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FORMATION OF A CUMULATIVE MODEL FOR MANAGING THE VALUE OF CONSTRUCTION PROJECTS

O. Bugrov
PhD, Associate Professor*
E-mail: bugrov.oleksandr@gmail.com
O. Bugrova
PhD, Associate Professor*
Department of economic theory
National University of Kyiv-Mohyla Academy
Skovorody str., 2, Kyiv, Ukraine, 04070
E-mail: bugrova.olena@gmail.com
*Department of project management
Kyiv National University of Construction and Architecture
Povitroflotsky ave., 31, Kyiv, Ukraine, 03037

Запропоновано комплексну модель управління будівельними проектами, яка в когерентний спосіб сприяє створенню далекоглядної, збалансованої цінності. Ця концепція представлена у вигляді «кристалу» кумулятивного застосування трьох пар методів. Перша синергетична пара – інжиніринг вартості та цифрова модель будівництва. Друга – аналіз «вигоди-витрати» і теорія динаміки цінності проекту. Третя – профілювання контрактних систем і стратегії ціноутворення

Ключові слова: управління проектами, інжиніринг, архітектура, збалансована цінність, синергетичний ефект, прийняття рішень

Предложена комплексная модель управления строительными проектами, которая когерентно способствует созданию дальновидной, сбалансированной ценности. Эта концепция представлена в виде «кристалла» кумулятивного применения трёх пар методов. Первая синергетическая пара – инжиниринг стоимости и цифровая модель строительства. Вторая – анализ «выгоды-затраты» и теория динамики ценности проекта. Третья – профилирование контрактных систем и стратегии ценообразования

Ключевые слова: управление проектами, инжиниринг, архитектура, сбалансированная ценность, синергетический эффект, принятие решений

1. Introduction

The mental structure "*Live and let others live*" has been popular for a long time. However, it is acquiring a special sense under current conditions. Over recent time, the theory and practice of project management have been actively improved in line with the modern requirements to the development of socio-economic systems. The most urgent global challenges include such issues as the need for reducing greenhouse gas emissions and increasing power efficiency of meeting social needs. In addition, the task of creation and implementation of forward-looking strategies for achieving optimal value throughout a whole range of consecutive project cycles is becoming increasingly important. This task is closely linked to the development of technologies for innovative solutions to engineering problems.

Thus, today it is more important than ever that projects should comply with the principles of optimal expediency by the vector of sustainable development in harmony with nature. People are responsible for what "living" environment they will leave to their descendants – upcoming generations. At the same time, investment and construction projects in various sectors of socio-economic reality is exactly the area where scientific-practical answers to these challenges can be most thoroughly and reliably worked out.

Formulation of a comprehensive model to solve these tasks in the process of project preparation and implementation is a scientific problem. In this case, it is important that such a model is not complicated and cumbersome, because it would be impractical to use otherwise. In addition, the model should not be amorphous, it must acquire a complete and distinct form.

2. Literature review and problem statement

In accordance with the concept of knowledge economy, development implies active application of creative technologies, which provide breakthroughs in production competitiveness [1]. This statement may be supplemented by the fact that it is related not only to the sphere of industry, but rather to the entire socio-economic system.

Under modern conditions, knowledge is becoming a major factor of competitive advantages. Sustainability of development largely depends on the system of knowledge in terms of the impact of innovations on the results of projects and programs [2].

A fundamental feature of modern approaches is the emphasis on project cycle management and a key role of investors in the entire diversity of projects' stakeholders. There are arguments that modern economy and construction management are of explicit program-targeted, project character. This sphere concerns not only the industry and contracting businesses, but also investors as economic activity entities. In this case, projects should be monitored throughout their entire life cycle [3].

Studies also pay attention to shortcomings that occur in the practice of construction management in Ukraine. Thus, for example, it is indicated that the current regulatory-estimating base and documentation solve the tasks on determining predictive cost of construction, without integrating it properly into the overall system of data and knowledge about a project. However, effective project management requires a whole range of inter-related project information. And though the construction stages, launch complexes, their costs, etc. are determined, it is not sufficient for actual successful management. Building Information Modeling (BIM) is the modern technology that must be actively implemented to achieve the appropriate level of competitiveness [4].

Advanced international practice has come to focus on actual integrated management of construction projects. In particular, all leading developers of building systems of design automation announced their support for BIM technology in their products. Each of these systems enables third-party developers to seamlessly and conveniently create their subsystems for determining construction costs and construction management in appropriate environments [5].

Attention is also focused on other important aspects of modern project management, in particular in the context of activization of creativity and development of processes of project participants' interaction. The basic concept in the field of revitalization of creativity is methodology of value engineering [6]. The development of models of interaction between construction project participants was revealed in [7] (construction organization systems) and [8] (integrated project implementation).

The task of creating optimal value as a result of project engineering and management was developed in many studies. In particular, in paper [9], it is proposed to tackle all consecutive stages of project preparation with the methodology of value management, however, this study applies only to the prediction and control of construction costs.

In article [10], it is highlighted that the methodology of value management has a positive impact not only on project costs and quality, but also on the environment. The specified publication proposes a good example of how value management and stable (sustainable) development are interrelated, though it does not provide a comprehensive concept for solving this global problem.

Study [11] proposes to consider building information modeling (BIM) in a combination with behavior of the project stakeholders. This, the authors of the specified work argue, defines prospects for projects' improvement. However, the model, proposed in [11], focuses only on the interests of the end-user of a building and does not include other basic aspects of project management.

Research [12] provides a model of the project process, which aims to enhance the project value through a properly organized procedure. This model may somewhat strengthen and enhance the potential of engineering activity; however, it is over- simplified.

In paper [13], it is shown that the integration of methodology of value management and the software PRIMAVERA yields a positive effect. Nevertheless, we will note that this concept involved only one pair "method–tool" for project improvement.

The studies also revealed that success of a construction project depends on the level of quality of systems, information and services [14]. Along with this, these studies were limited only to the issues of information systems. The fact that a system can be associated with the decision-making algorithm, information – with BIM, and service – with the contract models of project implementation, was not indicated.

Thus, certain issues in the creation of appropriate value by construction projects have already been explored by modern science.

On the other hand, there are some integrated methodologies, recognized in the world, which are the comprehensive frameworks of expertise on projects and programs management, particularly PMBOK [15] and P2M [16]. There are also approaches that are based on the combined use of a whole range of such integrated methodologies in a particular project. In this case, the structure of the package of methodologies, recommended for application, is specific for each stage of the project cycle [17]. At the same time, it is time to focus attention of scientific community on the relevance of development of cumulative "sectoral" methodologies for innovative project management, which are concentrated on the creation of forward-looking values. Their architecture is to be maximally effective, practical, clear, and convenient.

Thus, a "niche" in the research into cumulative, synergetic systems for creating a sustainable value of projects (a layer between individual methods and global methodologies) remains unfilled.

3. The aim and objectives of the study

The aim of present work is to formulate a scientifically-substantiated cumulative method, appropriate for practical application, to manage the creation of maximally rational values in the framework of preparation and implementation of construction projects.

To accomplish the given goal, the following tasks were set:

– to identify key principles that will underlie such a cumulative model;

– to propose a general structure and "architecture" for the cumulative concept of managing the creation of maximally rational values;

– to show possibilities to improve results in the construction projects' management under conditions of practical application of the proposed model.

4. Formulation of requirements to the created cumulative concept

The cumulative model for creating maximally rational values by the construction projects has to be based on the following key principles:

– correspondence of projects' missions and their implementation to the strategies for sustainable socio-economic development;

– emphasis on the application of preventive management measures, creative technologies and innovative solutions;

– vision of value creation not only over the entire project cycle, but also the project's place in a range (network) of inter-related project cycles;

– observance of the philosophy of "non-predator" competition by all project participants in the atmosphere of transparency, openness and cooperation;

– consideration by the value architecture of each project of interests of all stakeholders, including next generations;

– integration into a single system of appropriate, not excessive, number of related modern techniques that not only do not conflict with each other, but produce a synergistic effect instead.

Speaking about a general architecture of such a cumulative model, it should be noted that it has to take into account or to be based on:

– vision of changes in projects' values within project cycles;

– reliable mechanisms of interaction between projects' participants;

– search for technical innovation, solutions of inventive problems, ways of preventive responses to challenges;

– interests of stakeholders with appropriate distribution (or integration) of compensation, liability and risks;

– efficient exchange of relevant information between projects' participants;

– reasonable social costs for creating projects.

5. Structure and components of the proposed cumulative concept

The concept, proposed to solve the specified comprehensive task, is the model "Crystal" for creative management of the created rational project value. Originally, this idea was put forth in [18], highlighting the cumulative model in the frontal plane. Here it should be noted that the virtual "Crystal" of value creation management, similar to all physical crystals, is anisotropic. In line with this property, the proposed model is clearly aimed at achieving the balanced maximally appropriate value by the project.

We will start a three-dimensional examination of this model with coverage of a short list of methods that, to the greatest extent, cumulatively affect created rational project value and are, in their origin, modern creative products of knowledge economy (Fig. 1). Certainly, there are plenty of such products – technologies of influence on the actual value of results of investment and construction projects. However, the model should include only those that have the greatest impact and, create synergy, when applied in an integrated way. This effect by its nature adds to a project more innovative benefit than the rest of the methods, which are formally left outside the model.

The first problem we face is the number of methods that are appropriate to incorporate in such cumulative system. As it is known from fundamentals of management, it is difficult for a person to manage if the number of subjects or objects of management exceeds 7. This figure, by the way, is grounded in the method of hierarchy analysis of Saaty as the upper limit of the assessment scale of alternatives [19]. However, even 7 is already found in the risk zone, provided that the scope of management concerns creativity or innovations. On the other hand, the more coherent elements are in the system, the greater probability that they collectively will cover the entire mental plane. Thus, we can assume that the most expedient number of the created cumulative system is 6.

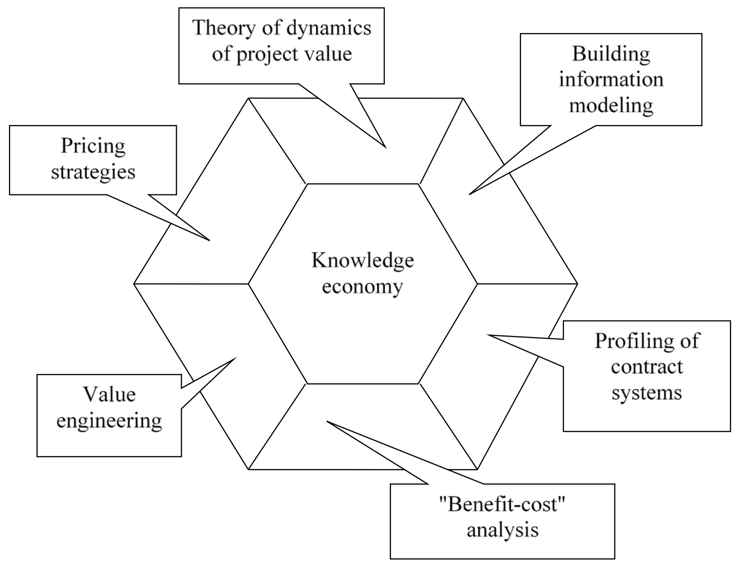


Fig. 1. "Crystal" of cumulative concept of management of value of investment-construction projects (upper side)

Based on the above general requirements to the cumulative model of management of value creation by construction projects, we can offer to include to the structure of the system the following elements (Fig. 1):

– theory of dynamics of project value, which brings in ability to feel and react to changes in balanced efficiency in real time mode;

– building information model (BIM), which provides information ability to create and implement the project comprehensively and then service the site in a predictable and appropriate way;

– profiling of contract systems, which provides the most useful interaction between projects' participants;

– "benefits-costs" analysis, which directs a project towards reasonable and pragmatic interests of investors and society;

– value engineering that puts a project on the most expedient path;

– pricing strategies, which provide determining of justified (reasonable) public expenditures on projects' implementation.

These elements act both jointly, and in pairs, enhancing reliability and credibility of making engineering and management decisions. In the visual image of the Crystal model (Fig. 1), elements (faces) of each such pair are located opposite each other:

– the first pair: "benefits-costs" analysis and the theory of dynamics of project value;

– the second pair: value engineering and building information model;

– the third pair: profiling of contract systems and pricing strategies.

Thus, every element of the system functionally supports and backs up the other methods, decreasing risks and increasing favorable opportunities for creation of the optimal project values by “back-to-back” principle. In other words, general principles of crystal symmetry place appropriate faces-methods in a mirror way, enhancing their reliability and accuracy of obtained results.

The above elements, according to existing terminology of cutting, along with a “platform” of the Crystal (which is knowledge economy in our case), make its “crown”. In the visual model (Fig. 2, 3), the faces of so-called ‘pavilion”, which show the role of each method in the proposed concept, are located below these items. These faces converge in “spike”, which reflects the cumulative result of application of the system.

5. 1. The front side of the “Crystal”

Now we will briefly describe each of the key elements (components) of the proposed system. As part of this, first look at the “Crystal” of the cumulative concept of value management from the front side (Fig. 2).

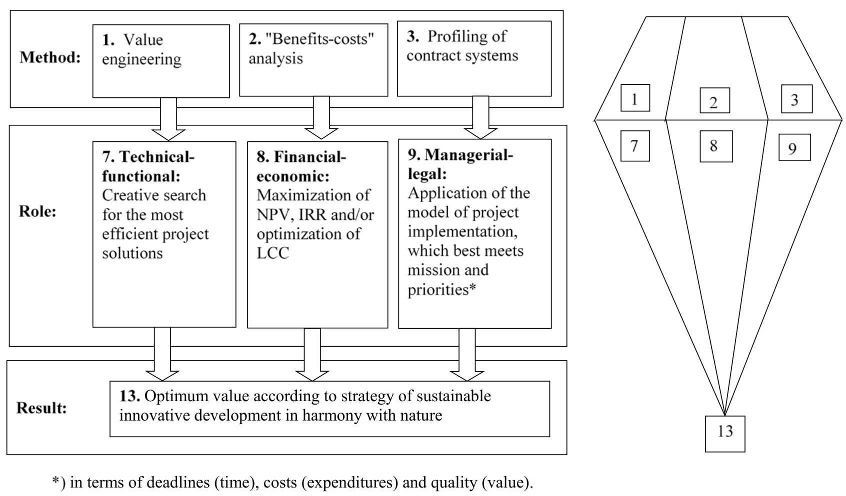


Fig. 2. “Crystal” of cumulative concept of value management of investment and construction projects (front side)

As we can see, the proposed approach in a comprehensive way considers a project in different planes.

5. 1. 1. Project value engineering

This element is a methodological means of creative search for the most logical and effective technical, architectural, and design solutions by a project team. The procedure, on which value engineering is based, is the following, if defined in general terms. First, a project team analyzes expected basic and secondary functions (requirements) of the created site. Then, alternative ways of meeting these requirements (at the level, acceptable for a consumer) are identified. Identified alternatives are evaluated and best of them are proposed for implementation.

This methodology in investment construction projects can be applied at any stages: creation of conceptual design, opportunities exploration (feasibility study), draft project (or TEO), working project, working documents, choice contractor, and construction. In addition, it can be applied several times – at two or more stages of the project cycle [6].

5. 1. 2. “Benefits-costs” analysis

This component of the system is the method for rational representation/calculation of the project cash flow and its integrated financial and economic evaluation. Correctly determined prediction of project cash flow within its life cycle makes it possible to assess reliably each of available alternatives from natural financial-economic positions of investors and society. Evaluation is carried out taking into account time value of money, which adequately reflects risks and the “threshold” level of acceptable interest for respective beneficiaries.

Therefore, “benefits-costs” analysis in the proposed system plays inherent financial-economic role. Thanks to this method, a project is aimed in the direction of expedient maximizing of Net Present Value (NPV), Internal Rate of Return (IRR), etc. and/or optimization of Life Cycle Costs (LCC).

5. 1. 3. Profiling of contracts

Profiling of contract systems on a certain project allows us to select and apply in it optimal economic and legal procedures of interaction between a customer, a contractor and a designer (as well as other participants).

Balanced distribution of such aspects as reward, responsibility and risks between key construction project participants is established with the help of market systems of organization of contract relationships “customer – designer – contractor”. In the world practice there are six “characteristic” types of such systems [7]:

– contracts with a number of contractors;

– traditional scheme;

– contract of construction management;

– phased development;

– design and construction model (including “turn-key”);

– project management (multi-profile scheme).

However, these systems – market institutional mechanisms, the obvious usefulness of which was proved by time and practice, – function as organizational-legal means of cooperation of “natural business antagonists”. These methods balance the business space on the vector of “intrest removal force” of commercial project partners: rights and obligations of the contract parties get balanced. To activate possibilities of interaction improvement on the vector of “gravity, interests merging” of a customer, designers, contractor and other participants, the world practice proposed approaches of Integrated Project Delivery (IPD). These innovative approaches can be applied as a separate method of projects delivery or within any of the above market systems. Along with this, IPD approaches in some of the aforementioned systems can have more profound and significant penetration than in the others [8].

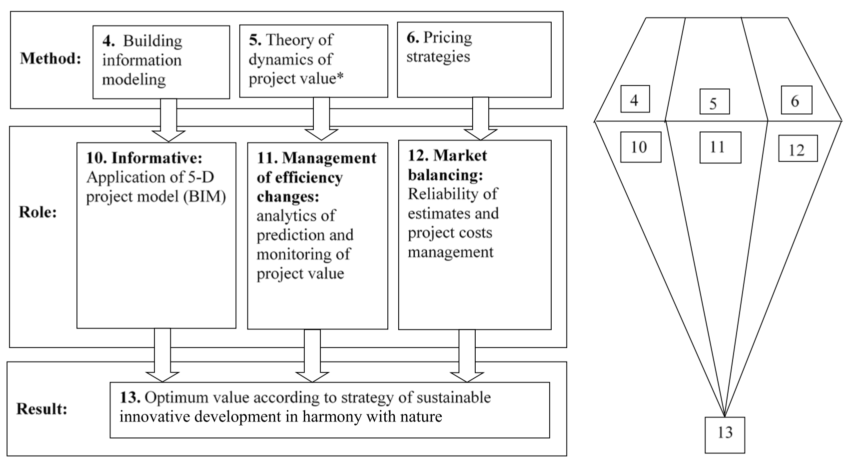
5. 2. The back side of “Crystal”

Now we will consider the back side of “Crystal”, focusing primarily on the role of the other three methods (Fig. 3).

The methods that make up this side of the proposed system, in a synergistic way are related with respective methods of the front side of "Crystal".

5. 2. 1. Building information modeling

The specified element acts as an instrument for visualization and information support for the system of management of the value creation process. This interactive tool is able to incorporate not only a three-dimensional structure of the building and physical-technical data about its elements (at all appropriate levels of aggregation, including both small details and a project as a whole). The model also includes necessary performance specifications and regulations, knowledge of soils, construction site and engineering networks. In addition, the BIM covers estimation and pricing information, digital project of building organization, calendar and resource schedule of a site's construction.



*) by stages of project value chain.

Fig. 3. "Crystal" of cumulative concept of management of value of investment and construction projects (back side)

Therefore, it is a modern information base for making the most expedient decisions throughout the entire project cycle, from consideration of an idea and a concept to knocking down a construction site.

5. 2. 2. Theory of dynamics of project value

This component allows systematic monitoring, analysis and prediction of changes in all three constituent elements (benefits, costs, time value of money) of the formula of Net Present Value (NPV). Analysis can also be carried out by other integral indicators of effectiveness, values throughout the entire project cycle. A construction project section by section (stage by stage) acquires its economic value, refining three aforementioned elements. The risk of an investment project covers two components: amount of funds, which run the risk, and uncertainty in terms of project cash flow. During transition of a construction project from phase to phase (sections), both of the specified components of risk change, which inevitably influences project effectiveness. This approach, methodological fundamentals and principles of which are cited in [20], makes it possible to manage project efficiency in its dynamics.

5. 2. 3. Pyramid of pricing strategies

This component of the model provides a project team with a toolkit for selecting a model of estimates preparation and project costs management, which is the most expedient for it (taking into account its type, scope, mission and priorities of a initiator/investors). There are five fundamental models. Three models out of five act primarily as alternative methods of measuring the costs of executed work. The higher the accuracy of project documentation, the greater portion of project financial risks can be reasonably taken by a contractor and the greater are reasonable estimate elements for costs determining and monitoring by a customer. This principle distinguishes the following main mechanisms of determining of contract prices: (1) compensation of contractor's costs with paying adequate compensation to him, (2) payment according to measured volumes of work, and (3) payment of determined complex sums.

An additional principle of specificity of pricing mechanisms is the following. Application of "threshold" values of construction price in contracts with consolidated forms of defining the volumes of work, executed by a contractor, are a riskier mechanism for him than in contracts with compensation of his costs, which are calculated for small elements. This additional principle adds two more key mechanisms to the basic classification: (4) target costs and (5) guaranteed maximum price.

5. 3. Substantiation of the model

The proposed system is characterized by the fact that due to its convenient coherence, it sets the influence of its separate methods (items) on the project value in a cumulative manner. Thanks to this, a synergistic effect is pronounced. This property of the model allows reaching high value results provided there is integration relative to a small number of methods/tools (there are six of them in the proposed model "Crystal"). This, in turn, makes the system practical in use. Such statement correlates with certain findings of the American Institute of Architects (AIA) [8].

Based on fundamental principles of the method of hierarchy analysis of T. Saaty [19], we will formalize the mechanism of impact of application of "Crystal" model on the project value. To begin with, we will state that a simple sum of project improvement potentials of six aforementioned elements, taken separately, does not allow us to maximize project value:

$$\sum_{i=1}^{6} Pe_i < 1, \qquad (1)$$

where Pe_i is the potential of impact of element i on project value.

Thus, this sum does not cover the entire field of possibilities of enhancement of functional characteristics of a construction site and reduction of project costs (it is less than a unit).

Along with this, integrated application of each pair of elements produces its synergy. Thus, the project improvement potential increases, however, it still does not reach maximum:

$$\sum_{i=1}^{6} Pe_i < k_1 \cdot \sum_{i=1}^{2} Pe_i + k_2 \cdot \sum_{i=3}^{4} Pe_i + k_3 \cdot \sum_{i=5}^{6} Pe_i < 1, \qquad (2)$$

where $\sum_{i=1}^{2} Pe_i$ is the potential of impact of the first pair of elements ("benefits – costs" analysis and theory of dynamics of project value) on project value; k_1 is the synergy coefficient of the first pair of elements; $\sum_{i=3}^{4} Pe_i$ is the potential of impact of the second pair of elements (value engineering and building information model) on project value; k_2 is the synergy coefficient of the second pair of elements; $\sum_{i=5}^{6} Pe_i$ is the potential of impact of the third pair of elements (profiling of contract systems and pricing strategies) on project value; k_3 is the synergy coefficient of the third pair of elements.

The cumulative model integrates all its elements, due to which the system synergistic effect is activated:

$$\left(k_1 \cdot \sum_{i=1}^{2} Pe_i + k_2 \cdot \sum_{i=3}^{4} Pe_i + k_3 \cdot \sum_{i=5}^{6} Pe_i\right) \cdot k_4 = 1, \tag{3}$$

k_4 is the synergy coefficient of the system as a whole.

As we see, the cumulative model as a whole provides an opportunity to demonstrate full potential of construction project improvement.

Now we will illustrate how the synergy model "Crystal" works, for example, in projects of construction of office complexes. The data, shown in Table 1, are calculated based on information of the best practices and expert polls.

Table 1

Assessment of potential of impact of model "Crystal" on value of the project of office complex construction

Components (methods)	Potential of impact of method on project value	Synergy coefficient of pair	Potential of impact of pair on project value	Synergy coefficient of the system as a whole	Cumulative potential of impact of the model on project value
Value engineering	0.171	–	–	–	–
Building information modeling	0.195	–	–	–	–
Total impact of pair	0.366	1.061	0.388	–	–
«Benefits – costs» analysis	0.145	–	–	–	–
Theory of dynamics of project value	0.127	–	–	–	–
Total impact of pair	0.272	1.051	0.286	–	–
Profiling of contract systems	0.134	–	–	–	–
Pricing strategies	0.113	–	–	–	–
Total impact of pair	0.247	1.043	0.258	–	–
Total impact of three pairs	0.885	–	0.932	1.073	1.000

Here it should be noted that for projects of construction of other types of sites (not office complexes), distribution of potential of impact on value will differ from the data shown in Table 1.

6. Results of application of the proposed concept

Let us consider results of application of the proposed approach on the example of the project of construction of an office-multifunctional center next to the international city airport. The results of this study got numeric representation with the use of a mathematical model that relies on:

– systematized procedures on rational decision making [21];

– procedure of calculation of usefulness vector by the method of hierarchy analysis [19];

– determining of value according to methodology of structural-functional analysis [6];

– principles of balanced scorecard (BS) [22].

Factors (criteria) of assessment of alternatives on usefulness vector, like BS, in this project were united in four groups (nodes of hierarchy of functional analysis):

– eco-safety, which directs a project to harmony with nature and proper technical-organizational reliability;

– architectural-spatial, which aims a project to optimum planning-design solutions;

– power-technical, which enhances engineering characteristics of a project;

– organizational-economic, which improves quality of business processes throughout a project's life cycle.

These factors of project improvement are put into action primarily with the use of such elements of the aforementioned model "Crystal" as value engineering and building information model, as well as profiling of contract systems. A subset of priorities of project usefulness by four above mentioned groups of factors is a numerical basis for comparative analysis of alternatives of project delivery.

Given the wealth of expertise of such companies as NOBLE GIBBONS (United States of America), COLLIERS INTERNATIONAL (Canada), Jones Lang LaSalle (United Kingdom) etc. in the field of characteristics of office buildings, the correspondent elements were included in each of the mentioned groups. Thus, for example:

– application of "green" technologies, modern fire prevention system; 24-hour security of the building, a reliable system of video surveillance, etc. are factors of eco-safety assessment group;

– architectural significance of a building; proper height of floors, their efficient lay-out decisions; reliability of structures and their appropriate load; rational arrangement of windows and lighting, etc. are factors of architectural-spatial evaluation group;

– high-quality heating, ventilation and air conditioning system, which allows adjustment of characteristics of the air in each separate building block, ability of the system to consistently maintain temperature in comfortable limits, comfortable high-speed elevators, etc. are factors of engineering assessment group;

– generation of new jobs; the most appropriate system of project implementation; reasonable mechanism of pricing for design and construction of a site facility; optimal business processes of the created office center, etc. are factors of organizational-economic assessment group.

The list of criteria – characteristics of a building also included other elements, each of which entered its own group. All the criteria and groups of the analytical hierarchy were ranked. Thus, a set of priorities of project usefulness was formed:

$$\left.\begin{bmatrix} \{a_{1,n}\}, \\ \{b_{1,k}\}, \\ \{c_{1,h}\}, \\ \{d_{1,p}\} \end{bmatrix}\right\} = v_c, \tag{4}$$

where $\{a_{1,n}\}$ is the subset of ranks of eco-safety factors from 1 to n; $\{b_{1,k}\}$ is the subset of ranks of architectural-spatial factors from 1 to k; $\{c_{1,h}\}$ is the subset of ranks of energy-technical factors from 1 to h; $\{d_{1,p}\}$ is the subset of ranks of organizational-economic factors from 1 to p; v_c is the set of priorities of factors of assessment of project usefulness.

The project has undergone four iterations of value engineering, which were carried out one by one at certain intervals (on average six weeks). Each of these successive design alternatives was ranked by all factors of the balanced usefulness of a construction site and the aforementioned groups. Thus, the rating of each design alternatives was mathematically formalized as:

$$\left.\begin{bmatrix} \{A^{\beta}_{1,n}\}, \\ \{B^{\beta}_{1,k}\}, \\ \{C^{\beta}_{1,h}\}, \\ \{D^{\beta}_{1,p}\} \end{bmatrix}\right\} = R^{\beta}, \tag{5}$$

where $\{A^{\beta}_{1,n}\}$ is the subset of ratings of project alternative β by eco-safety factors from 1 to n; $\{B^{\beta}_{1,k}\}$ is the subset of ratings of project alternative β by architectural-spatial factors from 1 to k; $\{C^{\beta}_{1,h}\}$ is the subset of ratings of project alternative β by energy-technical factors from 1 to h; $\{D^{\beta}_{1,p}\}$ is the subset of ratings of project alternative β by organizational-economic factors from 1 to p; R^{β} is the set of ratings of usefulness of project alternative β.

By multiplying ranks by appropriate ratings, each developed alternative received a comprehensive hierarchical evaluation of its usefulness:

$$\left.\begin{bmatrix} \{a_{1,n}\}\cdot\{A^{\beta}_{1,n}\}, \\ \{b_{1,k}\}\cdot\{B^{\beta}_{1,k}\}, \\ \{c_{1,h}\}\cdot\{C^{\beta}_{1,h}\}, \\ \{d_{1,p}\}\cdot\{D^{\beta}_{1,p}\} \end{bmatrix}\right\} = K^{\beta}, \tag{6}$$

where K^{β} is the set of project usefulness by alternative β.

In compliance with the procedure of the method of hierarchy analysis [19], a table of project usefulness by the developed alternatives was calculated (Table 2).

Based on the above, the summary table of comparative analysis of consumer characteristics (usefulness) of developed alternatives was calculated (Table 3).

Table 2

Project usefulness for developed alternatives

Indicators	Usefulness factors (by groups)				Total
	a	b	c	d	
Rank of group	0.225	0.263	0.270	0.242	1.000
Rating of alternative 1	0.1878	0.1912	0.1871	0.2130	–
Usefulness of alternative 1*	0.0423	0.0503	0.0505	0.0515	**0.1946**
Rating of alternative 2	0.2629	0.2509	0.2529	0.2561	–
Usefulness of alternative 2*	0.0592	0.0660	0.0683	0.0620	**0.2554**
Rating of alternative 3	0.2762	0.2767	0.2790	0.2639	–
Usefulness of alternative 3*	0.0621	0.0728	0.0753	0.0639	**0.2741**
Rating of alternative 4	0.2731	0.2812	0.2810	0.2670	–
Usefulness of alternative 4*	0.0614	0.0740	0.0759	0.0646	0.2759

*Notes: a – eco-safety; b – architectural-spatial; c – energy-technical; d – organizational-economic; * – calculated from formula 6 as product of multiplication of rank of the group by rating of the correspondent alternative*

The data, shown in this table, illustrate how step by step project usefulness increased from the initial conceptual design (alternative 1) to the most appropriate design solution (alternative 4). In this case, design solutions were formed using the proposed cumulative model of value management.

Table 3

Improvement of consumer usefulness of project of office center construction throughout a range of successive sessions of application of the cumulative model of value management

Successive steps of value engineering	Comparative assessment of usefulness of alternatives *	Increment in usefulness compared with previous stage	Increase in usefulness in % of total increment
Alternative 1	0.1946	–	–
Alternative 2	0.2554	0.0608	74.78
Alternative 3	0.2741	0.0187	23.00
Alternative 4	0.2759	0.0018	2.21
Total	1.0000	0.0813	–

*Note: * – taken from respective cells of column 6 in Table 2*

As Table 2 shows, project usefulness at the second stage of value engineering increased by 74.78 % of its total improvement, and at the fourth stage – only by 2.21 %. This indicates that during these four sessions, the project with the help of the proposed methodology "Crystal" closely approached its maximum usefulness. In other words, it was possible to realize almost to the full the potential of improvement of consumer characteristics of the construction site within iterations, it passed through.

Thus, Table 2 reflects dynamics of changes in project usefulness in the course of its balanced engineering improvement. In addition, these alternatives were compared by vector of costs, which were measured by the indicator of Discounted Costs of Life Cycle (DLCC). Here, it is also necessary to emphasize that DLCC takes into account time value of money, which, in turn, reflects project risks. This cumulative factor of project improvement is activated with the use of such elements of model "Crystal" as "benefits – costs" analysis and the theory of dynamics of project value, as well as selection of a pricing strategy.

According to both [6] and [19], value is calculated as a quotient of:

$$V = \frac{K^{\beta}}{c_d}, \tag{7}$$

where K^{β} is the functional project usefulness; c_d is the costs of project implementation.

Thus, based on the above formulas and approaches, we calculated changes in project values due to four sessions of application of the proposed cumulative concept (Table 4).

Table 4

Enhancement of the project value of office center construction over a range of successive sessions of application of the cumulative model "Crystal"

Successive steps of value engineering	Discounted costs of project cycle, mln USD	Ratio of alternatives by costs of project cycle*	Project value**	Value increment compared with previous stage	Value increase in % of total increment
Alternative 1	349.512	0.2617	0.7436	–	–
Alternative 2	334.821	0.2507	1.0187	0.2751	70.40 %
Alternative 3	326.407	0.2444	1.1215	0.1028	26.29 %
Alternative 4	324.805	0.2432	1.1345	0.0129	3.31 %
Total	1335.546	1.0000	–	0.3909	–

*Notes: * – calculated as a quotient of division of column 2 by the sum of column 2 in Table 4; ** – calculated from formula 7 as a quotient of division of column 2 in Table 3 by column 2 in Table 4*

Here we observe a certain similarity to dynamics of indicators in Table 2. As Table 3 shows, project value at the second stage of the procedure increased by 70.40 % of its overall improvement, and at the fourth – only by 3.31 %. This leads to the conclusion that within four conducted sessions, with the help of the proposed methodology "Crystal", the project closely approached its maximum value.

7. Discussion of results of research into properties of the proposed model

The proposed concept is focused primarily on holistically organized architectural, technical, economic, information and environmental engineering of an implemented project. Systematically combined "key" methods cumulatively contribute to the fact that when making project decisions, a whole range of factors of project usefulness and interests of all stakeholders are taken into account in a balanced way. This model is not cumbersome and difficult to use. Thanks to its functional multi-vector structure, the system enhances potential of environmental protection, of optimization of pricing in construction, rationalization of life cycle costs, improvement of operation characteristics of capital construction sites, etc.

The synergy, which is a basic feature of the proposed cumulative value-oriented model, provides availability of two characteristics in this system at the same time: full coverage of project tasks that are being solved and convenient compactness. This is the main advantage of the Crystal model of value management, for example, compared with P2M [16], which is a comprehensive framework of knowledge on projects and programs management, but not formed in a compact way. Compared to Value Engineering (VE) [6], the Crystal model offers the opportunity not only to find the optimum of functional-cost solutions more effectively, but also to manage a project throughout the life cycle.

Key priority of the cumulative model is preventive reaction to potential problems in the course of project management. In modern alternative concepts, such as the P2M and VE, preventiveness also exists, but it is not expressed so explicitly there.

A disadvantage of the cumulative Crystal model of value creation management is the limited scope of application. Since one of the components of the complex model is VIM, this methodology can be applied only in construction projects. In addition, for the same reason, the proposed approach is economically justifiable to apply only for large projects (or series of similar projects).

It is advisable to develop this study in the following directions:

– development of numerical model of selection of the method of project implementation (which can be recognized as the most appropriate under certain conditions);

– formalizing of mechanism for evaluation of engineering quality of business processes of a customer of real estate construction;

– formation of unified specialized Crystal models for construction projects of various types (power, agricultural, residential, etc.);

– testing of these models on pilot projects and development of recommendations regarding adaptation of resulting instruments for specific conditions of other projects of respective types.

8. Conclusions

1. Key principles of construction of the model of cumulative management of value creation of a construction project are determined according to major contemporary challenges. In this way, the model is set to: preventative management, compliance with strategies for sustainable development, application of creative technologies and innovative solutions, simulation of complete project cycle, taking into account the project place in portfolio or program, effective interaction of all project participants, taking into account interests of all stakeholders, synergetic integration of management methods.

2. The structure of such cumulative concept is composed of six interacting methods: building information model, profiling of contract systems, "benefit-costs" analysis, value engineering, pricing strategies, theory of dynamics of project value. The architecture of this system in the form of Crystal emphasizes its cumulative purposefulness and anticipated synergetic effect. Characteristics of each component of the proposed system prove its own feasibility and application efficiency. Each element of the proposed model, playing its natural role, complements its other components in a coherent and effective way. The place of each element in the total system of management of creation of rational values is determined according to synergy nodes of three pairs of methods.

Thus, application of appropriate methods both in pairs and jointly reduces risks and enhances opportunities for creation of optimum project value.

3. Testing of the proposed model proves its potential of positive impact on results of management of construction projects. Dynamics of usefulness and value of the project of office center construction was calculated for a range of several consecutive sessions of model application, it was shown that quality of project result almost reached its maximum. It demonstrates feasibility of further research in this direction and expansion of a range of projects for model testing.

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