The use of a virtual building design and construction model for developing an effective project concept in 5D environment

Vladimir Popov a, Virgaudas Juocevicius a, Darius Migilinskas a, Leonas Ustinovichius a,⁎, Saulius Mikalauskas b

a Vilnius Gediminas Technical University, Civil Engineering Faculty, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
b “Statybu ekonominiai skaičiavimai” Joint-stock Company, Ateities g. 9-524, LT-08304 Vilnius, Lithuania

Abstract

The growing diversity of disciplines, participants, tasks, tools and events associated with project management at the design and construction stages, the increasing pressure of costing competition and tighter production deadlines, as well as continually increasing quality requirements and the need for technological enhancements, are the driving force of information modeling and numerical simulation in the construction industry. When choosing the most effective investment project in construction, a major problem associated with the actual demand for resources is underestimated. In order to solve this problem in the most effective way, the application programs, covering virtually every phase of the specific construction product development, e.g. planning, design, cost estimation, scheduling, fabrication, construction, maintenance and facility management were developed and supplemented with the calculation of the demand for resources, comparison of alternatives and determination of the duration of all the stages of the project life. Theoretical principles and practical innovative applications of building information modeling and construction process simulation technique, used to determine the most effective alternative of the project by applying the appropriate multiple criteria evaluation methods, are considered in the article.

1. Introduction

The construction process is influenced by many factors. This applies to all the stages and parameters (e.g. development, infrastructure, execution time, the resources required, etc.) of the investment construction project being implemented. Efforts are made to determine the influence of these factors by making some calculations and databases, and using both statistical and expert-provided data. In calculation, it is assumed that some parts of the considered project or even the entire project are similar to the previously developed construction projects. However, these assumptions provide a biased view of the actual parameters of the completed project.

There are numerous research reports dealing with the analysis of construction projects from various perspectives [1], attempting to describe the specific features of the structure, the application and adequacy of the alternative solutions [2] and the main principles of their implementation. However, researchers tend to underestimate the problems of adequacy and precision of the evaluation data as well as the reliability of particular engineering methods and their application [3]. The present paper analyzes the application of efficiency criteria, determination of values and their precision.

The application of a 4D (four-dimensional) concept model to the project management [4] will also be described. We can define a traditional construction project analyzed from the beginning of its development to the end as a model (Fig. 1). The model is comprised of stages, in which the above-mentioned participants perform the particular actions (shown as blocks). The information collected at a particular stage is transferred to the next stage, but the data collected in this way are often not suitable and should be changed in order to implement the most effective project alternative. The cells marked in the model represent two blocks: the upper block is a model of the construction project developed and assessed by architects and designers — Design Block (architectural and technical drawings of the project, 3D models) [5,6]; the lower block represents the construction works performed by a contractor — Construction Block.

It is evident that, in this model, there is no interrelation between these two blocks in sharing information during the design and construction stages, i.e. engineering solutions are made related to the design without any consultation with construction specialists, while, in the process of construction, the contractor often attempts to implement the vision of architects and designers in the simplest way. A lack of cooperation in sharing the information among the participants of the project has a negative effect on smooth implementation.
of the construction project (e.g. the time of project implementation and the demand for non-scheduled resources are increased).

Therefore, to implement a construction project within the specified time period using the calculated resources, it is necessary to manage the flow of information, distributing it among the participants of the project in the most effective way at all the stages of lifecycle of the construction project and ensuring engineering support (The Building Continuum) [7].

For precise determination of theoretical values of the parameters influencing the construction process [8] and for reducing the errors in the field of design, planning and construction, the use of a full-scale PLM (Product Lifecycle Management) [5] or the so-called 5D Virtual Project Development concept is suggested.

2. New concept in design and construction

Close collaboration of the project's participants is the main condition ensuring the effective management of a construction project [9–12], which can be fulfilled by using the 5D (five-dimensional) modeling concept [3,13,14]. This abbreviation can be described as the complex of three essential component parts, interconnected for project's design and construction; the first component is 3D (three-dimensional) project's data, the second component is time related data (as 4th dimension) and the third component is cost-related data (as 5th dimension).

The first step in implementing this 'proper' management is the creation of the 3D model of the project [3]. The second step is the computer-aided calculation of the required resources and preparation of the list of product specifications and bills of quantities [1,2]. The third step is the calculation of the duration of particular construction processes (and the duration of the whole project implementation) as well as the association of 3D model elements with a time schedule for graphical simulation of construction project implementation [15,16]. The fourth step is the evaluation of possible solutions or even the alternative project by using a multicriteria decision-making system [13,21].

The realization of the steps listed above results in the development of a theoretical 3D information model [5] of the building (BIM — building information model), consisting of intellectual volume elements. This is followed by calculations of the required resources [13,14], determination of execution time of the project and comparison of the alternatives for all the stages of the project life [7,16–19]. The expression of a 3D model in time during its lifecycle and calculation of costs is the 5D project concept [20]. The complete cycle is being executed through the stages of the considered 5D concept model (Fig. 2) in order to make the best solution, while there is a continual exchange of the cycle information flow between the stages, encouraging the selection of the most effective variant [21]. Structurally, the 5D concept model is divided into levels as follows: at the first level (cells in bold), the stages and their interrelations are presented; at the second level (cells shown by a dotted line), the initial data (and procedures) are given; the third level (cells with arrows) presents the actions and processes taking place; the fourth level (big cells) shows the obtained results as well as some benefits and advantages; at the fifth level, the effectiveness criteria of the stages are obtained, which are further used for multiple criteria evaluation of the construction project alternatives.

The main principle of the 5D concept model application is as follows: the quantities of the modeled, described and parameterized elements [22,23] are obtained automatically from the developed 3D building information model (3D BIM) [1,2], and the demand for project resources is determined.

<table>
<thead>
<tr>
<th>STAGES</th>
<th>PARTICIPANTS</th>
<th>ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEVELOPMENT AND PLANNING</td>
<td>Customer, department (bank, buyer)</td>
<td>Realization of development strategies, preparation of design conditions, financing</td>
</tr>
<tr>
<td>DESIGN</td>
<td>Architect, designer (customer or his/her representative)</td>
<td>Development of the building model and getting permission for construction</td>
</tr>
<tr>
<td>ECONOMIC ASSESSMENT</td>
<td>Architect, designer</td>
<td>Determination of the initial cost and comparison of variants</td>
</tr>
<tr>
<td>TENDER AND NEGOTIATIONS</td>
<td>Customer, contractor</td>
<td>Determination of construction resources and time, contractual obligations</td>
</tr>
<tr>
<td>CONSTRUCTION</td>
<td>Contractor, architect, designer</td>
<td>Planning and execution of works, decision-making and adjustment</td>
</tr>
<tr>
<td>PUTTING INTO OPERATION</td>
<td>Customer, contractor, architect, designer</td>
<td>Checking the conformity of the constructed building to the model</td>
</tr>
<tr>
<td>PAYMENT FOR THE WORKS PERFORMED</td>
<td>Customer, contractor (bank)</td>
<td>Timely financing and payment for the works performed</td>
</tr>
<tr>
<td>MAINTENANCE</td>
<td>Customer, buyer (contractor, bank)</td>
<td>Planning of building's facilities management and maintenance</td>
</tr>
</tbody>
</table>

Fig. 1. A typical model of construction project implementation.
According to the specified technical capacities and based on the demand for resources, we can obtain the schedule of the project's works \[15,24\]. Then, based on technological sequence of these processes, the schedule of the entire construction project is derived. The main advantage of using Virtual Project Development \[13,25\] is the possibility to analyze the alternative solutions of project implementation. Every stage of the project can be analyzed by comparing the selected alternatives. In this way, flexible simulation and real-time analysis are ensured, and, in the case of any changes (at any stage of the project implementation cycle), the alternative solutions can be considered and the most effective alternative chosen \[26,27\], using the 5D concept and the data of a virtual 3D BIM model \[1,2,28\].

It is obvious that the primary elements in the model's structure can produce the greatest impact on the efficiency criteria \[29\], while the selection of the best alternative mostly depends on precise determination of the demand for resources, because, in the case of an error, the most effective variant determined can be misleading. Therefore, in order to determine the demand for project resources, a thorough calculation of the project-related quantities should be made \[2,3\]. This work is time-consuming, as most often, the calculation of quantities is performed manually. To reduce the time required for calculating the quantities related to the construction project and to avoid uncertainties, errors and inaccuracies that may occur due to manual calculation, the 5D concept model can be used.

3. BIM as an approach to building design and management

The first and the core component of the 5D concept described in this article is the 3D model of the building (BIM — building information model). One specific feature of BIM is that design is treated as an integral part of the building lifecycle \[5,30,31\]. Segmented work at the design stages is replaced by a continuous process. This is achieved by changing the design technology substantially and switching from the development of a set of 2D (two-dimensional) drawings to the development of a 3D computer-aided model of a building, comprising all the constituent parts of the design process, such as architectural, structural, mechanical, technological and construction process management and evaluation \[14,15,21,32\].

At the design stage, these goals are achieved by using the technology of the Building Continuum Model, which focuses on the finally completed and fully equipped 3D building model comprising all the design parts. The basis of this technology is the 3D graphical-information model \[5,9,33\], covering the following issues: a geometrical model of the

---

**Fig. 2. Stages of project development according to the 5D concept.**

<table>
<thead>
<tr>
<th>STAGE 1</th>
<th>STAGE 2</th>
<th>STAGE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vision of the project;</td>
<td>1. Costs and demand for project resources;</td>
<td>1. 3D information model of the project with assigned TE-F;</td>
</tr>
<tr>
<td>2. Model (drawings and descriptions);</td>
<td>2. Sequence of operations;</td>
<td>2. Documentation of the project;</td>
</tr>
<tr>
<td>3. Creation of 3D elements on the basis of the vision or 2D model and parameterization of typical elements (TE);</td>
<td>3. Scheduling based on evaluation of construction technology, work shifts and their sequence.</td>
<td>3. Management of the construction project’s documentation and further facilities management.</td>
</tr>
<tr>
<td>4. Calculation of estimates and resource demand according to TE-codes of 3D model with parameters and quantities.</td>
<td>4. Simulation of construction project execution, inspection of sequence of operations and determining of inconsistencies.</td>
<td>4. Maintenance costs of building elements;</td>
</tr>
<tr>
<td>5. Determining the exact amounts of construction elements according to the project's 3D model, saving the time spent on manual calculation of quantities;</td>
<td>5. Determining the duration of construction processes based on the number of workers and shifts;</td>
<td>5. Duration of the project’s stages of execution.</td>
</tr>
<tr>
<td>6. Checking the correctness of the project’s drawings;</td>
<td>6. Scheduling of the entire investment construction project and its individual processes including cash flows;</td>
<td>6.</td>
</tr>
<tr>
<td>7. Using uniform classifier of typical elements and building materials to facilitate the work, the analysis and control of work sequence and expenditure of resources in the system;</td>
<td>7. Determining the capacity (workers and equipment).</td>
<td></td>
</tr>
<tr>
<td>8. Assigning TE-F (fragments of typical elements) to the elements of 3D model, i.e. relating the element to the production technology;</td>
<td>8.</td>
<td></td>
</tr>
<tr>
<td>10. Estimating the value of the project (with arbitrary additions).</td>
<td>10. Combining the BIM model’s groups of alternatives and determining the values of criteria for further multiple criteria evaluation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>THE EVALUATION OF ALTERNATIVE USING MULTIPLE CRITERIA EVALUATION PROGRAM LEVI 3.0</td>
<td>Choosing an economically effective alternative of the BIM model.</td>
</tr>
</tbody>
</table>
One of the fundamental innovations of this technology is the component modeling (Fig. 3). The component modeling technology [33] allows simultaneous work with all design data at the level of data components, covering the entire design cycle on the scale of the users’ group. Engineering components are graphical numerical models of real objects. These models characterize the geometry, properties, links, and attributes of the real objects [9]. It is assumed that a building consists of the elements and parts which differ in their functions, properties, and manufacturing technologies [10]. A part may be a simple structural component or a complex structure. All elements or parts have a specific 3D shape and the properties of the elements of real structures (physical properties, class or standard). They are parametrically controlled as well as being intellectual [34–36], i.e. each object “knows” its quantitative information (length, area, volume, etc.) and qualitative information (material, contents, etc.) [37]. All this provides the unlimited possibilities for developing objects, changing and editing their shape quickly and effectively, and preserving and managing their attributive information, when the 3D building model [13,38,39] is used.

Meanwhile, the 2D information, i.e. different drawings (plans, sections, facades, details, and nodes) and other design documentation (a list of materials, specifications, reports, and estimates) are generated by the 3D model. Quantities and price of the specified components may be calculated using the measurement units and taking into account the volume, area and length, or just the parameter entered [1]. Since these reports are linked to the model, new editions of the model can automatically update the design data [3,35,39]. If required, some external databases may be connected and used. Thus, the accuracy, coordination, and synchronization of changes in the project documentation are ensured.

BIM is the driver with discipline-specific solutions working together. This may be achieved by applying information and model-based technological solutions, allowing the computer-aided generation of drawings and reports, design analysis [5], cost estimating [2], schedule simulation [15], facilities management, and, ultimately, enabling the building team to focus on the information and decision-making [14], rather than the documentation tools and the process itself [20]. This results in the creation of better working conditions for building teams, time saving, higher quality of work and better buildings because of the informed decisions made in the process. Using of BIM ensures that the entire lifecycle of the building (design/construction/operation) is considered [21]. All information about the building and its lifecycle, defining and simulating the building, its construction and maintenance, using the integrated tools, is included. BIM integrates the works, processes, and information for multiple disciplines, multiple companies and multiple project phases.

From the perspective of the time of design, there is a higher opportunity for design iterations, since the information is rapidly exchanged between the disciplines. Project documentation requires less time to be spent on grunt work [20]. Professionals can spend less time on documenting the decisions, devoting more time to making them [17]. Everyone can avoid the redundant effort, while construction can better support fast-tracking, tightly managed schedules, and the shared risks and rewards of design/build [11,12].

From the perspective of design quality, the user of the BIM can improve the coordination between the documents, disciplines, and across the entire team, reducing the number of errors and omissions. With the coordinated documents and well-captured design intent, the enhanced design process makes for a far more informed design environment [20].
4. Computer-aided evaluation system in design and construction

The second and the third components of 5D concept described in this article are cost-related data such as economic evaluation system and time related data as duration needed for implementation of construction works. CAES (computer-aided evaluation system) in construction based on Building Information Modeling concept [9] interconnects structural design, evaluation and scheduling. The main purpose of CAES (SAS in original language) is to ensure computer-aided evaluation of design expenditure, providing the user (designer, contractor or investor) with a possibility to evaluate economic expenditure at any stage of the project — from design to finished construction. One-click tools enable the user to get an estimate (of the expenditure of resources, the operations planned and costs) saving him/her from calculating the quantities, selecting work standards and evaluating the conditions of work because everything is computer-aided, i.e. obtained from the information model of construction [1]. An estimate is obtained in the file format of SES2004 [21], and can be edited relying on the wide functional possibilities of this application, as well as the largest databases of work specifications and construction resources (materials, labor and machinery) [3]. Since there are references to structural element (in the model) and estimate, anyone can get any cost-related and expenditure-related information for certain element. Changes in design can automatically regenerate the associated estimate. All information about the operations and resources can be passed from the estimate to scheduling applications [15,21], such as Microsoft Project. All information is stored in a general database, therefore the feedback is possible.

CAES database of Typical Structural Elements (DTSE) is oriented to typical up-to-day solutions in construction (Fig. 4). The basis of DTCE is the Classifier of Typical Structural Elements (CTSE), which arranges Typical Elements (TE or TE-F) into classes, groups and subgroups according to particular technological processes. Each description of a typical element contains a code, a name, a set of parameters, a fragment of an estimate and a macro, processing a fragment depending on its parameters (for example, it chooses the appropriate regulations and calculates quantitative information, etc.) [21]. The fragments of estimates for typical elements are based on standards, certified by governmental institutions of Lithuania and Russia. DTSE database can be easily updated by adding new elements adapted to any company and its technology. To facilitate the setting of parameters, most of the values can be taken from the list. Along with numerical parameters, DTSE provides proper versatility.

According to the calculation made, this system can save up to 40% [20,21] of the time required for design and calculation of the money and labor spent on preparing drawings, estimates, schedules and the analysis of a number of the alternative projects.

5. The development of virtual construction project

To determine precisely the theoretical values of the parameters influencing the project cost [33] and to reduce construction errors, the application of the 3D or 4D concept in time is offered. The time dimension is employed for simulation analysis [25,40,41], i.e. the project can be assessed in terms of time (by determining building resistance to long-term effects, duration of various construction project stages, savings in resources and energy in project implementation, the environment pollution, etc.).

Industrial Construction Work Project (ICWP) is aimed at ensuring the effective management, implementation and reduction of possible uncertainty. Technological construction work project can embrace several issues:

1. General site plan (with temporary facilities, temporary engineering systems, storage areas, traffic routes, lifting equipment, working zones, danger zones, fencing, security, fire protection measures, and health and work safety);
2. Technological solutions (with a description of construction processes, characteristics of cranes or other lifting equipment, the plan and section views, load–reach–height diagrams, etc.);
3. Organizational solutions and control of the related technological processes (including the particular solutions, graphical views, sequence of technological operations, tools and equipment, and provision of health and work safety);
4. Determining the demand for resources for the whole project and particular construction processes;
5. Project scheduling, determining the demand for labor force and machinery, cash flow and work sequence at particular workplaces.

The use of the real 3D model in ICWP is shown in Fig. 5, presenting the plan (a) and section (b) views, characteristics of cranes, occupational health and safety measures, sequence of operations with a detailed

Fig. 4. A diagram of the computer-aided generation of estimates in CAES in BIM environment.
AISKINAMAS RAŠTAS (VAIZDAS PLANE)


MONTAVIMO PRIEMONES: Įrenginii montuoti naudojamas specialus mobilus kranas LIEBHERR LTM 1500, kurio keliamoji gilia yra 500t. Kranas statomas pagal schemoje pateiktus matmenis (su tolerancija ± 2cm) ant surenkamų gub. keleto plokščių su sutankinto žvyro dangos.

Esant nepakankamai pagrindo stiprumui po autotergešių dedamos inventorines kranas pagrindo plokštės (pirmiausiai matmenys 1.00x2.00m). Kranas remiasi ant autotegerių, kurie išstumiami iki galo ir sudaro 16.0x9.0m ploko standų rėmą. Krano korpusas orientuotas bišangiui 6 ašiai, o kabina nukreipta į šiaurę.

Kranas montavimo darbams atlikti turi būti sukomplektuotas su 31.7m ilgio užfiksuota teleskopine strele ir prie strečės prižiūrintais papildomais standumo spyriais su autotarmirom. Taip sukomplektuotas kranas 10.0-12.0m astuma gali pakeisti krovinių kai maše neviršija 149–129t (keliamąją galią pagal siekias reikia tikslinti su krano savinininkais).

MONTAVIMO DARBŲ EIGA:
1. Įrenginio iškraunamas ir pastatomas bei orientuojamas pagal schema. Įrenginio stropuojamas sintetinis stropai už kiškvinios kėlimo „ausies“, kai kiškvinio stropo abi kūpos kabinetas ant kablio (t.y. už „ausies“ kabinetas ties stropo viduris, taip gaunama dviguba maksimali stropo keliameji giliai);
2. Neviršijant 11.0m sieko, kranas įrengini pakele i nemažesne nei ~15.50m aukščio altitudę (įrenginio apiečios altitudę);
3. Įrenginį prilaikant ir valdant lankėmis atotarmirom, strele sukama iki projektinio padeties;
4. Įrenginio pastatomas į projektine padeti nueilidžiant strečę ir kabių;
5. Įrenginį atkabinti leidžiant tik patikrinus prie pastato konstrukcijų projektinės padėties ir iššikinimą, kad tėra jokios pastato ir įrenginio nestabiliumo bei nestandumo grėsmės.

Fig. 5. An example of Industrial Construction Work Project (ICWPICWP).
VAIZDAS PIJUYJE
IR STROPAVIMO SCHEMA

PASTABOS:
1. Jrenginys stropojaams sintetinius stropais pagal stropavimo schema;
2. Montuojant jrenginij pagal pateiktas schemas kriniai kELIMO momento kranos streles priartéja prie labiausiai atsikesiaj Konstrukcijų 1.8m astumų, tačiau net ir tokio atveju darbai turi bti atlikami vengiant bet kokio streles susidurimo su konstrukcijomis;
3. Montavimo darbams turi vadovauti atestuoti asmenys;
4. Kranistai, stropotojai ir reguliatoriai turi bti sapažindinti su darbų eiga ir privalo jos laikyti (patirionaut Žiūrėti montavimo darbų aksonometrijų vaizdą).

LIEBHERR LTM 1500
Q= 500t; L = 31.70m (strele su standumo spyriais),
Hmax= 34.50m; Lmax= 30.00m;
Kelimo galia, kai siekis L= 11.00m, Q=138.0t;
Kelimo galia, kai siekis L= 9.00m, Q= 162.0t.

+ 23.382
+ 18.695
+ 14.645
+ 13.910
+ 4.945
+ 0.895
+ 0.000
+ 0.490

Fig. 5 (continued).
Fig. 5 (continued).
description and isometric projection (c). Some pictures illustrating work execution at the particular stages of construction (d) are also provided.

This kind of simulation as a part of Technological Construction Work Project is a good example of Virtual Project Development in the construction industry[13]. 3D simulation of construction operations and management of virtual work implementation should be performed in advance to avoid possible collision between the structures carried by cranes and the crane booms.

6. Determining the most effective project variant

When the main characteristics of the construction project are defined and the 5D concept is applied, a model suitable for determining the most effective project variant can be developed. It means that it is possible to combine the presented 5D concept with a multiple criteria decision-support system [3,7,8] based on the games theory and optimization methods[17,27].

In construction, the attributes of the implemented designs differ from those calculated according to the design and drafts. The lack of information makes the data incomplete or unreliable. When these uncertainties are caused by evaluations made according to the distribution laws based on various statistical methods, we have a problem of stochastic uncertainty [2,43]. Usually, the problems of this type may be solved by solely using the methods of the games theory. When weight ratios of efficiency criteria are unknown, the problem of decision-making under the conditions of uncertainty should be considered. In this case, the games theory methods may be applied [13]. This kind of an extra tool in methodology (in this article, LEVI 3.0 software) [7] gives the possibility to evaluate alternative solutions [44–47].

The generalized model of the computer-aided management of the construction project through its lifecycle (Fig. 6) consists of four separately used blocks. The data of each block obtained at every stage can be analyzed comparing the selected alternatives, and the collected information can be transferred to the next block, making flexible simulation and real-time analysis possible. In this way, in the case of any changes in the situation (at any stage of the project implementation cycle) the alternative solutions can be assessed and the most effective variant (for that time) chosen, using the 5D concept and the data provided by a virtual 3D BIM model.

The detailed description of blocks, model stages, actions, evaluation processes and results is given below:

1) BLOCK 1 (3D and TE): This block presents 3 stages: first, based on the available drawings and the construction project model, a 3D BIM (Building Information Model) is developed, then, the elements of the created 3D model are related to typical elements from the classification of structural components and resources. They are finally described in detail and parameterized [42]; the computer-aided cost estimate of the construction project is obtained. When all the data of the block are collected, a comparison (assessment) of the alternative solutions can be made;

2) BLOCK 2 (4D and 5D): This block consists of the previous block 1 and an additional stage, involving the calculation of the period of project implementation and scheduling. Given the data from the first block (demand for resources) and having entered the technological sequence, the schedule of the construction project is obtained with the duration of construction processes and the demand for resources within the time of construction. In this block, the simulation of the construction project implementation is also presented (visualizing the future construction process). When all the data of the block are collected, a comparison (assessment) of the alternative solutions can be performed;

3) BLOCK 3 (5D in LIVE): This block consists of the previous blocks 1 and 2 and an additional stage — supervision and management of the construction process. A virtual model of the project in terms of time (4D) is used for the control and comparison of the theoretical model and actual construction works, i.e. there is a possibility to determine the difference between the actual and theoretical demand for resources, and to see what works and on which day are to be performed (according to the scope and course of construction in the visualization). When all the data of the block are collected, the comparison (assessment) of the alternative solutions and the analysis of possible irregular supply of resources can be performed;

4) BLOCK 4 (5D PLM): This block consists of the previous blocks 1, 2 and 3 and an additional stage — the project facilities management and maintenance planning. All the available information about the elements is accumulated in the virtual model of the project (database), i.e. the data on the manufacturer of structures, their
characteristics, peculiarities of maintenance, warranty period, etc. are accumulated. When all the data of the block are collected, the comparison (assessment) of the alternative solutions and calculation of the potential demand for resources for regular maintenance procedures can be performed.

As shown in Figs. 2 and 6, it is possible to compare (assess) the alternative solutions or evaluate the alternative variants in each block of the model. At this stage, it is advisable to use multiple criteria evaluation methods. For this purpose, some scientists suggest that implementation of the construction project alternatives by selecting effective constructional–technological–organizational variants (a construction system) may be performed by applying the methods of synthesis of multicriteria solutions [42].

7. Conclusion

Theoretical principles and practical innovative applications of building information modeling, computer-aided evaluation and construction process simulation techniques based on the concept of Virtual Project Development (VPD) were analyzed in the article. This complex methodology was developed as an effective implementation of Project Management concept in the 5D environment. The use of BIM according to the 5D concept during the whole product lifecycle provides major advantages as follows:

1. BIM manages both graphical views and information, allowing the computer-aided generation of drawings and reports, design analysis, evaluation, scheduling, organization of works and facilities management.
2. BIM facilitates the creation and sharing of information relevant for design, construction, and maintenance of buildings over their entire lifecycle. It provides a collaborative environment, so that the participants of the project could effectively share this information by eliminating data redundancy, the need for re-entering data, data loss, miscommunication, and translation errors.
3. The concept of the relationship between a graphical-information model of a building and its estimate was defined, the technique for classifying the design elements and materials was devised, the required programming tools and data structures were developed, the integration of the systems was achieved and the technique for computer-aided evaluation of economic criteria of construction projects was developed.
4. CAES (SAS) — a computer-aided evaluation system in construction, based on Building Information Modeling concept interconnects structural design, cost estimation and scheduling. The main purpose of CAES (SAS) is to provide the computer-aided evaluation of the economic criteria of the project design, thereby providing the user (designer, contractor or investor) with the possibility to evaluate economic expenditure at any stage of the project — from design to finished construction.
5. Virtual Project Development in construction industry can be used as a 3D model for simulating the construction process and virtual work implementation management which should be performed in advance to avoid possible collisions of cranes and structures.
6. The main advantage of the PLM concept is the possibility to simulate the management of the project and, on the basis of the 3D model, to calculate precisely the demand for resources, to determine the schedule of project implementation and to identify the effective alternatives. The use of LEVI 3.0 multicriteria decision-support software may be recommended as the evaluation tool for choosing a set of effective construction project alternatives.

References


