

Article

# Structural Analysis of Factors Influencing the Costs of Facade System Implementation

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**Abstract:** External facades of buildings and other structures shape the image of every building, creating the architecture of cities. Traditional concrete forms, as a symbol of durability and stability, have been replaced by lightweight enclosures—for example, in the form of aluminium–glass facades and ventilated facades. In this paper, the authors attempt to verify the strength of influence and relations between the identified factors shaping the costs of facade system implementation using structural analysis. On the basis of the collected quantitative and qualitative data obtained as a result of research on design documentation and cost estimates of implemented public buildings, as well as on the basis of interviews conducted among experts, factors which have a real impact on the costs of facade systems in the form of aluminium and glass facades and ventilated facades were identified. The indicated factors were analysed and classified using the method of structural analysis, namely the MICMAC method (refers to the French acronym for Cross-Impact Matrix Multiplication Applied to Classification). Particular influences and relations between factors were examined. Finally, six groups of factors influencing the costs of facade systems were identified, including regulatory factors that do not have a very strong impact on the level of costs, but which show a strong correlation with other factors; determinants that have a very strong impact on the costs; and a group of external factors that show the smallest influence on the estimation of façade cost.

**Keywords:** facade systems; cost management; structural analysis; MICMAC method

## 1. Introduction

External facades of buildings and other structures shape the image of every building, creating the architecture of cities. The dynamic development of technology, the discovery of new innovative building materials [1], as well as the ever-increasing technical, production, and execution capabilities have resulted in exterior walls with complex shapes and forms. Traditional concrete forms as a symbol of durability and stability have been replaced by lightweight enclosures—for example, in the form of aluminium–glass facades and ventilated facades [2]. Aluminium and glass facades are built from aluminium sections, and the spaces between the aluminium construction is filled with glass. Glass that is used in construction should meet the requirements of thermal protection, fire protection, burglary protection, protection against noise, and safety of use [3]. A solid building made in the form of aluminium–glass facades is an indispensable element of architecture for a modern city [4]. Also, ventilated facade systems have gained much attention. It is a cladding system, which incorporates the insulation layer, positioned usually on the external surface of the wall, the air cavity and the outer skin [5]. The air gap allows air to enter and flow through the facade. The external part of the ventilated façade is a panel suspended, glued, or screwed to the substructure. Ventilated facades allow for shaping external claddings from various materials, structures, textures, or colours. The panels can be made of many materials, including wood, fiber concrete, aluminium and ceramics. Due to their high aesthetics, ventilated facades are increasingly often used as external parts of newly built buildings,

but they are also perfect for buildings undergoing renovations [2,6]. This makes the ventilated facade an effective form of finishing the building—it adds prestige and distinguishes it from the environment. Descriptions and photos or characteristics of the discussed facade systems can be found in a number of publications [4,7,8].

The modern trend in the design of exterior facades as lightweight structures is primarily reflected in examples of public buildings, and constitutes the mainstay of urban architecture. The construction of skyscrapers and high-rise buildings are symbols of all larger metropolises.

The external facades of such buildings are no longer just the outer cladding itself, but a combination of many interdisciplinary functions. They combine stability and reliability with aesthetics, usability [9], energy efficiency, and ecology [10]. All these aspects affect the quality of the assembly process, time of execution, and costs incurred [3]. These three elements determine the success of each construction project. Many studies presented in the literature concern the quality of construction projects [11], their costs [12,13], and time schedule [14], as well as the maintenance of the existing buildings [15] and the opportunity to improve the energy efficiency of buildings [16].

Reliable cost estimation is one of the most important aspects of construction projects, both from the investor's and the contractor's point of view [17]. Estimating the costs of facade systems is time-consuming and complicated [3]. The calculation process is influenced by architectural, construction, and system data, as well as parameters related to production and the type of assembly. It is necessary to have an individual approach to each investment, starting from the analysis of design documentation and ending with the location of the construction project. The cost amount is influenced not only by the prices of individual facade elements, but additionally by the costs of their execution in the production plant and assembly on the construction site. In the case of facade system implementation, one should take into account indirect costs, widely understood, which are closely related to the specific location of the investment, the availability of land around the building, or the option of setting scaffolding or others factors [18].

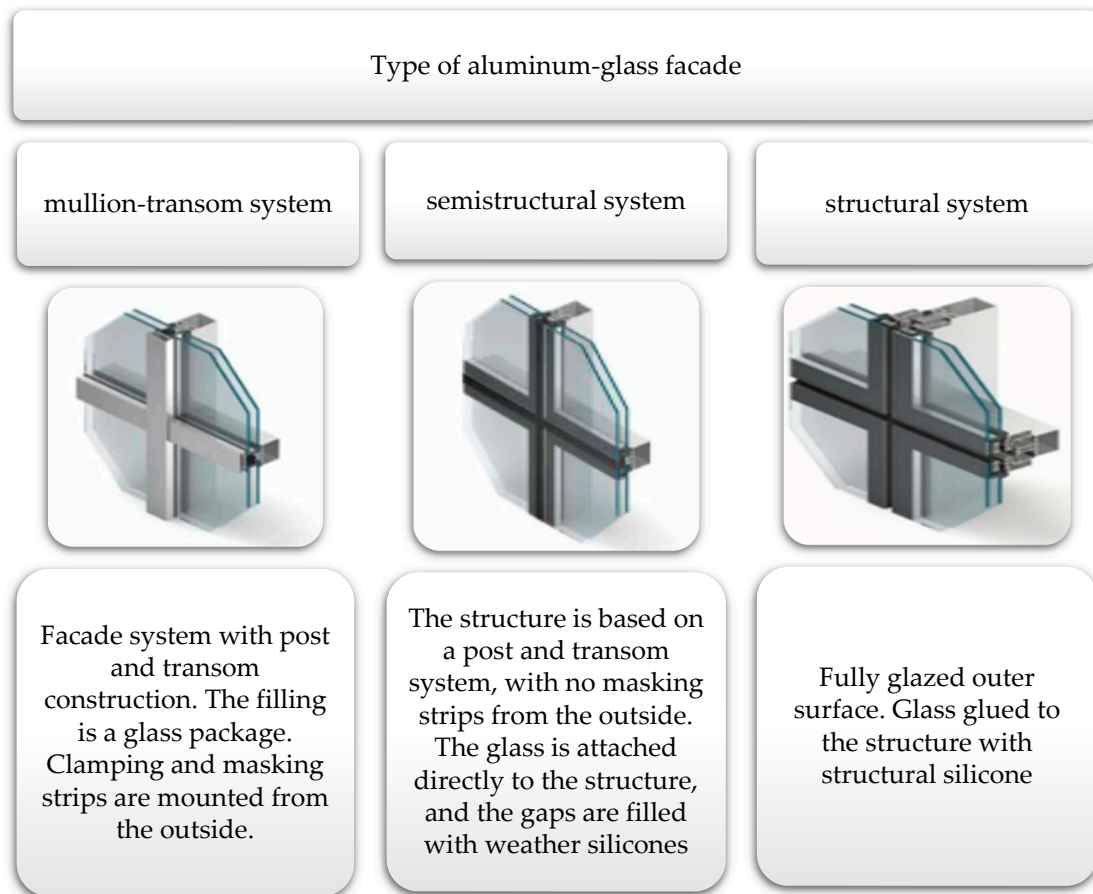
Many works present attempts to identify factors and analyse them in terms of research issues and problems in the construction industry. They concern, for example, factors shaping the costs of works [19], risk factors [20], factors affecting occupational safety [21], or determining energy consumption [22]. The study of these issues, their analysis, as well as the application of innovative solutions, mathematical methods, or artificial intelligence, enables the construction of models supporting decision-making in construction management [23,24].

In this paper, the authors attempted to verify the strength of influence and relations between the 15 factors shaping the costs of facade systems using structural analysis. The factors that have a real impact on the costs of aluminium and glass facades and ventilated facades were identified as results of research conducted in Poland. Quantitative and qualitative data were obtained as a result of research on design and cost documentation implemented between 2013–2019 for 80 public buildings. The details of data collection are described later in the paper. Finally, the factors were analysed and classified using a method of structural analysis, namely the MICMAC method (referring to the French acronym for Cross-Impact Matrix Multiplication Applied to Classification, developed by Michel Godet in 1971 [25]). This is one of the methods for organizing and analyzing a set of variables, which enables the study of relationships and mutual relationships between them.

## 2. Short Characteristic of Selected Facade Systems

Aluminium–glass facades are one of the solutions dedicated to public, office, commercial, and service buildings [4]. Such buildings have become the objects of designers' architectural ideas, attracting designers with their form and original shape. The facade of the building should give the character of the object, as well as ensure comfort in its use. The facades are used to shape external walls, thanks to which curvilinear facades can be designed and made; these are characterized by lightness of form. The core of the facade is made of aluminium sections, while the filling is glass. The most

frequently used systems are mullion–transom, semistructural, and structural systems [18]. Types of aluminium–glass facades are illustrated in Figure 1.



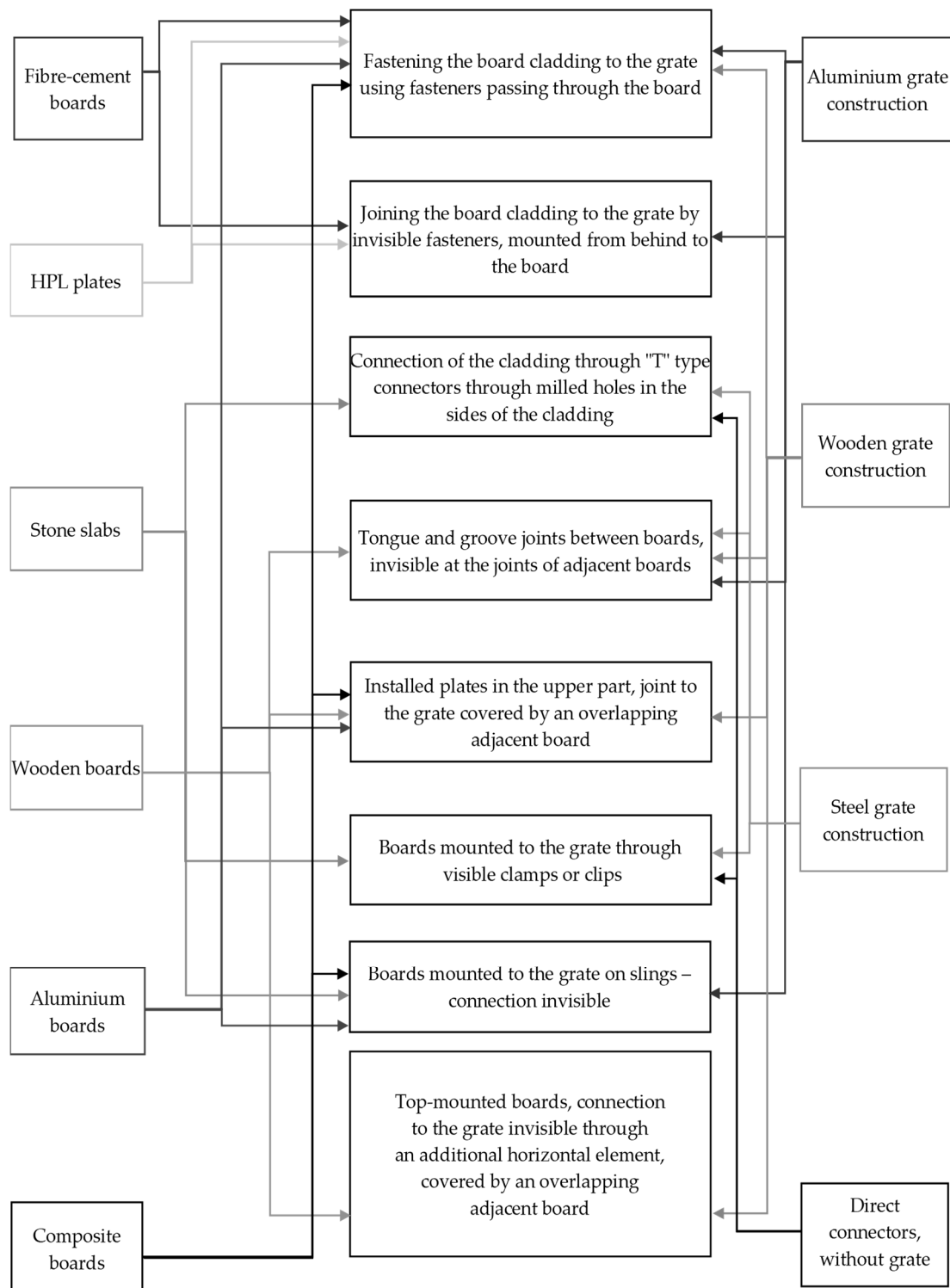
**Figure 1.** Type of aluminium–glass facades. Own study based on [26].

The first type of structure consists of mullion–transom, and the inner space is filled with glass. On the outside of the mullion–transom system are termination bars and masking strips. A semistructural facade is smooth. Glass is fixed directly to the construction, and the gap is filled with a special weather silicone. The structural system is characterized by the possibility of obtaining an external glass faced without visible elements. This effect can be achieved by gluing the glass directly to the aluminium structure.

The other facade system frequently used for public buildings in combination with aluminium and glass facades is a ventilated facade [18]. This solution is based on leaving a ventilation gap between the external cladding and the thermal insulation layer. A ventilated facade is defined as a set of elements for enclosing external walls, consisting of the following [2]:

- external panels (for instance, cement, stone, wood-based, plastic, metal, or laminate) attached to the grate (suspended, glued, or screwed to the grate);
- grate (made of metal or wood) attached—suspended, glued, or screwed—to the external wall;
- fastening elements;
- insulating material.

Due to the variety of materials used for the external panel and the substructure used (grate), it is possible to present the classification of ventilated facades, as shown in Figure 2.



**Figure 2.** Classification of ventilated facades, according to the material of the external panel and the method of installation. Own study based on [8].

Ventilated facades should meet all the requirements for technical assessment, and above all, should be tested for fire safety, namely, reaction to fire, resistance to fire, and ability to continuously smoulder [27]. Ventilated fire facade elements should be tested, and their fire class should be equal to class “A”. Aluminium and steel grates, which are substructures of ventilated facades, are classified as non-combustible in class A1, and they are most often used for fire-rated ventilated facades. On the

other hand, the external lining itself, whether in the form of composite panels or HPL (High Pressure Laminate) panels, should have a fire-resistant core, which gives the fire-resistant characteristics to the element in question.

### 3. The Structural Analysis: Methodology

Structural analysis, namely the MICMAC method (refers to the French acronym Matrice d’Impacts Croisés Multiplication Appliquée á un Classement/Cross-Impact Matrix Multiplication Applied to Classification), allows us to examine particular influences and relations between specific variables or factors. The MICMAC method examines direct influences, but also analyses indirect relationships that are not always noticed by experts and analysts [28]. The input element of the analysis is the evaluation and description of direct impacts made by the experts, and then indirect impacts that may occur between factors are additionally examined. As a result of the application of this method, it is possible to separate those factors which are the most decisive and crucial for the examined area from the set of variables. The method also makes it possible to prioritize and organize the variables that seemingly do not influence each other, but thanks to cross analysis, it is possible to show their mutual interactions [29,30]. The individual steps of the structural analysis are depicted in Figure 3.

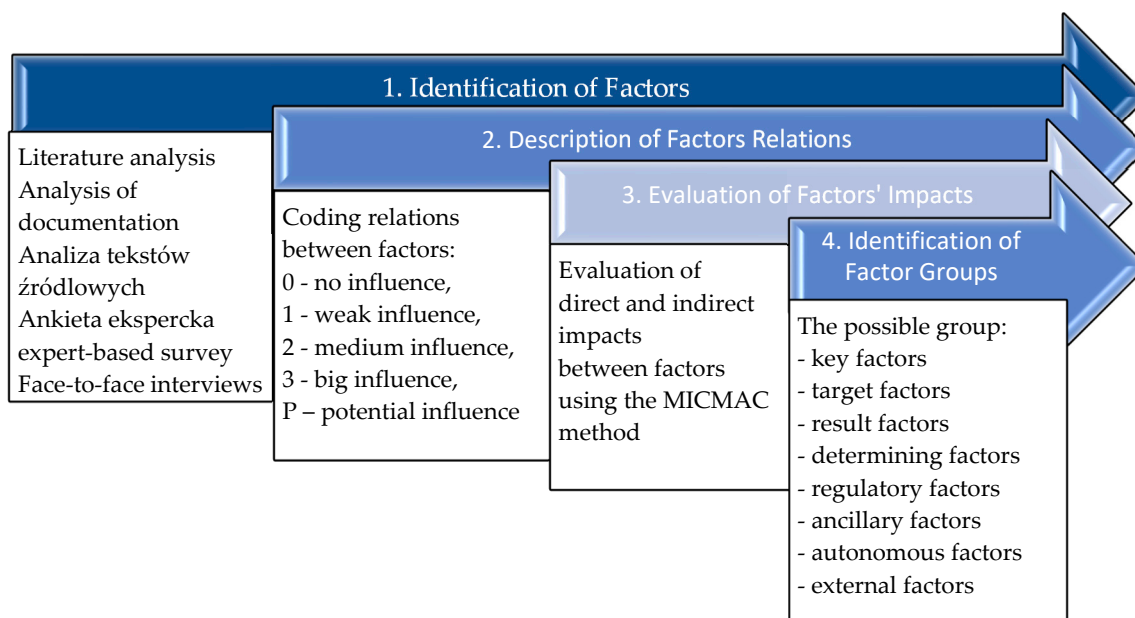


Figure 3. Structural analysis stages. Own study based on [28].

#### 3.1. The First Stage: Identification of Factors

The basis for structural analysis is the identification of the variables/factors that influence and shape a given research area. This is the first and most time-consuming stage. The collected research materials, documentation, literature studies, expert surveys, and face-to-face interviews allow us to distinguish a group of factors that have a decisive influence on the analysed problem.

#### 3.2. The Second Stage: Description of Factor Relationships

The second stage of the analysis involves a description of mutual relationships between individual factors by coding the relationships. Mutual relations are defined as follows [28]: 0 = no influence, 1 = weak influence, 2 = medium influence (significant but not decisive), 3 = big influence (decisive), and P = potential influence. This step is usually performed by experts.

### 3.3. The Third Stage: Examination of Factors' Impacts

The next step examines the direct and indirect impacts that may occur between factors. To evaluate and describe the direct and indirect factor relationships, the authors used the MICMAC free online software developed by French Computer Innovation Institute 3IE and LIPSOR Prospective (foresight) Strategic and Organisational Research Laboratory [25]. The software allows for a quick calculation. Its operation is based on the algebraic principle of Boole's logic, which is usually used to build scenarios at the initial stage of describing future trends.

On the basis of the experts' assessment, a direct impact matrix and a graph are built, the vertices of which represent the factors. In order to calculate the strength of each factor's influence on another factor, the number of paths (relationships) between them and their length is then determined as the strength of the relationship. Indirect relationships between the factors are obtained by successive exponentiation of the direct influence matrix. The total strength of influence is the sum of all elements of the matrix row of direct influence for a given factor, while the total strength of dependence is the sum of elements in the matrix column.

As a result, two matrices are built out of direct and indirect interactions, as well as two graphs of the direct and indirect impact strength of the variables.

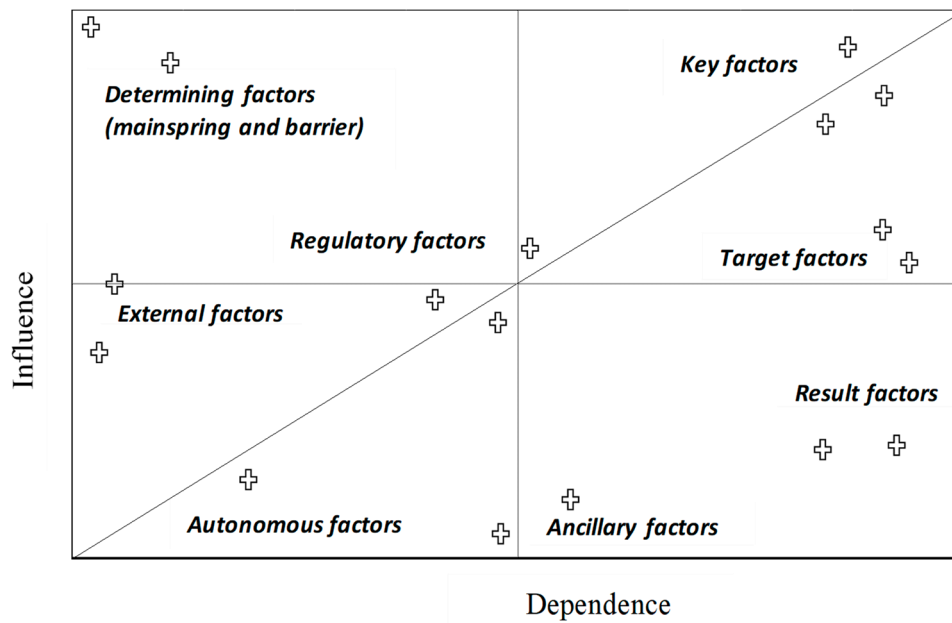
### 3.4. The Fourth Stage: Identification of Factor Groups

A comparison of the results of different classifications of variables as direct (dependent), indirect, or potential impacts enables an in-depth analysis of the subject under consideration.

Additionally, the analysis allows us to distinguish the following in the structure of the research area [31]:

- Key factors, which are characterized by a very high impact on other factors;
- Target factors, which involve variables that change themselves to a large extent under the influence of factors other than those that affect them;
- Result factors, which have a low impact on the structure of the research area, but are very dependent on other factors;
- Determining factors (mainspring and barrier), which describe, characterize, and control the structure of the research topic. These have a real impact on the whole system, either driving it or being a barrier to the whole operation;
- Regulatory factors and ancillary factors, which do not affect the structure and do not have any strong dependencies on other factors, but help to define the strategic objective;
- Autonomous and external factors, which include secondary factors that have very little influence on the system and its forecasts.

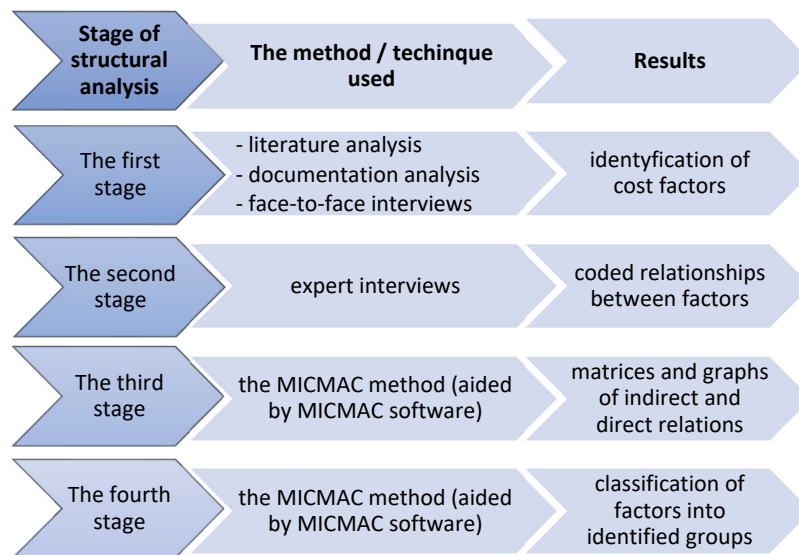
The result of the MICMAC method is ordered variables, where one can distinguish such factors that have the greatest real impact on the examined system [32]. The system of influence–dependence factors within MICMAC method is shown in Figure 4.



**Figure 4.** The system of influence–dependence factors within MICMAC (French acronym Matrice d’Impacts Croisés Multiplication Appliquée á un Classement, also known as Cross-Impact Matrix Multiplication Applied to Classification) method. Own study based on [29,30].

#### 4. Results and Discussion

The methods used and the results obtained through the successive stages of the research procedure are presented in Figure 5. A detailed description is provided in the subchapters below.



**Figure 5.** Methods and results of the conducted analysis.

##### 4.1. Identified Cost Factors

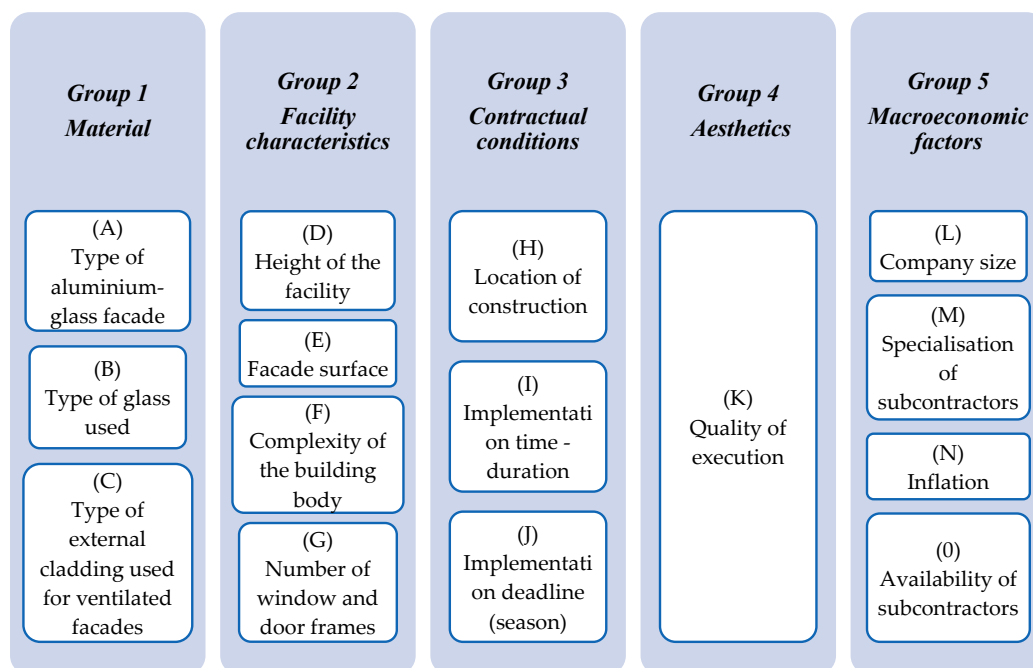
The cost of the construction of elevations of public facilities using facade systems is influenced by many factors. The authors identified cost factors with the analysis of project and cost documentation and as-built settlements for cases, as well as direct interviews with contractors and investors. The factor identification studies presented in this paper constitute an extension of the preliminary studies, the results of which have been previously presented [18]. Finally, the completed study included

80 cases of public buildings constructed in the years 2013–2019 in Poland. The characteristics of the analysed buildings due to their different parameters are presented in Table 1.

**Table 1.** Characteristics of the analysed buildings.

Public Buildings	
Building function	Service and commercial Office
Location	City centre Outside city centre Out-of-town
Type of facade	Aluminium–glass facade Ventilated facade
Type of aluminium–glass facade	Mullion–transom Semistructural Structural
Type of glass	Fire glass Single glass Insulated glass
Type of ventilated facade cladding	Composite board Aluminium sheet Board fiber cement

The conducted research identified 15 factors. Fourteen of them were proposed by the authors, while the remaining one, the availability of subcontractors, was proposed by the contractors participating in direct interviews. The factors were then assigned to five groups. The number and type of groups were intuitively proposed by the authors, based on the studies of literature on factors in the construction industry and on experience from engineering practice. The proposed division of factors is illustrated in Figure 6. The factors were additionally given letter symbols to facilitate further analysis.



**Figure 6.** Proposed division of the identified factors.

Group 1—materials—contains the following factors: type of aluminium–glass façade, type of glass used, and type of external cladding used for ventilated facades. These are the main parameters directly influencing implementation costs.

Group 2—facility characteristics—includes the height of the facility, facade surface, complexity of the building body, and number of window and door frames. The factors of this group describe the characteristics of the building body. Not only does the size of the area have an impact on costs, but its height is also important. High buildings generate additional costs due to the employment of building scaffolding and a crane, the method of transporting facade elements inside the facility, and the need to use specialised equipment dedicated to the assembly of glass panels. Complication of the building body, such as inclined surfaces in combination with straight surfaces, will generate additional costs related to difficult installation. The factor “the number of window and door frames” concerns the surfaces of windows and doors (in m<sup>2</sup>) and their condition. High functionality of the windows and doors requires the use of appropriate accessories, such as anti-panic hardware, actuators, automatic sliding door machines, or access control accessories.

Group 3 is contractual conditions. These factors have an indirect impact on the cost of the facade. The location of construction site (in or outside the city centre) has a significant impact on the costs of transporting and unloading large facade elements, e.g., aluminium sections or glass panes. Implementation time–duration is a factor that generates both labour costs (shorter implementation times will increase them) and indirect costs (such as construction site organisation). Implementation deadline (season), together with adverse weather conditions, can cause delays in facade installation.

Group 4—aesthetics—includes only one factor: quality of execution. It is expressed by the proper selection of materials, technology, and above all, by the correct execution of construction works. Its assessment can be obtained by performing a number of tests, including checking the facade planes and testing the tightness of a given building.

Group 5—macroeconomic factors—includes company size, specialisation of subcontractors, inflation, and availability of subcontractors. The factors listed in this group have an indirect impact on the cost of facade systems. Large companies have greater opportunities to access specialised machinery and equipment, which affects the time of assembly and prefabrication, and thus the cost of implementation. In addition, companies making facade systems use subcontractors, who support both the assembly and prefabrication process. Therefore, well-specialized subcontractors with large machine parks, experience, and highly qualified staff are valued companies, which results in their limited availability on the market. All these parameters describing subcontracting companies influence the price of their service, which additionally influences the final cost of the facade systems. Moreover, inflation and the related change in means of production—that is, the prices of materials and services—may determine the change of costs of facade execution in the form of lightweight casing.

#### *4.2. Conduct and Results of Factor Analysis*

The expert research was performed with 10 Polish companies dealing with and specialising in the implementation of external facades. In 2019, 15 experts were invited (including works managers, production managers, and bid managers) to describe the relationships between the identified factors. According to the principle of factor interdependence, one of the factors (*X*) may have a very strong influence on the other factor (*Y*), while the *Y* factor itself does not have to influence the *X* factor or the influence may be very weak. The evaluation involved a five-stage scale, where 0 = no impact, 1 = weak impact, 2 = medium impact (significant but not decisive), 3 = large impact (decisive), and P = potential impact.

On the basis of the results obtained, matrix A (direct influence) was constructed.

$$A = \begin{pmatrix} 0 & 2 & 0 & 0 & 0 & 0 & P & 0 & 2 & 0 & 2 & 0 & 0 & 0 & 0 \\ 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 3 & 0 & 0 & 0 & 0 \\ 2 & 2 & 2 & 0 & 3 & 0 & 1 & 0 & 3 & P & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 3 & 2 & 0 & 0 & 0 & P & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & P & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & P & 0 & 0 & 0 & 0 & 0 & 1 & P & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 1 & 2 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & P & 0 & 3 & 0 & 0 \\ 3 & 2 & 2 & 0 & 0 & 0 & 0 & 0 & 3 & P & 3 & 0 & 0 & 0 & P \\ P & P & P & 0 & 0 & 0 & 0 & 0 & P & 0 & 0 & P & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{1}$$

Using the example of the first row of the A matrix, the following interpretation of the influence of factor A on other factors can be made:

- Factor A affects on average factors B, I, and K, which is why the matrix was assigned a grade 2 according to a five-degree scale;
- Factor A does not affect factors C, D, E, F, H, J, L, M, N, and O—therefore, a degree of 0 is assigned in the matrix;
- Factor A potentially affects factor G; therefore, a grade P is assigned in the matrix.

Table 2 presents the results of the structural analysis as the total strength of influences and direct relationships for the analysed factors. The calculated values of the influence strength and dependencies are the dominants of the influence force of the factors on each other.

**Table 2.** Power of influence and dependence on identified factors.

No.	Group of Factors/Factor	Symbol	Total Strength of Influence	Total Strength of Dependencies
Material				
1	Type of aluminium–glass facade	A	6	16
2	Type of glass used	B	7	16
3	Type of external cladding used for ventilated facades	C	5	13
Facility characteristics				
4	Height of the facility	D	13	0
5	Facade surface	E	6	3
6	Complexity of the building body	F	13	0
7	Number of window and door frames.	G	3	1
Contractual conditions				
8	Location of construction	H	4	0
9	Implementation time–duration	I	8	29
10	Implementation deadline (season)	J	6	1
Aesthetics				
11	Quality of execution	K	2	16
Macroeconomic factors				
12	Company size	L	10	0
13	Specialisation of subcontractors	M	13	3
14	Inflation	N	2	0
15	Availability of subcontractors	O	4	4

The following variables reveal the greatest strength of direct influence on other factors: height of the facility (D), complexity of the building body (F), and specialisation of subcontractors (M). On the other hand, the variable showing the greatest dependence on other factors and the subsequent impact

on the costs of facade systems is implementation time–duration (I), while the following revealed less dependence on other factors, but also at a high level: type of aluminium–glass façade (A), type of glass used (B), and quality of execution (K).

The direct impact strength of the individual variables is illustrated in Figure 7.

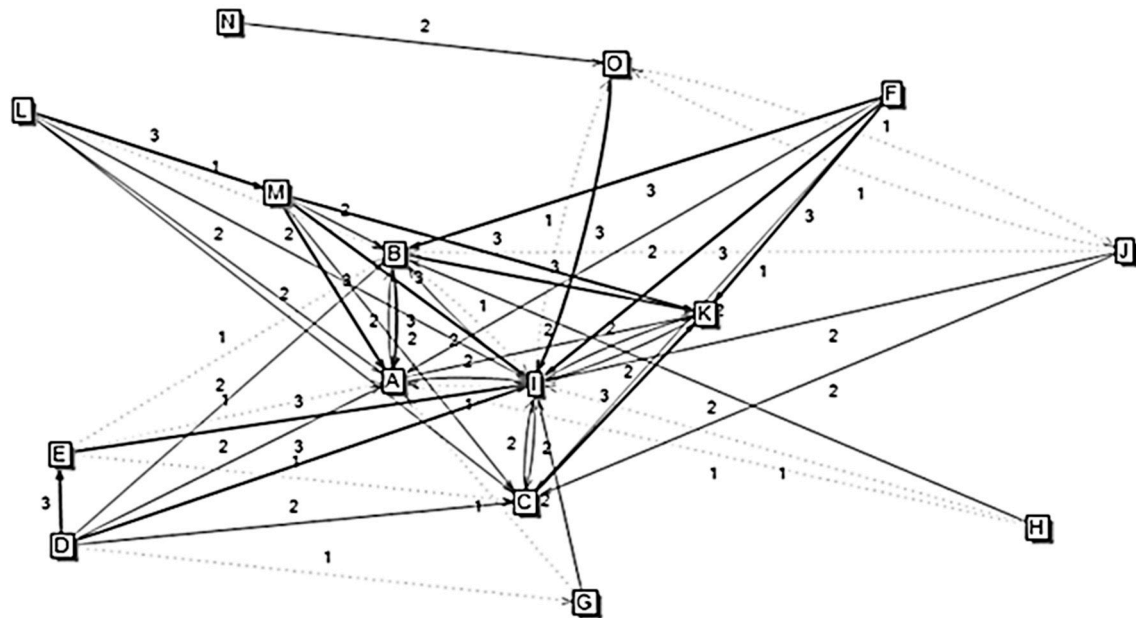


Figure 7. Direct impact graph.

The next stage of structural analysis of the identified variables was the analysis of impacts and indirect relationships between the identified variables. The MICMAC method allows us to analyse the spread of interactions through connections and feedback loops coming in and out of particular factors, which in turn extracts hidden relationships between variables, which are often not directly visible for experts or analysts. Using the MICMAC software [25], matrix B—indirect influence—was calculated.

$$B = \begin{pmatrix}
 18,826 & 20,432 & 13,684 & 0 & 0 & 0 & 0 & 0 & 36,270 & 1410 & 40,876 & 0 & 0 & 0 & 6842 \\
 18,920 & 22,354 & 15,308 & 0 & 0 & 0 & 0 & 0 & 36,759 & 1233 & 41,018 & 0 & 0 & 0 & 7654 \\
 12,838 & 14,612 & 9988 & 0 & 0 & 0 & 0 & 0 & 24,630 & 882 & 27,748 & 0 & 0 & 0 & 4994 \\
 45,916 & 51,890 & 35,030 & 0 & 0 & 0 & 0 & 0 & 89,116 & 3257 & 99,833 & 0 & 0 & 0 & 17,515 \\
 22,675 & 23,988 & 16,470 & 0 & 0 & 0 & 0 & 0 & 41,989 & 1639 & 48,262 & 0 & 0 & 0 & 8235 \\
 40,015 & 44,136 & 29,694 & 0 & 0 & 0 & 0 & 0 & 77,269 & 2923 & 86,842 & 0 & 0 & 0 & 14,847 \\
 12,224 & 12,992 & 9100 & 0 & 0 & 0 & 0 & 0 & 22,096 & 838 & 25,694 & 0 & 0 & 0 & 4550 \\
 15,208 & 16,246 & 10,892 & 0 & 0 & 0 & 0 & 0 & 29,051 & 1145 & 32,878 & 0 & 0 & 0 & 5446 \\
 21,123 & 24,523 & 16,092 & 0 & 0 & 0 & 0 & 0 & 43,042 & 1570 & 47,020 & 0 & 0 & 0 & 8046 \\
 19,970 & 21,729 & 14,614 & 0 & 0 & 0 & 0 & 0 & 38,444 & 1484 & 43,296 & 0 & 0 & 0 & 7307 \\
 8740 & 8924 & 6280 & 0 & 0 & 0 & 0 & 0 & 15,474 & 618 & 18,232 & 0 & 0 & 0 & 3140 \\
 46,432 & 51,596 & 34,924 & 0 & 0 & 0 & 0 & 0 & 89,172 & 3318 & 10,047 & 0 & 0 & 0 & 17,462 \\
 39,822 & 44,346 & 30,048 & 0 & 0 & 0 & 0 & 0 & 76,545 & 2835 & 86,154 & 0 & 0 & 0 & 15,024 \\
 5490 & 7190 & 4680 & 0 & 0 & 0 & 0 & 0 & 12,008 & 380 & 12,620 & 0 & 0 & 0 & 2340 \\
 16,789 & 17,688 & 12,388 & 0 & 0 & 0 & 0 & 0 & 30,275 & 1170 & 35,303 & 0 & 0 & 0 & 6194
 \end{pmatrix} \tag{2}$$

The interactions between variables are shown in Figure 8.

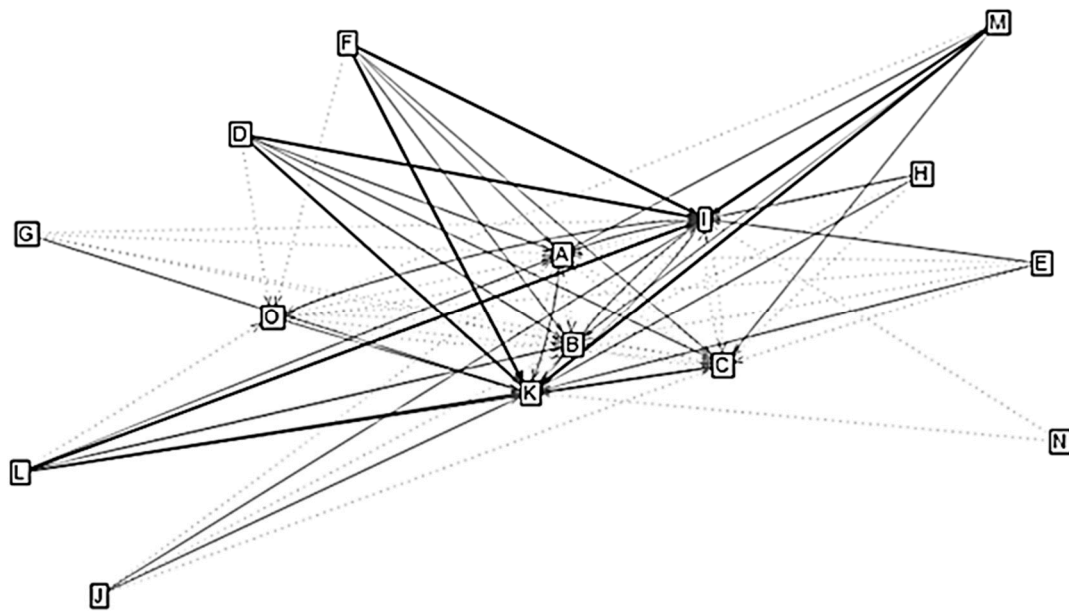


Figure 8. Indirect impact graph.

The analysis of the graph of indirect impacts of variables reveals that the following factors have the strongest influence on the factor quality of execution (K): height of the facility (D) and company size (L). Lower-strength impact on the factor quality of execution (K) is exerted by the following factors: complexity of the building body (F) and specialisation of subcontractors (M). The factor implementation time–duration (I) is strongly influenced by the factors company size (L), complexity of the building body (F), and specialisation of subcontractors (M).

The next stage of the research is to separate the structure of factors in the research area. Figure 9 presents the groups of factors that influence and describe the research problem of estimating the costs of facade systems.

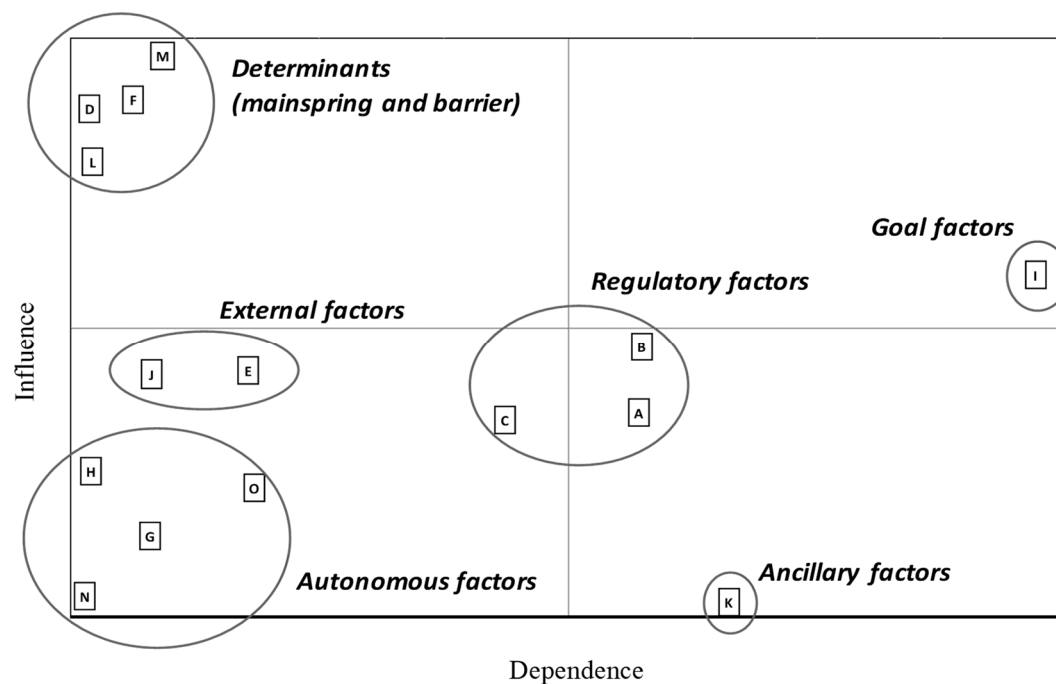


Figure 9. The system of influence–dependence factors on facade systems cost.

The analysis reveals that from among the identified factors shaping the costs of facade systems, six groups of defining factors can be distinguished. The first group of factors includes type of aluminium–glass facade (A), type of glass used (B), and type of external cladding (C). These are factors that do not have a very strong impact on the level of costs, but show a strong correlation with other factors, which in effect describes the strategic objective of the analysis, which is to estimate facade costs. The same role is played by a group of ancillary factors—quality of execution (K). The third group of factors involves determinants (mainspring and barriers), comprising the following variables: height of the facility (D), facade surface (E), complexity of the building body (F), and specialisation of subcontractors (M). These are factors that have a very strong impact on the costs of facade systems and characterise the facility and contractors, all of which have a real impact on the level of costs incurred. Another group of factors are the goal factors, where the factor implementation time (I) is the only one, and according to the analysis, changes as a result of the influence of other factors but does not influence them itself. The next group are external factors—company size (L) and implementation deadline (season) (J)—and autonomous determinants: number of window and door frames (G), location of construction (H), inflation (N), and availability of subcontractors (O). The factors belonging to these groups, according to the analysis, show the smallest influence on the estimation of facade costs.

### 5. Conclusions

The paper presents a structural analysis of mutual influences and relationships between factors identified on the basis of quantitative and qualitative studies of project documentation and cost estimates. This was done using the MICMAC free online software which, by means of cross-analysis of the interactions between variables, helped to determine the six groups of factors influencing the research area, being the estimation of costs of facade systems. The largest and strongest group of factors were determinants and regulatory factors. Determinants, also known as mainsprings and barriers, are factors that have a very strong influence on the cost estimation of the building facades under consideration, which include height of the facility, facade surface, complexity of the building body, and degree of specialisation of assembly companies. Another important group for the research problem are regulatory factors. They do not have a strong influence on the whole cost structure, but by interacting with each other and with other variables, they provide a basis for achieving the goal of estimating facade costs. The regulatory factors were the type of aluminium–glass facade, the type of glass used, and the external cladding for ventilated facades. During the analysis, a goal factor has also been identified, which is the implementation time. Limiting the assumptions for the isolated parameters may cause the implementation time to be shorter or longer. Such an effect makes the factor a goal in the time-and-cost relationship. The factors per group are presented in Table 3.

**Table 3.** Factors per group.

Regulatory Factors	Ancillary Factors	Determining Factors	Goal Factors	External Factors	Autonomous Factors
(A) Type of aluminium–glass façade	(K) Quality of execution	(D) Height of the facility (E) Facade surface (F) Complexity of the building body (M) Specialisation of subcontractors	(I) Implementation time	(L) Company size (J) Implementation deadline (season)	(G) Number of window and door frames (H) Location of construction (N) Inflation (O) Availability of subcontractors

Additionally, the analysis of direct and indirect influence matrices and relationships between the variables revealed which interactions occur between individual variables. The direct relationships were a reflection of experts’ opinions, which indicated that the strongest influence was shown by the following variables: height of the facility, complexity of the building body, and the level of

specialisation of contractors. The analysis of the indirect influence matrix showed hidden relationships and interactions between the variables. The strongest influence on the quality of execution was exerted by the variable height of the facility and company (contractor) size.

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