Information Modelling as a Tool to Manage Construction Project Information Flows

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Abstract. The technology of information modeling of buildings is a new tool for managing information flows in the implementation of a construction project. Based on the analysis of information flows in the activities of the construction organization, an integration methodology and a data flow interaction scheme based on modeling has been developed. The Knowledge Base is considered as an expert system, which interconnects design engineering models and acts as a transmitter of design solutions to estimated and financial decisions and a data accumulator for a decision-making analytical center. A factor analysis of specific costs for the production of construction products based on multiple linear correlation and regression analysis was carried out. The possibilities of machine learning and data requirements for the learning program are considered.

1. Introduction
Modern construction covering several stages of the facility life cycle (starting from the concept of a new building and ending with its disposal at the end of its useful life) is a complex system that generates thousands of financial, material and information flows (documents) requiring modern IT tools for management [1]. Construction lagging in terms of implementing integration information systems can be explained by the specifics of the industry, associated with various financial and economic activities of construction companies. The production cycle in the construction industry, where many projects are at different stages of implementation, has its unique features. Construction is also characterized by a large number of counterparties (investors, architectural companies, customers, contractors, subcontractors, etc.) with complicated relationships [2]. Currently, life-cycle data management in architecture, engineering, construction and facilities management remains a challenge.

2. Rationale
Basic principles of the building information modeling approach were formulated in the 1980s as a part of the Building Information Modeling (BIM) concept and include: 3D modeling; automatic drawing extraction (3D-2D); intelligent parametric components; relational databases; temporal phasing of construction processes [3, 4, 5]. A 3D model of a project is jointly created by architects, engineers and designers.
Efficient construction is possible if there is a single information structure bringing together finance, supply, and sales management systems and the production management process [6]. Among important features of information systems, feedback shall be distinguished. Logistics management systems, supply chain management systems and systems of data acquisition, transfer, storage and processing form a closed loop [7].

Up to the present time, no integrated program has been developed that — as per the terms of reference in the form of a design or architecture model — would provide detailed design documentation to be used at a construction site. Structural analysis (which is currently not possible without humans) and construction assignments from related departments get in the way of computer generation of drawings. Those procedures interfere with the process of smooth development of detailed design documentation. Preparing, conducting and evaluating structural analysis using the finite-element method (FEM) is the main challenge in achieving full automation of calculations [8]. In structural modeling, the geometric structure, design, kinematic links and external force impacts are idealized. Actual structural elements have particular shapes and sizes. However, to optimize computational resources, finite elements (FE) with infinitesimal dimensions are usually used [8]. As a result, the design process involves switching between volume and plane representations of an object and its elements, which requires participation of a structural analyst. Those procedures are subjective and not standardized.

Development of automated systems for control of processes and corresponding information flows, consistent alignment and integration into a single system for data acquisition and processing as well as operating management improve production efficiency in construction [9]. A developed computer model of a construction project (starting from its design on paper and ending with building's disposal) is variable. We can introduce any changes to such model and see instantaneously how they affect building construction and operation. Successful data management is aimed at ensuring interaction between various applications and stakeholders [7].

3. Aims
The aim of the research is to study capabilities of building information modeling to manage information flows (IFs) in construction using mechanisms and tools to develop a single information environment for multi-user access to data, efficient data management and extraction from the Knowledge Base (KB) to make decisions. In the course of the research, the following tasks were determined and solved:

- IF analysis in activities of a construction company, development of an IF integration method and interaction pattern based on BIM;
- analysis of the KB as an expert system bringing together engineering and technical models, coordinating design solutions with financial estimates, and accumulating data for the analytical decision-making center;
- factor analysis of unit costs for construction products based on the multivariate linear correlation and regression analysis;
- analysis of machine-learning capabilities and requirements for machine-learning program data.

4. Method for BIM-based integration of information flows
As for building the information space of a construction process, the following shall be noted: weak interaction between different departments during design, narrow focus of IFs, frequent data redundancy, incompatibility of drawings created by different design companies [9]. That is why to develop a single information environment for construction operations, it is suggested to use an information model (IM) that makes it possible to link basic data, graphical representation of objects and their description by main production departments in a single system and create an object-oriented archive of documents [10]. To achieve maximum efficiency of IM implementation, it is necessary to
consider the maximum of facility life cycle stages, ensure increased use of information, and organize processes in such a way so that the introduced information is re-used for various purposes.

A single BIM-based system for information flow management is suggested [12]. Construction departments usually have their own automation and management systems optimized for specific tasks. However, local systems that are quite good at preparing materials for external organizations (documents for tax offices, various drawings, engineering calculations, etc.) cannot improve efficiency of the management process [11]. It is proposed to distinguish two basic information structures in construction: the system for automation of accounting and management and the BIM system. Figure 1 shows the most important information flows in structural engineering. In structural engineering, it is reasonable to create information processing systems in the form of integrated databases. This is due to the increasing volume and structural complexity of the processed data, larger number of data users and functional requirements for information processing systems [11]. Each process at a certain stage in the model used is related to an array of data and their analysis for the purposes of current decision-making.

Throughout the entire life cycle (LC) of a facility, a common Knowledge (KB) is developed in the BIM system [12]. However, to manage IFs and make decisions, it is not sufficient to use BIM only. Data and their qualitative analysis are required. To create an object-oriented database, GISs, databases of standard solutions, manufacturers' databases, construction and operation management systems, data of corporate ERP (Enterprise Resource Planning) systems can be used along with BIM. Such systems are based on integration of financial and material flows' management within a single information field [13].

ERP systems include the following: estimating requirements of physical resources based on the construction plan; planning procurement of construction supplies; developing a schedule of construction supplies transportation; reserving physical resources in warehouses for planned construction works. ERP application in construction is complicated due to the duration of the production cycle. Moreover, ERP solutions for construction companies have a particular peculiarity: within a project, a great number of documents, purchase orders, supplies, and contracts can be used, and different stages of the project can be implemented simultaneously [14].

In the single environment of a construction project, an ERP system is inextricably linked with the following components of the BIM system through information flows: the design and analysis systems.
for architecture, structures and utilities, the estimating and scheduling systems, as well as the database (Figure 1). The KB can be considered as an expert system bringing together engineering and technical models, coordinating design solutions with financial estimates, and accumulating data for the analytical decision-making center.

The architecture of the integrated environment ensures data exchange between users of various categories. Information processing systems are understood at three levels of analysis: the “computational theory” level covers the goal of the computation and abstract task determination; the “representation and algorithm” level determines the information representation for the input and output, as well as the algorithm for the transformation of the input data into the output data; and the "hardware implementation" level represents physical realization of the system [15].

The names and quantities of the building model components are extracted from the 3D model of the building and parameters for all structures. The relationship of resources, duration of work, development standards and the definition of logical relations between them are set later. The calculation of data for the formation of the construction schedule and the automatic connection of the components of the 3D model with the parameters of work for creating the schedule complete the creation of a 4D model. This establishes a connection with a database of similar previous projects [16].

4D models expand the capabilities of familiar 3D models and create additional benefits, primarily due to the fact that they also contain a work plan in the form of a calendar network diagram. The result is a visual work plan, which helps to improve the understanding of team members [18]. The ability to test and improve existing versions of the project work plan is an advantage of such models. Synthesis of the calendar schedule and model of the building allows you to check visually and with the help of special tools, how truly the building process was. You can bind each structural element, equipment to a temporary stage and create a schedule of work using the classifier. Then you can view the whole process of construction in the dynamics, to identify inconsistencies or positions for optimization.

It is possible to calculate estimates with the help of plug-ins in BIM, using the integration of the design and audit programs of estimates into a single information model using application programming interfaces (API) from various applications. Special software environment KB allows the integration of design data from different systems into a single estimated project. KB communicates with the 3D model to transfer the results of estimated calculations. The generated estimate task is transferred to the 4D model and the 5D model is obtained [17].

The technology of creating a unified environment requires access of various groups of specialists (engineers, estimators, architects, designers, builders, analysts and experts) to the same model representations. Therefore, it is necessary to differentiate access to project information and exclude the possibility of unauthorized access and change of project information. The architecture of the integrated environment provides information exchange of data between different categories of users [18].

The data exchange strategy allows you to integrate structural analysis into a 3D model. The transfer of parametric information to the geometry of objects is possible through the use of APIs that are controlled using the programming languages VBA, C #, etc. The model on a single platform based on Bentley or Autodesk software has an advantage. Own closed file format allows data exchange between applications included in a single line, which ensures effective coordination of information [17].

We propose a cloud platform of facility LC management for interdisciplinary works of participants. The approach provides complete infrastructure management data, including a single mechanism for storing data through a handler, elaboration of a data processing mechanism, and a two-tier cloud storage mechanism along with a new data distribution strategy based on data query patterns. The embedded BIM tools are integrated with the main commercial BIM software such as Autodesk files. BIM files of various LC stages are extracted, converted and uploaded to the data storage where the BIM data is treated as engineering data of the project. The business network-based management platform is designed to collect and exchange information on the construction schedule, assignment of tasks and documentation in all joint companies in construction projects. Such project of managing data stored in a distributed DB is integrated with BIM for further development of a single data storage. The
recommended model can be used in the construction industry in the form of a business network, and not just for a single project. The proposed structure can be logically divided into three parts: a BIM server, a cloud-based collaboration platform, and several applications based on those two parts [7].

A rapid flow of information across international borders also needs to be managed keeping security in mind. Data should not be intercepted, lost or damaged. In our opinion, decentralized protocols (BlockChain technology) and innovations based on them are the most promising in the digital economy [19].

For BIM it is essential that the information stored in the BlockChain exists as a common and constantly verified DB. This way of using the network has the following advantages: records are kept publicly and can be easily verified; no centralized version of this information exists which could be damaged by a hacker; copies are stored on hundreds of computers at the same time. Information is stored in such object in small portions and is constantly updated (as when creating a model by developers from different departments). Each transaction and appearance of new blocks update the data simultaneously in real time [21]. If we take the technology as a reliable, distributed and transparent environment, new opportunities for its application arise. We propose to develop processing (an information processing system when creating a model) using the BlockChain technology. Its application is possible in three ways: for decentralization, data storage and data security [7].

With regard to information security, great opportunities arise as the chain of blocks is virtually unbreakable. Hacker attacks are aimed at penetrating the system through a "weak link". Malware locally destroys or replaces software. In case of BlockChain, the blocks are huge, and the perimeter is unlimited [19].

Data can vary from project to project. At the stage of the concept, we get particular volumes of materials for further calculations. In the financial module, at early stages, we can determine the cost of construction based on consolidated rates of the customer. During the next stages of object development, we can conduct a dynamic analysis of investment & construction project development, adding data of design, construction and operation models to the portal. Based on those data, project deviations from the initial investment model can be identified. The developed BIM system makes it possible to interpret and visualize information flows for the investor's better understanding of technical and economic parameters of investment & construction projects, as well track the dynamics of objects development and monitor deviations occurring at various stages of project implementation.

In perspective, such solutions result in accumulation of mass data on construction objects and their adaptation through changes in the data throughout the entire life cycle. The concept of learning is close to the concept of adaptation. According to [20], learning is a process of developing a particular response in a system to external signals through repeated stimuli of the system and external adjustments. Learning can be used in the adaptation process as one of the methods to obtain management information [20]. In future, it will be possible to develop analytical systems and even automate individual project tasks using machine learning.

5. Specifics of machine learning in structural engineering

Machine learning is one of the steps in Data Mining [21]. Initially, preliminary preparation of data and interpretation of the obtained result are required. Data are prepared in several stages. First of all, a smaller database (for instance, a database on materials, estimates, components) is created on the basis of the large database covering various design areas. At this stage, raw data are verified and inconsistencies are eliminated. Then, the data are transferred to the Data Warehouse for analysis. It is necessary to develop methods to identify patterns hidden in the large volumes of source data. By hidden knowledge we mean practically useful knowledge available for interpretation, which were unknown earlier. One of the ways to comprehend information is a multi-dimensional data cube where dimensions correspond to attributes, and data analysis operations are defined as operations on the cube (slicing, retrieval of subsets). Manual data analysis and visualization of results are easily done using Online Analytical Processing (OLAP) tools. Capabilities of analytical processing are restricted by human-generated hypotheses. For instance, when estimating the cost of a building, we cannot find a
connection between raw materials and construction-in-progress levels. This is possible only with an analysis using machine learning algorithms. To build a model based on data, we use regression, classification and clustering methods. All data are divided into two parts. We train the model using a training set, and then we determine accuracy of its predictions using a validation set. Visualization is one of the best data analysis tools.

Verification of program systems is an important requirement: those systems must do only what they are intended for [22]. Since training includes randomness in data, machine-learning programs are less predictable than traditional ones. It is of concern that models that learn through data can make errors in judgment if some data were missed or represented outliers. A machine-learning program also differs from a traditional one in that it represents a general pattern with variable parameters. Assigning different values to these parameters makes the program perform different actions. The machine-learning algorithm adjusts the model parameters and optimizes the efficiency criterion determined based on the data. As time passes, the efficiency of the program improves, and that is the essence of learning.

Let us consider building recognition using BIM. Buildings in hydraulic fill and industrial areas as well as standalone buildings in the historical part of Saint Petersburg differ from each other significantly. Analyzing various images of the building model, a machine-learning program identifies patterns typical for a specific type of buildings and then checks if those patterns are present in the image. This is an example of object recognition using BIM. The machine-learning algorithm finds discriminating elements and their combinations and determines the building type through analyzing a set of its images.

Large volumes of data do not guarantee that some hidden rules are present. It is necessary to make sure that there are patterns in the data generation process and that the data collected are sufficient for their identification with proper accuracy. Besides, a machine-learning algorithm shall be efficient to ensure fast and cost-effective learning. In many cases, the internal characteristics of tasks change over time, the data collected get obsolete, and the trained model needs to be trained continuously using new data. Finally, when the model is built and used for prediction, it should be efficient in terms of using the memory and computational resources. The efficiency of the model is as important as its prediction accuracy [23].

Another important aspect is that the task to be solved can vary over time. For instance, building operation depends not only on the labor input, duration of construction, period of inventory turnover, construction-in-progress level and material consumption, but also on the state of economy. If there are significant changes in the economy, prior trends are not applicable, since the characteristics of the random process underlying the data have changed. The models trained earlier are not applicable — new data should be collected and a new model should be trained. As an alternative, a feedback mechanism can be used. It feeds information on the model efficiency back to the model and then the model can be adjusted throughout its use.

One of the most important aspects in machine learning is a model that determines the pattern of relations between the input and output data. When the result can be recorded as a weighted sum of attributes, it is suggested to use a simple linear model where attributes have the additive property. Weights are model parameters and they can be obtained from the source data. In machine learning, the process of identifying parameters that best meet the data is implemented [20]. We suggest linear regression, which is one of the types of supervised learning. In regression, the efficiency is conditioned by how close the predictions made using the model are to the output in the training data. As a rule, the learning objective is correct prediction for new cases, when data are generalized for a limited set of possible cases. Machine learning and prediction are possible as patterns and regularities are quite typical and changes in the world are usually gradual [21].

The theoretical framework for creating machine-learning algorithms to develop detailed design documentation based on a design model has been existing for a long time. As for automating development of projects' architectural sections, the situation is more complicated as it is either extremely difficult or impossible (in general) to formalize corresponding algorithms with account for
all standards and regulations. Machine learning represents the most promising area in terms of automation of the architectural design section.

6. Modeling using linear correlation and regression analysis

Cost reduction and optimization of costs through implementation of resource-saving technologies, retooling and automation of processes including information flows are key methods to improve construction competitiveness and efficiency. To solve tasks related to automation of design and economic calculations in construction, efforts are taken to develop expert systems that can be programmed using rules and algorithms set manually. Solution to issues is associated with the speed of decision-making in terms of managing construction costs. In this regard, systems analysis and modeling of the conditions determining the production costs with subsequent development and implementation of measures to reduce them become extremely important [24].

Econometric modeling is an efficient tool to build production functions that are of interest for practical use in economic analysis, prediction and planning of the costs, as well as in management of production information flows. The construction specifics affects methods for modeling of economic processes. Correlation and regression analysis based on studies and quantitative measurement of links between different factors is the preferred modeling method.

Production inventory is one of the economic indicators in construction. Its state and movement are evaluated over time, based on deviations from the standard value if the latter is optimal. The optimal production inventory is determined based on the condition for minimum of the objective function of total costs in a construction company (transportation costs, inventory holding costs, non-recurring investments in current assets and warehousing capital stock).

Current assets are funds advanced by a construction company for working capital and circulating assets (except for depreciation charges), ensuring a continuous production process.

Material consumption is the ratio between the material costs and the cost of products manufactured, which shows how much material costs are required or actually used to manufacture a product unit. Material consumption is measured in per cent, and that value means the amount of material costs in the cost of finished products (without depreciation) [25].

The construction-in-progress level is determined as the ratio between the construction-in-progress costs and the cost of finished products. There are four levels in construction that determine the construction-in-progress level: level 1 (completeness up to 15%), level 2 (completeness up to 50%), level 3 (completeness up to 75%), level 4 (completeness up to 99%) [25].

In the course of the research, a factor analysis of unit costs for construction products based on the multivariate linear correlation and regression analysis was conducted. The period of inventory turnover, construction-in-progress level and material consumption in facility construction are selected as the main factors. Introduction of other possible factors to the model (duration of construction, labor input, etc.) does not improve the estimated figures, therefore, they were not taken into account. The parameters of the multivariate linear regression model were determined using Microsoft Excel tools and a program written in the VBA language. This made it possible to build the following three-factor function for the cost of construction products, which describes the dependencies between the parameters analyzed to the fullest extent possible:

\[ Y = 487.032 + 0.172 \cdot X_1 + 4.175 \cdot X_2 + 6.024 \cdot X_3, \]  

where \( X_1 \) — the period of inventory turnover,  
\( X_2 \) — the construction-in-progress level,  
\( X_3 \) — the material consumption in facility construction.

The coefficients derived show the quantitative impact of each indicator on the result with the remaining parameters unchanged according to the additive property. The results of the economic and mathematical modeling for the dependence of the cost of construction products on various factors allow for the following interpretation:
• decrease in the period of inventory turnover by 1 day results in reduction of the cost of construction products by 0.172 RUB/thous. RUB;
• decrease in the construction-in-progress level by 1% results in reduction of the cost of construction products by 4.175 RUB/thous. RUB;
• increase in the material consumption in facility construction by 1% results in reduction of the cost of construction products by 6.024 RUB/thous. RUB.

The analysis of the model makes it possible to obtain management information to optimize construction planning, determine the possibilities for cost reduction, improvement of construction competitiveness and efficiency.

7. Results
In the course of the research:
1. The new method combining BIM and the resource management system was described, the pattern for IF interaction in a construction company based on BIM was suggested.
2. The KB supporting data mining based on creation of a storage of structural data and representing an expert system was proposed. It brings together engineering and technical models, coordinates design solutions with financial estimates, and accumulates data for the analytical decision-making center.
3. The factor analysis of unit costs for construction products based on the multivariate linear correlation and regression analysis was conducted.
4. Machine learning capabilities and requirements for machine-learning program data were analyzed.

8. Conclusion
Information modeling takes design and construction to the next technological level. Thus, it is possible to improve the efficiency of the decisions made, but it requires transfer of information in digital form, its repeated use at different stages of the facility life cycle and information processing for the purposes of decision-making [26]. The concepts of Data Warehouse, Knowledge Base, OLAP applications and Data Mining tools are currently used to extract information from information systems.

Further researches on information exchange should be conducted. Creating an information platform is a challenging task comprising several autonomous, however, interrelated blocks: 3D modeling, input-output and storage of information, maintenance, 3D infrastructure, concept verification through pilot projects, possible development directions [27].

We suggest making passive data (that were the subject and the result of programs' operation) active so that they start managing operations and could determine further steps. The idea is to apply machine learning that makes it possible to process data and turn them into knowledge in order to automatically extract algorithms from data, thus, replacing programmers with machine learning programs. One of the purposes of Data Mining methods is to visualize the results of calculations, which allows people who do not have a special mathematical preparation using Data Mining tools. The BIM technology allows for such visualization.

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