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Model of investment appraisal of high-rise construction with account of cost of land resources

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Abstract. The article considers problems and potential of high-rise construction as a global urbanization. The results of theoretical and practical studies on the appraisal of investments in high-rise construction are provided. High-rise construction has a number of apparent upsides in modern terms of development of megapolises and primarily it is economically efficient. Amid serious lack of construction sites, skyscrapers successfully deal with the need of manufacturing, office and living premises. Nevertheless, there are plenty issues, which are related with high-rise construction, and only thorough scrutiny of them allow to estimate the real economic efficiency of this branch. The article focuses on the question of economic efficiency of high-rise construction. The suggested model allows adjusting the parameters of a facility under construction, setting the tone for market value as well as the coefficient for appreciation of the construction net cost, that depends on the number of storey's, in the form of function or discrete values.

1 Introduction

At present moment, special attention is paid to high-rise construction, as the most promising from the point of view of rational use of land resources, the introduction of new construction technologies, the creation of a modern image of cities. High-rise construction is revving up around the world, what is due not only to the high degree of urbanization, population growth, the deficiency of suitable territories for construction in many countries of the world, but also to the desire to make cities more modern, original, comfortable, and creative, using the latest innovative solutions and technologies in the field of construction.

At the very beginning of its development, high-rise construction took into account, mainly, a lack of land resources, what is a common problem for many countries. Nowadays, not only the shortage of land forces architects and builders to begin a kind of "vertical race". This is a tribute to the modern architectural fashion, the desire to modernize the cityscape, to make them comfortable for living and working.

Each high-rise building is an intellectual product. Its construction should be approached in a comprehensive way: innovative architectural and planning solutions must be supplemented with modern engineering infrastructure, which provides the best solution for creating a reliable, safe, comfortable building, allowing its owner to achieve maximum economic efficiency.

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A lot of scientists, including Russian ones: Alferov V.I., Balabanov I.T., Graboviy P.G., Panibratov Y. P., Maklakova T.G., Schukina N.M. - and their foreign colleagues: J. Friedman, N. Ordway, Pham H.X. studied the construction of high-rise buildings, its economic efficiency and relevance. So, there were stated main principles and methods of high-rise design, considered the questions of energy efficiency, complex security, fire protection, supervision over the facility and advanced building technologies and materials [1].

In the work of Pham H. X. "Innovative methods for evaluating the effectiveness of design solutions in the field of high-rise construction" [2], methods for appraising the economic efficiency of design solutions for the implementation of high-rise buildings are considered.

Despite the diversity of aspects of assessing the prospects for the development of high-rise construction in various countries of the world, the problem, in our view, is not sufficiently covered. In connection with the foregoing, the aim of the work is to review and analyze the factors, that determine the prospects for high-rise construction in various countries, evaluate the negative factors as project risks, and calculate the optimal number of storeys of the building in terms of maximum economic efficiency.

The solution of this task starts with an analysis of the process of high-rise construction in the aggregate of interrelated problems, and the break down of factors, that determine the trends and growth rates of high-rise construction as a modern global strategy for the construction industry. Moreover, the risks that accompany the erection and subsequent operation of high-rise buildings should be estimated.

2 Materials and Methods

The theoretical methods of research, which are used in the work, are presented by theoretical analysis and generalization of the scientific literature, as well as by studying the world experience in high-rise construction. The process of investment appraisal of the construction of a high-rise building can be classified as methods of experimental and theoretical level.

High-rise buildings are complex architectural and engineering structures. The problem in this case is not only a significant rise in the cost of construction. It is necessary to take into account many factors, for example, geographical ones. As it is known, there are many seismically active zones on the Earth, on the territory of which the erection of buildings, even of standard storeys, requires additional expenses to use constructional solutions that increase the seismic resistance of buildings. Another problem of operating high-rise buildings is the wind load. Therefore, various complex architectural forms are used, based on the larger size of the building's footing relative to its top. In addition, construction of high-rise buildings must take into account the architectural landscape of the adjacent territories from the point of view of their insolation [3].

The issue of the subsequent operation of the high-rise building also requires attention. First of all, complex utility systems are used in this type of buildings, which are necessary to run the building and ensure its functionality. Unfortunately, this also leads to a significant increase in the cost of the facility.

The increase in the cost of high-rise buildings should be compensated by the use of high-tech materials and structures, modern technologies for erecting buildings and organizing production. It is the systematic approach to the construction of high-rise buildings that makes it possible to assert that this branch is the most promising to develop not only in the countries with limited land resources, but also in the countries where this issue is not so burning.

High-rise construction allows increasing the economic impact from the sale of the object manyfold by increasing the total area of the building while reducing the costs of allocating (purchasing) a land plot for construction. At the same time, high-rise construction has many problems. It is possible to single out the positive factors that determine the profitability of the project, and negative factors that affect the growth of costs during its construction and operation [4].

Table 1. Factors that determine the efficiency of constructing high-rise buildings

Positive factors	Negative factors
Social	
Housing (residential construction)	Architectural and aesthetic assimilation (the need to harmonize high-rise buildings with old and historic ones)
The growth of retail, office and other type of spaces (construction of commercial real estate)	Excessive urbanization of the country
Increase in the number of jobs	Labor migration from other sectors of the national economy
Comfortable housing and high quality residential and commercial property	Increase in social differentiation
Change to the modern cityscape, reaching the world standards	
Dynamic development of the construction industry and related fields	
Economic	
Reducing the cost of purchasing land for construction	Shift in consumer preferences and decrease in consumer demand
Growth of the investor's income due to upgraded amenities of buildings, modern equipment, high quality of service, etc.	The level of income of the population, consumption possibilities
Attracting foreign investment, increasing capital inflows into the country	Increase in costs when erecting high-rise buildings
Development of intraeconomic relationships with other industries	Increase in the cost of sites for construction
Development of urban infrastructure	
Technological	
Use of modern technologies in construction	Complicated to construct
Modern building materials	Complex engineering support and subsequent maintenance and operation
Development and implementation of innovative technologies in construction, including buildings engineering	Use of sturdier structures
Geographical	
Rational use of land resources	Possible landscape change due to the industrial development of the country
Environmental	
Use of new technologies for treatment plants and waste processing	Worsen of the environment situation due to the growth of manufactures, decrease in natural areas and recreational zones, decrease in insolation of adjacent territories.

The complexity of high-rise construction, due to the need for large capital investments, has led to a specific form of construction organization.

The objective of initiators of such projects is a deep analysis and comparison of costs for the construction of a complex high-rise facility with the results of economic profitability from its operation. The next step to solve the problem is to construct a model for calculating the optimal height of a high-rise object from the point of view of its economic efficiency.

The cost of land resources determines the architectural and planning decisions in many ways. The issue to appraise the economic efficiency of an investor when constructing high-rise buildings and their subsequent implementation remains one of the most urgent in modern urban planning. To date, there is no universal algorithm that allows to solve with certain accuracy the issue of the optimal number of storeys and the height of the building [5].

The main objective of the investor is to solve the economic problem of finding the balance between saving the cost of acquiring land for construction, the possibility to utilize a larger number of areas on the one hand, and the cost of construction of high-rise buildings on the other hand. The increase in the cost of constructing a high-rise facility is due to the use of high-strength structures, taking into account wind effect and seismic resistance in some countries. In addition, the complexity of creating utility systems in high-rise buildings is many times more expensive than creating the same systems in buildings of low and medium height. The analysis of the factors that allow assessing the strengths and weaknesses of the construction of high-rise buildings is presented in Table 2.

Table 2. Economic impact and additional expenses.

Positive economic impact	Additional expenses
Reduction of the building area, saving of land resources, reduction of costs to acquire a land plot for construction	Increase in the cost of design works
Reduction of perimeter of load-bearing wall structures	Creation of more complex utility systems, lift maintenance
Reduction of costs for roofing and materials	Use of high-strength structures
Reduction of material costs for the floor structures	Complexity of installation, use of lifting machines and mechanisms, supply of materials and products
Localization of utility systems (water supply, heating, sewerage), minimization of expences for urban utility systems	Strengthening the load-bearing structures and foundation of buildings
Increase in the amount of sold area	Complexity to supply energy resources to the upper floors of the building

In order for the investor to assess the efficiency of investments in high-rise construction, it is necessary to determine which factors will have a greater impact on the financial result of the project. For this purpose, a model has been developed that makes it possible to evaluate the economic efficiency of investments in the construction of a high-rise building [6].

Assume the cost of a small storey building be equal to:

$$C_1 = S_1 \times n_1 \times z_1 , \quad (1)$$

where S_1 is the area of the 1st floor of a low-rise building, m^2; n_1 is the number of floors of a low-rise building; z_1 is the primecost of 1 m^2.

The cost of a high-rise building will be:

$$C_2 = S_2 \times n_2 \times z_2 , \quad (2)$$

where S_2 is the area of the 1st floor of a multi-storey building, m^2; n_2 is the number of floors of a multi-storey building; z_2 is the primecost of 1 m^2.

Assume the total area of buildings is the same, that is:

$$S_{total} = S_1 \times n_1 = S_2 \times n_2 = const \Rightarrow \frac{S_1}{S_2} = \frac{n_2}{n_1}, \tag{3}$$

The area of the land plot intended for building is reduced in proportion to the increase in the number of storeys of the building. Consider the cost of a land plot for two construction options.

$$L_1 = S_1 \times l, \quad L_2 = S_2 \times l, \tag{4}$$

where L_1 and L_2 are the cost to acquire land for construction for low-rise buildings and high-rise ones, respectively; l is the price of 1m2 of a land plot.

The coefficient of savings on land allocation is proportional to the growth of the number of storeys (provided the total area of the building is constant) and is equal to:

$$m = \frac{L_1}{L_2} = \frac{S_1}{S_2} = \frac{n_2}{n_1}. \tag{5}$$

It should be taken into account that the primecost of 1 m^2 increases due to the use of high-strength structures, construction of utility systems, the complexity of installation works, etc. with increasing the number of storeys of the building. Consequently,

$$z_2 = kz_1, \tag{6}$$

where k is the coefficient of increase in the cost of construction with the increase in the number of storeys.

The total project expenses function is defined as following:

$$y(x) = l(x) + z(x) + r(x), \tag{7}$$

where l is the cost of purchasing a land plot, which is intended for building, \$/m^2; z is construction primecost, \$/m^2; r are expenses to neutralize risks, \$; x is the number of storeys.

The function of total project expenses is shown in Figure 1.

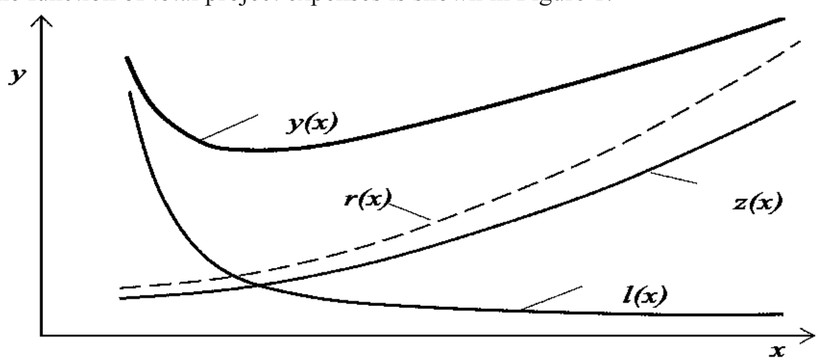

Fig. 1. Graphic definition of total expenses.

3 Results

The work of the model at a real high-rise facility is presented as the results of the study. As an example, the construction of a 35-storey building with certain parameters of the area, height of the building, the primecost of construction, selling price is considered. The initial data is the following:

- number of floors is 35;

- the area of one floor is 1500 m^2 (therefore, the total area of the building is 52.5 thousand m^2);
- Construction primecost of 1 m^2 is 650 $/$m^2$;
- selling price of 1 m^2 is 1800 $/$m^2$;
- coefficient of increase in price of construction is $k = 1.03$.

The coefficient of increase in price k according to the calculated data represents an exponential dependence of the form $k = 0{,}9707e^{\,0{,}0296\,n}$, where n is the number of floors (Fig. 2).

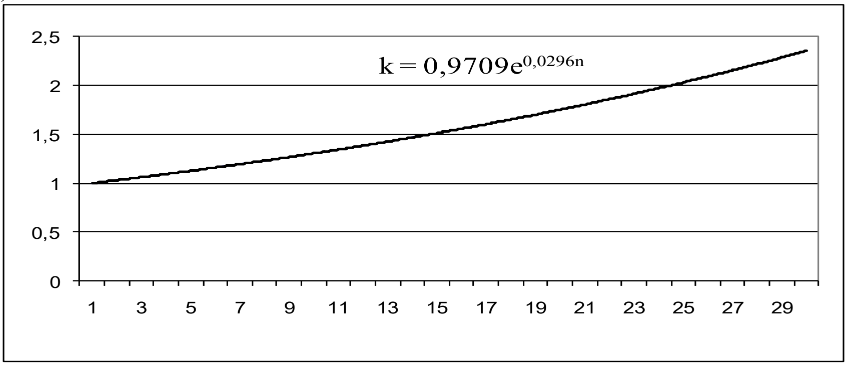

Fig. 2. Dynamics of the coefficient of increase in the primecost of construction, depending on the number of storeys of the building

Define the economic impact from the accomplishment of the building (Table 3).

Table 3. Calculation of economic efficiency from the accomplishment of a multi-storey facility depending on the number of storeys

Coefficient of increase in price of structures	Number of storeys	Primecost, thousand $	Revenue, thousand $	Profit, thousand $
1	1	975.0	2700	1725.0
1.06	2	2070.6	5400	3329.4
1.09	3	3200.5	8100	4899.5
1.13	4	4397.2	10800	6402.8
1.16	5	5663.9	13500	7836.1
1.20	6	7003.7	16200	9196.3
1.23	7	8419.9	18900	10480.1
1.27	8	9915.7	21600	11684.3
1.31	9	1149.9	24300	12805.1
1.35	10	13161.1	27000	13838.9
1.39	11	14918.1	29700	14781.9
1.43	12	16770.0	32400	15630.0
1.48	13	18720.7	35100	16379.3
1.52	14	20774.8	37800	17025.2
1.57	15	22936.6	40500	17563.4
1.62	16	25210.8	43200	17989.2
1.67	17	27602.2	45900	18297.8
1.72	18	30115.9	48600	18484.1
1.77	19	32757.1	51300	18542.9

Coefficient of increase in price of structures	Number of storeys	Primecost, thousand $	Revenue, thousand $	Profit, thousand $
1.82	20	35531.3	54000	18468.7
1.88	21	38444.1	56700	18255.9
1.93	22	41501.3	59400	17898.7
1.99	23	44709.1	62100	17390.9
2.05	24	48073.7	64800	16726.3
2.12	25	51601.9	67500	15898.1
2.18	26	55300.3	70200	14899.7
2.25	27	59176.2	72900	13723.8
2.32	28	63236.8	75600	12363.2
2.39	29	67489.9	78300	10810.1
2.46	30	71943.4	81000	9056.6
2.53	31	76605.5	83700	7094.5
2.61	32	81484.9	86400	4915.1
2.69	33	86590.5	89100	2509.5
2.77	34	91931.4	91800	-131.4
2.86	35	97517.3	94500	-3017.3

The profit graph is shown in Figure 3.

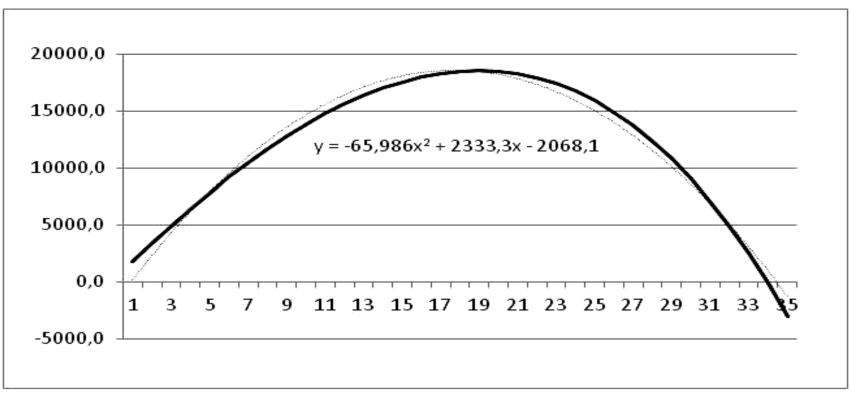

Fig. 3. The profit graph from the accomplishemnt of the facility depending on the number of storeys

Graphic interpretation of the model allows to visually evaluate the optimal number of floors. The maximum possible profit is achieved under the given conditions if the number of storeys is 19. For a more accurate calculation, the profit function should be scrutinized, which is approximated by a second-order polynomial [7]. The first-order derivative of the function, which is represented in the graph, will be the following:

$$y' = -131{,}97x + 2333{,}3$$

The optimal number of floors $x \approx 18$ is obtained by equating the first derivative to zero and solving the resulting equation, i.e. the construction of an 18-storey building under the given conditions will bring the developer maximum profit. Further increase in the number of storeys will gradually reduce the profitability of the project. Profit is almost zero at $x \approx 34$, further increase in the number of storeys can run up the expenses on the project so drastically, that they will exceed the revenue from the sale of the facility.

Dynamics of the k coefficient in further studies showed that the efficiency of increasing the number of storeys of the building is not infinite, and has a limit (Fig. 4).

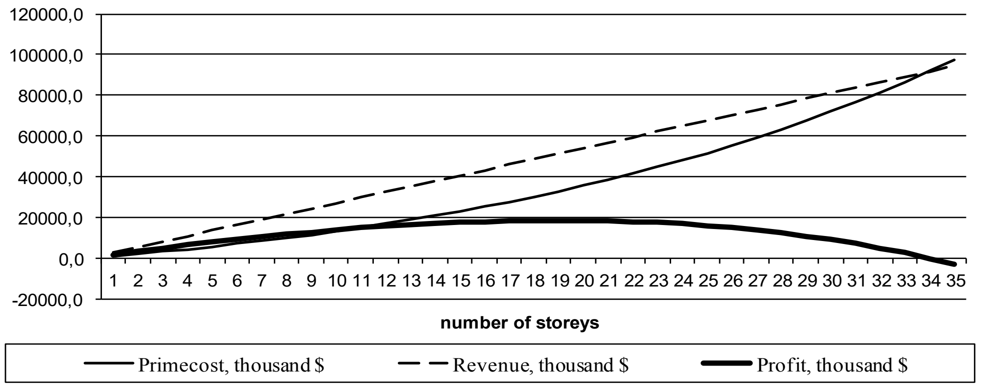

Fig.4. Graphic definition of the optimal number of storeys and the maximum profit for the investor.

Based on the preformed calculations, the optimal number of storeys of the building can be determined, which will bring the maximum profit to the investor. In this example (Figure 4), profit reaches its maximum value with an 18-storey structure. This point can be called the point of the optimal number of storeys for given parameters S_1 and S_2, as well as the dynamics of growth of the coefficient of primecost increase, which was determined by calculation.

4 Discussions

It is hard to call a building of 18 floors high-rise, but in this case it was required to prove the work of the model on some illustrative example. Verification of the model allows to conclude that it can be applied on a real and larger project. The suggested model allows to construct various options of architectural solutions, while linking them into a single mechanism with economic solutions [8, 9].

The considered example does not take into account the possibility of appreciation of the market value of 1m^2 of the area of a high-rise building, that is built with the use of new technologies and materials and has modern architecture, engineering, comfort of living, etc. In this case, the revenues from the accomplishment of this facility can significantly increase, especially from the sale of commercial space located on the first floor of the building. But at the same time, expenses will grow.

The suggested model allows to adjust all parameters and set, for example, the dynamics of the market value of 1m^2 or the coefficient of increase in the construction primecost, depending on the number of storeys, either in the form of functional dependence or in the form of discrete values.

For example, the coefficient of increase in primecost, depending on the number of storeys, is given by an exponential dependence of the form $k=e^{0,03n}$, where n is the number of storeys. Whereas, the cost of selling residential and commercial spaces of the facility increases depending on the design and comfort of the building, as well as depending on the number of storeys.

Assume that the real estate market appraisal showed the following results of appreciation of 1m^2 depending on the prestige, architecture, safficiency of the utility infrastructure and other factors: the market value of 1m^2 of the building of 10-14 floors is increased by 5%; 15-19 floors - by 10%; 20-24 floors - by 15%; 25-30 floors - by 20%. For the practical implementation of the model, both functional dependencies and discrete values can be used.

5 Conclusion

The model allows combining the architectural and cost characteristics of a building into a single system, consider the real estate market conditions, and also allows evaluating the investment project of high-rise construction for the inclusion of modern smart control systems of climate, energy resources and other elements of comfort, since the market value of such an facility is growing drastically.

Factors of increasing and descreasing character for more accurate appraisal of efficiency of high-rise construction are considered and systematized. Especially important in efficiency appraising are descreasing factors, which are defined as project risks.

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