UNIVERSITY OF ZIELONA GÓRA

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2025; 35 (2): 0280-0296
DOI: 10.59440/ceer/203344
Original Research Article

CORRELATION BETWEEN PROGRESS OF CONSTRUCTION WORKS AND THEIR FINANCIAL SPEND IN THE EXECUTION OF RESIDENTIAL BUILDINGS

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Abstract

The aim of the research was to determine and proof the real correlation of construction works and their financial spend in relation of the selected group of Residential Buildings X. Deviations and their impact on the correlation in relation to construction and financial throughput were determined and analysed using the basic indicators of the Earned Value Method (EVM), i.e.: estimated final cost of estimated at completion (EAC) projects and correlation with their deadlines for estimated time at completion (ETTC). Additional studies have attempted to approximate the final cost of the EAC more accurately, which is referred to in this study as EAC-S. The obtained results of observations over the entire period of implementation of the selected housing estate were also analysed in statistics used in standard deviation coefficients and Pearson linear correlation r. Such an experiment was performed both for investment X at the moment of flattening of the S curve for cumulative works. Having a dataset from the period of the excessive curve in the case of Residential Buildings X, the result closest to the actual final costs was obtained. The designated indicator overestimated the budget by only 0. 205%. Thus, the EAC Estimated Final Cost Index indicated a value of 0. 422%.

Keywords: construction works, Pearson correlation, financial spend, earned value method

1. INTRODUCTION

The subject of the article is to define the correlation of quantity of construction works with the utilization of investment spent on Residential Buildings in relation to the assumptions adopted in the Construction and Financial Schedule. The measure of the progress of the investment task in relation to time to financial spent expressed in monetary value is the Construction and Financial Schedule (CFS) [1,2]. CFS should reflect the planned scope of works of a given project defined and described by Tender Price Breakdown (TPB), as well as indicate the planned costs related to the realisation of the task [3,4]. The

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CFS presents a given investment task broken down into actions with possible sub-measures [5,6]. Detailed breakdown of data items and scope of the project allows for precise determination of the developed works in a given time and financial dimension [7,8]. The given items should be defined precisely enough to allow for a reliable assessment of the progress of the implemented project [9,10] without excessive detail, i.e. it should contain only the most important information, reflecting the actual nature of the implemented project, while maintaining the principle that individual items in CFS are also accounting items [11,12].

Due to the degree and nature of preparation of a given project for implementation, the Construction and Financial Schedule should be developed on the basis of a construction project and a collective statement of costs, an investor's cost estimate or a feasibility study of the project, approved by the investor and on the basis of the contract and schedule of implementation of the project constituting its attachment [13,14]. Planned costs should be given according to the expected prices of the task, possibly taking into account the possibility of their valorisation in progress [15,16].

The defined indicators of individual S-curves in the Earned Value Method are the output data for analysis and determination of subsequent values [17-20], which can be divided into: cost monitoring indicators and estimated value indicators.

The aim of the research was to determine and proof the real correlation of construction works and their financial spend in relation of the selected group of Residential Buildings X.

1.1. Cost monitoring indicators

1.1.1. CPI (Cost Performance Index)

$$CPI = BCWP / ACWP \tag{1.1}$$

where [21]:
BCWP - Budgeted Cost of Work Performed,
ACWP - Actual Cost of Work Performed.

The CPI indicates how much of the costs were incurred as intended. If CPI < 1 means that the cost of the work performed is higher than expected.

1.1.2. SPI (Schedule Performance Index)

$$SPI = BCWS / BCWP \tag{1.2}$$

where [21]:
BCWP - Budgeted Cost of Work Performed,
BCWS – Budgeted Cost of Work Scheduled.

Schedule completion rate in time. A rate of less than 100% means a delay.

1.1.3. CV (Cost Variance)

$$CV = BCWP - ACWP \tag{1.3}$$

- CV < 0 - negative indicator occurs when the actual cost of the ACWP project is greater than the value earned BCWP. The work carried out cost more than planned. During the implementation of subsequent tasks, additional costs may be offset as part of additional savings or the budget will be exceeded.

- CV > 0 - a positive indicator occurs when the actual cost of the ACWP is less than the earned value of the BCWP. This means that the work was carried out with less financial outlay than planned.
- CV = 0 - an indicator equal to zero occurs when, from the moment of commencement of the investment task to the date of the audit, the earned value is equal to the value of the costs actually incurred [21].

1.1.4. CV% (Cost Variance %)

$$CV\% = 100 \cdot [(BCWP - ACWP) / BCWP] \tag{1.4}$$

The CV% ratio is the percentage difference of how much or less financial resources were used to carry out the works assumed in the Financial Schedule [21].

1.1.5. SV (Schedule Variance)

$$SV = BCWP - BCWS \tag{1.5}$$

- SV < 0 - negative deviation will occur when the BCWS's initial budget is greater than the BCWP earned value. The deviation clearly indicates a delay in the works – the value of the work performed is lower than expected in the Construction and Financial Schedule.
- SV > 0 - positive deviation occurs when the BCWS value is less than the BCWP value. This means that the works are carried out above the planned plan.
- SV = 0 - an indicator equal to 0 indicates the implementation of the investment task in accordance with the previously determined budget [21].

1.1.6. SV% (Scheduled Variance %)

$$SV\% = 100 \cdot [(BCWP - BCWS) / BCWP] \tag{1.6}$$

Indicator as a function of costs, the negative value of which means the delay in the work schedule expressed by the amount of unused budget [21].

1.2. Estimated value indicators

1.2.1. EAC (Estimated at Completion)

$$EAC = BAC / CPI \quad \text{or} \tag{1.7}$$

$$EAC = ACWP + [(BAC - BCWP) / CPI] \tag{1.8}$$

where [21]:
BAC - budget at completion.

If the investment task is carried out below the assumed costs, we apply:

- formula (1.7) - optimistic forecast,
- formula (1.8) - pessimistic forecast.

If the investment task is carried out above the assumed costs, we apply:

- formula (1.7) - pessimistic forecast,
- formula (1.8) - optimistic forecast.

1.2.2. ETTC (Estimated Time at Completion)

$$ETTC = ATE + [(OD – (ATE \cdot SPI)) / SPI] \tag{1.9}$$

where [21]:
ATE - duration from the beginning to the day of the inspection,
OD - planned total construction duration.

2. METHODS AND MODELS

The observations were confronted with the tools of applied statistics [22]. Standard deviation will indicate deviations in the range of planned values, earned values and costs actually incurred. The linear correlation r Pearson will indicate whether planned values correlated with earned values and whether earned values correlated with actual costs incurred.

According to the Central Statistical Office, standard deviation is a classic measure of volatility. The standard deviation is the square root of variance. Intuitively speaking, the standard deviation tells you how widely the values of a given quantity are scattered around its mean. The smaller the deviation value, the more the observations are focused around the mean [23]. In other words, the standard deviation indicates how much the values of the tested feature deviate from the arithmetic mean on average and determines whether in the studied population (or sample) the units are similar due to the examined feature or significantly differ from each other. The deviation is calculated using neither arithmetic, harmonic, nor geometric mean. The root mean square is used to calculate the standard deviation. This mean is the grade 2 power mean. In the first stage, the arithmetic mean of the studied set of numbers is calculated. Then the difference between the value of the characteristic of each observed unit and the arithmetic mean is determined. In the next step, each of the differences is raised and squared and adds up to each other. The last step is to divide the obtained result by the number of observations (n) and extract the second degree element from this number. The result will indicate the standard deviation of the tested set of numbers. It should be noted that in this particular case, all values for the entire implementation of the investment task (after its completion) are examined, thus, the standard deviation counts for a given population. If the standard deviation were calculated for a given period, the calculation would have to be made for the sample and thus the denominator in the formula (10) would have to be subtracted from n in the denominator in the formula (10) by the number 1 (n-1).

The formula for the standard deviation for the population is:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{mean})^2}{n}} \tag{2.1}$$

where,
x_i - given value of the test set,
x_{mean} - mean value of the entire harvest examined,
n - number of values in the test set.

The calculations used the addition of standard deviation in the form of an indicator called the coefficient of variation. This coefficient, expressed as a percentage, indicates the measure of dispersion of the values tested and is given by the formula:

$$V = \frac{s}{x_{mean}} \cdot 100\% \tag{2.2}$$

where,
s - standard deviation.

According to the issues of statistics, if the coefficient fluctuates in the range of 0-20%, then the population diversity is small. If it is in the range of 20-40%, it is said [24] to be an average population diversity. The range of 40-60% is a big variation. When the coefficient of variation exceeds 60%, it means that the variation is very large.

The Central Statistical Office defines the linear correlation r Pearson as a coefficient determining the level of linear relationship between random variables for two sets of numbers. The value of the correlation coefficient is in the closed range: from -1 to 1. The greater its absolute value, the stronger the linear relationship between the variables.

- the value closer to 1 the stronger and positive the relationship is (if x grows, y increases);
- the value closer to -1 the stronger and negative the relationship is (if x increases, y decreases);
- r = 0 means no linear relationship between the variables.

$$r = \frac{\sum_i (x_i - x_{mean}) * (y_i - y_{mean})}{\sqrt{\sum_i (x_i - x_{mean})^2} * \sqrt{\sum_i (y_i - y_{mean})^2}} \tag{2.3}$$

where,
x_i - given value of the first set,
y_i - given value of the second set,
x_{mean} - average value of the first set,
y_{mean} - mean value of the second set.

In other words, the Pearson correlation indicates whether the same or different trends prevail in a given set of numbers. For example, it determines whether a given set of numbers grows similarly linearly, whether one of them grows and the other decreases, or whether both sets are definitively differentiated from each other.

The conducted analyses will indicate whether the standard deviation and the Pearson correlation are closely related issues, or on the contrary – they can work separately while indicating the given features of the analysed sets of numbers.

3. RESEARCH RESULTS CASE STUDY

3.1. Profile of Residential Buildings X

Investment X consisting of buildings A and B are located in south-western Poland, with a total of 64 apartments and one garage hall, is traditional erected. The garage hall was made in reinforced concrete technology – white bath technology, while the walls of the above-ground floors were entirely made of silicate blocks with local reinforcements in the form of reinforced concrete pins. The body of the buildings in both cases is characterized by a cuboid, but topped with a gable roof. According to the Construction and Financial Schedule, the cost of the entire undertaking should amount to 13,497,680 PLN (BAC according to the EVM method), and the realisation time was estimated at 17 months: November 2018 – March 2020 (OD value, according to EVM method). The buildings have been designed as multi-family buildings with a coherent character. The structural solutions of individual architectural building elements in both buildings are similar. This applies to the plinth, building, materials and form of walls and roof, windows, balconies, treatments, eaves, balcony railings. Functionally, each of the two buildings is organized around a centrally located vertical communication division. Entrances to the basement of the buildings are provided from a common inter-block interior. The buildings face each other through entrances. The project provided for apartments with an area from 37 m^2 to 92 m^2 with the number of rooms from 2 to 4. All apartments have a balcony, terrace or loggia.

3.2. Analysis of project X by EVM

Knowing the formulas and principles of creating EVM method meters (described in section 1), supplementing the data in the following months illustrates subsequent analysis and performed works and estimates even more approximate final costs and time of task completion.

The analyses carried out showed that it was only in December 2019 that the earned value was equal to the value provided for in the schedule. By analysing the S curve as a curve of accumulated throughput of construction works, the cause of the delays can be determined at first glance (fig. 1).

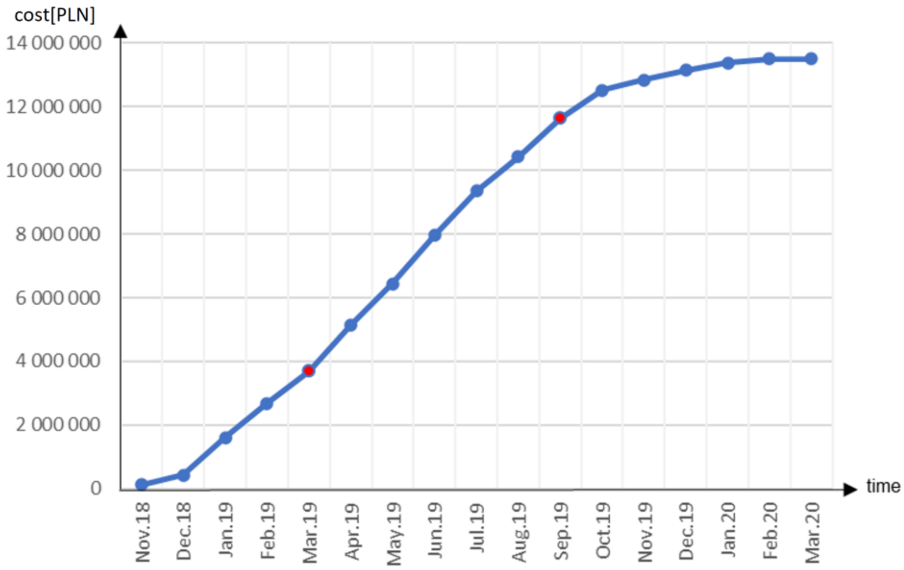

Fig. 1. Curve S of the cumulative planned construction works costs of Residential Buildings

The most cumulative works lasted from March 2019 to September 2019. The progress report already in January 2019 showed a delay. This was the biggest delay compared to the other months. The value of the unexecuted budget was estimated at 19.71%. It should be noted how important it is to draw up the S curve and plan the workload so that there are no delays at the beginning. In the example of investment X, it is noted that due to a not very good start, the S curve has shifted by a month (fig. 2).

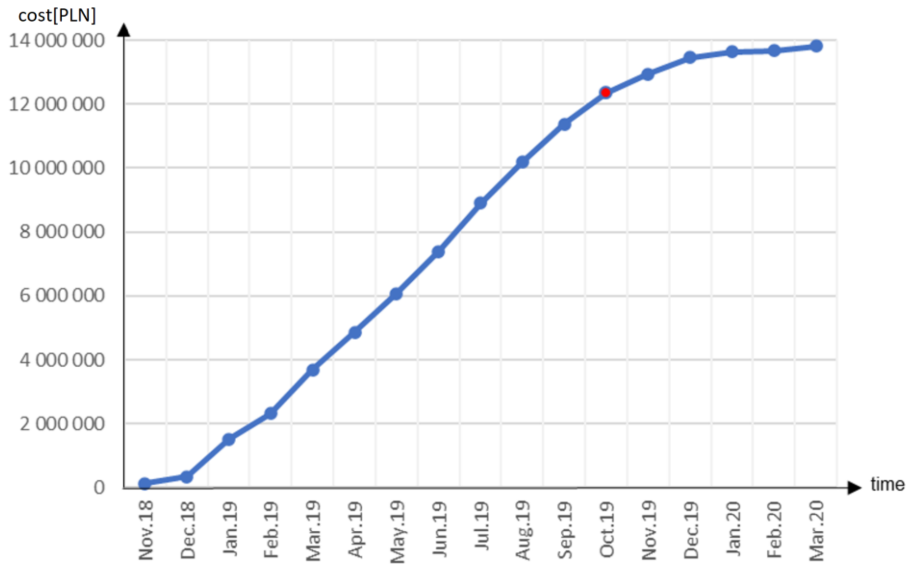

Fig. 2. Curve S of the cumulative earned construction works costs of Residential Buildings

Focusing on the final costs of the investment task which is Residential Buildings X, it is observed that it was exceeded by less than PLN 310,000, which is 0.023% of the total planned cost of BAC. Examining the reason for the budget overrun, it turned out that the values generated by the BCWP were identical to the values of the costs actually incurred by the ACWP. The problem concerned the unforeseen works that were not included in the Construction and Financial Schedule and one random event, independent of either the Investor or the Contractor (fig. 3).

The additions disclosed were::

- March 2019 - increase in value by 47,000 PLN - the implementation of an additional water connection;
- May 2019 - increase in value by PLN 76,000 – electricity and gas connection in the event;
- September 2019 - an increase in value by PLN 55,000 – from the garage as a result of a storm (random event);
- September 2019 - an increase in value by PLN 189,700 – in the construction of an extra part of the road.

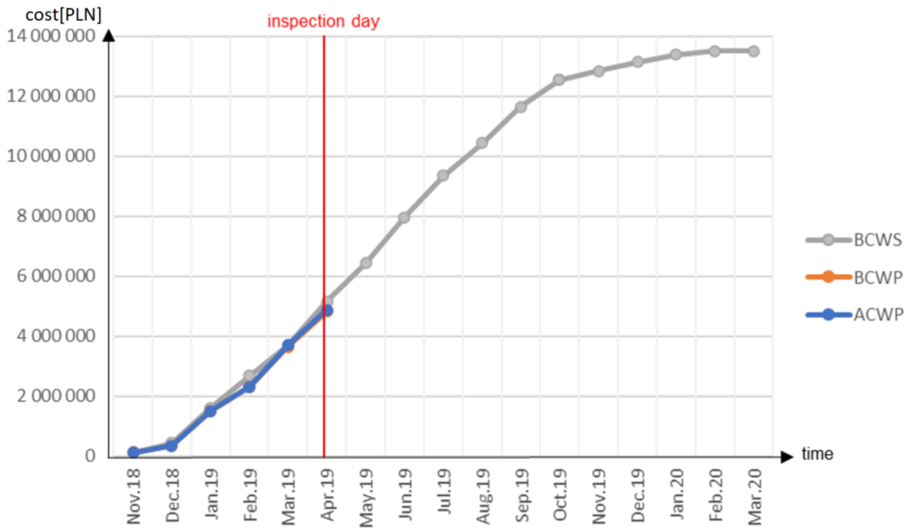

Fig. 3. Graph of EVM cost curves – inspection after March 2019

3.3. Standard deviation

After the completion of the Residential Buildings X, individual data and values were analysed in order to additionally analyse deviations from the value data set. Similarities and differences in schedule values, earned values and spent values were examined.

The formula (10) was used to calculate the standard deviation for the population, while *n* (11) was used to calculate the coefficient of variation.

Table 1. Standard deviation, coefficient of variation – Residential Buildings X

Date	BCWS x_1	BCWP x_2	ACWP x_3	average x_{mean}	standard deviation s	coefficient of variation [%] V
Nov.18	118,948	118,868	118,868	118,894.85	37.61	0.03%
Dec.18	433,825	348,303	348,303	376,810.13	40,315.32	10.70%
Jan.19	1,606,272	1,509,380	1,509,380	1,541,677.47	45,675.52	2.96%
Feb.19	2,678,618	2,319,484	2,319,484	2,439,195.35	169,297.06	6.94%
Mar.19	3,695,461	3,648,547	3,695,547	3,679,852.05	22,135.76	0.60%
Apr.19	5,159,740	4,821,781	4,868,781	4,950,100.82	149,473.98	3.02%
May19	6,431,811	5,951,139	6,074,139	6,152,363.23	203,879.93	3.31%
Jun.19	7,958,490	7,208,312	7,386,312	7,517,704.40	320,041.69	4.26%
Jul.19	9,348,926	8,718,916	8,896,916	8,988,252.63	265,185.49	2.95%
Aug.19	10,433,128	10,008,692	10,186,692	10,209,503.74	174,024.53	1.70%
Sep.19	11,636,261	10,999,538	11,367,238	11,334,345.62	260,979.65	2.30%
Oct.19	12,518,762	11,961,802	12,329,502	12,270,021.94	231,235.36	1.88%
Nov.19	12,842,105	12,579,643	12,947,343	12,789,696.81	154,619.47	1.21%
Dec.19	13,140,690	13,086,092	13,453,792	13,226,857.74	162,007.22	1.22%
Jan.20	13,381,458	13,261,567	13,629,267	13,424,097.24	153,110.86	1.14%
Feb.20	13,497,680	13,297,704	13,665,404	13,486,929.14	150,305.26	1.11%
Mar.20	13,497,680	13,439,365	13,807,065	13,581,369.85	161,356.37	1.19%

The obtained results determined individual deviations of given values in subsequent months. Volatility coefficients only once indicated exceeding the value above 10%. According to the theory of applied statistics, values in the range from 0% to 20% speak of small deviations. The received largest deviation, which took place in December 2018, at the same time confirms the conclusions regarding the observation of the investment task which Residential Buildings X and the analysis of the EVM method. It was this month that turned out to be crucial.

The range of deviation values given by the theorists of applied statistics is one. It should be noted and thus determined whether in the case of funds used in the implementation of a given investment – a deviation of almost 11% in relation to the planned budget does not significantly affect the individual phases of construction and thus the final time and cost of the project.

3.4. Linear correlation r Pearson with EVM

The correlation of construction works quantities with the financial spend, i.e. planned, actual and earned costs was made on the basis of the Pearson linear correlation coefficient r.

The Pearson correlation coefficient r is used to check whether two quantitative variables are related to each other by a linear relationship. Pearson's r score can vary from -1 to 1. The extreme values of -1 and 1 indicate an ideal, total correlation between variable A and variable B. A result equal to "zero" means that the values of these two variables do not coexist, i.e. there is no correlation. The correlation coefficient was calculated from the formula (12), where x_i – BCWS, y_i – BCWP.

As a combination of two variables it was assumed:

- correlation of the Construction and Financial Schedule (BCWS) with earned cost (BCWP)

- correlation of the earned cost (BCWP) with actual cost (ACWP).

Table 2. Pearson linear correlation - correlation of the Construction and Financial Schedule with the earned cost for the Residential Buildings X

Date	x_i	y_i	$x_i - x_m$	$y_i - y_m$	$(x_i - x_m)^2$	$(y_i - y_m)^2$	$(x_i - x_m)\cdot(y_i - y_m)$
Nov.18	118,948	118,868	-8,021,043	-7,721,081	$64{,}337 \cdot 10^9$	$59{,}615 \cdot 10^9$	$61{,}931 \cdot 10^9$
Dec.18	433,825	348,303	-7,706,167	-7,491,646	$59{,}385 \cdot 10^9$	$56{,}124 \cdot 10^9$	$57{,}731 \cdot 10^9$
Jan.19	1,606,272	1,509,380	-6,533,719	-6,330,569	$42{,}689 \cdot 10^9$	$40{,}076 \cdot 10^9$	$41{,}362 \cdot 10^9$
Feb.19	2,678,618	2,319,484	-5,461,374	-5,520,465	$29{,}826 \cdot 10^9$	$30{,}475 \cdot 10^9$	$30{,}149 \cdot 10^9$
Mar.19	3,695,461	3,648,547	-4,444,530	-4,191,402	$19{,}753 \cdot 10^9$	$17{,}567 \cdot 10^9$	$18{,}628 \cdot 10^9$
Apr.19	5,159,740	4,821,781	-2,980,251	-3,018,168	$8{,}881 \cdot 10^9$	$9{,}109 \cdot 10^9$	$8{,}994 \cdot 10^9$
May19	6,431,811	5,951,139	-1,708,180	-1,888,810	$2{,}917 \cdot 10^9$	$3{,}567 \cdot 10^9$	$3{,}226 \cdot 10^9$
Jun.19	7,958,490	7,208,312	- 181,501	- 631,637	$32 \cdot 10^9$	$398 \cdot 10^9$	$114 \cdot 10^9$
Jul.19	9,348,926	8,718,916	1,208,935	878,967	$1{,}461 \cdot 10^9$	$772 \cdot 10^9$	$1{,}062 \cdot 10^9$
Aug.19	10,433,128	10,008,692	2,293,136	2,168,743	$5{,}258 \cdot 10^9$	$4{,}703 \cdot 10^9$	$4{,}973 \cdot 10^9$
Sep.19	11,636,261	10,999,538	3,496,270	3,159,589	$12{,}223 \cdot 10^9$	$9{,}983 \cdot 10^9$	$11{,}046 \cdot 10^9$
Oct.19	12,518,762	11,961,802	4,378,771	4,121,853	$19{,}173 \cdot 10^9$	$16{,}989 \cdot 10^9$	$18{,}048 \cdot 10^9$
Nov.19	12,842,105	12,579,643	4,702,113	4,739,694	$22{,}109 \cdot 10^9$	$22{,}464 \cdot 10^9$	$22{,}286 \cdot 10^9$
Dec.19	13,140,690	13,086,092	5,000,698	5,246,143	$25{,}006 \cdot 10^9$	$27{,}522 \cdot 10^9$	$26{,}234 \cdot 10^9$
Jan.20	13,381,458	13,261,567	5,241,467	5,421,618	$27{,}472 \cdot 10^9$	$29{,}393 \cdot 10^9$	$28{,}417 \cdot 10^9$
Feb.20	13,497,680	13,297,704	5,357,689	5,457,755	$28{,}704 \cdot 10^9$	$29{,}787 \cdot 10^9$	$29{,}240 \cdot 10^9$
Mar.20	13,497,680	13,439,365	5,357,689	5,599,416	$28{,}704 \cdot 10^9$	$31{,}353 \cdot 10^9$	$29{,}999 \cdot 10^9$
	8,139,991	7,839,949			$397{,}941 \cdot 10^9$	$389{,}905 \cdot 10^9$	$393{,}449 \cdot 10^9$
	Average					Amount	
						Pearson's r correlation	0.9988

Pearson's correlation coefficient r showed that the planned costs of BCWS and the costs earned of BCWP correlate very strongly. It should be remembered that this correlation does not consist in the relationship between the values of sets x_i and y_i, because, as the analyses using the EVM method have shown, they differ from each other by up to several percent. The coefficient explains that separately in the set x_i and separately in the collection y_i there is a trend that closely correlates with each other (fig. 4). Despite the differences in each accounting period, accruing, the values generated to the planned values grew in a similar, linear way. This observation clearly indicates that the lack of correlation of EVM coefficients may result from incorrect distribution of the value of works over time according to the Construction and Financial Schedule, lack of proper planning of works or delays of the General Contractor in the first phases of the works.

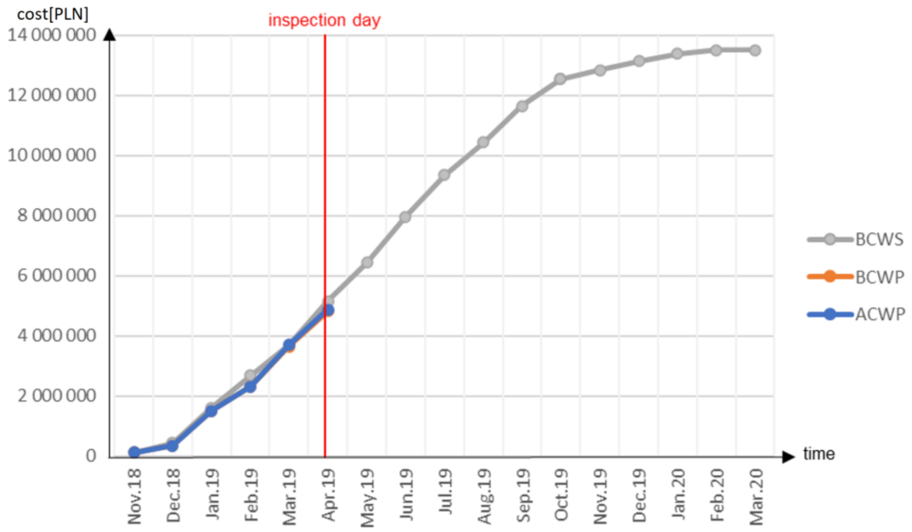

Fig. 4. Upward trend in BCWS and BSWP

3.5. Correlation of eaned value with actual costs incurred

The correlation coefficient was calculated from the formula (12), where x_i - BCWS, y_i - ACWP.

Table 3. Pearson linear correlation - correlation of earned value with the value of costs actually incurred for Residential Buildings X

Date	x_i	y_i	$x_i - x_m$	$y_i - y_m$	$(x_i - x_m)^2$	$(y_i - y_m)^2$	$(x_i - x_m)\cdot(y_i - y_m)$
Nov.18	118,868	118,868	- 8,021,123	- 7,721,081	64,338 · 10^9	59,615 · 10^9	61,931 · 10^9
Dec.18	348,303	348,303	- 7,791,689	- 7,491,646	60,710 · 10^9	56,124 · 10^9	58,372 · 10^9
Jan.19	1,509,380	1,509,380	- 6,630,611	- 6,330,569	43,965 · 10^9	40,076 · 10^9	41,975 · 10^9
Feb.19	2,319,484	2,319,484	- 5,820,507	- 5,520,465	33,878 · 10^9	30,475 · 10^9	32,131 · 10^9
Mar.19	3,648,547	3,695,547	- 4,491,444	- 4,144,402	20,173 · 10^9	17,176 · 10^9	18,614 · 10^9
Apr.19	4,821,781	4,868,781	- 3,318,210	- 2,971,168	1,101 · 10^9	8,827 · 10^9	9,858 · 10^9
May19	5,951,139	6,074,139	- 2,188852	- 1,765,810	4,791 · 10^9	3,118 · 10^9	3,865 · 10^9
Jun.19	7,208,312	7,386,312	- 931,680	- 453,637	868 · 10^9	205 · 10^9	422 · 10^9
Jul.19	8,718,916	8,896,916	578,924	1,056,967	335 · 10^9	1,117 · 10^9	611 · 10^9
Aug.19	10,008,692	10,186,692	1,868,700	2,346,743	3,492 · 10^9	5,507 · 10^9	4,385 · 10^9
Sep.19	10,999,538	11,367,238	2,859,546	3,527,289	8,177 · 10^9	12,441 · 10^9	10,086 · 10^9
Oct.19	11,961,802	12,329,502	3,821,810	4,489,553	14,606 · 10^9	20,156 · 10^9	17,158 · 10^9
Nov.19	12,579,643	12,947,343	4,439,651	5,107,394	19,710 · 10^9	26,085 · 10^9	22,675 · 10^9
Dec.19	13,086,092	13,453,792	4,946,100	5,613,843	24,463 · 10^9	31,515 · 10^9	27,766 · 10^9
Jan.20	13,261,567	13,629,267	5,121,575	5,789,318	26,230 · 10^9	33,516 · 10^9	29,650 · 10^9
Feb.20	13,297,704	13,665,404	5,157,712	5,825,455	26,601 · 10^9	33,935 · 10^9	30,046 · 10^9
Mar.20	13,439,365	13,807,065	5,299,373	5,967,116	28,083 · 10^9	35,606 · 10^9	31,621 · 10^9
	7,839,949	8,035,531			391,435 · 10^9	415,500 · 10^9	401,174 · 10^9
	average					amount	
						Pearson's r correlation	0.9948

At this point, Pearson's correlation coefficient r also showed a linear correlation between values earned and costs actually incurred. The lack of correlation could occur, for example, when the ACWP costs are incurred, but in the absence of generation of earned value of the BCWP. Such a situation may occur, among others: in the event of a breakdown, fire, flooding, fault of third parties. These events generate repair costs but do not generate earned value.

3.6. S-curve and Pearson's linear correlation r

As part of the experience in the course of conducting subsequent analyses and observations, in connection with the knowledge of the period of accumulated construction works quantities, using the Pearson linear correlation, during the flattening period of the S-curve and the available EVM indicators, it was possible to estimate the final cost of the Investment task with greater accuracy in relation to what the EAC indicator itself indicated.

The period of cumulative construction works fell between March and September 2019. The developed method consisted in calculating the weighted average of EAC coefficients (estimated final costs) in the period of cumulative works. The problem that had to be raised was to determine the weight of individual values for a given settlement period.

The SOLVER add-in for Microsoft Excel spreadsheet was used to determine them. This add-on allows you to designate a few unknowns if you want to get the desired result. The determination of weighted averages consisted in:

- statement of the EAC value during the period of cumulative workload;
- defining formulas in a spreadsheet according to the Pearson formula (in the following example, it is cell U10);
- using the SOLVER add-in with defining a goal so that the Pearson coefficient is 1 (full correlation).

After defining the formulas and the SOLVER add-in, the estimated values for September 2019 (S-curve flattening period), which were determined as EAC-S (estimated final cost "S").

Table 4. EAC-S pessimistic – estimated final cost S pessimistic

x_i	y_i	$x_i \cdot y_i$	$\sum y_i$	$x_i - x_m$	$y_i - y_m$	$(x_i - x_m)^2$	$(y_i - y_m)^2$	$(x_i - x_m) \cdot (y_i - y_m)$
13,671,555	1.27	17,415,263.45		- 95,345,74	- 2.82	$9{,}090 \cdot 10^6$	7.95	268,870.33
13,629,248	0.01	173,508.92		- 137,652,92	- 4.08	$18{,}948 \cdot 10^6$	16.66	561,768.78
13,776,654	4.38	60,336,156.66		9,753,57	0.29	$95 \cdot 10^6$	0.081	2,787.68
13,830,988	5.99	82,875,819.30	28.66	64,087,20	1.90	$4{,}107 \cdot 10^6$	3.60	121,653.91
13,773,240	4.28	58,981,567.65		6,339,61	0.19	$40 \cdot 10^6$	0.04	1,195.32
13,737,730	3.23	44,366,395.51		- 29,170,62	- 0.86	$850 \cdot 10^6$	0.75	25,210.83
13,948,890	9.49	132,325,103.46		181,988,91	5.39	$33{,}119 \cdot 10^6$	29.08	981,401.13
13,766,900	4.09				amount	$66{,}252 \cdot 10^6$	58.16	1,962,887.97
x_m	y_m							EAC-S September 2019 = 13,835,398 PLN

Table 5. EAC-S optimistic– estimated final cost S optimistic

x_i	y_i	$x_i \cdot y_i$	$\sum y_i$	$x_i - x_m$	$y_i - y_m$	$(x_i - x_m)^2$	$(y_i - y_m)^2$	$(x_i - x_m) \cdot (y_i - y_m)$
13,544,680	0.40	54,382,68.65		- 222,220.68	- 3.69	$49382 \cdot 10^6$	13.63	820,500.34
13,544,680	0.40	54,373,20.42		- 222,220.68	- 3.69	$49382 \cdot 10^6$	13.63	820,515.90
13,620,680	1.66	226,68,670.32		- 146,220.68	- 2,43	$21380 \cdot 10^6$	5.90	355,243.10
13,675,680	2.58	352,55,777.24	15.93	- 91,220.68	- 1.52	$8321 \cdot 10^6$	2.30	138,271.60
13,675,680	2.58	352,54,143.67		- 91,220.68	- 1.52	$8321 \cdot 10^6$	2.30	138,282.49
13,675,680	2.58	352,63,496.15		- 91,220.68	- 1.52	$8321 \cdot 10^6$	2.30	138,220.11
13,865,380	5.73	794,49,065.66		98,479.32	1.63	$9698 \cdot 10^6$	2.68	161,136.65
13,657,494	2.28				amount	$154806 \cdot 10^6$	42.74	2,572,170.18
x_m	y_m							EAC-S September 2019 = 13,731,560 PLN

Experience has shown that the defined new EAC (estimated final cost) cost analysis (EAC-S) proved to be the most accurate. The disadvantage of the method in this case is its one-time use – only after flattening the S curve.

Table 6. Comparison of EAC (estimated final costs) values with EAC-S (estimated final costs 'S') values

ACTUAL COST	**13,807,065 PLN**	**ESTIMATE**	**DIVERGENCE**
EAC OPTIMISTIC	13,865,380 PLN	58,315 PLN	0.422%
EAC PESIMISTIC	13,948,890 PLN	141,825 PLN	1.027%
EAC-S OPTIMISTIC	13,731,560 PLN	- 75,505 PLN	- 0.547%
EAC-S PESSIMISTIC	13,835,398 PLN	28,333 PLN	0.205%

4. SUMMARY AND DISCUSSION

The analysis of the data sets did not end only with the EVM method. The scope of research also indicated the need to address issues related to deviations and correlation. To this end, applied statistics were used. The determination of the standard deviation and Pearson correlation enabled deepening of research work and interesting, practical inference.

The EVM method, apart from the graphic form of the S curve graph, does not simultaneously take into account three variables in any of its indicators: the value of the Financial Schedule (BCWS), the value of earned (BCWP) and the value of actually incurred costs (ACWP) [25]. By using the standard deviation and its supplementation, i.e. the coefficient of variation, it was possible to determine – expressed as a percentage – to what extent these three values are different from each other in a given accounting period. EVM indicators are a set of seven values that, thanks to mutual confrontation, can illustrate a lot. The deviation expressed in a given percentage directly indicates the differentiation of the works worked out and the costs incurred in relation to the assumptions of the schedule. Applied statistics, of course, determine the range of deviations and indicate what a given value says, but translating theoretical weights into the investment process, individual values could have a completely different meaning. A continuation of this experience could be to determine such critical thresholds, which, using a single value, would trigger an alert about the disturbance of the process.

The Pearson linear correlation coefficient r indicates whether the values correlate with each other. Keep in mind that bias and correlation are two separate issues. The Pearson correlation shows how given values of numbers and their sets behave with each other. The deviation of the numbers may be significant, because they will be definitely different from each other, but their correlation may be close to the full, i.e. approximate to the value of 1, because both values indicate some, the same behaviour, e.g. an upward trend, a downward trend. Although the values of the numbers of one set in relation to the other are of the order of different quantities, the trends prevailing in sets can be much similar to each other.

The cited example indicated that the correlations of individual values did not fall below 0.99. In the analysed case, upward trends were observed in individual values: Financial Schedule (BCWS), costs earned (BCWP), actually incurred costs (ACWP).

The lack of correlation could occur if the costs incurred would not generate the development of the Construction and Financial Schedule. This would be the case, for example, in the case of damage caused by fire, flood and other weather anomalies. Bringing the investment to a proper condition after the destruction would result in significant generation of additional costs (increase in the value of ACWP), and the phenomenon itself could not only stop the increase in the value earned, but would also reduce the BCWP ratio.

It is therefore possible that individual situations arise:

- full correlation, small deviation;
- full correlation, large deviation – correlation of -1. Some values increase significantly, others decrease significantly in a similar, linear way;
- no correlation, large deviation.

A phenomenon that will not occur is the lack of correlation and a small deviation. A small deviation will be associated with a similar behaviour of values in given sets, thus indicating a full correlation.

5. CONCLUSIONS

The aim of the research - the methodology and results of which are presented in the article - was to identify typical scopes of construction works and their inputs in residential construction, and to determine the measures of control of the progress of the investment task in the dimension of constant quality and the variables of cost and time. Deviations were determined and analysed and their impact on the correlation to construction and financial throughput with the basic indicators of the EVM, i.e.: the estimated final cost of projects EAC and correlation with their completion dates ETTC. Additional research attempted to more accurately approximate the final cost of EAC, which was referred to as EAC-S in this study. The obtained results of observations over the entire period of execution of a given project were also analysed in terms of applied statistics issues within the standard deviation and Pearson's r linear correlation.

As the conducted analyses have shown, preparation for the start of the investment process should begin with the preparation of cumulative works – the S curve. The total implementation time of investment X, despite the low PUM ratio (usable area of apartments), was delayed by one month (by 6%), due to delays in the initial stages of construction before the period of cumulative works. An additional reason for not meeting the initial assumptions for Residential Buildings X was the lack of analysis of possible additional costs not directly related to the facility itself. The need to perform works and activities that were not provided for in the Financial Schedule contributed to exceeding the budget by PLN 309,000 (0.23%). In order to avoid delays as well as budget overruns, the S curve should be drawn up as cumulative works before the start of works and accompanying costs should be taken into account.

Pessimistic EAC indicators showed that the alert on exceeding the budget above the assumptions of the Financial Schedule after indexation (PLN 104,985,864) occurred already in December 2019, and in September 2020 the indicator was close to the actual costs of ACWP (PLN 108,257,635). The investor, despite conducting its own analyses, did not manage to predict such significant deviations in relation to the planned budget, because it did not use the EVM method.

Pearson's linear correlation was also used to attempt to optimize and approximate EAC final cost estimates. Such an experiment was performed both for investment X at the moment of flattening of the S curve for cumulative works. Already having a dataset from the period of the excessive curve, using the Microsoft Excel spreadsheet and the Solver add-in, in the case of Residential Buildings X, the result closest to the actual final costs of the ACWP was obtained. The designated indicator overestimated the budget by only 0.205%. Thus, the EAC Estimated Final Cost Index according to the EVM method indicated a value of 0.422%.

The developed indicator, which was tentatively called EAC-S, has a basic disadvantage. It can only be used once, i.e. during the period of flattening of the S curve. It is not possible to assess its accuracy at this stage, due to the insufficient number of tests performed. Both experiences cited once pointed in favour of the developed EAC-S index, the second time in favour of the EAC according to the EVM method.

Focusing on the possible cause of insufficiently reliable values of individual indicators of the Earned Value Method, one can point to:

- preparation of Construction and Financial Schedule,
- incorrect assessment of the progress of works,
- incorrect quantity survey of construction works in a given settlement period.

In the last stage of the research, the focus was on the impact of individual values of deviations of Earned Value Method indicators in relation to the correlation of construction works and their financial amounts. Both deviations and correlations have been discussed before, but an additional statement showed that:

- from the perspective of the calculations themselves, the deviations of EVM indicators were so small that they did not affect the correlation of construction works predictions with financial ones, because these values were close to the value of "1", i.e. close to the full correlation;
- exceeding the budget by 7% (PLN 6,716,175), despite the full correlation of construction works and financial spend, may – but does not have to – indicate a significant budget overrun; the conclusion for this point could be different in the case of a larger budget, a more accurate estimation of the value of price valorisation as in the case of investment X – a more accurate assessment of the works to be carried out;
- exceeding the investment implementation time by 6%, as in the case of investment X, may also – but does not have to – indicate delays; the deviation will be assessed on the basis of the initial assumptions of the Construction and Financial Schedule and critical deadlines

REFERENCES

1. Milat, M Knezić, S and Sedlar, J 2021. Resilient Scheduling as a Response to Uncertainty in Construction Projects. *Applied Sciences* ***11****(11)*, 6493.
2. Plebankiewicz, E Zima, K and Wieczorek, D 2021. Modelling of Time, Cost and Risk of Construction with Using Fuzzy Logic. *Journal of Civil Engineering and Management* ***27***, 412–426.

3. Leśniak, A and Zima, K 2018. Cost Calculation of Construction Projects Including Sustainability Factors Using the Case Based Reasoning (CBR) Method. *Sustainability* **10**, 1608.
4. Gupta, C. and Kumar, C 2020. Study of factors causing cost and time overrun in construction projects. *International Journal of Engineering Research and Technology* **9**, 202–206.
5. Grzyl, B Apollo, M Miszewska-Urbańska, E and Kristowski A 2017. Management of Exploitation in Terms of Life Cycle Costs of Built Structures. *Acta Scientiarum Polonorum Architectura* **16**, 85–89.
6. Połoński, M 2012. Prognozowanie czasu zakończenia inwestycji na podstawie jej bieżącego zaawansowania [Forecasting Civil Structure Duration on the Basis of Progress of Works]. *Metody ilościowe w badaniach ekonomicznych* **13**, 169–179.
7. Przywara, D and Rak, A 2021. Monitoring of Time and Cost Variances of Schedule Using Simple Earned Value Method Indicators. *Applied Sciences* **11**, 1357.
8. Szóstak, M 2023. Best fit of cumulative cost curves at the planning and performed stages of construction projects. *Buildings* **13***(1)*, 13.
9. Al-Naqdi, I Fattah, M 2024. Seismic considerations in case study of kindergarten building design: Ensuring safety and structural integrity. *International Journal of Civil Engineering and Architecture Engineering* **5**(2), 19-26.
10. Abdulaziz, M, Hamood, M, Fattah, J Mohammed, Y and Aal-Azawee, T 2024. Investigating seismic response in adjacent structures: A study on the impact of buildings' orientation and distance considering soil–structure interaction. *Open Engineering* **14**(1), 20220582.
11. Bozejko, W Hejducki, Z and Wodecki, M 2019. Flowshop Scheduling of Construction Processes with Uncertain Parameters. *Archives of Civil and Mechanical Engineering* **19**, 194–204.
12. Fazil, M, Lee, C and Tamyez, P. 2021. Cost estimation performance in the construction projects: A systematic review and future directions. *International Journal of Industrial Management* **11**, 217–234.
13. Project Management Institute 2017. *A Guide to the Project Management Body of Knowledge* (PMBOK Guide) 6th Edition; Project Management Institute (PMI), ISBN 9781935589679.
14. Zin, R Mohamad, M Mansur, S and Tee, D 2008. Guidelines for the preparation and submission of work schedule for construction project. *Malaysian Journal of Civil Engineering* **20**, 145–159.
15. Konior, J 2022. Determining Cost and Time Performance Indexes for Diversified Investment Tasks. *Buildings* **12**, 1198.
16. Rashid, H Al-juboori, O and Mahjoob, A 2021. New cost control techniques in mega construction projects. *Periodicals of Engineering and Natural Sciences (PEN)* **9**, 454–461.
17. Czarnigowska, A 2009.Kontrola postępu realizacji przedsięwzięcia metodą Earned Value [Monitoring of Project Progress Using the Earned Value]. *Przegląd Budowlany* **80**, 50–55.
18. Połoński, M 2015. Kontrola kosztów realizacji obiektu budowlanego Metodą Earned Value [Earned Valule Method for operational cost control of civil structure]. *Inżynieria przedsięwzięć budowlanych: Rekomendowane metody i techniki* **12**(2), 279-290.
19. Kasprowicz, T, Starczyk-Kołbyk, A and Wójcik, R 2022. The Randomized Method of Estimating the Net Present Value of Construction Projects Efficiency. *International Journal of Construction Management* **23**(3), 1-8.
20. Dziadosz, A Kapliński, O and Rejment, M 2014. Użyteczność i zakres stosowania metody Earned Value Management przy realizacji kontraktów budowlanych [Usefulness and Fields of the Application of the Earned Value Management in the Implementation of Construction Projects]. *Budownictwo i Architektura* **13**, 357–364.
21. Project Management Institute, 2017. *A Guide to the Project Management Body of Knowledge* (PMBOK Guide) 6th Edition; Project Management Institute (PMI), ISBN 9781935589679.

22. Stanisz, A 2006. *Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Tom 1. Statystyki podstawowe [Accessible Statistics Course with Application STATISTICA PL on Examples of Medicine. Volume 1. Basic Statistics*], StatSoft Polska Sp. z o.o., Kraków, 2006.
23. Główny Urząd Statystyczny. Available online: https://stat.gov.pl/en/metainformation/glossary/terms-used-in-official-statistics/2912,term.html (accessed on 28/11/2024).
24. Stanisz, A 2007. *Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Tom 3. Analizy wielowymiarowe [Accessible Statistics Course Witk Application STATISTICA PL on Examples of Medicine. Volume 3. Multidimensional Analysis*]. StatSoft Polska Sp. z o.o., Kraków. 2007.
25. Araszkiewicz, K and Bochenek, M 2019. Control of construction projects using the Earned Value Method - case study. *Open Engineering* ***9****(1)*, 186-195.