Multivariate model of construction project operational efficiency

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Abstract. Economic efficiency during the entire life cycle of a property is crucial when making a decision on an investment. The resulting performance indicators are influenced by various underlying factors. The purpose of the study is to determine the degree of the factors influence on the final result. The study considers an apartment building and 50 variants of the project implementation according to the chosen factors, which are construction period, selling price per square meter, discount rate, land plot cost and construction cost of one square meter. The net present value of the project (NPV) and internal rate of return (IRR) were selected as the resulting indicator. When performing the calculations, following method were used: project net present value calculation method (NPV); method for calculating the discounted payback period (PP); method for calculating the internal rate of return (IRR), sensitivity analysis, multiple correlation and regression analysis (multiple regression). We found that the selling price and construction cost of one square meter of the property affect the most on the net present value of the project (NPV). The obtained model can be used by investors to simulate various options for the effective projects implementation in changing environment.

Keywords: project management, sensitivity analysis, NPV, project life cycle, construction management.

1. Introduction
Design is the foundation of the investment and construction complex. Ultimately, the costs of the construction and operation of the property depend on the decisions made at the design stage and this value, distributed over time, represents significant amounts, which are much higher than the design costs [1].

A large number of scientific papers consider such topics as collection and analysis of databases in real time [2, 3], the level of detail at each stage of a construction project [4, 5], methods for integrating information into building information modelling applications for decision making and forecasting [6, 7], stimulating investment in NPV increasing through supply channels [8]. Internet of Things (IoT) technology is associated with continuous data processing to ensure safety at the workplace [9, 10]. Augmented Reality (AR) technologies are used to increase construction productivity [11].

Stiff competition with domestic and foreign companies on the AES market (AES - Architecture Engineering Construction) involves improving the quality of products and services through the introduction of new information modelling technologies (BIM), which will be used as a tool for interconnecting the stages of capital construction project life cycle [12, 13].

The modernization of the construction industry is caused by the need to strengthen traditional sectors of the economy [14], in the construction industry the development of digital technologies takes place in three spheres: market participants integration, efficiency increasing and introduction of innovations [15].

In scientific papers of leading peer-reviewed journals, there is an incomplete disclosure of the topic of the life cycle within the framework of BIM modelling [16, 17], the topic of sustainable development at the operational stage of the project is also not sufficiently disclosed [18,19].

Moreover, in literature sources 3D model of the project called “visualization” is more often mentioned, when the most complete picture can be obtained from the 7D model, “operation” of the
property, which will reveal the most significant factors affecting the performance indicators of the project.

Some authors in their studies pay special attention to project risk management [20, 21]. A positive point in risk assessment is the consideration not of the particular type of risk, but the creation of a "complete picture" of the property construction and operation project [22, 23].

In this regard, we set a goal to determine what factors influence the project performance indicators (NPV) during the construction and operation of a property.

2. Methods

2.1 Development of a project cash flow model for the construction and operation of the considered property

At the first stage, a cash flow model was developed over the 50 years of the life cycle of the project for the construction of an apartment building in Kazan (Russian Federation). At this stage of calculations, the main research methods were[24]:

– project net present value calculation method (NPV);
– method for calculating the discounted payback period (PP);
– method for calculating the internal rate of return (IRR).

This group of methods allows you to study the cash flow of the project, bringing its values to the current point in time. The calculations were carried out using the “Alt-Invest. Construction” software. The NPV criterion is calculated as the difference between the reduced (discounted) - as a rule, at the time of the start of the project - costs of all cash income and expenses for the project according to the following formula:

\[
NPV = \frac{P_{\text{apartments}} \times S_{\text{apartments}}}{(1 + d)^3} - \sum_{t=1}^{2} \frac{I_{\text{construction}}}{(1 + d)^t} + \sum_{t=3}^{50} \frac{C_f_t}{(1 + d)^t} - \sum_{t=3}^{50} \frac{I_t}{(1 + d)^t}
\]

where \(P_{\text{apartments}}\) – the price of apartments selling, \(S_{\text{apartments}}\) – floor area of the apartment, \(I_{\text{construction}}\) – construction costs during two years, \(C_f_t\) – the income of the property management company during \(t\) period of time, \(I_t\) – expenses of the property management company during \(t\) period, \(d\) – discount rate.

NPV is the main criterion of the project efficiency. Theoretically the project is considered feasible if NPV > 0.

IRR is the value of discounting coefficient at which NPV=0. The higher IRR is the more profitable the project is. The difference between IRR and the discount rate reflects the internal efficiency of the project.

Discounted payback period (PP) is the minimum period of time necessary for achieving zero NPV.

2.2 Sensitivity analysis

The sensitivity analysis method allows you to identify significant factors that most affect the outcome of the project and is the basis of the risk forecasting model. Such an analysis is also called one-parameter. As the resulting indicators we selected: NPV, PP, IRR, PI. As the underlying factors we selected:

– selling price;
– period of construction;
– discount rate;
– the cost of the land plot;
– the cost of construction.

During the calculations, the step of the initial factors changing ± 50 % was established. The calculations were carried out using the “Alt-Invest. Construction” software.

2.3. Multiple correlation and regression analysis

The net present value (NPV) indicator was chosen as the resulting indicator. Most researchers prefer this indicator due to the fact that it indicates the amount of future income and it takes into account the
discount rate. In addition, this indicator is the most understandable for an investor, because it determines the profit on investments made, and not the rate of profit receiving, which is shown by the indicator of internal rate of return (IRR). The payback period cannot also be chosen as the resulting indicator, since it does not take into account cash receipts after this period, and this is the factor in which projects can differ significantly.

All factors affecting the net present value of investment and construction projects and other performance indicators are interrelated, they cannot be considered as the sum of isolated influences, therefore, when performing further calculations, we studied the combined effect of the considered 5 factors on the net present value of the project based on modelling of 50 options for the implementation of the project for the construction and operation of an apartment building.

Multiple regression model allows creating and testing the correlation between one resulting variable and several independent factors that influence it. Multiple regressions can be divided into linear and non-linear. The general view of the linear regression model is represented by the formula:

\[ Y = a_0 + a_1 x_1 + \ldots + a_n x_n, \]

where
\[ Y \] – resulting indicator;
\[ a \] – regression parameters (coefficients);
\[ x \] – influencing factors;
\[ n \] – the number of factors in the model.

Factors should be quantifiable, should not contain trends, and should not be interrelated. The coefficients in the model that have the highest values have the greatest impact on the resulting indicator, therefore, they need to be paid the greatest attention. The calculations were carried out using “Statistica” software product.

### 3. Results and Discussion

Each construction project has a number of specific features, so it is unique. As an example, we consider a project of a 17-story residential tower block with offices. The structural system of the building includes a prefabricated monolithic braced reinforced concrete framework, which consists of vertical reinforced concrete columns and flat disks of floors and attic floors rigidly connected with them and roofs. The spatial rigidity of the building framework is provided by the installation of prefabricated reinforced concrete diaphragm plates. The diaphragm plates are joined with columns by means of embedded parts. According to the project the roof is flat, with an internal drain, fused from two layers of rolled roofing and waterproofing material. The ventilation shafts are made of brick, and the elevator shafts are monolithic. The building itself is equipped with two elevators, with carrying capacities of 630 and 400 kg. Stairs in a 17-storey apartment building are designed from prefabricated reinforced concrete in the form of Z-shaped staircase landings.

The planned construction period is 24 months (calculations were performed using the “Adept: Construction Management” software program). The sale of apartments will be carried out at a price of 60.5 thousand roubles per sq. m., office space will be leased at a rate of 600 roubles per sq.m. per month. The source data are presented in Table 1.

| Item number | Indicator name                  | Indicator value |
|-------------|---------------------------------|-----------------|
| 1           | Apartments floor area, sq. m.    | 6325            |
| 2           | Office space floor area, sq. m.  | 710             |
| 3           | Construction cost per sq. m., thousand roubles | 32       |
| 4           | Land plot cost, thousand roubles | 16794           |

The source: facility certificate/space-planning decisions.
When making the calculations, the creation of a property management company for house maintenance during 50 years was taken into account. We assumed that the inflation rate of 4% per annum was adopted unchanged.

The income of the property management company is formed by the apartments’ owners payment of the communal costs and the accumulated sums for major repairs. At the same time, the property management company buys the necessary equipment for cleaning the territory, pays salaries to staff, and carries out disinfection, removal of solid waste, current and major repairs of the building. The priority of the major repairs is determined by the service life of the residential building structural elements (Table 2).

**Table 2. Service life of structural elements of the considered apartment building for major repairs.**

| Item number | Name                  | Service life, years |
|-------------|-----------------------|---------------------|
| 1           | Roofing               | 10                  |
| 2           | Facade                | 30                  |
| 3           | Elevator              | 25                  |
| 4           | Cold water pipelines  | 30                  |
| 5           | Hot water pipelines   | 20                  |
| 6           | Ventilation system    | 7                   |
| 7           | Low-voltage devices   | 20                  |

Source: Building code.

In addition, the costs of renting a land plot during the construction of the house and the costs of maintaining offices were taken into account.

The final performance indicators of the project of the apartment building under consideration at a discount rate of 14% are presented in Table 3.

**Table 3. Performance indicators of the project for the construction and subsequent operation of the apartment building.**

| Item number | Name                             | Value                   |
|-------------|----------------------------------|-------------------------|
| 1           | Net present value of the project (NPV) | 47 452 thousand rub. |
| 2           | Discount payback period (PBP)     | 2.82 years              |
| 3           | Internal rate of return (IRR)     | 28.8%                   |
| 4           | Rate of return of the discounted expenses (PI) | 1.21 times |

Source: calculation tables from a software program “Alt-Invest. Construction” (calculated by the authors)

The authors conducted multiple simulations of the chosen project. The results showed that an increase in the construction time leads to the fact that the period for generating income is delayed in time and investor expenses are growing. If the construction period exceeds 5 years, the project will become ineffective (Figure 1). Reduction in sales prices by 20% is also adverse to the project.
Figure 1. Dependence of NPV on construction period.  
Source: calculated by the authors.

NPV also takes a negative value with an increase in the cost of the land by 5 times, with an increase in the discount rate to 29%, with an increase in construction costs by 30%. The results of the rating assessment of the initial factors by the degree of their influence on the net present value of the project and the internal rate of return for a one-parameter analysis are given in Table 4.

Table 4. Rating assessment of initial factors by the degree of their influence on the net present value and internal rate of return of the project.

| №  | Analysis factors name (X)       | Changing X, % | Result value | Result changing | Elasticity | Rating |
|----|---------------------------------|---------------|--------------|-----------------|------------|--------|
| 1  | Price                           | +50           | 171 097      | -260            | +5.2       | 2.28   | 1 1    |
| 2  | Construction time               | +50           | 34 766       | -27             | -22        | +0.54  | -0.44  | 4 3    |
| 3  | Discount rate                   | +50           | 22 193       | -53             | 0          | -1.06  | 0      | 3 5    |
| 4  | Land value                      | +50           | 40 771       | -14             | -7         | -0.28  | -0.14  | 5 4    |
| 5  | Construction cost               | +50           | -33 408      | -170            | -74        | -3.4   | -1.48  | 2 2    |

Source: calculated by the authors.

The calculations in Table 4 show that the most significant factors affecting project performance indicators in a one-parameter sensitivity analysis are the selling price and construction cost.

One-parameter analysis shows the dependence of NPV when changing each factor individually. However, all factors in a volatile external environment change simultaneously, it means that the resulting indicators for the project are, as a rule, determined by a large number of simultaneously acting factors. In this regard, there appears a problem of studying the dependence of the resulting variable Y on several explanatory factors simultaneously $X_1, X_2, \ldots, X_n$.

We chose the same factors: construction period (years) $X_1$, selling price per square meter (thousand roubles) $X_2$, discount rate (%) $X_3$, land plot cost (thousand roubles) $X_4$ and construction cost per square meters (thousand roubles) $X_5$. The resulting variable Y is NPV (thousand roubles).

To obtain correct model results, it is necessary to determine the minimum sample size, which depends on the number of factors included in the model taking into account the free term. The minimum sample size for obtaining a statistically significant model can be determined by the formula:

$$N_{\min} = 5(m+n),$$  \hspace{1cm} (3)
where
m – the number of factors included into the model;
n – the number of free terms in the equation.
For our research \( N_{mn} = 5 \cdot (5+1) = 30 \), and to develop a multivariate model, 50 project implementation options were used Table 5.

### Table 5. Options for the implementation of an apartment building.

| №  | Construction time, year | Operation period, year | Price, thousand rub. | Discount rate, % | Land plot cost, thousand rub. | Construction cost, thousand rub. | NPV, thousand rub. | PP, year | IRR, % | PI |
|----|------------------------|------------------------|----------------------|------------------|--------------------------------|---------------------------------|-------------------|---------|-------|----|
| 1  | 2                      | 48                     | 50                   | 10               | 13 435                         | 24                              | 69 171             | 2.72    | 35.7  | 1.35 |
| 2  | 2                      | 48                     | 53                   | 11               | 14 275                         | 25                              | 70 282             | 2.72    | 36.8  | 1.38 |
| 3  | 2                      | 48                     | 57                   | 12               | 15 114                         | 27                              | 69 924             | 2.73    | 36.5  | 1.35 |
| 4  | 2                      | 48                     | 59                   | 13               | 15 954                         | 30                              | 57 057             | 2.79    | 31.6  | 1.26 |
| 5  | 2                      | 48                     | 60.5                 | 14               | 16 794                         | 32                              | 47 452             | 2.82    | 28.8  | 1.21 |
| 6  | 2                      | 48                     | 45                   | 8                | 12 595                         | 20                              | 80 175             | 2.66    | 41    | 1.49 |
| 7  | 2                      | 48                     | 48                   | 9                | 13 435                         | 24                              | 66 110             | 2.74    | 32.8  | 1.36 |
| 8  | 2                      | 48                     | 52                   | 10               | 14 275                         | 25                              | 71 002             | 2.72    | 35.4  | 1.37 |
| 9  | 2                      | 48                     | 55                   | 11               | 15 114                         | 27                              | 66 944             | 2.74    | 33.9  | 1.33 |
| 10 | 2                      | 48                     | 62                   | 10               | 12 595                         | 25                              | 110 409            | 2.61    | 49.4  | 1.57 |
| 11 | 2                      | 48                     | 63                   | 11               | 13 435                         | 27                              | 98 206             | 2.66    | 44.5  | 1.48 |
| 12 | 2                      | 48                     | 65                   | 12               | 14 275                         | 31                              | 79 755             | 2.73    | 36.6  | 1.35 |
| 13 | 2                      | 48                     | 70                   | 13               | 15 114                         | 32                              | 87 295             | 2.71    | 39.6  | 1.38 |
| 14 | 2                      | 48                     | 72                   | 14               | 15 954                         | 34                              | 78 780             | 2.74    | 37.2  | 1.32 |
| 15 | 2                      | 48                     | 75                   | 15               | 17 200                         | 35                              | 78 472             | 2.75    | 37.9  | 1.32 |
| 16 | 3                      | 47                     | 50                   | 10               | 13 435                         | 24                              | 56 394             | 3.74    | 25.8  | 1.31 |
| 17 | 3                      | 47                     | 53                   | 11               | 14 275                         | 25                              | 56 070             | 3.75    | 26.6  | 1.3  |
| 18 | 3                      | 47                     | 57                   | 12               | 15 114                         | 27                              | 54 050             | 3.76    | 26.4  | 1.28 |
| 19 | 3                      | 47                     | 59                   | 13               | 15 954                         | 30                              | 40 133             | 3.82    | 23.1  | 1.19 |
| 20 | 3                      | 47                     | 60.5                 | 14               | 16 794                         | 32                              | 34 766             | 3.85    | 22.4  | 1.16 |
| 21 | 4                      | 46                     | 50                   | 10               | 13 435                         | 24                              | 56 048             | 4.76    | 22.5  | 1.32 |
| 22 | 4                      | 46                     | 53                   | 11               | 14 275                         | 25                              | 54 050             | 4.76    | 23    | 1.31 |
| 23 | 4                      | 46                     | 57                   | 12               | 15 114                         | 27                              | 50 208             | 4.78    | 22.8  | 1.27 |
| 24 | 4                      | 46                     | 59                   | 13               | 15 954                         | 30                              | 35 099             | 4.85    | 20.2  | 1.18 |
| 25 | 4                      | 46                     | 60.5                 | 14               | 16 794                         | 32                              | 20 649             | 4.9     | 18.2  | 1.1  |
| 26 | 5                      | 45                     | 50                   | 10               | 13 435                         | 24                              | 45 822             | 5.79    | 18.6  | 1.26 |
| 27 | 5                      | 45                     | 53                   | 11               | 14 275                         | 25                              | 42 607             | 5.8     | 19    | 1.24 |
| 28 | 5                      | 45                     | 57                   | 12               | 15 114                         | 27                              | 37 426             | 5.83    | 18.9  | 1.2  |
| 29 | 5                      | 45                     | 59                   | 13               | 15 954                         | 30                              | 21 582             | 5.9     | 16.8  | 1.11 |
| 30 | 5                      | 45                     | 60.5                 | 14               | 16 794                         | 32                              | 10 150             | 5.94    | 15.8  | 1.05 |
Due to the fact that the selected factors have different units of measurement, it is necessary to normalize them. Normalization of the data makes it possible to reduce all the numerical values used to dimensionless quantities, which allows bringing them together in one model. To perform data normalization, it is necessary to know the limits of change in the values of the corresponding variables, that is, the maximum and minimum theoretically possible values. In our case, it is impossible to establish the exact limits of the variables, therefore they were set taking into account the act limits of the variables, therefore they were set taking into account the

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The transition from traditional units of measurement to normalized ones using the linear normalization method is carried out according to the following formula:

$$X_{ik} = \frac{x_{ik} - x_{min}}{x_{max} - x_{min}}$$

(4)

where

- $X_{ik}$ – normalized value of a variable;
- $x_{ik}$ – the value of the variable from the sample;
- $x_{min}$ – minimum value from the sample;
- $x_{max}$ – maximum value from the sample.

For a project for the construction and operation of an apartment building, the multivariate model took the following form:

$$y = 0.842 - 0.582 X_1 + 1.026 X_2 - 0.31 X_3 - 0.069 X_4 - 0.845 X_5$$

(5)

The results showed that the NPV is most affected by the selling price and the construction cost per one square meter of the property.
To assess the accuracy of the model and the strength of relationship between the resulting variable and the factors included in the model, a multiple correlation coefficient was calculated. The formula for multiple correlation coefficient calculating is the following:

\[ R = \sqrt{1 - \frac{S^2_{res}}{S^2_y}} \]  

(6)

where

- \( S^2_{res} \) – residual sum of squares for the equation \( y = f(x_1, x_2, \ldots, x_n) \);
- \( S^2_y \) – total sum of squares of the resulting feature.

The result obtained in our case represents 0.983, which indicates a strong relationship and accuracy of the model.

In addition to this coefficient, the determination coefficient \( R^2 \) was calculated, which shows the proportion of variation in the resulting variable explained by the variation of factor attributes. \( R^2 = 0.97 \), i.e. 97% of the changes in the resulting variable are due to the selected factors, and only 3% are explained by factors not considered in the model.

4 Conclusions

Risk identification and analysis are very important for the successful management of investment and construction projects throughout the life cycle.

The analysis made it possible to identify the main risk factors of the project, evaluate them and form the basis for developing a response strategy.

Simulation modelling conducted in the course of the study showed how a possible increase in the period and cost of construction, discount rates, the cost of the land plot, and a drop in the selling price can affect the overall financial stability of the project.

The results obtained indicate that the greatest influence on the NPV indicator is exerted by the selling price per square meter, for which the coefficient value in the model is the highest 1.026. In second place was a factor of the cost of construction per square meter. The performed regression analysis will allow you to make optimal management decisions by identifying priority causes that affect the final indicator.

Future research will allow the development of risk response strategies during the construction and operation of facilities.

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