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Multiple-criteria decision analysis of the transformable low-rise building technological construction process

Elena Korol [1] and *Alexander* Pleshivcev [1*]

[1]Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

Abstract. One of the promising areas of improving the constructive and technological solutions of low-rise buildings is the fast-erecting systems. Increase of efficiency of the erection process of these systems can be implemented on the basis of the results of a multiple-criteria analysis of the organizational and technological processes by decomposing it into separate technological processes and operations and assessing their impact on the overall building erection process. The structure of a multiple-criteria model includes such indexes as the duration of separate technological processes and the operation of the overground part in the building erection. The subject of the study – technological operation parameters during the installation process of the transformable low-rise buildings with sandwich panel walls. Based on selection, classification, and systematization of the factors determining the resultant indicators, the relationship between the effective indicator (function) and the factors (arguments) was studied and their forms of dependence were determined based on the linkage modeling. The calculation of the influence of various factors and their assessment on the change in value of the effective indicator was performed. The selected factors include several parameters in the form of technological operations, which are expressed in hours. The simulation of technological process using a multiple-criteria model allows determining the efficiency reserves of the developed technology. Its application in installation control processes could help the construction industry with transformable low-rise building erection.

1 Introduction

The development of low-rise housing construction is an actual task related to ensuring the comfort of various social layers of the population. Its solution is in the plane of balanced interests of all participants of the investment and construction process and consumers of construction products.

Modern low-rise building construction technologies are developing in the direction of construction time reducing. The ratio between labor costs in the factory and at the construction site is changing toward to installation works reduction during the process of building erection. The fast-erecting construction technology means a significant reduction of labor costs at the construction site in comparison with the factory works.

* Corresponding author: perspektiva-aa@mail.ru

For construction effective form organization of alternative structural and technological systems, it is necessary to have an information about the composition and structure of construction process technological parameters. The technological parameters of low-rise building erection are significantly different in dependence of the chosen design and technological solution.

Low-rise buildings have a difference in their factory readiness. It affects the processability of construction process. The container-type buildings have the least installation specific labor intensity – 0,1-0,3 man-h./m^2. For buildings of collapsible construction (modular buildings from block-containers, rack-panel and frame-panel construction), this interval is 0,7-0,9 man-h./m^2. The folding type buildings (transformable) hold an intermediate position. They have in 2-3 times more laboriousness in comparison with the container type buildings, but much less than the collapsible ones [1]. The degree of assembly of buildings significantly affects their manufacturability [2,3]. The transformable type low-rise buildings are the least studied [4,5].

2 Materials and methods

Rational technological parameters for low-rise buildings with the walls made of sandwich panels erecting are determined by the method of timing measurements. Its main structural and technological elements are (fig.1): roof slope panels (1, 2, 9); lengthwise wall panels (3, 18); end half-panels (4); overlap half-panels (5); hinge joint rod-pins (7); ridge knot joint rod-pin (8); ridge knot joint loops (10, 11); semi-pediments (12); vertical rod-pin (13); roof slope angular bearing elements (14); jack for turnbuckle connection (15); turnbuckles (16); end half-panels (17); overlap half-panels (20).

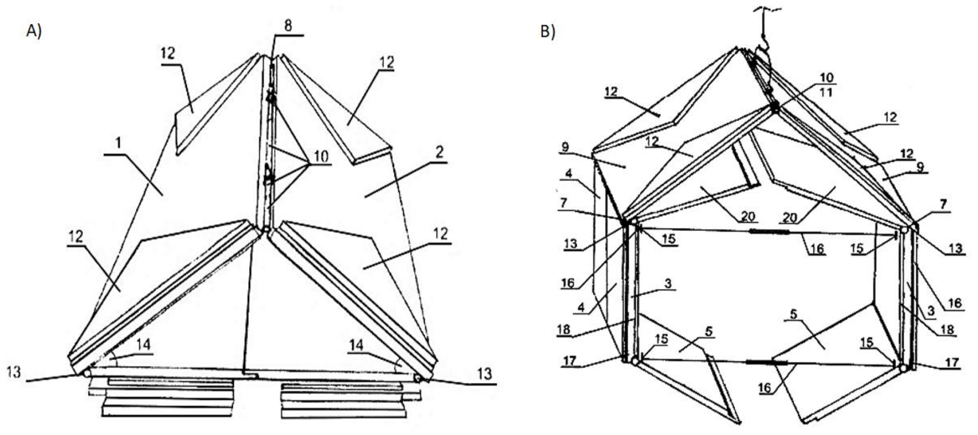

Fig. 1. The transformation process of a fast-erecting low-rise building. A) Folded building. B) The building during the installation process.

Based on the overground part erection technological process analysis of the transformable low-rise buildings with sandwich panel walls, the selection of factors for the model construction was carried out. It was determined that the resulting duration indicator of the overground part erection (Z) can be influenced by specific factors such as duration of the separate technological processes and operations (X1, X2...X11). The initial data for the correlation analysis are presented in Table 1.

Table 1. Initial data for the correlation analysis.

Transformable low-rise bulding (TLB) №	Overall assembling time	Factors										
		Preparing for assembling	TLB packages storing on the foundation	TLB packages unpacking	Roof ridge detail assembling	Roof ridge detail installation	TLB construction elements fixing	Roof ridge detail alignment and unsliging	Panel joints sealing	Turnbuckle connection to lengthwise walls	Leghtwise walls tying up with a turnbuckle	Corner bearing elements installation
	Z	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
1	8,64	1,26	0,54	0,35	0,30	0,33	0,21	0,20	2,33	0,19	0,41	2,52
2	8,87	1,27	0,59	0,37	0,38	0,35	0,18	0,22	2,36	0,20	0,42	2,53
3	8,88	1,28	0,57	0,39	0,39	0,34	0,22	0,19	2,34	0,19	0,45	2,52
4	8,91	1,29	0,59	0,40	0,38	0,36	0,19	0,21	2,33	0,19	0,40	2,57
5	8,77	1,28	0,58	0,36	0,31	0,37	0,22	0,18	2,32	0,22	0,42	2,51
6	8,87	1,26	0,57	0,37	0,38	0,33	0,20	0,19	2,37	0,19	0,45	2,56
7	8,81	1,30	0,56	0,36	0,39	0,35	0,19	0,20	2,32	0,17	0,43	2,54
8	8,73	1,29	0,57	0,37	0,40	0,38	0,21	0,22	2,35	0,16	0,43	2,35
9	8,81	1,29	0,58	0,35	0,39	0,37	0,18	0,19	2,37	0,19	0,44	2,58
10	8,88	1,31	0,53	0,45	0,40	0,34	0,20	0,20	2,36	0,14	0,43	2,52
11	8,90	1,27	0,57	0,37	0,38	0,38	0,20	0,20	2,35	0,18	0,42	2,58
12	8,91	1,30	0,57	0,35	0,41	0,39	0,22	0,18	2,38	0,20	0,45	2,56
13	8,71	1,31	0,56	0,38	0,40	0,35	0,21	0,21	2,36	0,18	0,41	2,34
14	8,73	1,29	0,58	0,36	0,42	0,38	0,18	0,20	2,33	0,19	0,47	2,33
15	8,70	1,28	0,59	0,40	0,40	0,32	0,20	0,20	2,35	0,21	0,44	2,31

A combination of these factors was used to construct a model and a multiple-criteria analysis, which makes possible to assess the significance of factors. To assess the significance of factors in the general equation, the multiple-criteria analysis methodology was used. The main purpose of multiple regression is to build a model with a huge number of factors, parallelly separately determining the influence of each of them and a combined effect on the modeled indicator.

Above factors correspond to the inclusion conditions of the general model, since all of them are quantitatively measurable. Also, during the study, factors were checked for intercorrelation and the presence of a functional measure.

The results of the calculation are summarized in Table 2.

The analysis of the data in Table 2 shows that the closest correlation Z with such factors as X1, X2, X4, X5, X8, X10, X11. On the other hand, with factors X3, X6, X7, X9 the correlation link is weak, and these factors will be excluded from the general model.

In accordance with Table 3, three combinations with different factor sets were considered.

The quality of the model can be verified with three formal criteria: the determination coefficient, the Fisher’s and the Student's criteria. The results of calculations for each of three variants are given in Table 3.

Table 2. Correlation analysis of the data.

	Z	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Z	1,00											
X1	0,5	1,00										
X2	0,4	-0,23	1,00									
X3	0,2	0,35	-0,28	1,00								
X4	0,9	0,55	0,19	0,28	1,00							
X5	0,43	0,29	0,25	-0,42	-0,42	1,00						
X6	-0,2	0,01	-0,32	0,01	0,01	-0,01	1,00					
X7	0	0,09	-0,06	0,11	0,11	0,09	-0,37	1,00				
X8	0,57	0,11	-0,02	0,07	0,07	0,07	0,01	-0,07	1,00			
X9	-0,1	-0,47	0,66	-0,54	-0,54	0,06	0,12	-0,47	-0,12	1,00		
X10	0,43	0,02	0,13	-0,14	-0,14	0,14	-0,08	-0,45	0,25	0,06	1,00	
X11	0,64	0,10	0,42	-0,10	-0,10	0,20	-0,32	-0,03	0,42	0,02	0,05	1,00

Table 3. Multiple-criteria analysis results.

Combination set №	Factors in combination	Fisher's criterion	Coefficient of determination	Student's criterion		Multiple regression
1	X1, X2, X4, X5, X8, X10, X11	21,536	0,955	Z	1,851539	0,977
				X1	1,169259	
				X2	1,556910	
				X4	1,296695	
				X5	0,564879	
				X8	1,275544	
				X10	0,175783	
				X11	0,342405	
2	X2, X4, X5, X8, X10, X11	20,476	0,939	Z	4,205309	0,969
				X2	1,188710	
				X4	1,820343	
				X5	0,795318	
				X8	1,115212	
				X10	-0,224910	
				X11	0,195782	
3	X1, X2, X5, X8, X10, X11	12,304	0,902	Z	-2,485330	0,950
				X1	2,695870	
				X2	1,949752	
				X5	0,349926	
				X8	1,650847	
				X10	1,194153	
				X11	0,892405	

3 Results

Using the methodology of multiple-criteria analysis, mathematical models are constructed for the low-rise transformed buildings erecting technological process, based on factor importance ranking. These factors are affect the resulting indicator of the technological process duration of the transformable low-rise building construction.

The main task of the regression analysis is to find an assessment of the unknown regression ratios of the model in a *n* volume sampling.

As a result of the multiple-criteria analysis (Table 3) in combination №1 next values of the ratio assessment are obtained:

$\beta_{1Z} = 1{,}85;$ $\beta_{5X5} = 0{,}56;$
$\beta_{2X1} = 1{,}17;$ $\beta_{6X8} = 1{,}28;$
$\beta_{3X2} = 1{,}56;$ $\beta_{7X10} = 0{,}18;$
$\beta_{4X4} = 1{,}30;$ $\beta_{8X11} = 0{,}34.$

Thus, the model can be represented with the next equation (1):

$$Z' = 1{,}85 + 1{,}17 \cdot X1 + 1{,}56 \cdot X2 + 1{,}3 \cdot X4 + 0{,}56 \cdot X5 + \\ +1{,}28 \cdot X8 + 0{,}18 \cdot X10 + 0{,}34 \cdot X11 \quad (1)$$

After the same operations with combination №2 we get next ratios:

$\beta_{1Z} = 4{,}21;$ $\beta_{5X8} = 1{,}12;$
$\beta_{2X2} = 1{,}19;$ $\beta_{6X10} = -0{,}22;$
$\beta_{3X4} = 1{,}82;$ $\beta_{7X11} = 0{,}20.$
$\beta_{4X5} = 0{,}80;$

The model has the following form (2):

$$Z' = 4{,}21 + 1{,}19 \cdot X2 + 1{,}82 \cdot X4 + 0{,}80 \cdot X5 + 1{,}12 \cdot X8 - \\ -0{,}22 \cdot X10 + 0{,}20 \cdot X11 \quad (2)$$

Combination №3 ratios:

$\beta_{1Z} = 2{,}48;$ $\beta_{5X8} = 1{,}65;$
$\beta_{2X2} = 2{,}69;$ $\beta_{6X10} = 1{,}19;$
$\beta_{3X4} = 1{,}94;$ $\beta_{7X11} = 0{,}89.$
$\beta_{4X5} = 0{,}34;$

And the model (3):

$$Z' = 2{,}48 + 2{,}69 \cdot X2 + 1{,}94 \cdot X4 + 0{,}34 \cdot X5 + 1{,}65 \cdot X8 + \\ +0{,}19 \cdot X10 + 0{,}89 \cdot X11 \quad (3)$$

Analysis of the data in Table 3 (the determination coefficient, the Fisher's and the Student's criteria) shows that the first variant can be used for the best quality model formation.

4 Discussion

The duration of a construction site is one of the most important manufacturability indicators [6,7]. It is the duration summarization of the simple technological processes and operations which the building erection process consists of. In technology developing based on a new design and technological solutions, it is necessary to analyze and establish the structure and sequence of technological processes and operations, to identify the most significant and affecting one on the process of the building erection.

To implement the research practice tasks, multiple-criteria modeling methods are applied [8,9]. They allow to estimate the influence of each factor on the resultant indicator. From a practical point of view, using a multiple-criteria model allows to manage the building erection processes and improve its efficiency.

Conclusion

In accordance with the analysis, the factors influencing the resulting indicator of the low-rise building assembling duration were selected. To assess the significance of factors, the multiple-criteria analysis methodology was used.

Performed intercorrelation and established factor functional connection checks were used for a model construction. Its quality was verified with three formal criteria: the coefficient of determination – 0.955; the Fisher's criterion – 21.356 and the Student's criterion, the coefficient of multiple regression – 0.977.

Modeling of the low-rise building construction process can reveal the reserves of manufacturability increasing and its integration can improve the efficiency of installation processes.

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