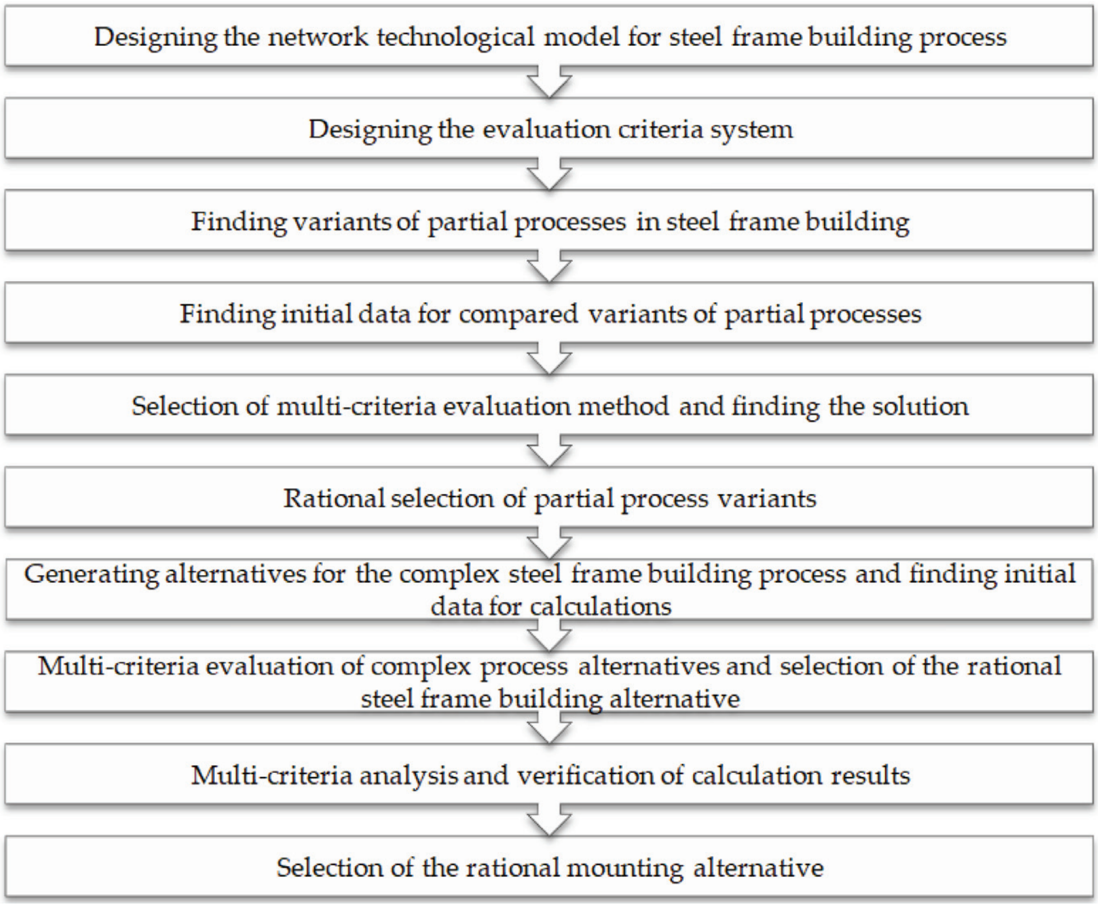


**Figure 12.** Algorithm for the selection of the rational alternative for the complex process.



## 6. Conclusions

Taking into consideration the factors that affect the rationality of steel frame building process solutions, it is feasible to do the technological modelling of multi-criteria evaluation of alternative buildings.

A criteria system for the evaluation of alternative partial processes must be designed in order to find the rational steel frame building alternative. Criteria values and importance may be subsequently adjusted taking priorities and the current situation into account.

In practice, it is possible to find the most rational technological alternatives for metal framework, roof and wall structures separately with the help of network technological model and multi-criteria analysis of steel frame building solutions.

In multiple criteria evaluation of technological solutions for assembling buildings from steel frame structures by pairwise comparison method, the criteria by significance are distributed as follows: durability is the most important criterion in the evaluation of alternatives; the price (EUR/unit of measurement) of a part of assembly process; construction workers' qualification level (category); mechanisation level of a part of assembling process (%); and complexity of assembling work (in points) are less important criteria.



## Conflict of interest

The author declares no conflict of interest.

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