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COSTS OF FACADE SYSTEMS EXECUTION

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Cost estimation in the pre-design phase both for the contractor as well as the investor is an important aspect from the point of view of budget planning for a construction project. Constantly growing commercial market, especially the one of public utility constructions, makes the contractor, at the stage of development the design concept, initially estimate the cost of the facade, e.g. office buildings, commercial buildings, etc., which are most often implemented in the form of aluminum-glass facades or ventilated elevations. The valuation of facade systems is of an individual calculation nature, which makes the process complicated, time-consuming, and requiring a high cost estimation work. The authors suggest using a model for estimating the cost of facade systems with the use of statistical methods based on multiple and stepwise regression. The data base used to form statistical models is the result of quantitative-qualitative research of the design and cost documentation of completed public facilities. Basing on the obtained information, the factors that shape the costs of construction façade systems were identified; which then constitute the input variables to the suggested cost estimation models.

Keywords: facade systems, cost estimation, statistical models, multiple regression, stepwise regression

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1. Introduction

The main activities undertaken during the implementation of construction projects are primarily the ones based on a reliable estimation of costs, time and quality of construction works for a given project. Moreover, additional factors such as safety of construction works, application of innovative solutions, mutual cooperation between participants of a construction project are the constituents, that affect its success. The literature on the subject is widely discussed regarding the analysis of construction projects, both relating to costs [7], [15], [21], implementation time, security conducting construction works [5], or planning issues and organization [7]. However, one of the key issues of the proper functioning and management of a given construction project are the aspects related to correct and reliable cost calculation. Implementation of the above allows you to plan in advance the project budget and related financial flows, reflecting the correct stages of construction works in their duration. Cost calculations are important elements of every construction venture from the point of view of both the investor and the contractor. Proper calculation of implementation costs is not only the data concerning the size of the projected budget, but also information about the profitability of a given venture for the investor. Therefore already at the stage of project preparation, an indicative estimation based on a pre-design research, including a feasibility study, is made. The basis for the correct calculation of the construction project implementation costs is the analysis of conceptual, construction, executive and design documentation. The development of conceptual construction project makes it possible to estimate its implementation costs. Such estimates allow the investor to plan financial outlays intended for the implementation of a given project. Accurate graphic and descriptive study of the projects affects the level of detail of the cost calculations performed at a later stage.

The purpose of the article is an attempt to estimate the cost of making facade systems of public facilities using mathematical models, in particular multiple and progressive regression. The range of costs analyzed includes the costs of labor, equipment and construction materials. The data used to create the regression functions were developed by the authors based on the analysis of project, executive and cost estimate documentation of public facilities construction. A data base containing the main factors affecting the costs of public facilities facade systems has been developed. The implemented elevation systems were in the form of aluminum-glass and ventilated facades.

2. COST CALCULATION OF CONSTRUCTING FACADE SYSTEMS AND VENTILATED ELEVATIONS

Performing the cost calculation of the facade systems and ventilated elevations is a complicated and, above all, time-consuming task. It also requires high workload of the estimator. The level of valuation complexity is affected by the construction, architectural and system data, as well as parameters related to production, or assembly method (technology). The enterprises calculating the costs of making aluminum-glass facades and ventilated elevations prepare such calculations usually in the form of individual calculation. Contractor, preparing the valuation of facade implementation costs, not only calculates the prices of individual facade elements, but additionally verifies whether the design assumptions are feasible not only on the construction site, but also in the production plant. Therefore, the calculation of costs is based on knowledge and experience of the contractor. The contractor must approach each construction project individually, starting from the analysis of project documentation, as well as location of the undertaking in the context of a possible impact on additional costs of transport processes and the use of specialized construction equipment. The lack or incomplete knowledge of available aluminum facade systems, their solutions and availability among designers may result in many shortcomings or inaccuracies in the project documentation. In addition, no specific parameters or ironwork profile causes that for a potential contractor, complete analysis of data necessary for cost estimation, becomes a laborious task.

The cost of making the facade of public buildings in the form of aluminium-glass facades and ventilated facades is influenced by many factors. The basic costs are labor, equipment and construction materials. The cost of material for aluminum-glass facades is the cost of aluminum profiles forming the skeleton of the construction and glass as fillings. Depending on the type of individual glazing units and their technical characteristics, the price of such filling varies. This very important aspect was described, among others at work [12]. Ventilated facades, in turn, are the constructions in the form of, for example, an aluminum grate additionally filled with mineral wool, with external cladding in the form of composite panels, aluminum sheets or fiber-cement boards. The largest part of the costs incurred for ventilated facades is, above all, the type of external cladding used. In addition, the costs of facade systems are affected by the costs of labor and equipment. Assembly works are carried out by trained employees, using specialized equipment such as winches or suction cups for glass.

3. Regression models

The regression model is one of the statistical models by which you can examine the strength and dependence between individual variables. Thanks to statistical models it is possible to evaluate the prediction of a given variable by values correlated with another one. Regression models are widely used, among others when estimating costs, which is confirmed by publications [2], [9], [16], [19].
The general form adopted by the linear regression model for the dependent variable Y relative the set of explanatory variables $X_1, X_2, \ldots, X_{k+1}$ is shown by the following equation [1], [3].

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{k+1} X_{k+1} + E \tag{1.1}$$

where:
Y – explained variable, $\beta_0, \beta_1, \beta_2, \ldots, \beta_{k+1}$ – regression coefficients (structural parameters) of the equation model in the collection, $X_1, X_2, \ldots, X_{k+1}$ – explanatory variables or functions of explanatory variables, E – random factor.

To construct the regression model, the basic assumptions should be specified [1], [3].

- explanatory variables must show a relation to the variable which they will explain,
- explanatory variables should have an appropriate own volatility indicator,
- explanatory variables can not be interdependent,
- number of estimated parameters (k) of the equation, can not exceed the observation number (n).

Additional assumptions for the regression model describe a random factor (E) that indicates the lack of random elements correlation, their normal distribution, variance of components and their expected value.
The regression model is created for the database, observed for the variable value dependent Y and independent variables X. The model is built in such a way to achieve as little estimation error as possible. The estimation error is interpreted as a difference between real values obtained through observation and analysis of data, and corresponding predicted values. The errors arising during the regression analysis is the average square error (MSE) and the standard estimation error (s), i.e. root of MSE. The average square error is the adjustment of the regression surface to real data and is an unweighted estimator of the variance of the random component.

On the other hand, the measure of adjustment of the regression surface, which reflects both the set dependent and independent data is the multiple determination coefficient R^2. This coefficient takes values from the range <0;1> which means that for the value equal to 1, the regression function in 100% explains the variability of the explained variable Y.

4. AN EXAMPLE OF USING REGRESSION MODELS TO ESTIMATE THE COST OF FACADE SYSTEMS IMPLEMENTATION OF PUBLIC UTILITY BUILDINGS

4.1. DATA AND ASSUMPTIONS ADOPTED FOR THE MODEL

16 factors of independent model variables and one dependent variable (output), i.e. the cost of the facade, were proposed to construct the cost prediction model. The authors assumed that all identified factors affect the costs of facade systems. These are the basic parameters characterizing the given object and the material from which the facade of the public building will be made. The mentioned factors were discussed in detail by the authors in their publication [13]. The developed database for 61 cases of public facilities, served to construct the model.
The factors are presented in Table 1.

Table 1. Factors shaping the costs of facade construction

No.	Factors	Designation	Value
1.	Function of the building	X_1	Office building Service and commercial building 0%
2.	Total area of the analyzed facade	X_2	m^2
3.	Height of the building	X_3	m
4.	Shape of the building	X_4	Rectangle Polygon
5.	Level of complexity	X_5	Low Medium High
6.	Posst and beam facade	X_6	Not occurs Occurs
7.	Semi-structural facade	X_7	Not occurs Occurs
8.	Fire protection facade	X_8	Not occurs Occurs
9.	Ventilated facade – composite panels	X_9	% in relations to the entire analyzed area
10.	Ventilated facade – fiber cement board	X_{10}	% in relations to the entire analyzed area
11.	Glass – emalit	X_{11}	% in relations to the entire analyzed area
12.	Single-chamber combined glass	X_{12}	% in relations to the entire analyzed area

13.	Double-chamber combined glass	X_{13}	% in relations to the entire analyzed area
14.	Doors	X_{14}	% in relations to the entire analyzed area
15.	Windows	X_{15}	% in relations to the entire analyzed area
16.	Location of the building	X_{16}	In the city centre Oustside the city centre Extra-urban area

Before proceeding with regression modeling, all collected cases were described by general features, technical parameters and factors affecting calculation of the price of facade systems, which were then coded in a standardized way.

The coding method is shown in Table 2. For all the variables of a hard to measure character, pseudo-fuzzy scaling was used, on the other hand, binary positions were coded accordingly 0, when not present and 1, when it occurs.

Table 1. Coding method – selected factors

No.	Factors	Designation	Character *
1.	Function of the building	X_1	H
2.	Total area of the analyzed facade	X_2	Me
3.	Posst and beam facade	X_6	Bin
* Bin – binary (occurs or not), Me – measurable, H – Hard to measure.			

4.2. Cost prediction model using multiple regression

Based on the identified factors shaping the cost of facade execution, for 61 public utility buildings, a multiple regression model was built using STATISTCA software. Table 3 shows the basic characteristics of the evaluation of the regression model for the dependent variable Y, with the analysis of 61 cases.

Table 3. Basic characteristics of the multiple regression model assessment

Coefficient of determination R^2	0.92141132
Corrected Coefficient of determination R^2	0.89283362
Coefficient R	0.95990172
Standard estimation error	0.75942999
F Statistics p-value	32.24232 < 0.005

Durbin-Watson test DW test statistic Serial correlation of remainders	 1.556801 0.10688
Intercept	-3.75027
Standard error	2.564838
t statistics	-1.462

Analysing the obtained results it can be seen that the coefficient of determination R^2 is 0,9214, which means that the combination of explanatory variables (X_1, …, X_{16}) explains the variable Y (facade cost) in approx. 92,14%. In addition, the coefficient is adjusted very much the unadjusted R^2 (0,8928 and 0,9599 respectively), which additionally confirms that the regression model fits very well with the results of observation, because the greater part of the variability Y has been explained by explanatory variables. In addition, the result of multiple regression is a statistically significant result (F Fisher's statistics = 32,2423, $p < 0{,}005$). The proposed model meets the assumptions of the least squares method. Durbin-Watson test results confirm that there is no autocorrelation between the remainders of the model (DW = 1,5568).

The remainder analysis allows you to check whether the assumption of normal distribution is correct a random component, and the assumption that the variance of this component is constant, i.e. that data scattering along the regression line is monotonous [17]. Graphical analysis of remainders for the analyzed model is presented in Figure 1 and Figure 2, which was generated using the STATISTICA program.

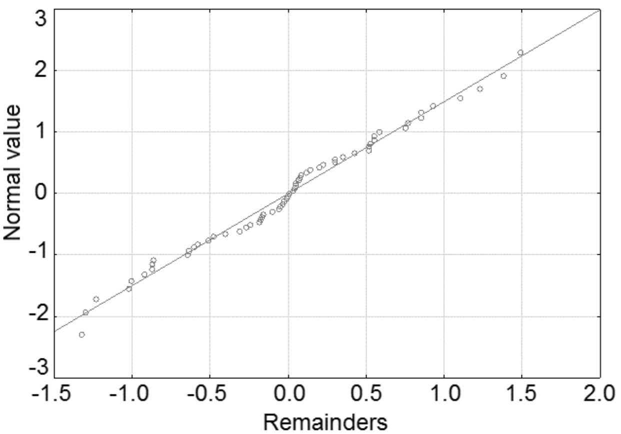

Fig 1. Normality diagram of remainders – multiple regression

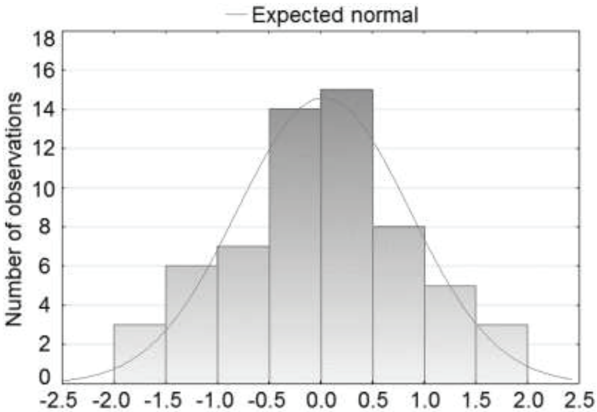

Fig 2. Histogram of distribution of standardized remainders – multiple regression

Based on the obtained data, the estimated multiple regression model takes the following form:

$$
\begin{aligned}
Y = -3{,}75027 + 0{,}77326X_1 + 0{,}00096X_2 - 0{,}01046X_3 + 0{,}41398X_4 + 1{,}07674X_5 + \\
-0{,}03426X_6 + 0{,}26287X_7 + 0{,}51756X_8 + 0{,}03156X_9 + 0{,}04316X_{10} + 0{,}04860X_{11} + \\
+0{,}02798X_{12} + 0{,}03189X_{13} - 0{,}00263X_{14} + 0{,}00556X_{15} - 0{,}32131X_{16}
\end{aligned} \tag{2.1}
$$

where:

Y – explained variable, X_1, X_2, …, X_{16} – explanatory variables.

4.3. COST PREDICTION MODEL USING PROGRESSIVE STEPWISE REGRESSION

In the second approach, a stepwise progressive regression was proposed, in the case of which at each stage, the significance assessment of each variable is reviewed. It minimizes the risk of leaving an important variable outside the model or maintain an invalid variable in the model.

The construction of this type of regression model requires finding one explanatory variable with the highest degree of materiality. Then, using the partial test, the variables that remain outside the models are tested and the variable of the highest materiality is included in the model, as long as it meets the pre-condition imposed on the level of materiality [1], [17]. At this point the backward elimination starts to work in the model. The variables found in the model are evaluated again, examining whether after the inclusion of the last variable, they still meet the requirements imposed in advance on the variables level of materiality. If any variable does not meet the requirement it is removed from the model [17]. Table 4 presents the basic results of the stepwise regression model for the dependent variable Y, having analyzed 61 cases.

Table 4. Basic characteristic of the stepwise regression model assessment

Coefficient of determination R^2	0.91669070
Corrected Coefficient of determination R^2	0.90387389
Coefficient R	0.95743966
Standard estimation error	0.71924880
F Statistics p-value	71.52251
Durbin-Watson test DW test statistic Serial correlation of remainders	< 0.005
Intercept	
Standard error	1.647166
t statistics	0.145078

The determination coefficient is at the level of 0,9167, i.e. around 91,67% the combination of explanatory variables explains variable Y. Corrected determination coefficient remains at the level of 0,9039 and indicates a better adjustment to observation results than in the case of multiple regression. The result of stepwise progression regression is also a statistically significant result (F Fisher's statistic = 71,55225; p < 0,005) and meets the assumptions of the least squares method. Durbin-Watson test results confirm that there is no autocorrelation between the remainders of the model (DW = 1,6472). The analysis of the normality of remainders (Figure 3, Figure 4) indicates that the variance of the random component is fixed and follows the regression line, and the remainders histogram takes the standard distribution.

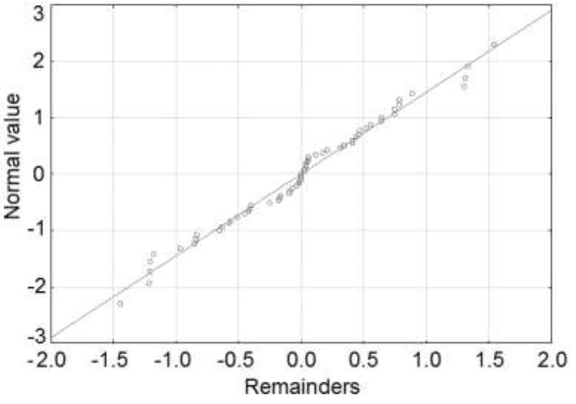

Fig 3. Normality diagram of remainders – stepwise regression

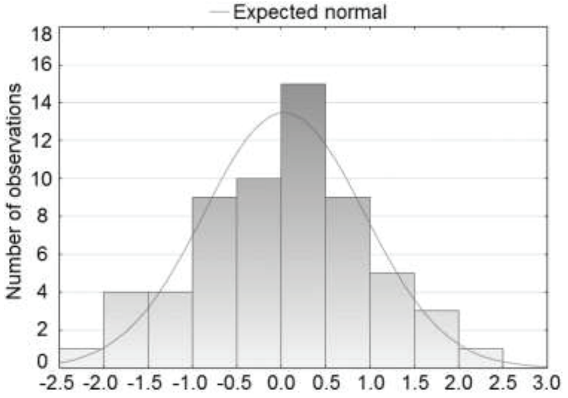

Fig 4. Histogram of distribution of standardized remainders – stepwise regression

Based on the obtained data, the estimated progressive stepwise regression model takes the following form:

(2.2)
$$Y = -0{,}926543 + 0{,}000931X_2 + 1{,}34587X_5 + 0{,}879273X_1 + 0{,}502921X_8 + \\ + 0{,}015198X_{11} + 0{,}348262X_7 + 0{,}012541X_{10} - 0{,}003891X_{12}$$

where:

Y – explained variable, X_1, X_2, X_5, X_7, X_8, X_{10}, X_{11}, X_{12} – explanatory variables.

4.4. Comparison of regression models

For each regression model, the mean square error and root of mean square error were calculated. The results of individual parameters for models are included in Table 5.

Table 5. Comparison of multiple and stepwise models

Designation	Characteristic	
	Multiple regression	Stepwise regression
Coefficient R	0.9599	0.9574
Coefficient of determination R^2	0.9214	0.9166
RMSE error %	29.05%	30.09%
MSE error	0.3990	0.4257

The analysis of the models shows that the values of the correlation coefficient R are formed into a comparable level (0,9599 for the multiple regression model and 0,9574 for stepwise regression). The R^2 determination coefficient is better for multiple regression (0,9214 greater than 0,9166 for progressive stepwise regression). Through analysis of the mean square error RMSE (29,05% for multiple regression and 30,09% for progressive regression) and the root of mean square error MSE (values 0,3990 for multiple regression and 0,4257 for progressive regression), it can be concluded that the multiple regression model reflects the better quality prediction.

5. CONCLUSIONS

Individual calculation executed for the works related to the implementation of facade systems is complicated, time-consuming operation also requiring high workload of the estimator. Therefore, solutions which will facilitate making such valuations and in particular minimizing the duration of the above are sought. The authors of the publication attempted to create models for estimating the cost of facade implementation in the form of aluminum and glass facades; and ventilated elevations. The statistical models of multiple regression and stepwise regression were used for the analysis. Through detailed investigation of project and costing documentation, factors determining the costs of facade execution were described. The results were encoded in the database and subjected to further statistical analysis. Statistical models obtained from the research are characterized by a very good reality mapping. The determination coefficients R^2 were on the level between ca. 92%, what additionally confirms that independent variables (i.e. identified determinants facade execution costs) properly describe the dependent variable, which is the cost of elevation execution.

Furthermore, the percentage error of the root mean square MSE for the multiple regression model is around 29%, which is acceptable when estimating the costs of implementing facade systems at the stage of developing a design concept for both the contractor and the investor.

The statistical models built by the authors can be used to estimate the costs of facade systems based on aluminum-glass facade solutions and ventilated facades at the stage of developing the design concept. The developed models will improve the estimations of facade execution costs by contractors without the need for individual calculations of each building.

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KOSZTY WYKONANIA SYSTEMÓW ELEWACYJNYCH

Słowa kluczowe: systemy elewacyjne, oszacowanie kosztów, modele statystyczne, regresja wieloraka, regresja krokowa

STRESZCZENIE:

Główne działania podejmowane w trakcie realizacji przedsięwzięć budowlanych to przede wszystkim czynności oparte na rzetelnym oszacowaniu kosztów, czasu i jakości robót budowlanych dla danego przedsięwzięcia. Ponadto, dodatkowe czynniki takie jak bezpieczeństwo realizacji prac budowlanych, stosowanie innowacyjnych rozwiązań, wzajemna współpraca pomiędzy uczestnikami przedsięwzięcia budowlanego, to składowe, które wpływają na jego sukces. Jednak jednym z kluczowych zagadnień właściwego funkcjonowania i prowadzenia danego przedsięwzięcia budowlanego są aspekty związane z prawidłową i rzetelną kalkulacją kosztów. Właściwa kalkulacja kosztów realizacji to nie tylko informacja zawierająca wielkość przewidywanego budżetu, ale także informacja o opłacalności danego przedsięwzięcia dla inwestora. Dlatego już na etapie przygotowania przedsięwzięcia dokonuje się oszacowania wskaźnikowego na podstawie badania opracowań przedprojektowych, w tym studium wykonalności.

Celem artykułu jest próba oszacowania kosztów wykonania systemów elewacyjnych obiektów użyteczności publicznej z wykorzystaniem modeli matematycznych, a w szczególności regresji wielorakiej oraz regresji krokowej postępującej. Dane użyte do budowy funkcji regresji zostały opracowane przez autorów na podstawie analizy dokumentacji projektowych, wykonawczych i kosztorysowych obiektów użyteczności publicznej. Opracowano bazę danych zawierającą główne czynniki wpływające na kształtowanie się kosztów wykonania systemów elewacyjnych obiektów użyteczności publicznej. Systemy elewacyjne realizowane były w formie fasad aluminiowo-szklanych oraz elewacji wentylowanych.

Wykonanie kalkulacji kosztów realizacji systemów fasadowych oraz elewacji wentylowanych jest zadaniem skomplikowanym i przede wszystkim czasochłonnym. Wymaga ponadto wysokiego nakładu pracy kosztorysanta. Na poziom skomplikowania wyceny mają wpływ dane konstrukcyjne, architektoniczne, systemowe, ale także parametry związane z produkcją, czy sposobem (technologią) montażu. Przedsiębiorstwa kalkulujące koszty wykonania fasad aluminiowo-szklanych oraz elewacji wentylowanych dokonują takich obliczeń zazwyczaj w formie kalkulacji indywidualnej. Wykonawca, sporządzając wycenę kosztów wykonania fasad, nie tylko kalkuluje ceny poszczególnych elementów elewacji, ale dodatkowo weryfikuje, czy założenia projektowe, są możliwe do wykonania nie tylko na placu budowy, ale także w zakładzie produkcyjnym.

Na koszt wykonania elewacji obiektów użyteczności publicznej w formie fasad aluminiowo-szklanych oraz elewacji wentylowanych ma wiele czynników. Podstawowe to koszty robocizny, sprzętu i materiałów budowlanych. Koszt materiału dla fasad aluminiowo-szklanych to koszt kształtowników aluminiowych, tworzących szkielet konstrukcji oraz szkła jako wypełnienia. W zależności od rodzaju poszczególnych szyb w zespoleniu oraz ich charakterystyk technicznych, zmienia się cena takiego wypełnienia. Elewacje wentylowane to z kolei konstrukcje w formie np. rusztu aluminiowego dodatkowo wypełnionego wełną mineralną, z okładziną zewnętrzną w postaci paneli kompozytowych, blachy aluminiowej lub płyt włókno-cementowych. Największa część kosztów ponoszona na elewacje wentylowane to przede wszystkim rodzaj zastosowanej okładziny zewnętrznej.

Autorzy pracy, w celu szybkiego szacowania kosztów wykonania systemów elewacyjnych wykorzystują regresję wieloraką oraz krokową. Do budowy modelu predykcji kosztów zaproponowano 16 czynników, które mają charakter zmiennych niezależnych modelu oraz jedną zmienną zależną (wyjściową), tj. koszt elewacji. Opracowana baza danych

dla 61 przypadków obiektów użyteczności publicznej, posłużyła do budowy modelu. Przed przystąpieniem do modelowania regresyjnego, wszystkie zgromadzone przypadki zostały opisane przez cechy ogólne, parametry techniczne oraz czynniki mające wpływ na kalkulację ceny systemów elewacyjnych, które zostały następnie zakodowane w sposób znormalizowany.

Dla regresji wielorakiej uzyskano wyniki, gdzie współczynnik determinacji R^2 wynosi 0,9214, co oznacza, że kombinacja zmiennych objaśniających ($X_1 \ldots X_{16}$) wyjaśnia zmienną Y (koszt elewacji) w ok. 92,14%. Ponadto współczynnik R^2 skorygowany jest wartością bardzo bliską nieskorygowanemu R^2 (odpowiednio 0,8928 i 0,9599) co dodatkowo potwierdza, że model regresji bardzo dobrze pasuje do wyników obserwacji, gdyż większa część zmienności Y została wyjaśniona przez zmienne objaśniające. Ponadto, wynik regresji wielorakiej jest wynikiem istotnie statystycznym (statystyka F Fishera = 32,2423; $p < 0{,}005$). Zaproponowany model spełnia założenia metody najmniejszych kwadratów. Wyniki testu Durbina-Watsona potwierdzają, iż między resztami modelu nie występuje autokorelacja (DW = 1,5568).

Natomiast dla regresji krokowej uzyskano wyniki, gdzie współczynnik determinacji kształtuje się na poziomie 0,9167. Tym samym w ok. 91,67% kombinacja zmiennych objaśniających wyjaśnia zmienną Y. Skorygowany współczynnik determinacji pozostaje natomiast na poziomie 0,9039 i wskazuje lepsze dopasowanie do wyników obserwacji niż w przypadku regresji wielorakiej. Wynik regresji krokowej postępującej jest również wynikiem istotnie statystycznym (statystyka F Fishera = 71,5225; $p < 0{,}005$) i spełnia założenia metody najmniejszych kwadratów. Wyniki testu Durbina-Watsona potwierdzają, iż między resztami modelu nie występuje autokorelacja (DW = 1,6472).

Z przeprowadzonych badań uzyskano modele statystyczne, które charakteryzują się bardzo dobrym odwzorowaniem rzeczywistości. Współczynniki determinacji R^2 kształtowały się na poziomie ok. 92%, co dodatkowo potwierdza, że zmienne niezależne (czyli zidentyfikowane czynniki determinujące koszty wykonania elewacji) dobrze opisują zmienną zależną, jaką jest koszt wykonania elewacji. Ponadto procentowy błąd pierwiastka średniokwadratowego MSE dla modelu regresji wielorakiej kształtuje się na poziomie ok. 29%, co jest akceptowalne przy oszacowaniu kosztów realizacji systemów fasadowych na etapie opracowania koncepcji projektowej zarówno dla wykonawcy, jak również inwestora.

Otrzymane przez autorów modele można wykorzystać do szacowania kosztów wykonania systemów elewacyjnych w formie fasad aluminiowo-szklanych oraz elewacji wentylowanych. Stworzone modele usprawnią szacowanie kosztów wykonania elewacji, przez wykonawców, bez potrzeby wykonywania kalkulacji indywidualnych każdego obiektu.

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