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Course of Cumulative Cost Curve (CCCC) as a Method of CAPEX Prediction in Selected Construction Projects

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Abstract: Forecasting the actual cost of the implementation of a construction project is of great importance in the case of technical management and enables financial resources to be initially maintained in a controlled manner and in a way that is as close as possible to the actual state. Based on the analysis of the developed knowledge base, which contains data from 612 reports of the Bank Investment Supervision regarding 45 construction projects from 2006 to 2023 with a total value of over PLN 1,300,000,000, best-fit curves were determined, and the expected area of the cumulative actual cost of selected construction projects was specified. The obtained polynomial functions and graphs of real areas of cost curves (in the form of nomograms) constitute a reliable graphical representation that enables the application of research results in typologically similar groups/sectors of the construction industry. The elaborated course of the cumulative cost curve (CCCC) as a method of CAPEX prediction in selected construction projects stands for a combined approach of the S-curve, polynomial functions, and the best-fit area of cumulative earned cost. The research used scientific tools that can be practically and easily used by both managers and participants of the investment process.

Keywords: construction project; course of cumulative cost curve (CCCC); capital cost estimation (CAPEX); S-curve; EVM

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1. Introduction

Each participant in the investment process plays a crucial role in limiting the cost of implementing the construction project. The investor, construction manager, and designer must plan the value and structure of the investment cost and also control its cumulative course over time. The issue refers mainly to execution costs, which constitute the lion's share (over 80%) of the capital cost estimation (CAPEX) of any construction project.

It is the manager of the construction project that faces a fundamental managerial challenge, which involves managing the cumulative investment cost in such a way that its actual value (performed and paid construction works) is as close as possible (with the least deviation) to the planned value.

Exceeding the budgeted cost and extending the work completion time are commonly fundamental elements in the realization of numerous construction projects [1–3]. The exceedance values vary depending on the source of the data. According to Flyvbjerg et al. [4], cost overruns occur in as many as 9 out of 10 construction projects, and the overrun value can reach up to 183%. For example, in the Netherlands, the average cost overrun was 16.5% [5], in Portugal, 24% [6], and in Qatar, 54% [7].

A cost overrun (alternatively: cost increase; CAPEX overrun) in the construction industry refers to a situation in which the actual cost incurred during the implementation of a construction project exceeds the initial budget or the estimated cost determined by the investor. This means that a budget overrun occurs when the final cost of a construction project exceeds its original budget. Engineering practice confirms that in most construction projects, the actual cost increases when compared to the budgeted cost [8,9], and this phenomenon has become an almost natural part of construction projects, both for buildings and infrastructure.

Inaccurate estimated costs at the initiation phase of a construction project (i.e., when budgeting and defining the scope of the project) and improper planning of the investment process are some of the most often discussed causes of cost overruns in the literature [10]. Other causes of cost overruns include: errors or omissions in design documentation that lead to design changes [11–15], an unrealistic duration of construction works [16], a lack of availability of qualified labor [17], a lack of management staff [18], a lack of effective coordination between the participants of the investment process [19], a lack of experience of contractors [20], and variable weather conditions [21].

Cost overruns have become a global problem due to the complex nature of the planning, design, implementation, and maintenance of a construction project. Discrepancies between budgeted and actual costs have both negative effects and financial consequences for the public and private sectors. They cause negative economic consequences for the entire construction industry, as well as for construction contractors, subcontractors, designers, etc.

Cost overruns have a substantial impact, among others, on the profitability of construction companies and the deadline for completing the construction project. They may also damage the reputation of the construction company and lead to a loss of trust among stakeholders (including investors, customers, and employees). Additionally, banks granting investment loans face a significant challenge related to financing and unrealistic budget reserves.

When preparing construction projects, investors prepare investment budgets, which, as professional experience shows, do not always reflect reality. To make budget provisions more realistic, banks need engineering specialists who will conduct research to measure the actual cost of implementing a construction project that is intended to be financed with an investment loan. Therefore, it seems justified to conduct research that leads to adjusting investment reserves to the actual situation and then matching the budgeted cost of forecast construction projects to their actual cost.

The international organization PMI (Project Management Institute), which has existed since 1969 and brings together over 600,000 project management experts operating in almost every country in the world, states that 80% of construction projects currently end in budget overruns.

Cost overruns constitute a significant challenge for investors and construction contractors, making it difficult to achieve a profit from the completed project. It is only thanks to effective monitoring mechanisms that it is possible to minimize the occurrence of this phenomenon, which is why it is so crucial to implement an effective method of planning the investment budget and controlling the actual cost during the implementation of a construction project. Exceeding the time limit (alternatively: delay, extension of time) in construction refers to a situation in which the actual duration of a construction project is longer than the planned time in the schedule and in the concluded construction contract [22].

On the basis of the literature review, the main causes of delays in construction projects can be distinguished. One of the most common reasons for delays indicated by subsequent researchers is the incorrect development of the work schedule [23], also understood as inefficient resource planning [24], or inaccurate estimation of the duration of individual tasks as well as the entire construction project [25]. Other reasons for delays in construction projects include financial difficulties of contractors [26], changes in the scope of the project during implementation [27], lack of effective communication between participants in the investment process [28,29], shortage of skilled labor [30], mistakes during construction [31], low productivity of work teams [32], weather conditions [33], as well as insufficient archeological exploration of the area [34].

Delays in construction projects are closely correlated with cost overruns [35]. The reasons for project delays are, in most cases, the causes of cost overruns and vice versa. Some researchers even treat delay and cost overruns as the same [36,37]. In the research by

Belay and Torp [38], it was also shown that there is a positive, strong correlation between the increasing duration of the project and the cost variance.

The goal of the research was to develop a method that would allow for the forecasting of the cumulative budgeted cost with the greatest fitting to/smallest deviation from the actual cost in a selected group of construction projects.

2. Methods and Models

The commonly known and used methods and tools for planning and monitoring construction projects include a method based on the analysis of the curve of the cumulative cost of implementing a construction project (the "S" curve method), and the earned value method (EVM). Both methods presented in the article (the "S" curve method and the earned value method), are used to control and monitor the course of construction works. The scientific research and professional experience of the authors of the article indicate that the existing models of planned cumulative cost curves often diverge from reality and are overly complex, making them impractical for managing construction projects. Therefore, in the research, attempts were made to find a compromise between the affordability and low degree of complexity of calculations and the information potential of the proposed proprietary method of forecasting the actual course of the implementation cost in selected construction projects. The essence of the method is its applicability, based on commonly available computer systems/programs.

2.1. Cumulative Cost Curve-S-Curve Method

Presenting planned financial flows on a timeline using a cumulative cost chart is a simple and efficient tool for measuring the use of financial expenditures in a construction project [39]. The cumulative cost curve "S" illustrates the project's progression from the start of construction activities to their completion. It represents the total expenditure incurred by all allocated resources for each task. Graphically, the cumulative cost curve typically resembles the shape of the letter "S". By continuously collecting financial data, it is possible to generate and compare budgeted versus actual cost curves [40].

Many tools have been used to map the shape of the cumulative cost curve, including: the theory of fuzzy sets [41,42], the method of least squares and fuzzy regression [43], methods using elements of artificial intelligence [44,45], and elements of BIM technology [46].

The research also uses empirical methods of forecasting the course of the cumulative cost curve in various construction projects. The mathematical models of the cost curve existing in the literature are based on real, historical data concerning construction projects conducted, among others, in the UK [47], Iran [48], Taiwan [49], the United States [50], and Asian countries [51].

Subsequent researchers have endeavored to depict the trajectory of the cost curve by formulating mathematical relationships involving variables such as time and cost. Figure 1 presents their graphical interpretation in the form of cumulative cost curve charts.

The cumulative cost curves presented in Figure 1 determine the area of cash flows within the specified envelope. It was noticed that it is not possible to use one theoretical model or one empirical mathematical expression that illustrates the course of the cumulative cost curve. When planning and monitoring the cost curve, it is advisable to utilize the curve envelope.

When comparing the mathematical models proposed by various authors to describe the shape of the cumulative cost curve, the most frequently used are a sixth-degree polynomial [41,52,53], a third-degree polynomial [49,54,55], and less commonly, a second-degree polynomial and a linear function [56].

The cumulative cost curve is characterized by varying slopes, making it inappropriate to use first-degree polynomials (linear functions) or second-degree polynomials (quadratic functions) to accurately depict its course. Employing descriptions may lead to inaccuracies and produce an unreliable representation of the cost curve [56,57].

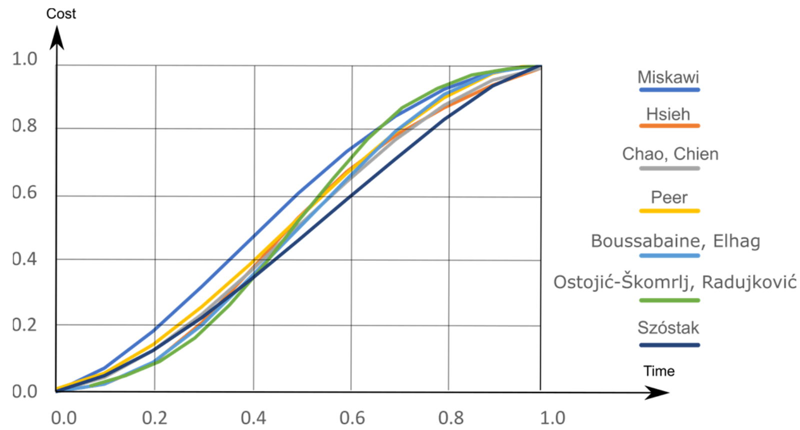

Figure 1. Selected cumulative cost curve charts.

Therefore, it is justified to use higher-order polynomials, at least of the third degree, to describe the course of the cumulative cost curve. While a sixth-degree polynomial allows for a high correlation coefficient (close to unity, indicating a strong relationship and a good description of the phenomenon) and a low coefficient of variation (indicating low variability and homogeneity), its practical application may prove challenging and overly complex for decision-makers, including investors and contractors.

2.2. Cost Curves—The Earned Value Method (EVM)

Using the earned value method (EVM) is a popular project management system that is recommended by well-known methodologies such as the PMBoK Guide [58] and the International Project Management Association [59]. It combines the cost and timing of the managed project [60,61]. The EVM is a method for measuring the actual progress of the project [62]. It involves controlling (in accordance with the adopted planned material and financial schedule developed at the beginning of the implementation of a construction project) the investment task by periodically comparing the actual completed scope of work with the planned execution time and planned implementation cost [63]. This method enables cost and schedule deviations and performance indicators to be calculated, as well as the cost and duration of a construction project to be forecasted [64,65]. It also allows project implementation indicators to be recognized early, which in turn is helpful for planning possible corrective actions [66].

In EVM, cost values are a function of time and can be graphically presented in the form of curves, as in cumulative cost curve analysis. Therefore, at the planning stage of a construction project, a BCWS (budgeted cost of work scheduled) curve is created, which shows the budgeted cost of the planned works. The remaining two curves, BCWP (budgeted cost of work performed) and ACWP (actual cost of work performed), are calculated during the project based on data collected during its monitoring. These curves represent the current status of the investment at the time of monitoring, specifically on the current inspection day.

The EVM assumes that the duration and cost are determined for the current moment of investment monitoring, and its indicators show whether the construction project is delayed or whether the budget has been exceeded. The earned value method does not determine whether the deviations from actual values are within (or not) the range of possible deviations from the planned values that result from the expected variability of the project. In other words, even if a construction project is delayed at the time of inspection, given the inherent variability of the project and its tasks, the delay is likely to remain within the range of possible and acceptable delays. In such a case, the decision-maker is not forced to suddenly take corrective action. Moreover, due to the deterministic estimation of, e.g., the completion date, the earned value method does not allow the range of possible expected implementation effects to be determined.

As a result of the research, the EVM has been, and still is, constantly modified [67]. The extension of the method was achieved by introducing new, previously unavailable parameters/indicators, which allow (according to their authors) for more accurate calculations, e.g., the Schedule Forecast Indicator (SFI) [68], the Earned Value Forecasting Stability Indicator [69], the risk effectiveness index [70], the determination of the impact of unplanned time and cost deviations on the financial liquidity of a construction project [71], risk analysis [72], the analysis of uncertainty conditions [73], the assessment of the profitability of construction projects in random implementation conditions [74,75], and also the introduction of time variance of the schedule and the budgeted cost [76].

Despite the availability of various methods and tools that support the planning and monitoring of construction projects, contractors still very often do not achieve the planned cost and time goals.

Both presented methods (the S-curve method and earned value method), in their basic applications, are used to control and/or monitor the progress of construction works. The planned cumulative cost curve models proposed so far often diverge from reality and are overly complex, making them impractical for effectively managing construction projects. As some researchers and practitioners point out, it is important for the decision-makers of construction projects (i.e., investors, construction managers, and work managers) to use available and easily functional algorithms, programs, or calculation methods when planning, as well as when monitoring and controlling the progress of work. It is crucial that these methods are not burdened with many variables and uncertainties that are difficult to measure and difficult to define unambiguously. The computational appliance should be handy to any user [77].

Therefore, in the research, efforts were made to find a compromise between the accessibility and low complexity of calculations and the informative potential of the proposed proprietary method of forecasting the actual implementation cost of selected construction projects. The essence of the proposed original method is its applicability, which is based on commonly available computer systems/programs.

2.3. Approach to the Research

The definite objectives of the research and analyses were as follows:

- Building (through research) a representative set of data concerning the course of construction projects for the purpose of the research;
- Developing an original research methodology for forecasting the course of the cumulative cost curve and the cost area in selected construction projects;
- Analyzing the planned cost resulting from the work schedule and the actual cost incurred during the implementation of construction projects;
- Proposing an original, effective method for forecasting the actual cost in selected construction projects;
- Developing and using correlation coefficients to evaluate the proposed methods and models, as well as the providing of their parameters;
- Proposing, based on the course of the planned and actual accumulated costs, a model for forecasting the best adjustment of the cost curve in selected construction projects in the form of a polynomial function;
- Proposing the area of best adjustment of the cost curve for planning and monitoring the cumulative cost in selected construction projects.

2.4. Research Sample

The data collected for the research comes from the authors' own investigations and professional work. This work involved providing the services of the Bank Investment Supervision (BIS) inspector on behalf of banks that grant investment loans for non-public procurement.

As part of the research, a targeted research sample was collected, containing data on 45 construction projects, with limitations resulting from:

- The duration of construction projects;
- Access to reliable data on the course of construction projects.

Collecting a complete data set for the course of a single construction project takes from 6 to sometimes even 34 months and results from the total duration of the analyzed construction project. In the collected data set, the average duration of a single construction project is 18 months.

The research sample contains data on selected construction projects, which means that it is a closed set. To facilitate comparison of the collected research material, it is essential that the source documents, in this case reports, adhere to a standardized method of collecting data on construction projects, irrespective of the type of construction project. And so, in the research, a research sample was created, which comes from a single, independent entity providing the services of the BIS.

In the conducted research, the characteristics of homogeneous construction sectors were important; therefore, the selection of the research sample was deliberate. On the basis of the collected data, it was possible to distinguish typological research samples for construction projects with a similar profile and category of construction objects, which allowed for the gathering of a typologically representative research sample.

The collected knowledge base from 2006 to 2023 contains data on 45 construction projects, i.e., 612 reports with a total value of over PLN 1,300,000,000. A summary of the number of analyzed construction projects and obtained reports is presented in Table 1.

Table 1. Summary of the number of analyzed construction projects and reports.

Category	Group/Construction Sector	Number of Construction Projects	Number of Reports
A	Apartment houses	14	218
B	Office buildings	4	69
C	Hotels	9	110
D	Commercial and service buildings	8	113
E	Logistics centers	6	37
F	Health centers	1	12
G	Manufacturing plants	1	6
H	Airport buildings	1	36
I	Transport hub	1	11
		45	612

Table 2 presents a detailed knowledge base that is divided into the analyzed construction sectors and the type of report (RW—Preliminary report, RM—monthly report, RK—final report).

Table 2. Number of cost monitoring reports in BIS reports.

Cat.	Group/Construction Sector	Number of Construction Projects	RW	Total RM	RK
A	Apartment houses	14	14	197	7
B	Office buildings	4	4	64	1
C	Hotels	9	9	93	8
D	Commercial and service buildings	8	8	97	8
E	Logistics centers	6	6	29	2
F	Health centers	1	1	10	1
G	Manufacturing plants	1	1	4	1
H	Airport buildings	1	1	35	-
I	Transport hub	1	1	9	1
	Total number of reports RW-RM-RK		45	538	29
	TOTAL NUMBER OF REPORTS			612	

Research concerning the cost trend of a construction project was carried out in a constant cycle. It is long-lasting and cannot be accelerated or repeated. Therefore, it constitutes value itself and has an original and authorial character (it is not survey research). Each time, at each construction site, the actual (percentage) advancement of the work performed was measured by the Bank Investment Supervision. It involved measuring the amounts of the performed construction works (including earthworks, foundations, floors on the ground, the reinforced concrete structure, the steel structure, the roof, facades, finishing works, land development, etc.). An example structure of the work progress report for one of the analyzed construction projects is presented in Table 3.

Table 3. A sample structure of the work progress report.

No.	Type of Construction Works	Value of Works [EUR]	Value of Works Performed Now [EUR]	Value of Works Performed Previously [EUR]	Value of Cumulative Works EUR]	Value of Works to Be Executed [EUR]
1.	Foundations	100,000.00	000	100,000.00	100,000.00	0.00
3.	Reinforced concrete structure	1,250,000.00	0.00	1,250,000.00	1,250,000.00	0.00
4.	Steel structure	250,000.00	0.00	250,000.00	250,000.00	0.00
5.	Roof	300,000.00	50,000.00	250,000.00	300,000.00	0.00
6.	Facade	1,000,000.00	100,000.00	900,000.00	1,000,000.00	0.00
7.	Finishing works	2,000,000.00	200,000.00	1,100,000.00	1,300,000.00	700,000.00
8.	Electrical and telecommunications installations	750,000.00	150,000.00	450,000.00	600,000.00	100,000.00
9.	Sanitary installations	1,750,000.00	200,000.00	950,000.00	1,150,000.00	600,000.00
10.	Networks	1,000,000.00	100,000.00	800,000.00	900,000.00	100,000.00
11.	Land development and earthworks	2,500,000.00	200,000.00	1,800,000.00	2,000,000.00	500,000.00
12.	Overall cost	700,000.00	50,000.00	500,000.00	550,000.00	150,000.00
	Total	11,600,000.00	1,050,000.00	8,350,000.00	9,400,000.00	2,150,000.00

The measurements were made on the basis of acceptance reports for the completed works (work progress reports), which confirm the quantitative performance of the works and are made for the purpose of monthly settlements of remuneration between the investor and the contractor. This means that under one cost value, which characterizes one measurement for a single construction project, there are from several dozen to several hundred measurements of work progress for individual types of work, which in turn leads to several thousand measurements in the entire research sample.

As part of the research, a purposeful research sample was collected, which contains data on 45 construction projects. The data have limitations resulting from, among others:

- the duration of construction projects,
- the availability of reliable data concerning the progress of construction projects.

Obtaining reliable research material for the research (in the form of preliminary, monthly, and final reports) is a long-term and labor-intensive process. Collecting a complete set of data for a single construction project takes from 6 to even 34 months. This time is due to the total duration of the analyzed construction project. In the collected data set, the average duration of a single construction project is 18 months.

The collected research sample contains data about the selected construction projects, which means that it is a closed set. The selection of the construction projects for the research was independent and resulted directly from the orders for providing the services of the BIS. In order for the collected research material to be compared with each other, it is essential that source documents (in this case reports) are prepared according to a uniform method of collecting data on construction projects, regardless of the type of building structure. Therefore, the research included a research sample that came from one independent entity that provides Bank Investment Supervision services.

In the research, characteristic features of homogeneous construction groups/sectors were important, and therefore the selection of the research sample was purposeful. Based on the collected data, it was feasible to obtain typological research samples consisting of construction projects with similar profiles and categories of construction objects. This approach facilitated the assembly of a typologically representative research sample.

2.5. Research Methodology

In order for the obtained results to be reliable and for the analyses and decisions made on their basis to be correct, the research should be comprehensive and methodical. A methodology for conducting comprehensive research was developed, verified, expanded, and improved. The research methodology consists of seven stages and is presented in Figure 2:

- Stage 1: Obtaining data on construction projects;
- Stage 2: Development of the knowledge base;
- Stage 3: Processing of collected data;
- Stage 4: Graphical representation of the processed collected data;
- Stage 5: Determination of best-fit curves;
- Stage 6: Determination of the area of cost curves;
- Stage 7: Designation of procedure scenarios.

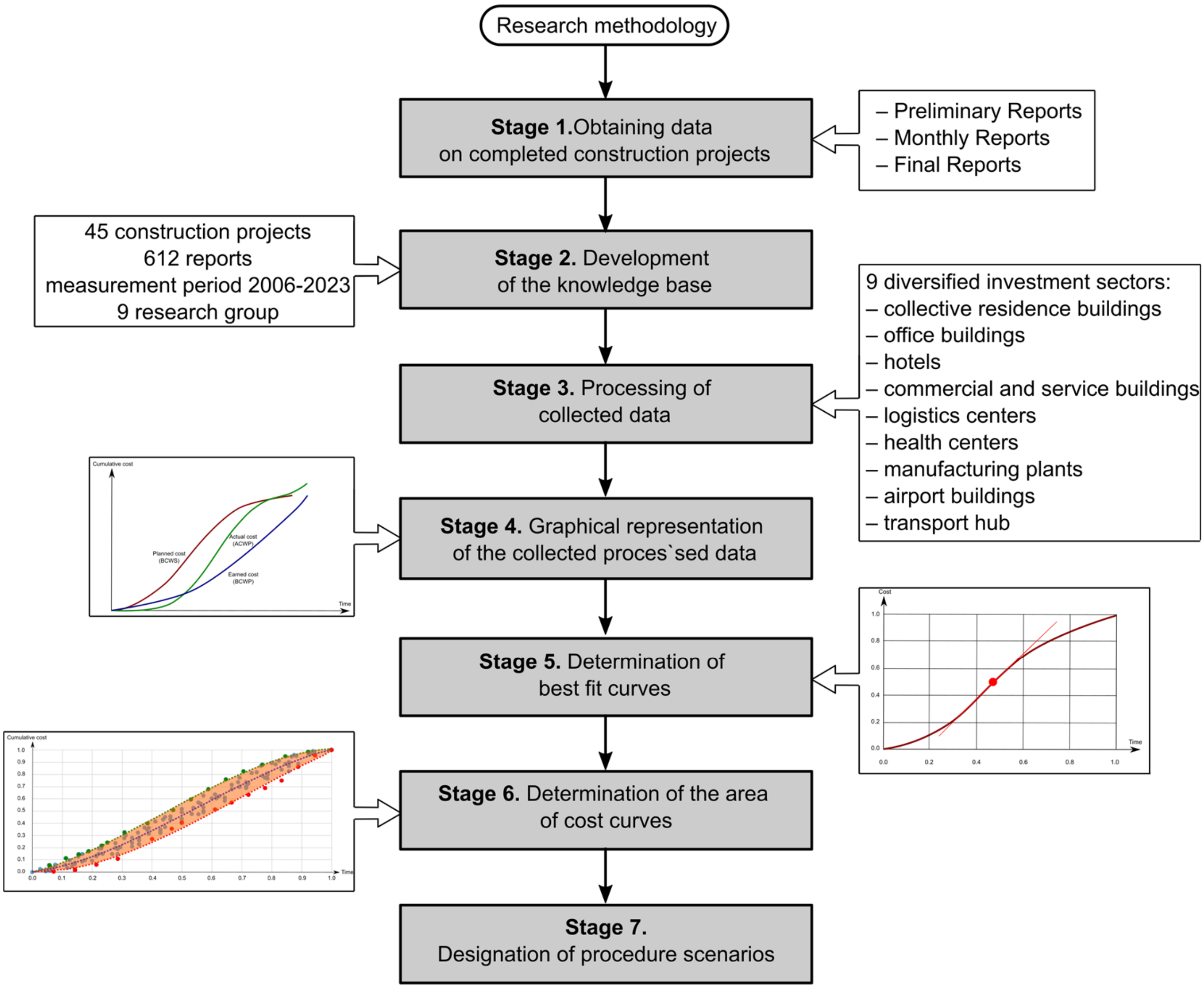

Figure 2. Flowchart of the research methodology.

The research methodology allows for the examination of the shape and trajectory of the cost curve during the implementation of investment projects. This is achieved through the cyclical calculation of cost and schedule deviations, as well as performance indicators, cost forecasts, and project duration. The research focused on the cost of construction works, which constitutes 75–85% of the budget of the construction project (commonly called "hard cost").

2.6. Development of a Knowledge Base

In stage 2, based on the analysis of reports, a knowledge base was developed—a summary of data in Microsoft Excel—characterizing individual construction projects. Data for each project are organized in a two-dimensional table. Each row in the table represents data for subsequent reporting periods. Each data set includes the following values: planned cost of the construction project, cumulative value of the planned cost, planned percentage of the progress of work, earned cost of the construction project, cumulative value of the earned cost, percentage of the progress of work performed, incurred cost of the construction project, cumulative value of the incurred cost, and percentage of the progress of invoiced work.

The research assumed that the cost of a construction project is the sum of financial outlays allocated to the implementation of construction works, in particular:

- The budgeted cost of the construction project (the cost of construction works planned before the commencement of the investment task);
- The earned cost of the construction project (the cost of actual performed construction works);
- The incurred cost of the construction project (the cost of paid construction works).

Table 4 presents a fragment of the summary of the knowledge base for apartment houses (group A). Under the main headings in Table 4, the column number (1–7) has been added as an auxiliary number, along with the determination of the relationship between the data contained in the table (for columns 4 and 7).

Table 4. Fragment of the knowledge base.

Investment	Scheduled Time	Actual Time	Scheduled Time/Actual Time	Budgeted Cost	Incurred Cost	Budgeted/Incurred Cost
1	2	3	4 = 2/3	5	6	7 = 5/6
A.1	13	16	1.23	17,002,557.00	17,002,557.00	1.00
A.2	14	16	1.14	12,580,200.00	12,580,200.00	1.00
A.3	14	16	1.14	15,231,003.00	15,231,003.00	1.00
...	...	...	...	...	...	...
B.1	21	30	1.43	54,136,619.00	54,136,619.00	1.00
B.2	15	27	1.80	23,284,800.00	23,284,800.00	1.00
B.3	19	23	1.21	24,553,200.00	24,553,200.00	1.00
...	...	...	...	...	...	...
C.1	22	34	1.55.	42,313,695.00	58,646,384.15	1.39
C.2	15	17	1.13	14,670,506.00	15,811,877.84	1.08
C.3	14	16	1.14	18,772,396,15	22,234,333.17	1.18
...	...	...	...	...	...	...
D.1	13	15	1.15	135,000,00.00	157,112,077.84	1.16
D.2	10	13	1.30	65,000,000.00	65,000,000.00	1.00
D.3	10	11	1.10	16,000,000.00	16,708,000.00	1.04
...	...	...	...	...	...	...
E.1	6	8	1.33	3,539,000.00	3,586,422.60	1.01
E.2	6	8	1.33	8,795,000.00	8,988,911.20	1.02
...	...	...	...	...	...	...
F.1	10	13	1.30	7,870,000.00	7,895,911.00	1.01
...	...	...	...	...	...	...
G.1	24	25	1.04	86,902,405.00	89,191,782.66	1.03
...	...	...	...	...	...	...
H.1	9	10	1.11	11,550,865.65	11,786,564.80	1.02
...	...	...	...	...	...	...
I.1	11	26	2.36	89,148,640.24	123,139,268.70	1.38

In the knowledge base and in the table in column 1, the method of coding construction projects adopted in the research is presented: *X.Y*, where:

X—symbol of a category/group of building objects (A–I), according to Table 1;

Y—number of the analyzed construction projects (1–14), according to Table 1.

2.7. The Processing of Collected Data

The data collected in the knowledge base describes individual construction projects, each with unique durations and implementation costs. To facilitate comparative analysis, the data were normalized in stage 3. This involved processing and standardizing the collected data.

Each project varies in duration and implementation cost. Therefore, to enable meaningful comparison across different construction projects, the collected data needed to be processed accordingly. For each analyzed construction project, processed data were determined based on the primary data (a fragment of the data presented in Table 5). The processed data (a fragment of the data is presented in Table 6) was derived for this purpose. Normalization consisted in determining the unitary value of cost and time for each individual examined period, assuming that for each construction project, regardless of the number of settlement periods, the total planned duration is 1.0 and the total planned budget is 1.0.

Tables 5 and 6 present a fragment of the knowledge base.

Table 5. Primary data—a fragment of the knowledge base.

Investment	Group	Number of Measurements	BCWS.1	BCWS.2	BCWS.3	BCWS.4	…
A.1	1	16	1,025,000.00	2,125,000.00	3,255,000.00	4,705,000.00	…
A.2	1	16	315,000.00	800,000.00	1,613,891.00	2,440,787.00	…
A.3	1	16	168,600.00	1,143,500.00	2,038,395.00	2,868,920.00	…
…	…	…	…	…	…	…	…
B.1	2	30	743,145.00	2,086,106.00	4,048,603.00	5,835,332.00	…
B.2	2	27	2,414,590.00	1,096,788.00	1,797,060.00	2,649,172.00	…
B.3	2	23	72,998.00	90,196.79	863,427.28	2,409,888.26	…
…	…	…	…	…	…	…	…
C.1	3	34	500,00.00	2,719,466.57	8,735,718.00	17,585,116.49	…
C.2	3	17	480,000.00	1,220,000.00	2,570,000.00	3,970,000.00	…
C.3	3	16	143,886.00	388,386.00	613,386.00	859,386.00	…
…	…	…	…	…	…	…	…
D.1	4	15	10,415,764.00	22,589,476.00	35,372,128.00	49,014,882.00	…
D.2	4	13	500,00.00	2,719,466.57	8,735,718.00	17,585,116.49	…
D.3	4	11	125,000.00	325,000.00	1,325,000.00	2,055,128.21	…
…	…	…	…	…	…	…	…
E.1	5	8	129,805.00	714,083.00	1,609,364.00	2,595,410.00	…
E.2	5	8	694,983.00	1,996,676.00	3,504,169.00	5,663,252.00	…
…	…	…	…	…	…	…	…
F.1	6	13	102,667.00	323,221.00	743,880.00	1,530,622.00	…
…	…	…	…	…	…	…	…
G.1	7	25	2,010,000.00	3,265,000.00	5,253,612.00	10,480,173.00	…
…	…	…	…	…	…	…	…
H.1	8	10	176,168.75	371,994.10	656,962.85	1,193,466.25	…
…	…	…	…	…	…	…	…
I.1	9	26	3,923,924.31	6,801,636.71	8,738,049.69	13,611,138.49	…

Table 6. Processed data—a fragment of the knowledge base.

Investment	Group	Number of Measurements	BCWS.1	BCWS.2	BCWS.3	BCWS.4	...
A.1	1	16	0.08	0.15	0.23	0.31	...
A.2	1	16	0.07	0.14	0.21	0.29	...
A.3	1	16	0.07	0.14	0.21	0.29	
...	...	...	...	...	...	...	...
B.1	2	30	0.05	0.09	0.14	0.18	...
B.2	2	27	0.07	0.13	0.20	0.27	...
B.3	2	23	0.08	0.15	0.23	0.31	...
...	...	...					...
C.1	3	34	0.01	0.04	0.13	0.27	...
C.2	3	17	0.08	0.17	0.26	0.36	...
C.3	3	16	0.01	0.02	0.08	0.13	...
...	...	...					...
D.1	4	15	0.08	0.17	.026	0.36	...
D.2	4	13	0.01	0.04	0.13	0.27	...
D.3	4	11	0.04	0.09	0.15	0.20	...
...	...	...					...
E.1	5	8	0.04	0.20	0.45	0.73	...
E.2	5	8	0.08	0.23	0.40	0.64	...
...	...	...					...
F.1	6	13	0.01	0.04	0.09	0.19	...
...	...	...					...
G.1	7	25	0.02	0.04	0.06	0.12	...
...	...	...					...
H.1	8	10	0.02	0.03	0.06	0.10	...
...	...	...					...
I.1	9	26	0.05	0.08	0.10	0.16	...

3. Results

3.1. The Course of Cumulative Cost Curves (CCCC)

As part of the research concerning the implementation of the selected construction projects, an analysis and comparative appraisal of the planned, incurred, and completed schedule and costs were carried out.

For the developed data characterizing the analyzed construction projects, full modeling of the planned, earned, and incurred cost curves was carried out. After that, charts of the planned, earned, and incurred cost values were developed for the surveyed typological construction groups/sectors. The charts were prepared in homogeneous groups and also in a diversified group (which consisted of all the analyzed construction projects). An assessment of the actual earned cost was carried out for various construction projects.

Figure 3 shows the course of the planned cumulative cost curves for the construction projects from group/construction sector A—apartment houses, while Figure 4 shows the course of the incurred cost curves for the same analyzed group of projects.

The research revealed that there is a certain level of similarity in the cumulative cost curve for the various analyzed groups/sectors of the construction industry, but there is no similarity in the cost curves for the entire set of analyzed construction projects.

To confirm the presented conclusion, Figure 5 shows the course of the planned cumulative cost curves for construction projects from sector/group C—hotel buildings, which have visibly different shapes than the ones for group A (presented in Figure 3).

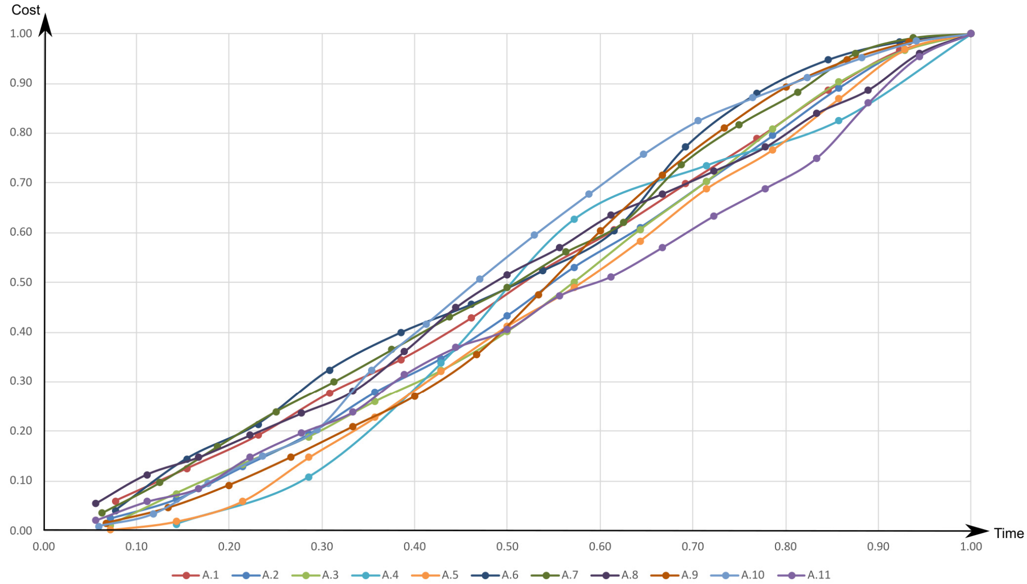

Figure 3. The planned CCCC of construction group/sector A—apartment houses.

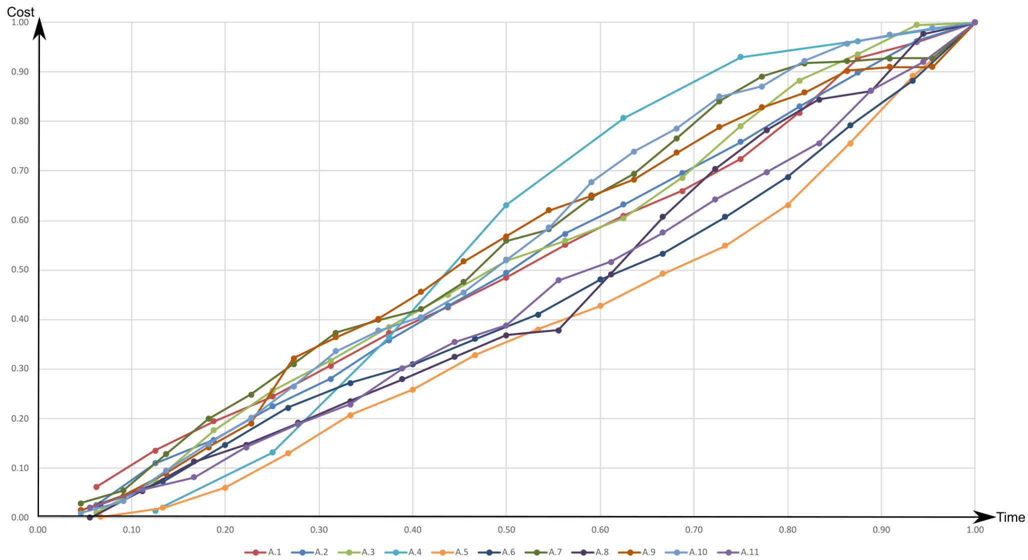

Figure 4. The incurred CCCC of construction group/sector A—apartment houses.

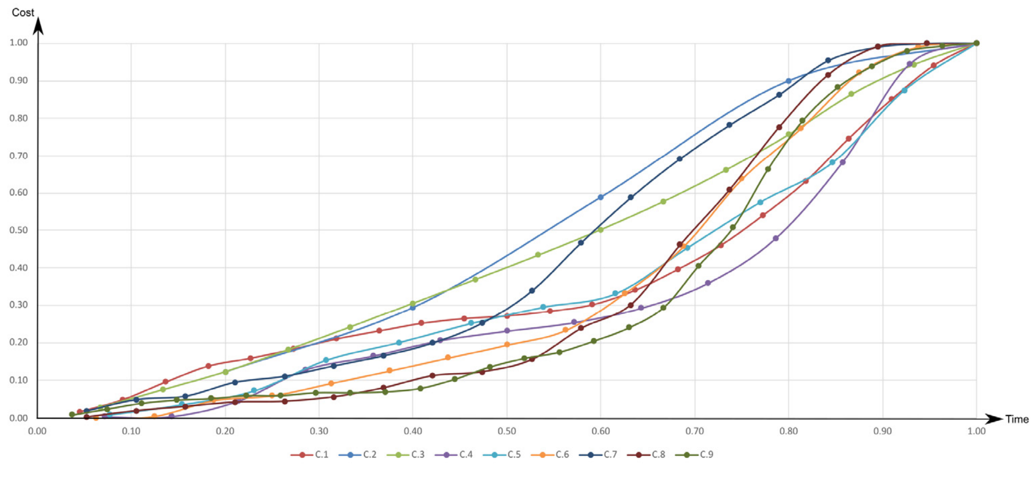

Figure 5. The planned CCCC of construction group/sector C—hotel buildings.

3.2. Determining the Area of Cumulative Cost Curves

Using the determined cost curves, the area in which the analyzed construction projects were located was determined. The area of the cumulative cost of the construction project is presented in a chart in the form of two lines. These lines limit the area that contains the cumulative actual cost of the construction project during its implementation.

A third-degree polynomial was used to describe the best-fit curve

$$y = a_1 \cdot x^3 + a_2 \cdot x^2 + a_3 \cdot x + a_0$$

where:

- Variable y means the standardized duration of a construction project;
- Variable x means the standardized cost of a construction project;
- Variables a_1, a_2, and a_3 are parameters characterizing the analyzed group of construction sectors.

To specify parameters a_1, a_2, and a_3, the following assumptions were made:

- The abscissa axis ranges from 0 to 1;
- The elevation axis ranges from 0 to 1;
- The cost curve starts at two points (0,0), which means that a_0 = 0;
- The polynomial for x = 1 always equals 1 for a completed investment;
- A third-degree polynomial can have at most one inflection point, meaning the second derivative of the function y = 0.

In order to determine the area of the cost curves, three curves were defined for each analyzed data set, presented in the Table 7, namely:

- The curve with the best fit;
- The curve that limits the area of the curves' "upper bound line";
- The curve that limits the area of the curves' "lower bound line".

Table 7. Envelope of the actual cost curve—fragment of the results.

Construction Group/Sector	Actual Cost Curve that Limits the Area "Upper Bound Line"	Actual Best-Fit Curve	Actual Cost Curve that Limits the Area "Lower Bound Line"
Apartment houses (A)	$y = -1.06x^3 + 1.19x^2 + 0.87x$	$y = -1.04x^3 + 1.72x^2 + 0.32x$	$y = 0.09x^3 + 0.54x^2 + 0.37x$
Office buildings (B)	$y = -1.16x^3 + 1.49x^2 + 0.47x$	$y = -0.94x^3 + 1.64x^2 + 0.16x$	$y = 0.56x^3 + 0.23x^2 + 0.15x$
Hotel buildings (C)	$y = -1.20x^3 + 2.01x^2 + 0.19x$	$y = -0.60x^3 + 1.59x^2 + 0.01x$	$y = 0.94x^3 + 0.04x^2 + 0.02x$
Commercial and service buildings (D)	$y = -1.30x^3 + 1.99x^2 + 0.31x$	$y = -0.77x^3 + 1.56x^2 + 0.21x$	$y = 0.94x^3 + 2.34x^2 - 0.40x$
Logistics centers (E)	$y = -1.26x^3 - 1.67x^2 + 1.45x$	$y = -0.12x^3 + 0.11x^2 - 0.07x$	$y = -0.01x^3 + 0.06x^2 - 0.01x$
All buildings	$y = -1.20x^3 + 1.40x^2 + 0.82x$	$y = -0.67x^3 + 1.36x^2 + 0.31x$	$y = 0.86x^3 + 0.10x^2 + 0.04x$

Understanding the projected trajectory of cumulative financial expenditures over time, as well as the shape of the cost curve and its deviations, enables informed decision-making to achieve the intended objectives during the execution of a construction project.

3.3. Elaborating the Best Fit of Cumulative Cost Curves

Based on the specified area, the course of the curve with the best fit to the function was determined. Initially, polynomial regression (sixth-degree polynomial) and the trend function were used to describe the course of the cost curve. The use of a sixth-degree polynomial trend facilitated achieving a high correlation coefficient (close to unity). This proved the existence of a very strong correlation relationship and a very good description of the studied phenomenon. Moreover, a low coefficient of variation was achieved, indicating the consistent nature of the analyzed feature and the uniformity of the studied projects. However, applying higher-order polynomials (higher than a fourth degree) may prove overly complex for practical decision-makers such as investors and contractors. Therefore, further scientific research aimed at identifying simpler mathematical models or formulas was pursued to accurately represent the cumulative cost curve. It was therefore considered reasonable to use a third-degree polynomial in order to describe the best fit of the cost curve.

The shape of the cumulative cost curve was analyzed, noting its initial and final flat segments during the construction project. This is attributed to the gradual commencement and completion of the project. Initially, activities involve organizing human resources, finalizing contracts with contractors and subcontractors, preparing the construction site, and conducting basic preparatory work. As time progresses, activities accelerate, as reflected in the curve's shape. Multiple workstations operate concurrently with specialized work brigades, leading to increased construction activity and costs. This phase contrasts sharply with the slower initial and final stages of implementation.

Based on the analysis of both the literature on this subject and the shape of the cost curve for construction projects collected in the knowledge base, an attempt was made to best fit the cost curve using a third-degree polynomial. An S-shaped cost curve can be mathematically described by two convexities and one inflection point (x_0).

The cost curve in the initial phase of construction (the first phase) exhibits convexity, geometrically meaning that the curve lies above its tangent at each point within the interval $< 0, x_0)$. As construction progresses and activities intensify over time, the cost curve steeply inclines relative to the time axis in the missile phase. The cost curve reaches an inflection point (x_0), signaling the transition to the second phase of implementation, where the rate of cost increase begins to decelerate. In the second phase of construction, the cost curve becomes concave, meaning it curves upwards; geometrically, this indicates that the curve lies below its tangent at each point within the interval $(x_0, 1 >)$. This description of the cost curve's trajectory supports the use of a third-degree polynomial to accurately predict its shape and behavior, presented in the Table 8.

Table 8. Best fit curves—some of the results.

Construction Group/Sector	Third-Degree Polynomial		
	The Actual Cost of Works Performed	**Coefficient of Determination**	**Inflection Point**
Apartment houses (A)	$y = -0.57x^3 + 0.94x^2 + 0.63x$	$R^2 = 0.9535$	x = 0.5497
Office buildings (B)	$y = -0.67x^3 + 1.36x^2 + 0.31x$	$R^2 = 0.9172$	x = 0.6766
Hotel buildings (C)	$y = -0.65x^3 + 1.71x^2 - 0.06x$	$R^2 = 0.9279$	x = 0.8769
Commercial and service buildings (D)	$y = -1.30x^3 + 1.99x^2 + 0.31x$	$R^2 = 0.9438$	x = 0.5103
Logistics centers (E)	$y = -0.57x^3 + 0.94x^2 + 0.63x$	$R^2 = 0.9536$	x = 0.5497
All buildings	$y = -0.78x^3 + 1.49x^2 + 0.29x$	$R^2 = 0.9162$	x = 0.6368

3.4. Development of the Three Sigma Rule

When implementing construction projects, it is crucial for decision-makers to make informed decisions in response to anomalies or changes that may occur at various stages of the investment implementation. For example, a construction manager, depending on his role, when preparing to implement an investment, determines certain parameters that characterize the investment project. When planning a construction project, the investor determines the available investment budget and completion date. In turn, the contractor develops a material and financial schedule to estimate the cost of construction works and subsequently determines the required time for their completion.

The best-fit curves and designated areas of cost curves, which were obtained as a result of the research, help decision-makers plan the course of the construction project and, at the same time, take into account the investment's budget and its duration. Additionally, using the proposed cost curve areas, it is possible to monitor the progress of the construction project and respond appropriately to emerging situations. Depending on the moment in time at which the inspected project is completed, it is possible to quickly estimate deviations from the planned values in terms of cost and time. The determined polynomial functions and graphs of real areas of cost curves (in the form of nomograms) constitute a reliable graphic representation that is useful for the simple application of research results in typologically similar construction sectors.

In order to monitor and control the progress of a construction project, it was proposed, in accordance with the Three Sigma Rule, to divide the area of cost curves into three ranges that correspond with three scenarios. The area was divided according to this rule due to the fact that such a division is used (with great effectiveness) as a warning system about danger, abnormal behavior, or something unusual. For this purpose, a model with specific parameters/"a warning system for irregularities" was developed. Therefore, the cost curve area was divided into the following three areas:

- The range within <−σ, σ>, identified as the acceptable range (green in Figure 6);
- The range within <−2σ, σ> ∪ <−σ, 2σ>, identified as the tolerable range (orange in Figure 6);
- The range within <−3σ, 2σ> ∪ <−2σ, 3σ>, identified as the unacceptable range (red in Figure 6).

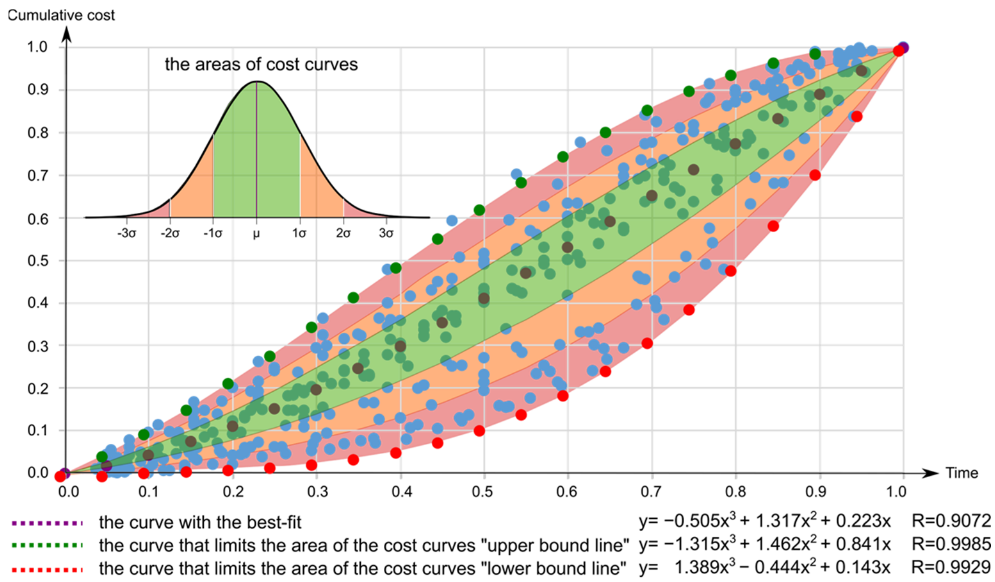

Figure 6. Example of the best-fit curve and the area of cumulative cost curves (nomogram).

Monitoring is conducted based on the material and financial schedule planned by the decision-maker, specifically verifying against the budgeted cost of work scheduled (BCWS) curve. When evaluating the status of a construction project, three scenarios may arise, each with corresponding recommendations:

- Scenario 1: The analyzed value falls within the acceptable range (green area). This indicates that the project is progressing as planned with minor deviations, and ongoing monitoring relative to the BCWS curve suffices.
- Scenario 2: The analyzed value falls within the tolerable range (orange area). This indicates deviations that could impact the budget and project completion date. It is advisable to compare the cost curve with the reference ACWP curve.
- Scenario 3: The analyzed value falls within the unacceptable range (red area). This indicates significant deviations that could significantly increase costs and extend project completion time. In such a situation, it is crucial to compare the cost curve with the reference ACWP curve and develop corrective actions accordingly.
- Figure 6 shows an example area (nomogram) of cumulative cost curves.

4. Conclusions

A manager of a construction project faces a fundamental managerial challenge, which consists of managing the course of the accumulated investment cost in such a way that its actual value (actually performed and paid for construction works) is as close as possible (with as little deviation as possible) to the planned value. Therefore, forecasting the actual course of the implementation cost is of great importance in the management of construction projects and enables predictable maintenance of planned investment budgets in a controlled manner and as close to the actual state as possible.

On the basis of the analysis of the developed knowledge base, containing data from 612 reports of the Bank Investment Supervision on 45 construction projects from 2006 to 2023 with a total value of over PLN 1,300,000,000, the best-fit curve was determined, and the predicted area of the accumulated cost in selected construction projects belonging to different groups/sectors of the construction industry was determined. The determined polynomial functions and graphs of the areas of real cost curves, in the form of nomograms, constitute a reliable graphical representation enabling the application of research results in typologically similar groups/sectors of construction.

The conclusions from the research, applied methods, and developed modeling are as follows:

a. Research related to the analysis of the cumulative cost curve with the potential to forecast costs and their exceedances was carried out.
b. On the basis of the collected reports of the Bank Investment Supervision, a representative set of data was created to conduct research on the development of an original method for forecasting the best match of cost curves and cost area in selected construction projects.
c. A model was developed, and the course of planned, actual, and developed cost curves for selected construction projects collected in the developed knowledge base was developed.
d. A methodology of cost curve research has been proposed by combining two methods used so far for the control and monitoring of construction projects (the cumulative cost curve and the earned value method) into one original method of forecasting the best fit of the cost curve and the cost area in selected construction projects.
e. It has been shown that the shape of the cumulative cost curve within a homogeneous group/sector of construction is similar, but when comparing them between different groups of investment projects, a large diversity is visible.
f. A research model was developed and its parameters were given in order to elaborate the best fit of the cost curve based on the course of the planned and actual cost of selected construction projects in the form of a third-degree polynomial function.
g. The area of best matching of the course of cost curves to the planning and monitoring of costs in various construction projects has been proposed.
h. Developed a model with specific parameters of the 'irregularity alert' system, based on the area of cost curves and the three sigma rule.

5. Discussion and Summary

The verification of the models was carried out, and is still being carried out, by the main recipient and user of the proposed solutions, i.e., banks. Banks granting investment loans for construction projects are interested in the research results prepared by the author, and they implement them into everyday practice.

The research results were presented and discussed with a leading bank in Poland during a seminar/training entitled "Variability of the trend and size of deviations of the planned and incurred costs in various investment tasks". The seminar was conducted for over 45 employees. The participants of the training were employees of, among others, the Real Estate Valuation and Analysis Office, the Risk Department, the Risk Management Division, and also the Investment Banking and Real Estate Financing Department.

The training was a response to the needs of the financial market, which has a problem with unrealistic budget reserves being accepted by investors when granting investment loans. The correct financing of an investment depends on how the bank, but also the auditor—the Bank Investment Supervision—assesses the construction project. Banks try to adjust the budget of a construction project and take into account the actual cost by adopting differentiated budget reserves depending on construction groups/sectors and by reducing the budget failure rate from 0.8 (given by PMI) to a value corresponding with the adjusted budget reserve.

The research results presented in this paper do not cover all the problems related to the modeling of construction projects. Within the scope of the discussed issue, the subject is developing and should be continued, e.g., by examining the possibility of using other methods, such as artificial intelligence methods, to predict cost curves and their areas in various construction projects. Moreover, it can be used to examine the relationship between the amounts of the performed construction works and the deviation of the actual cost from the budgeted one.

It is also advisable to further update the knowledge base with new construction projects, because with an increasing number of analyzed construction projects, it will be possible to iteratively narrow the area of actual costs in various construction projects (shown in Figure 7). It will then be possible to provide banks with new, practical results in the form of, e.g., correction factors that will bring the budgeted cost closer to the actual cost.

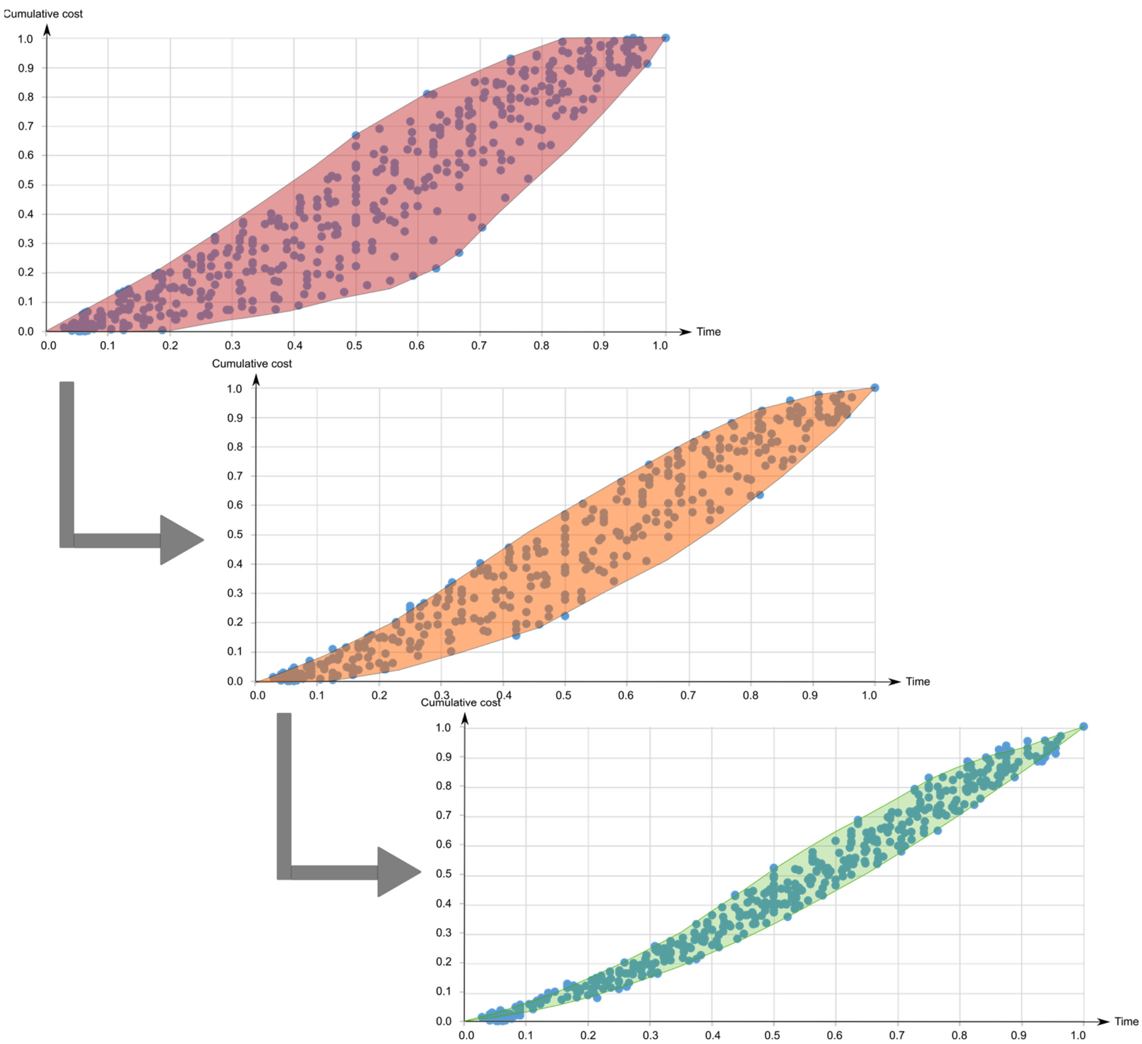

Figure 7. Iterative narrowing of the real cost area in various construction projects.

The presented approach is the result of many years of research on the methodology and tools for modeling construction projects. As a result, a method was developed that allows the course of the actual implementation cost to be forecasted, the best fit of the cost curve to be determined, and the area of the correct cost planning for selected construction projects to be specified. The method was developed using a reliable knowledge base that contains archival information on various construction projects.

The research extends the previously applied approach that uses the earned value method and aims to propose a comprehensive approach to forecasting cost curves. The developed model allows the decision-maker to receive an early warning about the possibility of the occurrence of cost overruns. By developing the original method, two previously used methods for controlling and monitoring construction projects were combined (the cumulative cost curve method—the "S" curve method and the earned value method) into one original course of cumulative cost curve (CCCC) method—the best fit of the cost curves and the area of the curves in selected construction projects. Monitoring that is carried out in accordance with the elaborated model that has specific parameters/"an irregularity warning system" allows for the effective cost management of a construction project and also reduces the possibility of cost overruns.

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References

1. Rachid, Z.; Toufik, B.; Mohammed, B. Causes of schedule delays in construction projects in Algeria. *Int. J. Constr. Manag.* **2019**, *19*, 371–381. [CrossRef]
2. Makesh, S.; Mathivanan, M. Analysis on causes of delay in building construction. *Int. J. Innov. Technol. Explor. Eng.* **2019**, *8*, 335–341.
3. Kowalski, J.; Połoński, M.; Lendo-Siwicka, M.; Trach, R.; Wrzesiński, G. Method of Assessing the Risk of Implementing Railway Investments in Terms of the Cost of Their Implementation. *Sustainability* **2021**, *13*, 13085. [CrossRef]
4. Flyvbjerg, B.; Skamris Holm, M.K.; Buhl, S.L. What Causes Cost Overrun in Transport Infrastructure Projects? *Transp. Rev.* **2004**, *24*, 3–18. [CrossRef]
5. Cantarelli, C.C.; Molin, E.J.E.; Van Wee, B.; Flyvbjerg, B. Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases. *Transp. Policy* **2012**, *22*, 49–56. [CrossRef]
6. Miranda Sarmento, J.; Renneboog, L. Cost Overruns in Public Sector Investment Projects. *Public Work. Manag. Policy* **2017**, *22*, 140–164. [CrossRef]
7. Senouci, A.; Ismail, A.; Eldin, N. Time Delay and Cost Overrun in Qatari Public Construction Projects. *Procedia Eng.* **2016**, *164*, 368–375. [CrossRef]
8. Karunakaran, P.; Abdullah, A.H.; Nagapan, S.; Sohu, S.; Kasvar, K.K. Categorization of potential project cost overrun factors in construction industry. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *140*, 012098. [CrossRef]
9. Plebankiewicz, E. Model of predicting cost overrun in construction projects. *Sustainability* **2018**, *10*, 4387. [CrossRef]
10. Asiedu, R.O.; Adaku, E. Cost overruns of public sector construction projects: A developing country perspective. *Int. J. Manag. Proj. Bus.* **2020**, *13*, 66–84. [CrossRef]
11. Love, P.E.D.; Edwards, D.J.; Irani, Z.; Walker, D.H.T. Project pathogens: The anatomy of omission errors in construction and resource engineering project. *IEEE Trans. Eng. Manag.* **2009**, *56*, 425–435. [CrossRef]
12. Han, S.; Love, P.; Peña-Mora, F. A system dynamics model for assessing the impacts of design errors in construction projects. *Math. Comput. Model.* **2013**, *57*, 2044–2053. [CrossRef]
13. Polat, G.; Okay, F.; Eray, E. Factors affecting cost overruns in micro-scaled construction companies. *Procedia Eng.* **2014**, *85*, 428–435. [CrossRef]

14. Larsen, J.K.; Shen, G.Q.; Lindhard, S.M.; Brunoe, T.D. Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects. *J. Manag. Eng.* **2016**, *32*, 04015032. [CrossRef]
15. Aslam, M.; Baffoe-Twum, E.; Saleem, F. Design Changes in Construction Projects—Causes and Impact on the Cost. *Civ. Eng. J.* **2019**, *5*, 1647–1655. [CrossRef]
16. Gunduz, M.; Maki, O.L. Assessing the risk perception of cost overrun through importance rating. *Technol. Econ. Dev. Econ.* **2018**, *24*, 1829–1844. [CrossRef]
17. Derakhshanalavijeh, R.; Teixeira, J.M.C. Cost overrun in construction projects in developing countries, Gas-Oil industry of Iran as a case study. *J. Civ. Eng. Manag.* **2017**, *23*, 125–136. [CrossRef]
18. Alhammadi, A.S.A.M.; Memon, A.H. Ranking of the factors causing cost overrun in infrastructural projects of UAE. *Int. J. Sustain. Constr. Eng. Technol.* **2020**, *11*, 204–211.
19. Yap, J.B.H.; Skitmore, M. Ameliorating time and cost control with project learning and communication management: Leveraging on reusable knowledge assets. *Int. J. Manag. Proj. Bus.* **2020**, *13*, 767–792. [CrossRef]
20. Amusan, L.M.; Afolabi, A.; Ojelabi, R.; Omuh, I.; Okagbue, H.I. Data exploration on factors that influences construction cost and time performance on construction project sites. *Data Brief* **2018**, *17*, 1320–1325. [CrossRef]
21. Senouci, A.B.; Mubarak, S.A. Multiobjective optimization model for scheduling of construction projects under extreme weather. *J. Civ. Eng. Manag.* **2016**, *22*, 373–381. [CrossRef]
22. Hamzah, N.; Khoiry, M.A.; Arshad, I.; Tawil, N.M.; Che Ani, A.I. Cause of construction delay—Theoretical framework. *Procedia Eng.* **2011**, *20*, 490–495. [CrossRef]
23. Gebrehiwet, T.; Luo, H. Analysis of Delay Impact on Construction Project Based on RII and Correlation Coefficient: Empirical Study. *Procedia Eng.* **2017**, *196*, 366–374. [CrossRef]
24. Susanti, R. Cost overrun and time delay of construction project in Indonesia. *J. Phys. Conf. Ser.* **2020**, *1444*, 012050. [CrossRef]
25. Negesa, A.B. Assessing the Causes of Time Overrun in Building and Road Construction Projects: The Case of Addis Ababa City, Ethiopia. *J. Eng.* **2022**, *6*, 8479064. [CrossRef]
26. Egwim, C.N.; Alaka, H.; Toriola-Coker, L.O.; Balogun, H.; Ajayi, S.; Oseghale, R. Extraction of underlying factors causing construction projects delay in Nigeria. *J. Eng. Des. Technol.* **2021**, *21*, 1323–1342. [CrossRef]
27. Zidane, Y.J.T.; Andersen, B. The top 10 universal delay factors in construction projects. *Int. J. Manag. Proj. Bus.* **2018**, *11*, 650–672. [CrossRef]
28. Arantes, A.; Ferreira, L.M.D.F. Interpretive structural model-based for analysis of causes of delays in construction projects: The Portuguese case. In Proceedings of the 10th International Conference on Operations Research and Enterprise Systems (ICORES 2021), Online, 4–6 February 2021; Curran Associates Inc.: New York, NY, USA, 2021; pp. 366–374.
29. Othman, I.; Shafiq, N.; Nuruddin, M.F. Time Overrun in Construction Project. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *291*, 012016. [CrossRef]
30. Mahamid, I. Relationship between delay and productivity in construction projects. *Int. J. Adv. Appl. Sci.* **2022**, *9*, 160–166. [CrossRef]
31. Latif, Q.B.A.I.; Al Saadi, A.M.D.; Rahman, I.A. Identification of delay factor in oman construction industry. *Int. J. Sustain. Constr. Eng. Technol.* **2019**, *10*, 34–45.
32. Kubečková, D.; Smugala, S. Determination of construction process duration based on labor productivity estimation: A case study. *Organ. Technol. Manag. Constr.* **2021**, *13*, 2521–2538. [CrossRef]
33. Al Kulabi, A.K.; Atiea, H.M.J. Time overruns in the construction projects in Iraq: Case study on investigating and analyzing the root causes. *Open Eng.* **2022**, *12*, 702–715. [CrossRef]
34. Apollo, M.; Grzyl, B.; Jakubowicz, P. Risk of Delays in Implementation of Building Investment in Urban Conditions in the Aspect of Historical Background of its Location. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *471*, 112054. [CrossRef]
35. Anysz, H.; Buczkowski, B. The association analysis for risk evaluation of significant delay occurrence in the completion date of construction project. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 5369–5374. [CrossRef]
36. Le-Hoai, L.; Lee, Y.D.; Lee, J.Y. Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. *KSCE J. Civ. Eng.* **2008**, *12*, 367–377. [CrossRef]
37. Bin Seddeeq, A.; Assaf, S.; Abdallah, A.; Hassanain, M.A. Time and Cost Overrun in the Saudi Arabian Oil and Gas Construction Industry. *Buildings* **2019**, *9*, 41. [CrossRef]
38. Belay, A.M.; Torp, O. Do Longer Projects Have Larger Cost Deviation Than Shorter Construction Projects? *Procedia Eng.* **2017**, *196*, 262–269. [CrossRef]
39. Cristóbal, J.R.S. The S-curve envelope as a tool for monitoring and control of projects. *Procedia Comput. Sci.* **2017**, *121*, 756–761. [CrossRef]
40. Tijanić, K.; Car-Pušić, D. Application of S-curve in EVA Method. In Proceedings of the 13th International Conference "Organization, Technology and Management in Construction", Poreč, Croatia, 27–30 September 2017; pp. 103–115.
41. Hsieh, T.-Y.; Hsiao-Lung Wang, M.; Chen, C.-W. A Case Study of S-Curve Regression Method to Project Control of Construction Management via T-S Fuzzy Model. *J. Mar. Sci. Technol.* **2004**, *12*, 209–216. [CrossRef]
42. Mohagheghi, V.; Meysam Mousavi, S.; Vahdani, B. An Assessment Method for Project Cash Flow under Interval-Valued Fuzzy Environment. *J. Optim. Ind. Eng.* **2017**, *22*, 79–80.

43. Hsieh, T.Y.; Wang, M.H.L.; Chen, C.W.; Chen, C.Y.; Yu, S.E.; Yang, H.C.; Chen, T.H. A new viewpoint of s-curve regression model and its application to construction management. *Int. J. Artif. Intell. Tools* **2006**, *15*, 131–142. [CrossRef]
44. Chao, L.-C.; Chien, C.-F. A Model for Updating Project S-curve by Using Neural Networks and Matching Progress. *Autom. Constr.* **2010**, *19*, 84–91. [CrossRef]
45. Chao, L.-C.; Chen, H.-T. Predicting project progress via estimation of S-curve's key geometric feature values. *Autom. Constr.* **2015**, *57*, 33–41. [CrossRef]
46. Wang, K.C.; Wang, W.C.; Wang, H.H.; Hsu, P.Y.; Wu, W.H.; Kung, C.J. Applying building information modeling to integrate schedule and cost for establishing construction progress curves. *Autom. Constr.* **2016**, *72*, 397–410. [CrossRef]
47. Blyth, K.; Kaka, A. A novel multiple linear regression model for forecasting S-curves. *Eng. Constr. Archit. Manag.* **2006**, *13*, 82–95. [CrossRef]
48. Banki, M.T.; Esmaeeli, B. Using historical data for forecasting s-curves at construction industry. In Proceedings of the 2008 IEEE International Conference on Industrial Engineering and Engineering Management, Singapore, 8–11 December 2008; pp. 282–286.
49. Chao, L.-C.; Chien, C.-F. Estimating Project S-Curves Using Polynomial Function and Neural Networks. *J. Constr. Eng. Manag.* **2009**, *135*, 169–177. [CrossRef]
50. Jiang, A.; Issa, R.R.A.; Malek, M. Construction Project Cash Flow Planning Using the Pareto Optimality Efficiency Network Model. *J. Civ. Eng. Manag.* **2011**, *17*, 510–519. [CrossRef]
51. Mohamad, H.M.; Mohamad, M.I.; Saad, I.; Bolong, N.; Mustazama, J.; Razali, S.N.M. A case study of s-curve analysis: Causes, effects, tracing and monitoring project extension of time. *Civ. Eng. J.* **2021**, *7*, 649–661. [CrossRef]
52. Ostojic-Skomrlj, N.; Radujkovic, M. S-curve modelling in early phases of construction projects. *Gradevinar* **2012**, *64*, 647–654.
53. Szóstak, M. Best Fit of Cumulative Cost Curves at the Planning and Performed Stages of Construction Projects. *Buildings* **2023**, *13*, 13. [CrossRef]
54. Peer, S. Application of Cost-Flow Forecasting Models. *J. Constr. Div.* **1982**, *108*, 226–232. [CrossRef]
55. Miskawi, Z. An S-curve equation for project control. *Constr. Manag. Econ.* **1989**, *7*, 115–124. [CrossRef]
56. Boussabaine, A.H.; Elhag, T. Applying fuzzy techniques to cash flow analysis. *Constr. Manag. Econ.* **1999**, *17*, 745–755. [CrossRef]
57. Cioffi, D.F. A tool for managing projects: An analytic parameterization of the S-curve. *Int. J. Proj. Manag.* **2005**, *23*, 215–222. [CrossRef]
58. Project Management Institute. *Guide to the Project Management Body of Knowledge (PMBOK Guide)*, 6th ed.; Project Management Institute (PMI): Newtown Square, PA, USA, 2017; ISBN 9781935589679.
59. IPMA. *IPMA Individual Competence Baseline*; PIMA: IJsselstein, The Netherland, 2015.
60. Abba, W.F. How earned value got to primetime: A short look back and glance ahead. In Proceedings of the Project Management Institute Annual Seminars & Symposium, Houston, TX, USA, 7–16 September 2000.
61. De Marco, A.; Narbaev, T. Earned value-based performance monitoring of facility construction projects. *J. Facil. Manag.* **2013**, *11*, 69–80. [CrossRef]
62. Zohoori, B.; Verbraeck, A.; Bagherpour, M.; Khakdaman, M. Monitoring production time and cost performance by combining earned value analysis and adaptive fuzzy control. *Comput. Ind. Eng.* **2019**, *127*, 805–821. [CrossRef]
63. Chen, H.L.; Chen, W.T.; Lin, Y.L. Earned value project management: Improving the predictive power of planned value. *Int. J. Proj. Manag.* **2016**, *34*, 22–29. [CrossRef]
64. Bhosekar, S.K.; Vyas, G. Cost Controlling Using Earned Value Analysis in Construction Industries. *Int. J. Eng. Innov. Technol.* **2012**, *1*, 324–332.
65. Waris, M.; Waris, A.; Idrus, A. The Cost Monitoring of Construction Projects through Earned Value Analysis. *J. Constr. Eng. Proj. Manag.* **2012**, *2*, 42–45.
66. Khamidi, M.; Khamidi, M.; Idrus, A. The Performance Measurement of Private Finance Initiative Project n Malaysia by Using Earned Value Management Technique. In Proceedings of the 3rd International Conference on Built Environment in Developing Countries (ICBEDC2009), Penang, Malaysia, 2–3 December 2009; pp. 799–806.
67. Vandevoorde, S.; Vanhoucke, M. A comparison of different project duration forecasting methods using earned value metrics. *Int. J. Proj. Manag.* **2006**, *24*, 289–302. [CrossRef]
68. Czemplik, A. Application of earned value method to progress control of construction projects. *Procedia Eng.* **2014**, *91*, 424–428. [CrossRef]
69. Wauters, M.; Vanhoucke, M. Study of the Stability of Earned Value Management Forecasting. *J. Constr. Eng. Manag.* **2014**, *141*, 04014086. [CrossRef]
70. Babar, S.; Thaheem, M.J.; Ayub, B. Estimated Cost at Completion: Integrating Risk into Earned Value Management. *J. Constr. Eng. Manag.* **2016**, *143*, 04016104. [CrossRef]
71. Przywara, D.; Rak, A. The time-cost analysis of schedule monitoring using the earned value method. *Tech. Trans.* **2017**, *5*, 57–66.
72. Dziadosz, A.; Kapliński, O.; Rejment, M. Usefulness and fields of the application of the Earned Value Management in the implementation of construction projects. *Bud. Archit.* **2014**, *13*, 357–364. [CrossRef]
73. Almeida, R.; Abrantes, R.; Romão, M.; Proença, I. The Impact of Uncertainty in the Measurement of Progress in Earned Value Analysis. *Procedia Comput. Sci.* **2021**, *181*, 457–467. [CrossRef]
74. Starczyk-Kołbyk, A.; Kruszka, L. Use of the EVM method for analysis of extending the construction project duration as a result of realization disturbances—Case study. *Arch. Civ. Eng.* **2021**, *67*, 373–393.

75. Kasprowicz, T.; Starczyk-Kołbyk, A.; Wójcik, R.R. The randomized method of estimating the net present value of construction projects efficiency. *Int. J. Constr. Manag.* **2022**, *23*, 2126–2133. [CrossRef]
76. Przywara, D.; Rak, A. Monitoring of Time and Cost Variances of Schedule Using Simple Earned Value Method Indicators. *Applied Sciences* **2021**, *11*, 1357. [CrossRef]
77. de Neufville, R.; Scholtes, S.; Wang, T. Real Options by Spreadsheet: Parking Garage Case Example. *J. Infrastruct. Syst.* **2006**, *12*, 107–111. [CrossRef]