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DETERMINATION OF THE CONTRACT RISK BUFFER IN THE CONSTRUCTION INDUSTRY

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Abstract

This article presents an analysis of the volatility of construction project implementation costs, with a particular focus on medium- and long-term projects. Inherent fluctuations in the prices of construction inputs require contractors to use advanced methods of calculating bid prices and formulating base budgets, in accordance with best practices in cost risk management.

The article presents an algorithm for determining the contract risk buffer resulting from the increase in the cost of construction work, taking into account the key determinants of risk and their impact on final investment costs. It also discusses legal issues, such as the allocation of risk between contracting parties, and economic aspects related to the construction sector, including the improvement of forecasting tools in the area of investment costs. In addition, the analysis covers issues related to the management of construction projects, the organization of construction processes and the complexity of project structures. The multi-criteria approach used enables a comprehensive assessment of the risks involved in estimating the cost of construction projects.

Keywords: construction costs, risk buffer, heterogeneity of construction processes, construction economics

1. INTRODUCTION

Construction projects are characterized by high resource intensity, heterogeneity and high complexity, with inherent uncertainties related to potential increases in the cost of procuring construction materials after the contract is signed [1], [2], [3]. In response to these challenges, it is imperative that contractors develop and implement advanced risk management strategies that are based on precise data analysis, flexible planning, and dynamic adaptation of budgets and operational strategies to changing market and technical conditions [4], [5]. One of the most important responsibilities of a construction contractor is to accurately determine the bid price and basic project budget, including the inclusion of a risk buffer to account for the materialization of standard contractual risks. Errors in this process can result in significant financial losses and potentially threaten the long-term financial stability of the construction

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company [6], [7], [8]. Despite the importance of this issue, there is a noticeable lack of research in the literature on adaptive financial provisioning solutions for construction bid pricing [9], [10].

This article presents a robust and flexible approach to calculating a financial buffer for the materialization of contractual risk, as defined by:

1) Volatility of the macroeconomic situation and legal framework,
2) the complexity of the construction work and the specificity and nature of the construction work,
3) location of the construction object,
4) the duration of the construction work and the duration of the quality guarantee/defect warranty (whichever is longer),
5) Actions and omissions of stakeholders, including participants in the investment process.

Risk factors and their impact were identified through a comprehensive analysis of literature, case law and empirical studies of budgets from cubic and linear investments carried out by domestic construction companies in 2018-2024.

2. DETERMINANTS OF THE VARIABILITY OF THE COST OF CONSTRUCTION WORKS

2.1. Volatility of the macroeconomic situation and regulatory framework

Key macroeconomic factors affecting the cost of construction include the consumer inflation index (CPI), interest rates, exchange rates, national fiscal policy, conventional energy costs, trade restrictions and sanctions, environmental regulations, and global events [11], [12]. The impact of these determinants on the price volatility of key cost drivers in the construction sector is illustrated in Table 1.

Table 1. Key macroeconomic factors affecting the cost of construction and assembly production in Poland

Factor	Characteristics of the factor
CPI inflation	An increase in the CPI inflation rate leads to an increase in construction production costs, material prices and wages in the construction sector, resulting in increased financial outlays for construction projects.

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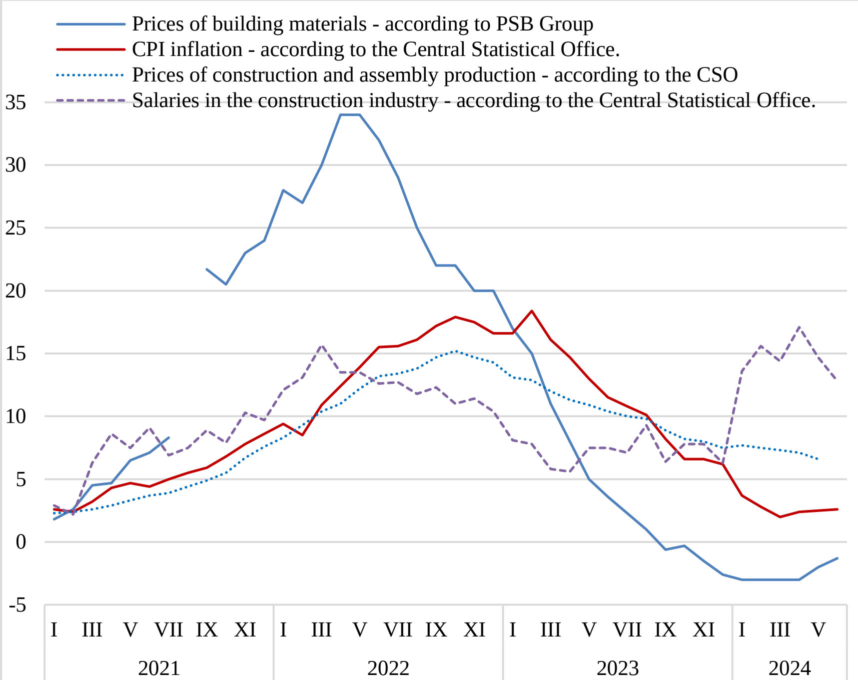

Fig. 1. Volatility of construction output prices, construction material prices, construction wages and CPI inflation in Poland in January 2021-June 2024 in month-on-month terms of the previous year [18], [19]

Analysis of Figure 1 indicates that construction material prices and construction output prices show more pronounced fluctuations and exhibit a stronger correlation with CPI inflation. Construction wages, on the other hand, are growing more gradually, although they also show some consistency with inflation trends.
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<tr>
<td>Interest rates</td>
<td>The increase in interest rates triggers an increase in the cost of raising capital (loans, leases), leading to higher debt service expenses and an increase in the total cost of construction investments, mainly as a result of higher financing costs.</td>
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<td>Exchange rates and fiscal policy</td>
<td>The depreciation of the zloty against the euro and the U.S. dollar raises the cost of importing raw materials and construction technology, complicating precise budget planning and generating additional exchange rate risk in construction projects.</td>
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<td>Tax burden</td>
<td>Changes in fiscal burdens, VAT rates and minimum wage regulations increase labor and operating costs, directly affecting the profitability of construction projects.</td>
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<td>Energy costs</td>
<td>Rising energy prices, especially from conventional sources, are driving up the cost of producing construction materials and operating equipment, raising the operating costs of project implementation.</td>
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<tr>
<td>Trade restrictions and sanctions</td>
<td>Trade restrictions and international sanctions are leading to disruptions in global supply chains, causing shortages of construction raw materials and increasing their prices, which increases the cost of implementing projects.</td>
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<td>Global events</td>
<td>Global events, such as the COVID-19 pandemic and the war in Ukraine, are disrupting the availability of raw materials and destabilizing supply chains, causing construction material prices to rise and projects to be delayed [11], [12], [13].</td>
</tr>
</table>

Own elaboration

The formation of macroeconomic conditions is significantly influenced by changes in government policies and regulations, especially tax laws, administrative regulations, environmental standards and trade policies, which directly determine the cost of construction projects (Table 2) [13].

Table 2. Legal factors determining the cost of construction work

Factor	**Characteristics of the factor**
Government policies/policy objectives	Public support instruments, including subsidies, tax breaks and non-refundable grants, affect the capital cost structure of construction projects. Programs supporting the implementation of energy-efficient technologies can result in lower capital expenditures, while accelerating the implementation of innovative technological solutions.
Tax regulations	Changes in the tax system, such as modifications to VAT rates on construction materials and services and new regulations on depreciation and tax deductions, directly shape the level of operating costs of companies operating in the construction sector.
Administrative regulations	Legal norms regulating the deadlines and procedures of the architectural and construction administration and construction supervision authorities affect investment implementation schedules. Delays in the issuance of administrative decisions, permits and technical arrangements result in an increase in the cost of capital due to the need to extend bridge financing, and may lead to a reorganization of construction work schedules.
Environmental standards	Environmental regulations, including CO_2 emissions reductions and building energy efficiency standards, generate additional investment costs due to the need for advanced low-carbon technologies and certified building materials that comply with sustainable building standards.
Customs duties and trade sanctions	Trade restrictions, such as import tariffs, embargoes and international sanctions, are driving up the price of construction materials and advanced technologies, while disrupting global supply chains, leading to higher investment costs and longer lead times.

Own elaboration

In order to develop reliable forecasts of changes in construction factor prices resulting from macroeconomic fluctuations, construction companies use advanced analyses developed by specialized research centers and forecasting institutions [12]. Among the most important sources of information are:

1) SEKOCENBUD Sp. z o.o., which publishes the quarterly "Aggregate Indexes of Valorization and Forecasts of ZWW". These reports include forecasts of long-term trends in the prices of production factors, construction facilities and construction and assembly production costs. The forecasts also include annual projections of construction material prices, net and gross labor rates, construction equipment operating costs, and valuations of individual groups of construction facilities. The analyses used are based on advanced statistical and econometric models, verified by industry specialists;
2) PMR Ltd. which publishes reports including long-term forecasts of general inflation and construction output price inflation, based on advanced econometric models and historical time series analysis.

Construction companies also use CPI inflation forecasts and salary analyses published by institutions such as the National Bank of Poland, the Institute for Economic Forecasting and Analysis and commercial banks. These forecasts are based on advanced statistical models and take into account a wide range of macroeconomic variables. Nevertheless, forecasts of medium- and long-term economic and political stability are subject to considerable forecasting uncertainty due to macroeconomic and political instability [12].

2.2. The complexity of construction work, the specificity and nature of the construction object

The cost of producing a construction object is strictly dependent on the complexity of the construction work, as well as the specificity and nature of the construction object itself. According to the Decree of the Minister of Development and Technology of December 20, 2021 on determining the methods and bases for preparing the investor's cost estimate, calculating the planned costs of design works and the planned costs of construction works specified in the functional-utility program [17], the following factors influence the category of complexity of construction works (Table 3):

– The type and function of the building object,
– Geotechnical category of the construction object,
– functional, installation and technological requirements, including specifications for installation systems, technical infrastructure and technological level;
– The standard of finish and prestige of the building facility.

Table 3. Factors influencing the complexity category of a construction object

Factor	Characteristics of the factor
Type and function of construction of the building	The type of building structure (volume, linear, engineering, historic) and its intended use determine the technical and architectural requirements. For the renovation of buildings, especially historic ones, the preservation of the original structure and the integration of modern technologies are key challenges.
Geotechnical category of the construction object	Soil and water conditions affect the choice of foundation technology. Historic buildings use minimally invasive techniques so as not to disturb the original structures.
Functional, installation and technological requirements	Technical specifications of the building and installation systems (e.g., HVAC, BMS) influence the choice of design solutions. Renovation requires integration of modern installations while maintaining architectural qualities and compliance with preservation regulations.
Standard of finish and prestige of the building facility	The high standard of finish and prestige of the building require the use of materials with improved technical and aesthetic parameters. Historic renovations use materials in accordance with the original design, while applying modern conservation technologies.

Own elaboration based on the data contained in the Ordinance of the Minister of Development and Technology of December 20, 2021 on determining the methods and bases for preparing the investor's cost estimate, calculating the planned costs of design works and the planned costs of construction works specified in the functional-utility program [17].

An empirical analysis of the case law of the common courts and the National Board of Appeals clearly indicates that, from the contractor's perspective, the execution of construction works billed on a lump sum basis - such as renovation, expansion (especially vertical expansion requiring interference with the structure, functional layout or installations of an existing facility), superstructure and reconstruction - involves a higher economic risk, higher than in the case of new construction. The main reason for this risk is the potential underestimation of the material scope of construction work, caused by the inconsistency between the contractual documentation and the actual technical condition of the facility.

Technical specifications often do not take into account the full technical and functional requirements necessary to integrate newly designed structures with existing building elements, resulting in additional construction work not included in the contract. Many investors assume that any inaccuracies in the documentation should be discovered by the bidder at the bidding stage, and this risk should be included in the lump-sum bid price.

However, such an approach is contrary to established case law, which indicates that the responsibility for defects in design documentation rests with the investor. The investor is obliged to provide complete and accurate design data, and transferring this risk to the contractor violates the principle of economic balance between the parties to the contract, which contradicts the basic principles of contract law [12], [13], [14].

2.3. Location conditions

The cost of construction works is closely dependent on the site conditions of the construction facility (Table 4), which can significantly affect the timing of the project, technical requirements and overall investment costs. Key factors affecting the cost of construction works include:

- geological, geotechnical and hydrological conditions,
- climatic conditions,
- The availability of local human and material resources,
- The distance of the construction site from the contractor's warehouses and wholesalers of construction materials and equipment,
- The state of road infrastructure,
- The presence of harmful or hazardous factors,
- Availability of the construction site or work front.

Table 4. Location factors determining the cost of construction work

Factor	Characteristics of the factor
Geotechnical, geological and hydrological conditions	Complex ground conditions, such as high groundwater levels, non-bearing soils or landslides, require detailed geotechnical investigations and the design of specialized foundation systems [1]. Techniques such as microboring, jet grouting or slurry walls increase foundation costs due to the need to reinforce the foundation and protect it from groundwater inflow. In addition, in infrastructure projects, such as the construction of electric power line facilities, foundations must take into account dynamic loads caused by the operation of power equipment [2].
Climatic conditions	Extreme weather conditions, such as high winds, snowfall and prolonged sub-zero temperatures, have a direct impact on the construction schedule. The occurrence of frost and precipitation leads to the need for winter construction technology, including heating of concrete, use of thermal insulation for the time of concrete maturation and snow removal from structures. In the case of work at height and overhead work (such as power lines), it is important to monitor weather conditions, which may require advanced meteorological detection systems.
Availability of local human and material resources	The limited availability of construction materials in a given region and the scarcity of skilled labor make it necessary to transport materials and mobilize personnel from remote locations. In large-scale projects, such as the construction of large electric power facilities, these difficulties can result in the need to organize welfare and logistics facilities for the crew, which generates significant operating costs. In addition, the lack of local availability of specialized construction machinery requires renting or transporting equipment from long distances, which increases logistics expenses.
Distance of the square construction from magazines and wholesalers materials	The considerable distance of the construction site from the location of the contractor's warehouses and building materials wholesalers increases logistics costs due to longer transportation routes and the need to intensify deliveries. Projects that require the delivery of bulky items (e.g., transformers, girders) may require the use of specialized means of transportation, such as multi-axle vehicles, which are required to transport heavy infrastructure components.

Condition of road infrastructure	The quality of local transportation infrastructure is crucial to the timeliness and smoothness of the delivery of materials and equipment to the construction site. Inadequate road infrastructure (e.g., roads with limited carrying capacity, lack of paved surfaces) necessitates the organization of alternative transportation routes or the construction of temporary access roads. Projects in mountainous or wetland areas may require the use of specialized technologies, such as temporary bridges, which significantly increases implementation costs.
Harmful or dangerous factors	Implementation of work in conditions of exposure to hazardous substances (chemical, biological) or physical hazards (e.g., work at height, work in explosive conditions) requires strict compliance with OSH standards and the use of advanced personal protective equipment. Work at height, especially in energy projects (e.g., installation of overhead lines), requires the use of rope access techniques, aerial lifts and specialized safety systems, which significantly increases the cost of organizing the work [12].
Restrictions on access to the construction site or work front	Limited site availability (e.g., works in active industrial plants, energy infrastructure upgrades in public places) necessitates the execution of works during non-standard working hours (night work, shift work). This forces optimization of the work schedule and increases labor costs resulting from shift and night work. In the case of electric power projects, uninterrupted operation of facilities requires close coordination of schedules for power line disconnections and switching [12].

Own elaboration

2.4. Timeline

A key factor affecting the cost of construction works is the duration of their execution and the duration of the quality guarantee/ warranty for defects (whichever is longer). Accordingly, the calculation of the bid price for construction works should take into account factors [7], [8], among others:

1) Seasonality, which has a significant impact on the contractor's operating costs. Construction work carried out during the winter period may require additional expenditures on site heating, snow removal and providing adequate working conditions for work crews. In addition, there may be interruptions due to adverse weather conditions, which may periodically impede the progress of construction work.
2) Potentially extending the construction period, which can lead to increased indirect costs (such as administrative staff salaries and site maintenance operating costs), as well as direct costs (including construction material prices, labor and equipment costs). Accelerating construction work can be used as a strategy to minimize delays and associated additional costs (e.g., avoiding contractual penalties for delays); however, this approach carries the risk of increased direct costs due to overtime, wages for accelerated work, and a potential decrease in the quality of workmanship resulting from time pressure.

2.5. Actions and inactions of stakeholders

The cost of construction works is determined by the decisions of key stakeholders, such as the investor, designer, contractor and construction supervision authorities. Each of these stakeholders has a significant influence on the course of the investment, which has a direct impact on the cost structure, schedule and quality of the executed works.

The investor, as the party responsible for the strategic management of the project, makes decisions on the location of the investment, the implementation schedule and the allocation of contractual risks between the parties. The selection of the designer and contractor is crucial to the technical and economic parameters of the project. Improper selection can lead to increased technical and financial risks, resulting in delays and increased costs [4], [5].

The designer, acting under the Construction Law, is responsible for developing design documentation that complies with regulations and technical standards. His decisions regarding the choice of technology and materials affect not only the cost of implementation, but also subsequent operating costs. Lack of in-depth analysis of technical alternatives can lead to escalating expenses both at the stage of implementation and during the operation of the facility [6].

The contractor, performing work under a construction contract, is responsible for selecting subcontractors and suppliers of construction materials. Improper selection, especially of entities with insufficient qualifications, can lead to a reduction in the quality of the work, the need to correct defects and delays in the schedule. Proper coordination of works and supervision of subcontractors are key to ensuring timeliness and minimizing operational risks [5].

Construction supervision authorities, in accordance with the provisions of the Construction Law, exercise control over the compliance of executed works with the design documentation and applicable regulations. Within the scope of their competence, they supervise compliance with technical requirements, issue decisions to allow objects for use and supervise final acceptance. Possible delays in administrative procedures can result in longer implementation times and increased costs associated with longer construction site maintenance and equipment rental [6].

Interpretive discrepancies regarding the scope of contractual obligations and inconsistent expectations of the parties often lead to conflicts that negatively affect the implementation of the project. Disputes over the scope of work or the need for changes in design documentation generate additional costs and lead to an extended work schedule. Contractual conflicts resulting from differing interpretations of contract terms can contribute to escalating costs and postponement of project completion dates [12], [13].

3. DETERMINE THE RISK BUFFER ASSOCIATED WITH THE INCREASE IN THE COST OF CONSTRUCTION WORK

The contractor, acting as a professional market participant, is required to include in the bid price an adequate financial buffer to protect the project from the effects of the materialization of standard contractual risks [12].

3.1 Algorithm for determining the risk buffer

Based on the empirical study, an algorithm was developed to accurately determine the financial reserve required to cover the materialization of contractual risk:

1) *Identification and categorization of* risk *factors* that may affect the total cost of project implementation. This process requires a thorough analysis of all determinants affecting the cost of the investment. The identified factors are then classified into five groups (Table 5), which allows for a systematic examination of them in relation to their potential impact on the project budget.

Table 5. Importance indices and projected cost changes for different categories of risk factors

Group of risk factors *and*	**Importance indicator W_i**	**Expected change in costs ΔC_i [%]**	**Expected value of risk R_i [%]**
Volatility of macroeconomic situation and regulatory framework *i=1*	0.05-0.70	1 - 25	0.05 - 10
The complexity of the construction work, the specifics and nature of the construction object *i=2*	0.05-0.20	1 - 10	0.05 - 2
Location of the construction site, including accessibility to the construction/work site *i=3*	0.05-0.20	1 - 10	0.05 - 2
Duration of construction works and duration of quality/defect warranty *i=4*	0.05-0.35	1 - 15	0.05 - 5.25
Actions and inactions of stakeholders *i=5*	0.05-0.20	1 - 10	0.05 - 2

Own elaboration

2) *Assign an importance index to each identified risk factor* (W_i), according to the values shown in Table 5. These values reflect the relative impact of the factor on the overall cost of the project. The rule requires that the sum of the importance indicators for all factors be 1.00 to ensure that each risk is proportionately reflected in the overall financial assessment of the project.

$$\sum_{i=1}^{5} W_i = 1{,}00 \qquad (3.1)$$

3) *Determination of the expected range of changes in costs associated with a risk factor* (ΔC_i *).* The range of changes in costs due to a given risk factor is estimated based on the analysis of historical data and the use of advanced forecasting tools, such as those provided by forecasting institutions such as SEKOCENBUD sp. z o.o. The use of these methods makes it possible to accurately forecast potential cost deviations that may result from various risk factors.
4) *Determination of the risk value for each factor* (R_i). The risk value for each factor is calculated using the formula:

$$R_i = W_i \times \Delta C_i \qquad (3.2)$$

5) The formula integrates the importance index with the estimation of cost changes, which provides an accurate assessment of the impact of a given factor on the overall value of the project's financial risk.
6) *Determination of the total risk buffer* (B) as the sum of the risk values assigned to the individual factors:

$$B = \sum_{i=1}^{5} R_i \qquad (3.3)$$

Risk buffer limits have been set at 2.5% for low-complexity construction projects carried out under extremely favorable operational and contractual conditions from the contractor's perspective. On the other hand, for projects of high complexity, carried out under conditions that are highly unfavorable from a technical and economic perspective, the maximum risk buffer was set at 21.25%. This buffer range takes into account the potential risks associated with dynamic macroeconomic changes and the technological and organizational specifics of the project, ensuring adequate financial security for the contractor.

$$B_{min} = (0.05x1\%) + (0.05x1\%) + (0.05x1\%) + (0.05x1\%) + (0.05x1\%) = 2.5\%$$

$$B_{max} = (0.4x25\%) + (0.3x10\%) + (0.2x10\%) + (0.35x15\%) + (0.2x10\%) = 21.25\%$$

Table 6 shows the dependence of W_i and ΔC_i on the identified risk factors.

Table 6. dependence of W_i and ΔC_i on risk factor group

Group of risk factors *and*	**Classification of implementation conditions**			
	Favorable conditions	**Moderate conditions**	**Unfavorable conditions**	**Extremely adverse conditions**
Volatility of the macroeconomic situation and regulatory framework *i=1*	W_1 = 0.05 ΔC_1 = 1% Stable macroeconomic conditions, low inflation, stable exchange rates, favorable regulations and/or an appropriate valorization clause in the contract	W_1 = 0.06-0.30 ΔC_1 = 2%-10% Moderate inflation, little change in exchange rate, moderately favorable regulations	W_1 = 0.31-0.40 ΔC_1 = 11%-24% High inflation, unstable exchange rates, less favorable regulations	W_1 = 0.41-0.70 ΔC_1 = 25% Macroeconomic volatility, high inflation, unstable exchange rates, unfavorable regulations
The complexity of the construction work, the specifics and nature of the construction work *i=2*	W_2 = 0.05 ΔC_2 = 1% Simple designs, standard utility function, low technological complexity	W_2 = 0.06-0.12 ΔC_2 = 2%-4% Moderately complex projects, standard utility function, medium technological complexity	AT_2 = 0.13-0,.19 ΔC_2 = 5%-7% Complex designs, advanced technologies, higher standard of finishes	W_2 = 0.20 ΔC_2 = 8%-10% Highly complex designs, highly advanced technologies, high standard of finishes
Location of the construction site, including accessibility to the construction/work site *i=3*	W_3 = 0.05 ΔC_3 = 1% Simple geotechnical conditions, favorable climatic conditions, good availability of local resources, proximity to warehouses and wholesalers, good road infrastructure, no harmful factors and accessibility restrictions to the construction site	W_3 = 0.06-0.13 ΔC_3 = 2%-6% Complex geotechnical conditions, moderate climatic conditions, moderate availability of local resources, moderate distance from warehouses and wholesalers, moderate road infrastructure, moderate damage factors and site accessibility restrictions	W_3 = 0.14-0.18 ΔC_3 = 7%-9% Complex geotechnical conditions, unpredictable climatic conditions, limited availability of local resources, significant distance from warehouses and wholesalers, poor road infrastructure, presence of harmful agents and site access restrictions	W_3 = 0.19-0.20 ΔC_3 = 10% Complicated geotechnical conditions, extreme climatic conditions, lack of local resources, long distance from warehouses and wholesalers, very poor road infrastructure, high damage rates and significant site access restrictions
Duration of construction works and duration of quality guarantee/ warranty for defects *i=4*	W_4 = 0.05 ΔC_4 = 1% Short lead time - up to 6 months, no seasonal restrictions, quality warranty/defect warranty period - up to 5 years	W_4 = 0.06-0.18 ΔC_4 = 2%-8% Implementation period of more than 6 months, but not more than 1 year, moderate seasonal restrictions, quality / defect warranty period - up to 5 years	W_4 = 0.19-0.29 ΔC_4 = 9%-14% Deployment period from 1 to 2 years, greater seasonal restrictions, quality / defect warranty period - more than 5 years	W_4 = 0.30-0.35 ΔC_4 = 15% Long implementation period - more than 2 years, significant seasonal restrictions, quality / defect warranty period - more than 10 years
Actions and inactions of stakeholders *i=5*	W_5 = 0.05 ΔC_5 = 1% Good communication with the investor, minimal design errors, high reliability of subcontractors	W_5 = 0.06-0.09 ΔC_5 = 2%-3% Moderate communication with investor, moderate number of design errors, average reliability of subcontractors	W_5 = 0.10-0.14 ΔC_5 = 4%-5% Worse communication with the investor, more design errors, lower reliability of subcontractors	W_5 = 0.15-0.20 ΔC_5 = 6%-10% Poor communication with the investor, large number of design errors, low reliability of subcontractors

Own elaboration

The validity indicators were established based on a multifaceted analysis of the literature on the subject, the empirical experience of authors serving as expert witnesses in the construction field, and expert assessments. In addition, the indicators were quantified because of a detailed analysis of the budgets of four construction projects - three cubic objects and one linear object, implemented in different regions of Poland in 2021-2024. The comparison of baseline and as-built budgets made it possible to precisely determine the impact of the identified risk factors on the final costs of those investments.
The values of the indicators were estimated using advanced analytical methods, considering their relative relevance to project implementation costs. The aggregate value of the weights was normalized to a value of 1, which ensured proportional representation of each factor in the financial risk assessment. Statistical analysis made it possible to accurately estimate the impact of each factor on budget deviations, which made it possible to assign appropriate weights.
Projections of cost changes were developed using advanced econometric models that took into account key macroeconomic variables, such as inflation. Data from financial and research institutions (including the Institute for Economic Forecasting and Analysis, the National Bank of Poland, commercial banks, SEKOCENBUD z o.o.) provided the basis for accurately estimating potential cost deviations under various scenarios.
The quantified indicators and projected cost changes were verified by means of scenario simulations that took into account a variety of implementation conditions. The results confirmed the correctness of the assigned values and their adequacy in forecasting costs under real conditions. The algorithm can be successfully applied in the analysis of projects characterized by high complexity and unpredictability, such as the renovation of historic buildings, where unforeseen technical difficulties often arise, such as the revelation of hidden structural defects or the need to replace or preserve elements of historical significance. In the course of such projects, the algorithm makes it possible to model the risks arising from the need to carry out additional work not included in the original schedule, to use specialized conservation technologies and to meet formal and legal requirements related to the protection of historical monuments. The flexibility of the algorithm allows for dynamic updating of the cost estimate and schedule, taking into account changes resulting from the progress of the work and the discovery of unexpected technical problems.
Subsequent research will include validation of the risk buffer algorithm in real construction projects, which will enable further refinement of cost forecasting and adaptation of the tool to changing economic, technological and organizational conditions.

3.2 Example of risk buffer determination

Make a calculation of the bid price in 2Q. 2024 for the execution of electrical works involving the construction of a 110kV HV power line in the Mazowieckie province under the "build" formula. Varied geological conditions. Duration of construction works - 1 year - from 3Q 2024 to 2Q. 2025.

Table 7. Values of importance indicators and expected changes in the cost of construction works, which were estimated using a four-stage risk level classification

Group of risk factors i	**Compartment** W_i	W_i	**Justification for value selection** W_i	**Compartment** ΔC_i	ΔC_i	**Justification for value selection** ΔC_i
1. volatility of the macroeconomic situation and regulatory framework	0.31 - 0.40 (unfavorable conditions)	0.40	High interest rate due to macroeconomic instability, inflation risk, currency fluctuations and regulatory changes. In addition, possible delays in the delivery of contracted	11% - 25% (unfavorable to extremely unfavorable conditions)	25%	In this regard ΔC_1 is based on economic forecasts and the risk of an increase in the cost of materials and equipment,

			materials and equipment due to supply chain disruptions.			particularly imported ones, due to inflationary instability and currency fluctuations. Potential changes in tax and trade regulations and delays in deliveries are also taken into account.
2. the complexity of the construction work, the specifics and nature of the construction work	0.13 - 0.19 (moderate to unfavorable conditions)	0.19	The importance indicator W_2 was adopted due to the complex nature of construction work, such as pole installation, cable laying, and transformer installation, as well as the risks associated with the need to repair defective work.	5% - 7% (moderate to unfavorable conditions)	7%	The projected change in costs reflects the risks associated with technical failures, the need to correct defective work and the use of alternative technologies.
3 Location of the construction object	0.14 - 0.18 (moderate to unfavorable conditions)	0.14	Moderate risk due to local geological, geotechnical and hydrological conditions that may require specialized construction technologies.	7% - 9% (moderate to unfavorable conditions)	9%	The anticipated change in costs ΔC_3 takes into account additional costs associated with the need for specialized technological solutions resulting from geological, geotechnical and hydrological conditions.
4. duration of construction works (1 year), duration of construction works and duration of quality/defect warranty (5 years)	0.06 - 0.18 (moderate conditions)	0.12	Moderate risks related to the seasonality of the work and adverse weather conditions, which may lead to delays and the need to intensify the work. Also included are risks of accidents and execution errors that may result from the intense pace of work and poor project management.	2% - 8% (moderate conditions)	7%	The projected change in costs ΔC_4 takes into account potential additional costs associated with seasonality and the need to intensify work.
5. actions and inactions of stakeholders	0.06 - 0.09 (moderate conditions)	0.09	Moderate risk associated with coordination between stakeholders, including suppliers, subcontractors and administrative authorities. The risk includes decision-making delays related to, among other things, changes in the originally adopted design solutions as a result of the identification of errors and deficiencies in the design documentation. Also included are potential changes in regulations that may affect project implementation and compliance with established standards.	2% - 5% (moderate conditions)	4%	The anticipated change in costs ΔC_5 reflects additional costs that may result from stakeholder actions and inactions.

Based on the identified risk factors and their underlying values, an updated risk buffer was calculated:

$$R_1 = W_1 x \Delta C_1 = 0.40x25\% = 10\%$$
$$R_2 = W_3 x \Delta C_3 = 0.19x7\% = 1.33\%$$
$$R_3 = W_4 x \Delta C_4 = 0.14x9\% = 1.26\%$$
$$R_4 = W_5 x \Delta C_5 = 0.12x7\% = 0.84\%$$
$$R_5 = W_6 x \Delta C_6 = 0.09x4\% = 0.36\%$$

Calculation of the optimal risk buffer:

$$B_{optimal} = R_1 + R_2 + R_3 + R_4 + R_5 = 13.79\%$$

The optimal contract risk buffer for a 110 kV high-voltage line construction project, taking into account selected importance indicators and projected cost changes, is 13.79%. Errors in cost forecasts can be reduced by using time series analysis [10], which allows modeling of changes in the project budget. This analysis includes factors such as the timing of resource purchases, rework and sales invoice payments, taking into account the valorization of the contractor's remuneration.

4. RECOMMENDATIONS FOR CONTRACTORS TO MANAGE CONSTRUCTION COSTS

In order to ensure profitability and financial stability in a dynamically changing economic environment, a construction company should implement an effective performance management system based on optimal allocation of resources, monitoring and real-time control of the progress and quality of construction work [13]. The contractor's operational strategy should provide for rapid response of the participants in the investment process to events that may affect the achievement of milestones, quality, scope or cost of construction works [12].

The following are recommendations for contractors, the implementation of which can help optimize the cost of construction work by minimizing risks arising from:

1. **The volatility of the macroeconomic situation and changes in regulations**:
   a) Forecasting the cost of construction works based on analyses of inflation reports and forecasts and the dynamics of construction material prices, developed by public institutions, central banks and research centers, taking into account potential changes in fiscal and monetary policy [10], [11], [12], [14];
   b) constant monitoring of legislative changes in construction, environmental and economic regulations affecting project costs and schedules, in close cooperation with legal advisors and participation in industry training [12], [13];
   c) Include in contracts mechanisms for automatic salary adjustment, based on inflation indices and construction material prices, to protect the budget from market changes [14], [15], [16];
   d) Using a strategy to diversify suppliers of construction materials and raw materials to reduce the risk of supply disruptions;
   e) The use of financial instruments, such as purchase options, to hedge against unfavorable changes in material prices while maintaining purchasing flexibility;
   f) Negotiating detailed terms of contracts with subcontractors and suppliers in terms of regulatory compliance and minimizing legal risks by precisely defining the scope of work, responsibilities and financial terms [14];

2. **The complexity of the construction work and the specifics of the projects**:
   a) use of advanced design technologies (e.g., BIM) and project management tools (e.g., MS Project, Primavera) to minimize project risks, optimize schedule and project costs [3], [12];
   b) Controlling the quality of ongoing works through regular audits and inspections, and implementing modern techniques for monitoring progress, such as photogrammetry and laser scanning [12];
   c) training and development of employees' competencies in modern technologies and methodologies for the implementation of construction projects, which translates into efficiency and quality of execution [12];
3. **The location of the construction project**:
   a) Conducting urban and environmental analyses of the location, including an assessment of potential legal barriers, local resources and logistics infrastructure, which affects the cost of project implementation [14];
   b) Working with local suppliers and subcontractors to ensure continuity of supply and minimize the risk of delays [16];
4. **The duration of the construction work**:
   a) precise planning of the work schedule, taking into account seasonality and risks associated with adverse weather conditions [7], [12];
   b) real-time monitoring of project progress using remote monitoring technologies (such as drones) and project management tools [14];
   c) Effective management of working time and human resources through optimal planning of work stages to maximize productivity and minimize downtime [8];
5. **Actions and omissions of key participants in the construction process**:
   a) Entrusting contract implementation to teams with advanced project management competencies and risk management expertise [14];
   b) Negotiate clear contract terms with subcontractors to minimize the risk of disputes and conflicts during implementation [12];
   c) Maintaining continuous cooperation with investors, supervisors, designers and other stakeholders to effectively manage the implementation of investments;
   d) holding regular coordination meetings to monitor progress, solve problems and make strategic decisions [14];
   e) Documenting the actions and decisions of all parties in order to effectively manage potential disputes and ensure transparency in decision-making processes [12];
   f) Promoting a culture of safety at work and ensuring compliance with OSH regulations by all those involved [12];
   g) ensuring compliance of activities with accepted ethical and professional standards [12];
   h) Building long-term relationships with reliable contractors [12];
   i) constantly updating the subcontractor base to eliminate cooperation with unreliable contractors [11];
   j) drawing lessons from previous implementations and developing post-project reports indicating areas for improvement [14].

It should be emphasized that, according to the judgment of the Supreme Court of 29.10.2015, ref. I CSK 901/14, LEX No. 1818856, even a carefully planning construction entrepreneur is not able to predict all significant market changes, including sharp increases in the price of construction materials. Therefore, in order to protect the interests of the parties to the contract, effective valorization clauses should be used to maintain the economic balance between the parties to the contract and prevent the need to pursue claims in court [9], [15].

5. FINAL CONCLUSIONS

The article presents the own results of a study of cost variability in construction projects and the development of an algorithm for determining the contract risk buffer, which makes it possible to quantify these risks and accurately determine the financial reserve that compensates for potential cost changes resulting from their materialization.

The algorithm is based on a multi-criteria risk analysis, taking into account such aspects as macroeconomic variability, technical complexity, geotechnical and hydrological conditions, and resource availability. With the weights assigned to the various factors, it is possible to estimate their impact on the project budget. The algorithm is characterized by high flexibility and adaptability to projects of different levels of technical complexity, making it a suitable tool for both cubic and linear projects.

One of the key advantages of the algorithm is its ability to dynamically adapt to changing market conditions. The tool not only supports cost forecasting at the investment planning stage, but also enables monitoring of risks and budget adjustments during implementation. Integration with technologies such as BIM and project management systems increases precision and efficiency in investment management, minimizing technical and operational risks.

The use of the algorithm also brings benefits to contract management. Thanks to the precise estimation of the risk buffer and the use of valorization clauses, it is possible to reduce the risk of contract disputes and protect the parties from the effects of economic changes. In the context of volatility of construction material prices, currency fluctuations and changing legal regulations, the algorithm supports the process of negotiation and financial risk management.

In conclusion, the developed algorithm provides an advanced tool to support cost risk management in construction projects. Its flexibility, adaptability to changing market conditions and integration with modern project management technologies make it an effective tool for cost forecasting and risk management. Further research should focus on validating the algorithm under different investment conditions and optimizing it to more accurately predict cost changes in future construction projects. Implementation of the algorithm can help improve the efficiency of project management and the financial stability of construction companies.

ADDITIONAL INFORMATION

The research results presented in the article are an integral part of the doctoral dissertation of Lidia Więcław-Bator, whose goal is to develop analytical tools and information technologies, such as an intuitive application, based on predictive models capable of integrative processing and analysis of data from different sources. These tools, including the implementation of artificial intelligence algorithms, enable dynamic adaptation to changing market and technical conditions, offering construction companies a realistic and flexible approach to the calculation of the cost of construction works, taking into account the financial provision for managing standard contractual risks.

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