

Article

Model of Predicting Cost Overrun in Construction Projects

Edyta Plebankiewicz 

Institute of Construction Management Cracow University of Technology, Warszawska 24, 31-155 Kraków, Poland; eplebank@L3.pk.edu.pl; Tel.: +48-12-628-23-30

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Abstract: During the construction phase, significant differences between the planned and actual costs of construction projects frequently occur. The paper describes the concept of a model of prediction of the increase in the costs of construction works in relation to those planned. The assumption of the model is to determine the probability of the cost increase for the elements of the object for which it is the largest. A fuzzy Mamdani inference method was proposed for the selection of the elements to be evaluated. In the cost prediction model, fuzzy relations and the compound max-min relations were used. The result of the model are the probabilities of cost overrun for works most exposed to changes in costs. The model can be helpful mainly for the contractor who wants to know not only the probability of the total cost overrun but also the possibility and amount of increase in the costs of individual packages of works or detailed construction works necessary to complete a construction project. Such an approach may help to properly plan expenses related to the implementation and schedule of works along with the cash flow for the project.

Keywords: cost overrun; construction project; fuzzy sets

1. Introduction

The implementation of a construction project is preceded by the preparation of various types of cost calculations [1]. Unfortunately, during the implementation phase, significant differences between planned and actual costs of works frequently occur. These differences are a common phenomenon, practically impossible to avoid. Practice also reveals that in most cases the actual costs grow in relation to those planned.

The term “cost overrun” is often referred to as a budget increase, cost increase, or cost growth. Yet literature on the subject lacks an unambiguous definition of this concept. For example, Hinze et al. [2] suggested that cost overrun is the difference between the original contract value and cost at practical completion. Flyvbjerg et al. [3] and Odeck [4] defined a cost overrun as the difference between forecasted and actual construction costs. In this instance, the budget at the decision to build is used as the reference for determining the overrun that may be incurred and actual construction costs are defined as accounted construction costs at the time of project completion. This definition is applied in the present paper.

In many countries, attempts have been made to assess the scale of cost overruns in construction projects. Odeck [4] analysed 420 road construction projects and found a mean cost overrun of 7.9% and a range of 59 to 183%. For bridges and tunnels, Skamris and Flyvbjerg [5] found the cost estimates from the decision to build to actual completion experienced a cost overrun of 50 to 100%. Using the contract award as the reference point, Love et al. [6] analysed cost overruns from 276 construction and engineering projects. The research revealed a mean cost overrun of 12.22%. No significant differences for cost overruns were found among procurement method, project type and contract size.

There has been many studies devoted to factors affecting cost overrun. In Reference [7] the authors presented an overview of the different explanations for cost overruns. The most common explanations include: economic rational behaviour, strategic behaviour, optimism bias, structure of the organisation, relationship between actors and actors' values, as well as their relationship to the environment. According their research, the explanations can be grouped into four different categories: technical explanations, economic explanations, psychological explanations and political explanations. Another study [8] determine the factors responsible for impacting the cost performance of Ethiopian public construction projects. The research [9] is based on a survey approach, eventually compiling information on 321 completed educational projects. Five variables: initial contract sum, gross floor area, number of storeys, source of funds and contractors' financial classification are observed to influence cost overruns.

In Reference [10] the authors identified and analysed 44 factors affecting cost overrun, 11 of which have a decisive influence. These include: financial condition of the owner, cash flow of contractor, method of procurement (open tender or selective tender), material cost increase due to inflation, competition at tender stage (aggressive or not), fluctuations in the currency that the payment will be made in, project size (small or large), delay in design and approval, risk retained by client for quantity variations, drawings (detailed or not) and inaccurate material estimating.

Many studies reveal that most cost overruns occur in the planning stages up to the final design [11,12]. They are related to design changes and tend to increase in the amount of inputs needed because of technical and administrative problems [13]. Regarding cost overruns, the three main causes were identified as contractor-related problems, material-related problems and, again, owners' financial constraints [14].

On the basis of the literature, the most significant reasons for cost overrun were collected (Table 1).

Table 1. Cost overrun causes.

Cost Overrun Categories	Causes	Study
Technical	Price rises	Cantarelli et al. (2010); Lind and Brunes (2015); Derakhshanavijeh (2017)
	Poor project design	Hinze et al. (1992); Koushki et al. (2005);
	Incompleteness of estimations	Cantarelli et al. (2010); Lind and Brunes (2015);
	Scope changes	Derakhshanavijeh (2017)
	Inappropriate organisational structure	Cantarelli et al. (2010); Derakhshanavijeh (2017)
	Inadequate decision-making process	Koushki et al. (2005); Cantarelli et al. (2010);
	Inadequate planning process	Lind, H and Brunes (2015)
	Additional works	Cantarelli et al. (2010)
Economical	Replacement works	Cantarelli et al. (2010)
		Cantarelli et al. (2010); Derakhshanavijeh (2017)
Economical	Lack of incentives	Cantarelli et al. (2010)
	Lack of resources	Koushki et al. (2005); Cantarelli et al. (2010)
	Inefficient use of resources (poor financing)	Koushki et al. (2005); Cantarelli et al. (2010)
Contractual	Tendering strategy (open; selective)	Hinze et al. (1992); Ahiaga-Dagbui and Smith (2014);
	Procurement option (Design-bid-build; Design and build)	El-Kholy (2015); Asiedu et al. (2017)
		Ahiaga-Dagbui and Smith (2014)
Psychological	Optimism bias among local officials	Flyvbjerg et al. (2002); Cantarelli et al. (2010)
	Cognitive bias of people	Cantarelli et al. (2010)
	Cautious attitudes towards risk	Flyvbjerg et al. (2002); Cantarelli et al. (2010)
Political	Deliberate cost underestimation	Flyvbjerg et al. (2002); Cantarelli et al. (2010)
	Manipulation of forecasts	Flyvbjerg et al. (2002); Cantarelli et al. (2010)

The previous studies used various methodologies to solve the problem of predicting construction cost and cost overrun for construction projects. Some of the methods used in the previous studies include statistical methods, such as multiple regression analysis (MRA) for predicting construction cost [15,16]. Attala and Hegazy [17] and, Hegazy and Ayed [18] presented a regression and ANN models for predicting cost overrun of reconstruction projects. Many authors applies

analogical methods, such as Case-based reasoning (CBR) for predicting the construction cost [19–21]. El-Kholy [10] proposed predictive models intended to be applicable for predicting cost overrun percentage of construction projects. These models are based on regression analysis and case based reasoning. Ahiaga-Dagbui and Smith [22] made a case for using data mining in modern construction management as a key business tool to help transform information embedded in the construction data into decision support systems that can complement traditional estimation methods for more reliable final cost forecasting. Using a combination of non-parametric bootstrapping and ensemble modelling in artificial neural networks, cost models were developed to estimate the final construction cost of water infrastructure projects.

Few authors focus on selected aspects of cost overrun [23,24]. Marzouk and Amin [23] see the need for developing a system that is capable of estimating the size and amount of the change in materials prices at a reasonable accuracy. There is also a need to predict the change in building materials prices (either increase or decrease) during the execution phase of the project, as well as during the preparation of tenders. Their research presents a system that utilizes fuzzy logic to identify construction materials that are most sensitive to the change in prices. The research proposes a methodology for identification of construction materials that are most sensitive to the change in prices to be used in modifying the contract price with an attempt to predict the amount of future change in materials prices using neural networks technique.

The purpose of the article is to build the concept of a prediction model for the increase in the cost of the implementation of construction works in relation to those planned. The assumption of the model is the analysis of selected construction works, the impact of which on cost overrun is significant.

2. The Concept of a Cost Prediction Model

The increase in the construction work costs in relation to those estimated ones is influenced by a considerable number of factors. Many of them is typical for one particular type of works; for instance, some will apply to earthworks where the main risk involves the change in the amount of works, others will be relevant to finishing works for which the decisive factor is the cost of the building materials used. As the analysis of every element of the building may be time consuming and, in most cases, ineffective, the first stage should concern those elements that are the most prone to cost increase. One of the premises involves the price of the building element in the whole cost estimate.

An example share of building element costs in the price estimate is illustrated by Table 2.

Table 2. The share of the cost elements in the price of multi-family buildings by BCO I quarter of 2018.

Building Elements	A	B	C	D
	% of the Share in the Building Price			
Raw state	7.9	6.8	11.5	13.0
Earthworks	2.5	2.2	4.2	0.8
Foundations	2.0	1.7	1.9	3.8
Underground walls	1.9	1.6	2.6	3.8
Insulation	1.4	1.3	0.5	0.7
Other	0.1	0.0	2.3	3.9
Building shell	45.6	39.8	35.1	45.9
Superstructure walls	17.2	15.0	9.0	16.0
Ceilings, vaults, stairs, landings	10.5	9.1	12.3	12.8
Partitions	3.1	2.7	2.1	5.5
Roor – structure + covering	4.4	3.8	2.4	3.6
Superstructure insulation	5.1	4.5	3.7	5.2
Other	5.3	4.7	5.6	2.8

Table 2. Cont.

Building Elements	A	B	C	D
	% of the Share in the Building Price			
Interior finishing state	13.6	22.6	21.9	13.3
Plaster and facing	3.6	4.5	7.9	4.5
Windows and doors	7.9	6.8	6.2	5.0
Other	2.1	11.3	7.8	3.8
Exterior finishing state	17.6	15.4	10.1	10.2
Other	15.3	15.0	21.4	17.6

A—4-family building, 2-multi-storey, without a basement, traditional technology, shell units; B—4-family building, 2-storey, without a basement, traditional technology, full finishing state; C—multi-family 4-storey, with an underground garage; D—multi-family 5-storey building, 2-segment with the connector and an underground garage—shell units.

Costs presented in Table 2 apply to multi-family housing units according to BCO I quarter of 2018, part I—cubature buildings [25]. The data concern the construction elements without installation or technical equipment. Table 2 reveals that the cost share of most of the elements is no greater than 20%. Yet the cost of some elements does not exceed 1% and therefore it can be believed that they have insignificant influence on the change in the construction costs. However, this is not the only index determining the possibility of increase in the element cost. The proposed model assumes that the reason for growing costs can also involve the elements whose share in the estimated costs is not high but the probability of the change in the amount of works or the change in the unit price is considerable.

2.1. Scheme of the Cost Increase Prediction Model

To determine the increase in the cost of building elements, a model was proposed, the scheme of which is presented in Figure 1. The details of the model are discussed in the next part of the paper.

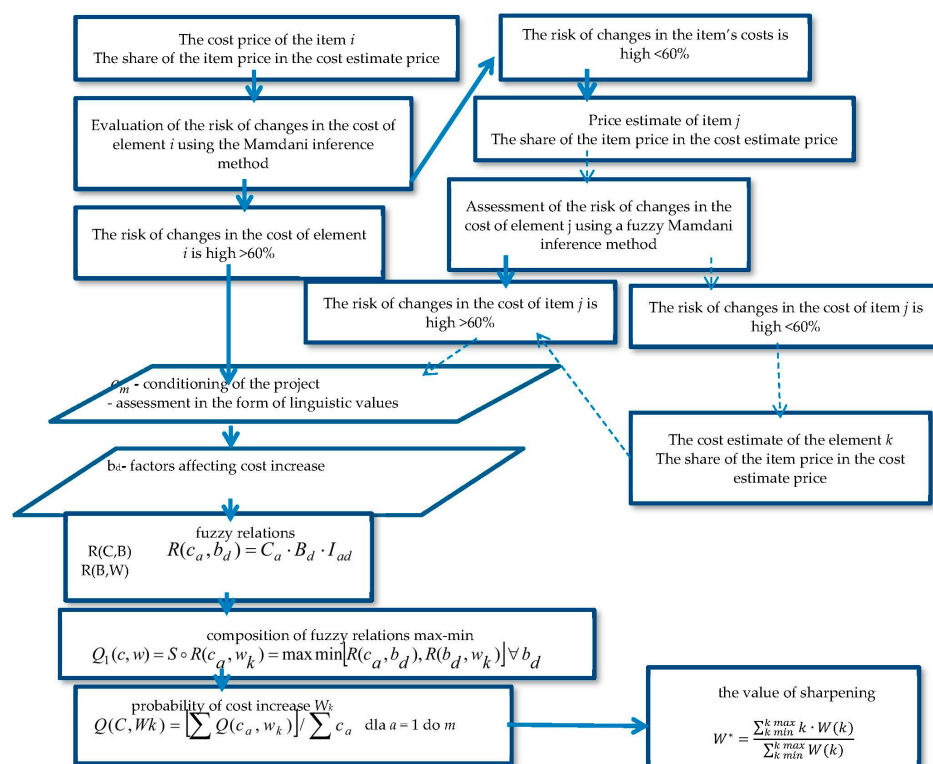


Figure 1. A model for predicting the actual costs of building construction.

2.2. Development of the Cost Increase Prediction Model—I Stage

The assumption of the model is to determine the increase in costs for those elements for which the risk of cost changes is high. The first stage, therefore, involves the selection of elements subject to further assessment. The model proposes the Mamdani fuzzy inference method. The following rules are used:

Rule 1 If “the share of element costs in the building costs is high”
And “predicted changes in the number of works are high”
Or “the expected changes in the unit price are high”
Then “the risk of changing the cost of the item is high” (1)

Rule 2 If “the share of element costs in the building costs is high”
And “predicted changes in the number of works are low”
Or “the expected changes in the unit price are low”
Then “the risk of changing the cost of the item is average” (2)

Rule 3 If “the share of element costs in the building costs is average”
And “predicted changes in the number of works are high”
Or “the expected changes in the unit price are high”
Then “the risk of changing the cost of the item is high” (3)

Figure 2 presents the proposed membership functions for the share of element costs in the building costs, as well as the expected change in the number of works and the expected change in the unit price.

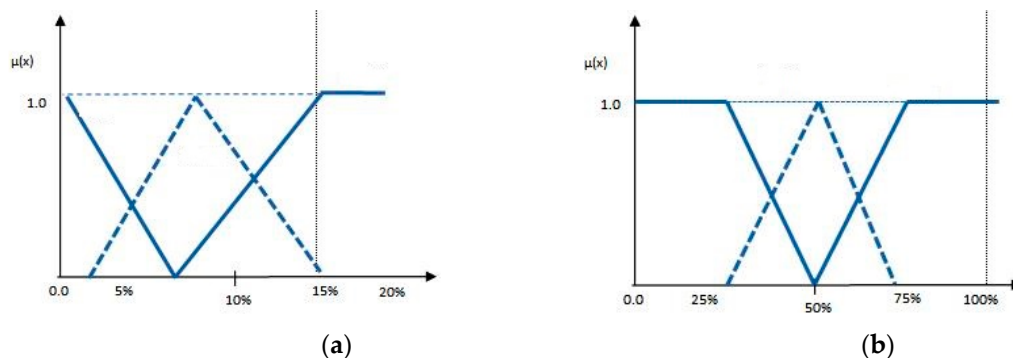


Figure 2. Membership functions to (a) share of the cost element in the cost of the object and (b) the expected changes in the quantity of work and the expected change of the unit price.

2.3. Development of the Cost Increase Prediction Model—II Stage

For elements for which the risk of cost element changes is high, it is proposed to use the mathematical model (II stage) presented below.

- The decision maker determines the conditions of the project c_m which may have an impact on cost increase (examples in Table 1).
- Factors b_n affecting cost increase are determined. These factors, unlike the conditions of the project, are characteristic of a given building element. Example factors are as follows: price range, change in unit price over time, time limit, the risk of replacement works, the risk of changing the amount of works.
- The ranges of cost increases W_k are determined.
- The project conditions and factors using linguistic values are assessed: {Very Good (Very High), Good (High), Above Average, Average Good (Average High), Below Average, Weak (Low), Very Weak (Very Low)}.
- Linguistic values are transformed into a fuzzy form according to Figure 3 and Table 3.

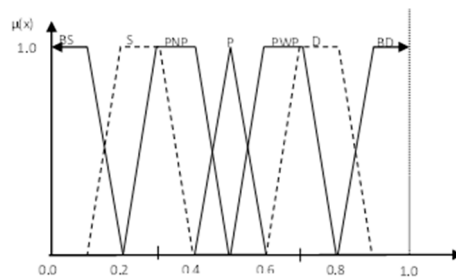


Figure 3. Graphic representation of fuzzy numbers for linguistic variables.

Table 3. Fuzzy interpretation of linguistic variables.

Linguistic Values	Fuzzy Assessment (Interpretation)
VG/VH Very Good (Very High)	(0.8; 0.9; 1.0; 1.0)
G/H Good (High)	(0.6; 0.7; 0.8; 0.9)
AA Above Average	(0.5; 0.6; 0.7; 0.8)
A Average Good (Average High)	(0.4; 0.5; 0.5; 0.6)
BA Below Average	(0.2; 0.3; 0.4; 0.5)
W/L Weak (Low)	(0.1; 0.2; 0.3; 0.4)
VW/VL Very Weak (Very Low)	(0.0; 0.0; 0.1; 0.2)

For each of the conditions of the project, the sharpening value according to the formula in (4) is determined:

$$C_a = (C_{a1} + C_{a2} + C_{a3} + C_{a4}) / 4 \quad (4)$$

Then, as in the case of conditions, factors influencing the increase in costs are assessed.

Elements of the relation $R(c, b)$ are calculated, establishing the relationship between the conditions of the project and the factors influencing the increase in costs, according to the following formula:

$$R(c_a, b_d) = C_a \cdot B_d \cdot I_{ad} \quad (5)$$

Elements $R(b, w)$ are determined, where $R(b, w)$ is a fuzzy relationship that determines the impact of a factor on a given increase in costs W_k .

Elements $Q(c, w)$ are determined, which are the composition of two fuzzy relations $R(c, b)$ and $R(b, w)$ and determine the relationship between the conditions of the project c and the level of cost increase w , through their relationship with factor b .

Relationship compositions are determined in accordance with the maximum-minimum principle (max-min).

Relationship compositions max-min for the given c_a and w_k are determined by:

$$Q_1(c, w) = S \circ R(c_a, w_k) = \max \min [R(c_a, b_d), R(b_d, w_k)] \forall b_d \quad (6)$$

For a given value of cost increase W_k , its probability of occurrence is calculated according to the formula:

$$Q(C, W_k) = [\sum Q(c_a, w_k)] / \sum c_a \text{ dla } a = 1 \text{ do } m \quad (7)$$

The value of sharpening can be obtained by the centre of gravity method:

$$W^* = \frac{\sum_{k \min}^{k \max} k \cdot W(k)}{\sum_{k \min}^{k \max} W(k)} \quad (8)$$

The achieved value of sharpening is the most probable value of the increase in the costs of a given element.

2.4. Calculation Example

The object of consideration is the possibility of increasing the cost of walls of superstructure in a 4-family building, 2-storey, without basement, traditional technology, with full finishing.

- (1) Using (1), (2), (3) the risk of changing costs is assessed.

The following data was assumed: participation in the price of the object: 15%; anticipated changes in the number of works—50%; expected changes in the unit price—100%.

Applying rules (1), (2), (3):

Rule 1 $\min(1,0; 0,0) = 0,0$ $\max(0,0; 1,0) = 1,0$

Rule 2 $\min(1,0; 0,0) = 0,0$ $\max(0,0; 0,0) = 0,0$

Rule 3 $\min(0,0; 0,0) = 0,0$ $\max(0,0; 1,0) = 1,0$

Conclusions:

The risk of changing the item costs is high to 100%

The risk of changing the element's costs is average at 0%

Because the risk of changing the cost of an element is high to the degree of 100%, the building element, that is the walls of superstructure, is subject to further analysis.

- (2) The following cost increase intervals are adopted: $W_1 = 10\%$; $W_2 = 25\%$; $W_3 = 40\%$; $W_4 = 55\%$; $W_5 = 70\%$; $W_6 = 85\%$; $W_7 = 100\%$.
- (3) The conditions of a given project are determined. The analysed example assumes: quality, completeness of project documentation, cost estimator experience, competitiveness in the tender.

Project conditions are evaluated using linguistic variables that are subsequently converted to the fuzzy form in accordance with Table 3. The results are shown in Table 4.

Table 4. Assessment of project conditions

Project Conditions	Evaluation	
Quality of project documentation	High	0.6; 0.7; 0.8; 0.9
Cost estimator's experience	Very good	0.8; 0.9; 1.0; 1.0
Competitiveness in the tender	Average high	0.4; 0.5; 0.5; 0.6

Sharpening values are determined according to (4):

$$C_1 = (0.6 + 0.7 + 0.8 + 0.9)/4 = 0.75$$

$$C_2 = (0.8 + 0.9 + 1.0 + 1.0)/4 = 0.93$$

$$C_3 = (0.4 + 0.5 + 0.5 + 0.6)/4 = 0.50$$

- (4) Factors influencing the element cost increase are determined. Factors adopted: price range, change in the unit price of walls superseded in time, the risk of changing the number of works.

The factors are evaluated using linguistic variables that are subsequently converted to fuzzy in accordance with Table 3. The results are shown in Table 5.

Table 5. The assessment of factors influencing the increase of costs.

Factors	Evaluation	
Price range	Very high	0.8; 0.9; 1.0; 1.0
Changing the unit price of walls of superstructure in time	Low	0.1; 0.2; 0.3; 0.4
The risk of changing the number of works	Low	0.1; 0.2; 0.3; 0.4

Sharpening values are determined according to (4):

$$B_1 = 0.925$$

$$B_2 = 0.25$$

$$B_3 = 0.25$$

- (5) Basing on expert knowledge, values I_{ad} are established—the relationship between conditioning a and factor d . The results are presented in Table 6.

Table 6. The relationship between the project condition a and factor d .

Project Conditioning (C_a)	Factors (B_d)	The Relationship between Conditioning and the Factor (I_{ad})
C_1	B_1	$I_{11} = 0.10$
C_1	B_2	$I_{12} = 0.10$
C_1	B_3	$I_{13} = 1.00$
C_2	B_1	$I_{21} = 0.50$
C_2	B_2	$I_{22} = 0.50$
C_2	B_3	$I_{23} = 0.50$
C_3	B_1	$I_{31} = 0.20$
C_3	B_2	$I_{32} = 0.20$
C_3	B_3	$I_{33} = 0.50$

- (6) Relationships $R(C,B)$ are calculated employing the formula in (5). The results are presented in Table 7.

Table 7. Elements of the $R(C,B)$ relation.

Relation $R(C,B)$	B_1	B_2	B_3
C_1	$0.75 \cdot 0.925 \cdot 0.10 = 0.069$	$0.75 \cdot 0.25 \cdot 0.10 = 0.019$	$0.75 \cdot 0.25 \cdot 1.00 = 0.188$
C_2	$0.93 \cdot 0.925 \cdot 0.50 = 0.430$	$0.93 \cdot 0.25 \cdot 0.50 = 0.116$	$0.93 \cdot 0.25 \cdot 0.50 = 0.116$
C_3	$0.50 \cdot 0.925 \cdot 0.20 = 0.093$	$0.50 \cdot 0.25 \cdot 0.20 = 0.025$	$0.50 \cdot 0.25 \cdot 0.50 = 0.063$

- (7) Relationships $R(B,W)$ are determined based on the most appropriate value of the cost increase for a given pair: determinant—factor, as specified in Table 8.

Table 8. Fuzzy relations $R(B,B)$.

Relation $R(B,B)$		Increase $W_1 = 10\%$	Increase $W_2 = 25\%$	Increase $W_3 = 40\%$	Increase $W_4 = 55\%$	Increase $W_5 = 70\%$	Increase $W_6 = 85\%$	Increase $W_7 = 100\%$
C	B							
C_1	B_1	0.4	0.6	0.8	1	0.8	0.6	0.4
C_1	B_2	1	0.8	0.6	0.4	0.2	0	0
C_1	B_3	1	0.8	0.6	0.4	0.2	0	0
C_2	B_1	0.4	0.6	0.8	1	0.8	0.6	0.4
C_2	B_2	1	0.8	0.6	0.4	0.2	0	0
C_2	B_3	1	0.8	0.6	0.4	0.2	0	0
C_3	B_1	0.2	0.4	0.6	0.8	1	0.8	0.6
C_3	B_2	0.6	0.8	1	0.8	0.6	0.4	0.2
C_3	B_3	0.8	1	0.8	0.6	0.4	0.2	0

For instance, for the pair C_1, B_1 the most appropriate value is $W_4 = 55\%$. Thus $R(C_1, W_1)$ receives the value 1.00 and for the subsequent sizes W_k these values are gradually reduced by 0.20.

- (8) The max-min relationship is determined using the formula (6).

For example, for W_1 the calculation is performed as follows:

$$Q(C_1, W_1) = \max \min [(0.069; 0.40), (0.019; 1.00), (0.188; 1.00)] = \max [0.069; 0.019; 0.188] = 0.188$$

$$Q(C_2, W_1) = \max \min [(0.43; 0.40), (0.116; 1.00), (0.116; 1.00)] = \max [0.40; 0.116; 0.116] = 0.400$$

$$Q(C_3, W_1) = \max \min [(0.093; 0.20), (0.025; 0.60), (0.063; 0.80)] = \max [0.093; 0.025; 0.063] = 0.093$$

On the basis of (7), the following are determined:

$$Q(C, W_1) = (0.188 + 0.40 + 0.093) / 2.18 = 0.31$$

The remaining calculation results $Q(C, W)$ are presented in Table 9.

Table 9. Elements of $Q(C,W)$ relation using the max-min composition operation.

Relation Composition $Q(C,W)$	Increase $W_1 = 10\%$	Increase $W_2 = 25\%$	Increase $W_3 = 40\%$	Increase $W_4 = 55\%$	Increase $W_5 = 70\%$	Increase $W_6 = 85\%$	Increase $W_7 = 100\%$
C_1	0.188	0.188	0.188	1.188	0.188	0.069	0.069
C_2	0.400	0.430	0.430	0.430	0.430	0.430	0.400
C_3	0.093	0.093	0.093	0.093	0.093	0.093	0.093
$Q(C,W)$	0.310	0.330	0.330	0.330	0.330	0.270	0.260

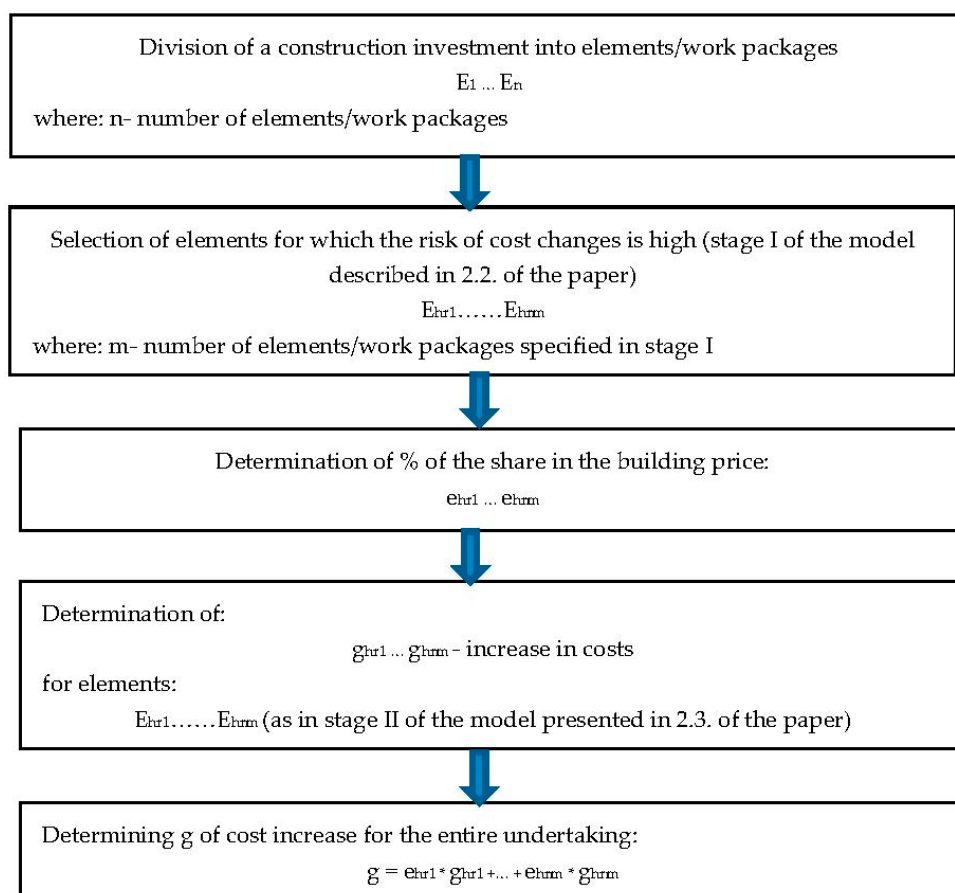
(9) According to (8) the value of sharpening is determined:

$$W^* = (10 \cdot 0.31 + 25 \cdot 0.33 + 40 \cdot 0.33 + 55 \cdot 0.33 + 70 \cdot 0.33 + 85 \cdot 0.27 + 100 \cdot 0.26) / (0.31 + 0.33 + 0.33 + 0.33 + 0.33 + 0.27 + 0.26) = 53\%$$

The calculations show that the most likely increase in costs of the analysed element will be 53% in relation to the costs specified in the cost estimate.

3. The Cost Increase Prediction Model for Whole Project

The model presented in the previous section can be used primarily to assess the anticipated increase in the costs of implementing a selected element of a building structure. The proposed model can also be adjusted to determine the increase in costs for the entire investment, as schematically depicted in Figure 4.

**Figure 4.** A model for the cost increase prediction for whole project.

The individual stages of the model will be characterized more closely in the following case study.

3.1. Case Study

As an example, a construction project will be analysed, which involves changing the way the warehouse and service building is used for social housing. The building in question was made as a detached, single-storey building with a non-usable attic and a part of a basement.

Parameters of the building after the change of use:

- cubic capacity: 2933.0 m³.
- usable area: 263.49 m².

To achieve the goals, the contractor specified and priced 15 work packages. The scope of individual work packages and cost estimates are presented in Table 10.

Table 10. The scope of individual work packages and cost estimates.

No.	Type and Scope of Works	Net Cost Price [EURO]
	Wall and plaster work	
1	- demolition of unnecessary walls and pillars, forging door and window openings, supplementing or walling openings in walls, building partition walls of bricks, laying prefabricated lintels, making exhaust and ventilation ducts, mending cracks in brick walls, making internal plasters, fitting small elements in walls	7644
	Renovation of ceilings	
2	- mould elimination in wooden elements, replacement of sound boarding and headliners, reinforcement of ceiling joists, mould elimination in 25% of the brick ceiling areas, execution of suspended ceilings with mineral wool insulation, cladding of fire protection boards in rooms with a wooden ceiling	10,446
	Painting and cladding work	
3	- removal of internal wall plasters, along with making new plasters, veneering walls with glued tiles, filling and painting walls and ceilings with oil paints	7189
	Carpentry works	
4	- removing old frames, windows and protective steel gratings with sills, fitting windows and window sills, door and window frames, internal and external doors, putting plaster on the jambs	12,429
	Flooring works	
5	- removal of plastic floors, dismantling of wooden floors, horizontal water insulations in non-basement rooms, thermal insulation of Styrofoam boards in all rooms, new cement floors on reinforcing mesh, tile floors with baseboards, in bathrooms, kitchens and corridors, floors with plastic carpeting with baseboards in the rooms	13,924
	Roof works	
6	- dismantling of chimneys, tar paper covering, flashing, gutters and downpipes, supplementing formwork, dehumidifying wooden elements of the roof, replacement of faceplates, repair of damaged places in brick walls, assembly of new flashings, breaking the cement floor of the roof together with making a new one, erection of new chimneys, fireproofing of wooden roof elements, roofing with tar paper, installation of new gutters and downpipes, removal of debris	16,394
	Facade works	
7	- installation of external scaffolding, demolition of concrete elements, supplementation of external plasters, abrasive cleaning of brick walls, wall joints, foundation walls excavation, cleaning and plastering of foundation walls, damp insulation, foundation of ramps for the disabled and stairs, reinforced concrete stairs, reinforced concrete structure of the ramp for the disabled, balustrades, stair cladding and incline from stoneware tiles, backfilling excavations	12,735
	Disassembly of the installation	
8	- disassembly of steel pipelines, washbasin and shower taps and boilers, disassembly of washbasins, fittings, as well as water and sewage equipment	454

Table 10. Cont.

No.	Type and Scope of Works	Net Cost Price [EURO]
9	Central heating installation - making new installation pipelines, steel radiator installations	9438
10	Sewage installation - execution of excavations and penetration of openings through walls and foundations, installation of new sewage pipelines together with instrumentation	4498
11	Water installation - execution of plastic pipelines with equipment installation	3329
12	Water connection - linear excavations with backfilling and compaction, making a water supply connection	481
13	Connection of rainwater and sanitary sewage system - execution of linear excavations and their strengthening, along with subsequent backfilling and hardening, installation of sewage and sewage wells, PVC pipe ducts	4656
14	Electrical and teletechnical installations - disassembly works, installation of multicore cables and cable wires in insulation, sockets, lighting fixtures, installation of switchboards with enclosures,	8896
15	Connection for central heating - execution of necessary excavations, disassembly of steel pipeline and concrete channel elements, breaking necessary openings, heat piping installations, debris removal	2805

In order to assess the expected cost overrun of the project, a scheme of the procedure is proposed, as presented in Figure 4.

First, using the stage I of the model described in Section 2.2, the work package for which the probability of the increase in costs is the highest, was specified, namely: renovation of ceilings, roof works, painting and cladding works, flooring works and facade works. Then, for each of the listed packages, its share in the cost price was determined and the expected increase in costs according to stage II of the model described in Section 2.3 was calculated, which in turn allowed to determine the expected increase in costs for the entire project. The results are presented in Table 11.

Table 11. The expected cost overrun according model results.

Works Listed in Stage I	% of Share in the Cost Estimate Price	% of Cost Increase	Cost Increase for the Investment [%]
Renovation of ceilings	9.01	43	3.87
Roof works	14.22	51	7.25
Painting and cladding works	6.23	64	3.99
Flooring works	12.07	21	2.53
Facade works	11.04	46	5.08

$$\Sigma = 22.73.$$

The total predicted increase in costs is 23 of the total costs of the undertaking.

3.2. Comparison of Model Results and Actual Cost Increase

After completing the project, the actual costs were analysed and compared with those planned. The results are presented in Table 12.

Table 12. The expected cost overrun according the actual costs.

No.	Type of Works	Net Cost Price [EURO]	Real Cost [EURO]	% of Difference	% of Share	Cost Increase [%]
1	Wall and plaster works	7644	7650	0.08	6.63	0.01
2	Renovation of ceilings	10,446	15,434	47.75	9.01	4.33
3	Painting and cladding works	7189	12,358	71.90	6.23	4.48
4	Carpentry works	12,429	12,500	0.57	10.78	0.06
5	Flooring works	13,924	13,800	−0.89	12.07	−0.11
6	Roof works	16,394	21,057	28.44	14.22	4.04
7	Facade works	12,735	18,860	48.10	11.04	5.31
8	Disassembly of the installation	454	450	−0.88	0.39	−0.00
9	Central heating installation	9438	9442	0.04	8.18	0.00
10	Sewage installation	4498	4502	0.09	3.90	0.00
11	Water installation	3329	3343	0.42	2.89	0.01
12	Water connection	481	470	−2.29	0.42	−0.01
13	Connection of rainwater and sanitary sewage system	4656	5080	9.11	4.04	0.37
14	Electrical and teletechnical installations	8896	8600	−3.33	7.71	−0.26
15	Connection of central heating	2805	2830	0.89	2.43	0.02
Σ		115,318	136,376			18.26

The real increase in costs was 18%. The greatest impact on this was exerted by the increase in costs for elements: renovation of ceilings, painting and cladding works, roof works and facade works, which amounted to 18.16% of the total cost increase. The concurrence of the results obtained in the model and the actual increase in costs confirm the usefulness of the model.

4. Discussion

The paper presents the initial concept of developing a model for predicting the cost of a building. The first stage of the proposed model is the selection of building elements for which the increase in costs can be significant. Taking into account the conditions of the project and the factors affecting the increase in costs, the most likely increase in the costs of individual elements is calculated with the use of fuzzy logic.

The simple example illustrates the way the model operates. The object of consideration was the possibility of increasing the cost of walls of the superstructure. The first part of the model developed (stage I) allowed to confirm the high probability of the cost increase for the analysed element. The results of the second part of the model, in turn, showed that the most likely increase in costs of the analysed element will be 53% in relation to the costs specified in the cost estimate.

The subsequent part of the paper proposes a diagram of the model supporting the estimation of cost overruns for the entire construction project. The presented case study compares the value of cost overrun determined by means of the proposed model with actual cost overrun. In the analysed example, a large concurrence of the results obtained was observed, which confirms the usefulness of the model in predicting the increase in costs in construction projects.

The proposed model is a preliminary study which requires further research and analysis. The I stage of the model allows a simple selection of elements/work packages that will be subject to further study. The simplified approach used here may not be sufficient in some cases and it may lead to the omission of works that could generate an increase in costs. This can be prevented by the development and refinement of the rules applied and an analysis based on the real data. The analysis of the project conditions and factors affecting the increase in the costs of individual construction works requires further work. The research also requires the adaptation of the model to various building objects and works characteristic of them, as well as various degrees of a merge of works.

The cost increase prediction model for the whole project was tested only on select, simple building projects. It definitely requires further testing, confirming its usefulness in construction. It should be noted that the use of the model requires that the user possesses a very good knowledge of the project

conditions and factors affecting the increase in the analysed investment which can prove to be a barrier to its practical use.

With more sophisticated projects and a large number of elements/work packages, the model requires many complex calculations. However, the development of a suitable computer application will allow the use of the mathematical model in practice.

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