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REDUCTION OF THE BIM DIMENSION OF THE FULL LIFE CYCLE OF BUILDING AND FACILITIES *

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Statement of the problem. The subject of the research is information models of a complete life project in the sector of architecture, design and construction and maintenance of buildings and structures. The purpose of the research is to optimize BIM technologies by building a model based on a discrete vector data description.

Results. Analyzed the main obstacles to the widespread introduction of BIM technologies and procedures for the full life cycle of a construction project in the practice of the construction complex of the Russian Federation throughout the entire life cycle of the project, including the stages of construction, operation and disposal, as well as global trends in this process. The method of BIM dimension reduction based on discrete vector data description is formulated. The technology of forming a hierarchical dynamically added and updated information base BIM, taking into account the possibility of its aggregation, has been developed. The algorithms proposed in this work are implemented in the shell of a relational database management system.

Conclusions. BIM dimension reduction, based on a discrete vector description of data, allows you to completely solve the problems of both designing and updating the BIM information base, and its transfer between project participants. BIM data formats are determined by the stage of the complete project life cycle. Fully functional for the stage of determining the scope of work on a project, BIM is one-dimensional and is simply determined by the vector of clusters of a lower degree of integration, which allows you to completely overcome all obstacles to the widespread introduction of BIM technologies and procedures of the full life cycle of a construction project into practice. The optimal shell for the implementation of BIM technologies is relational databases.

Keywords: information modeling of buildings, organizational levels, life cycle, digitalization.

Introduction. The digital transformation of the global economy has been causing a significant increase in its efficiency. By «digitalization» we mean the optimization of processes, or-

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ganizational structures and methods of project implementation which must be aligned with digital technologies. In [1], a positive correlation was identified between the growth of the industry and its digitalization index (hereinafter — DI). This fact is illustrated in Fig. 1. At the same time, the speed of the digital processing process qualitatively varies for different industries.

Fig. 1. Correlation between productivity growth and digitalization index in various industries in Europe for 2015—2018. The frame indicates the construction industry (Remes et al. 2018)

Unfortunately, the construction industry is an absolute outsider of the transformation occurring in the world and is thus one of the outsiders of industrial growth. In Europe, less than in the construction industry, growth was demonstrated only by the extraction of minerals (including hydrocarbons) and utilities. Nevertheless even these industries have surpassed construction in terms of digitalization and accumulated a considerable growth potential. A similar situation developed in the United States where the construction industry is only ahead of agriculture and hunting in regards to DI. This gap can only be addressed by means of embedded and comprehensive implementation of BIM technologies and processes at all levels of the construction industry.

Due to the growing lag in the construction industry, accelerating the adoption of BIM technologies is an absolute imperative. However, as evidenced by the results of studies [2], this implementation even in the developed countries of Europe, North America and Asia is characterized by unevenness and imbalance. This fact is illustrated in Fig. 2.

The extreme limited and imbalanced implementation of BIM in Russia revealed by international research is calling for an extra focus.

Fig. 2. Nine distribution rates of BIM in 21 countries in 2017

1. Study of the implementation of BIM technologies at all stages of the life cycle of buildings and structures in various countries. In order to describe the balanced distribution of BIM, three BIM implementations (technology, process and policy) were examined which are superimposed on the same number of BIM capabilities (modeling, collaboration and integration), which summarizes the nine areas of distribution. The results indicate an uneven distribution of diffusion rates across countries. E.g., in the Netherlands, Great Britain, Finland and Korea, the diffusion is quite balanced. In contrast, 2017, including Russia, saw extremely unbalanced BIM diffusion rates and even the complete absence of some of its area. According to experts, over the past four years, the situation in Russia has almost not turned round [3]. Overall, this study shows the prevalence of the technology diffusion and modeling domains. This contrast considerably degrades performance related to cooperation/integration processes and policies. These indications of the worldwide trend in the construction industry put a lot of emphasis on the adoption of digital technologies and related modeling techniques. Much less attention is paid to the processes and policies of cooperation and integration. In particular, in

Russia this area of BIM application is still an uncharted territory. However, these processes are essential for taking the best advantage of the benefits offered by digital transformation.

In [4] the synchronization of organizational changes calling for digital innovation support is assumed. At the same time, among the top players in digitalization, the processes of insufficiently developed cooperation and integration, organizational changes associated with digitalization have not yet been developed. As shown in [5] in regards to the multidimensional nature of changes caused by digitalization, the article [6] sets forth a conceptual framework consisting of three areas of change: technology, process and organization.

Some of the tasks of increasing the efficiency of cooperation and integration can be solved locally. To achieve the overall goal of deepening digital processing at the enterprise level, efforts need to be made to meet the following joint objectives:

- implementation of process-oriented changes that involve the introduction of digital technologies in architectural and engineering firms as well as forms that contribute to the achievement of all the benefits of digitalization;
- performing organizational changes. The introduction of digital technologies generates progressive forms of organization that contribute to the achievement of all the benefits of digitalization in architectural and engineering firms.

So, according to [7], a study of a representative sample of Italian and Canadian firms revealed the following set of the most effective ganizational and technological solutions:

- improving communication between architecture (A) and engineering (E) group and between groups A and visualization (R);
- expanding marketing and business opportunities;
- introduction of new equipment, software and tools.
- integrated decision making for teams A and E;
- improved consistency of results A and E;
- automation of exchange files between commands A and R.

However, a considerable part of the tasks of digital implementation of the construction industry cannot be efficiently addressed at the local level of a separate organization of project participants and requires state participation. Awareness of this need for the implementation of state programs of the digital complex of the building complex in a number of countries of the European Union. The Federal Republic of Germany led the way in the area in 2015. The Federal Ministry of Transport and Digital Infrastructure (FMTDI) in coordination with the private sector developed a three-step roadmap and the diffusion of BIM in Germany up to 2020.

The preparatory phase of setting standards and legal solutions to the associated issues was successfully implemented in 2017. At the second pilot stage in 2020, experience was collected from the practical use of BIM in the implementation of a part of infrastructure projects funded by FMTDI. Since 2021, BIM has been compulsory in the implementation of all FMTDI infrastructure projects. All participants in the state contract sign a multilateral agreement, which includes a schedule of key BIM development operations based on the general and implementation of contributions of the parties (*Mehrparteienvereinbarung*).

Although the use of BIM is formally only mandatory in the public sector, the successful experience of using BIM and the developed legal and technical norms are successfully and increasingly used by the private sector of the construction complex in Germany. The non-governmental self-governing association of German engineers (*Verein Deutscher Ingenieure* — VDI) in 2020 developed and published and is working on improving the guidelines [8] including the technical aspects of the use of BIM. The requirements set forth in these guidelines will be recognized in Germany as progressive technologies (*Stand der Technik*). The document describes the following elements of interaction between the participants in the implementation of the contract:

- information exchange protocols between participants
- volume and content of transmitted information;
- BIM exchange schedule;
- BIM coordinator;
- level of detail (LOD) and required data format (e.g., formats for representing geometry data and part attribute references (*Bauteilattribute*)).

The major disadvantage of the currently implemented BIM is that in the overwhelming majority of cases the systems describe the design stage of new buildings and structures [9]. The exception is BIM of architectural heritage objects where a considerable progress has been made in automatic collection of topological and geometric data (most frequently based on laser scanning) [10] and the conversion of primary analog information into digital form [11], which makes it possible to obtain a three-dimensional model of the object. Adding 2D documents (e.g., text or numeric) allows one to obtain the so-called 5D «smart container» with interrelated information not only on the current state of the object, but also on its transformation in time [12]. The task of building 5D BIM is relevant not only for heritage sites, but also for the optimal operation of modern buildings throughout the entire life cycle [13], including the stages of construction, operation and disposal has not been sufficiently

addressed globally [14] and domestically [15]. At the same time, the directive documents of the Russian Federation call for information models of the full cycle [16].

According to [17] and [18], the major obstacles to the wide introduction of BIM technologies and procedures for the full life cycle of a project into practice are as follows:

1. A high dimensionality of BIM of the full life cycle (up to 5D—6D [19]).
2. The need to use costly, commonly unique, software and computers.
3. The need to use highly professional specialists throughout the full life cycle of BIM [20].
4. The need to agree on protocols and technologies along the entire chain of project executors.

Domestic researchers also drew similar conclusions [21].

The objective of the study is the formation of a BIM free from the indicated shortcomings at the stages of identifying the scope of work and the formation and implementation of the construction production schedule.

2. Hierarchical vector description of BIM at the stage of identifying the scope of work on the project. The key point in addressing the above difficulties and based on this widespread introduction of BIM technologies into the practice of construction production is reducing the model dimension. It is the need to make use of high-resolution 3D models at the design stage of a building and structure that calls for costly material and human resources [22]. At the same time, only a small part of this information is employed at the remaining stages of the project. Moreover, practically essential data (nomenclature of structural elements, scope and sequence of work, etc.) must be obtained by means of high-dimensional models by using costly and highly skilled computer resources (e.g., visual object recognition systems) [23].

Addressing this downside of the existing BIM without losing the necessary information is made possible by designing an initial model based on a discrete vector data description. This is the approach set forth in the study.

The progress of modern construction largely relies on the widespread use of elements of industrial production (hereinafter - EII). Naturally, this process has received the greatest attention in the mass urban development [24]. However, even in individual and low-rise construction, the use of elements of a high degree of factory readiness makes it possible to reduce the terms of work performance as well as the cost and to improve the quality of a finished object [25]. Hence a considerable (and in industrial construction and critical) part of BIM can be based on the description of the list of EII and their attributes that influence the examined stage of the full BIM life cycle. The formation of a hierarchical dynamically added

and updated library of EII considering the possibility of their aggregation makes it possible to form the basis of BIM for industrial construction. At the same time, the dynamic nature makes it possible to considerably expand the area of practical application of this library and not only take into account the development of industrial construction production, but also, if necessary, to include non-standard or new elements. Such a combined dynamic library (hereinafter — CDL) is the information basis for the BIM of any construction project.

The natural shell for the implementation of a dynamic hierarchical library is relational database management systems (RDMS), the most common globally being the Microsoft Office Access shell. The choice of this shell as a means of implementing the ODB is due to the fact that it is an integral part of the Microsoft Office suite and sets low requirements on the characteristics of the technical platform. As a result, this RDMS has an interface familiar to the overwhelming majority of users. In addition, the data presentation format is compatible with the formats of other Microsoft Office applications (especially Microsoft Office Excel and Microsoft Office Word) where accounting and executive documents are implemented in most enterprises and organizations, which greatly facilitates the widespread implementation of the generated CDL and interaction between co-executors of projects. The relational nature of this DBMS makes it possible to separate the structure (whose development calls for the use of highly qualified personnel) and the content of the CDL. Updating the content of CDL for specific tasks does not require high qualifications of operating organizations and can be performed directly in construction organizations. The academic and educational institutions that make up the core developers have a free license program. On top of that, there is a generally available, unlicensed version of limited functionality. The legal transparency of the procedures for the exchange of the results of the implementation and improvement of the CDL considerably facilitates both interdepartmental and international cooperation. Thus, the approach suggested in the study makes it possible to completely address the problems of both designing and updating the information base of BIM, and its transfer between the project participants.

The hierarchical structure of the CDL is graphically shown in Fig. 3.

The fundamental structure of the CDL is a table of types of elements used, each element of characterized by two textual attributes. A fragment of this table for BIM of a typical development of the Voronezh region is shown in Table.

The next mandatory structure of the CDL is a table of standard sizes which assigns to each element of the table of types several elements that inherit all the attributes of the table of types with the addition of new data that have the format of an actual number and characterize the

geometric parameters of objects (e.g., the length and width for rectangular elements with the possible addition of a radius curvatures for arched elements, etc.).

Fig. 3. Hierarchical structure of the combined dynamic library at the stage of identifying the total scope of work for the project

Furthermore, based on the primary structures, clusters of an increasing degree of integration are consistently designed. The attributes of the i -th cluster are a list of clusters of lower levels (in text format) with an indication of their number in the format of a short integer and/or standard sizes with an indication of their number in the form of integers or actual numbers.

Table

Segment of the type table for BIM of the typical construction of the Voronezh region

Type	Technology
Room door	Metal plastic
	Wood
	Cardboard
Entrance door	Metal plastic
	Metal
	Wood
Flight of stairs	Monolith
Stair railings	Metal+wood
	Metal+plastic
Surfacing	Coating 1
	Coating 2
	Tile 1
	Tile 2

So, e.g., based on the table of standard sizes, a first-order cluster «Wall» can be designed. To do this, the following set of parameters must be specified:

- 1) length, height, height of the lower part;
- 2) types of surfacings of the upper and lower parts;

- 3) the number of standard sizes of windows, the number of each standard size, the distance of each standard size from the bottom edge to the floor;
- 4) the number of standard sizes of doors, the number of each standard size.

The horizontal coordinate characterizing the position of doors and windows has no influence on the volume of work, hence it is not included in the CDL. At the same time, an indication of the standard sizes of all elements is designed using the fundamental structures of the CDL and, within the framework of a relational RDMS, does not call for the repetition of textual attributes, but has an integer format, which causes a considerable decrease in the amount of analyzed and transmitted information. Clusters of the first order «Floor» and «Ceiling» are constructed similarly. Based on the first-order clusters, the second-order cluster «Premises» is designed. Integration can be continued further by designing the third-order clusters «Floor» using the «Room» clusters. The limits of the increase in the degree of integration (thick arrow in Fig. 3) are identified by the stability and frequency of repetition in the practice of high-order clusters in actual construction conditions. In particular, for mass scale buildings it is possible to integrate within the entire structure.

At the same time, with any degree of integration, BIM, which is fully functional for the stage of identifying the scope of work on the project, is one-dimensional and is simply determined by the vector of clusters of a lower degree of integration. This approach enables one to completely address all of the obstacles to the widespread introduction of BIM technologies and procedures for the full life cycle of a construction project. Let us estimate the ratio of vector and raster BIM description in the simplest case of a 3D model of a room. A full raster grayscale description of six surfaces, even with a minimum size of 107 pixels and a minimum practically usable number of gradations equal to 16, requires specifying an array of ~ 109 . The use of full color images considerably increases the amount of information required [26]. In contrast, a vector description, whose primitives are first-order clusters, only calls for six elements to be specified. Even while describing unique rooms directly through a non-clustered set of standard sizes, their number does not commonly exceed 101—102 and, more importantly, the components have a fixed number format.

Adding a list of works necessary for the formation of CDL elements allows one to design a BIM for the stage of identifying the scope of work for the project. Implemented in the Microsoft Office Access shell by the program, the CDL formation and analysis complex has the following functionality:

1. Hierarchical formation of sequential CDL elements up to the second stage of clustering based on the previous ones.

2. All higher-ranking clusters are automatically updated when data is refreshed.
3. Automatic analysis of CDL for connectivity and consistency.
4. Calculation of the scope of work required for the formation of CDL clusters.
5. Automatic updating is the amount of work required while updating data.

Conclusions. The high dimension of BIM of the full life cycle of a construction project curbs the implementation of information technology in the construction industry. The suggested BIM dimension reduction method based on a vector data model makes it possible to efficiently address the construction of a fully functional local information model for the stage of identifying the scope of work on a project. The resulting dynamic model has a hierarchical structure that describes objects of various degrees of integration, which makes it possible to effectively carry out BIM transfer between project participants, and the dynamic nature of the information model considerably expands the area of its practical application. The most effective framework for software implementation of a dynamic hierarchical library is relational database management systems. From a practical standpoint, the development of BIM of the full life cycle of a construction project calls for the agreement on the scope of work and non-stock resources for their implementation. It is also critical to investigate the dynamics of the project implementation. Besides, it is necessary to optimize the interaction of project participants based on BIM technology. These problems are to be tackled at the next stages of the study.

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