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Digital twins of complex technical systems for management of built environment

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Abstract. The development of digital technologies captures a significant part of the economy and production, as well as business and management processes. Asset owners are given the opportunity to become additionally owners of digital assets, while the need for conceptual approaches and digital asset management is growing. With the increasing application of Building Information Modelling (BIM) for asset management within architecture, engineering, construction and owner-operated (AECO) sector, BIM-enabled asset management has been increasingly attracting more attentions in both research and practice. The problem associated with the development and production of facilities is related to the discrepancy between as-built as-designed and as-is facilities or complex technical systems. During the stages of design, construction, operation and maintenance (O&M), the actually manufactured (i.e. as-built) complex technical object (or production infrastructure) differs, sometimes significantly, from the designed (as-designed), and at the same time inconsistency between the created production and production infrastructure within which it should operate grows. Solving the problem of discrepancy between the actually created and designed facility or the complex technical system, in the absence of digital technologies, requires considerable time for the so-called “trial operation”, during which the discrepancies are eliminated and a mechanism for managing production and production infrastructure in real conditions is developed. With the development of the digital economy, the need for digitalization of asset management is growing. An analysis of existing information technologies shows that there is a possibility of reducing the cost of production and operation of an asset by concentrating the main costs at the design stage. The article discusses basic approaches to organizing the lifecycle management of technical systems, production and infrastructure in the context of global digitalization which become a useful tool for reduction of trial operation time. Further directions of research are formulated

1. Introduction

The implementation of advanced production technologies in the context of digitalization of production and production infrastructure is facing a large number of gaps in information flows and corresponding information losses during the transitions between the stages of the digital asset lifecycle, which is primarily due to the lack of an integrated management system and adequate basic approaches, which will be considered in the article.



In this case, there are gaps both “vertical” and “horizontal”, i.e. during the stages of design, construction and O&M (operation and maintenance) phase, the actually manufactured (i.e. as-built) complex technical object (or production infrastructure) differs, sometimes significantly, from the designed (as-designed), and at the same time inconsistency between the created production and production infrastructure within which it should operate [1] increases. Solving the problem of the discrepancy between the actual created and designed facility or the complex technical system, in the absence of digital technology, requires considerable time for the so-called “trial operation”, during which the discrepancies are eliminated and a mechanism for managing production and production infrastructure in real conditions is developed.

This article reveals the essence of the described problem, and also offers basic approaches to organizing the lifecycle management of complex technical systems, production and production infrastructures in the context of global digitalization. Thus, the object of this study is the process of managing the lifecycle of complex technical systems, in particular, both their production and structural components. And the main tasks are: 1) analysis of the nature of the discrepancy between the actual production process and the technical documentation for the production system at different stages of the lifecycle of objects; 2) based on this analysis, the formulation of basic approaches to the management of complex technical systems in the context of digitalization of construction and production, and, finally, 3) the justification and formulation of areas for further research.

Moreover, if we are talking about production assets, which are buildings, structures and complex technical systems, such as petrochemical complexes, then digitalization is connected with the development of building information modeling (BIM) technologies. BIM (building information modeling) is primarily a process related to the management, lossless transfer and storage of information about an object with all its relationships and dependencies throughout the entire lifecycle - from research to direct operation. All technologies that support this process are called BIM technologies, and the models that are used are called BIM models. In this article, we primarily consider intelligent 3D models of objects.

The development of digital technologies in the areas of construction and production [2], stimulates a change in approaches to the design and operation of complex technical systems.

The relevance of digitalization of the construction industry is confirmed by the order of the President of the Russian Federation [3], according to which, in order to modernize the construction industry and improve the quality of construction, it is necessary to ensure:

- transition to a lifecycle management system for capital construction projects (hereinafter referred to as the management system) by introducing information modeling technologies;
- the use of standard models of the control system (design, construction, operation and utilization), as a matter of priority in the social sphere.

In the context of this article, the key is to mention concepts such as “lifecycle management” and “operational model of a management system”. Moreover, as of the beginning of 2020, in Russian normative documents mentioning BIM or digital modeling of buildings, the topic of operation is poorly disclosed [4] [5], mentioning only the requirements for operational documentation based on the project, that is, as-designed.

In accordance with the aforementioned GOST [4], the concept of “asset management” is defined as the implementation of all the functions and tools available to the organization - the owner of the asset or operating organization, designed to monitor the status of the asset and make decisions on the implementation of planned and / or unscheduled work services - from the generation of applications and work orders to the registration of actually implemented activities; on reconstruction or technical re-equipment; on decommissioning.

From the point of view of the classical division of the real estate management spheres into asset management, property management and facility management [6], the definition proposed in GOST is more suitable for describing a facility rather than an asset, since it focuses on the organization of technical operation of an object.

In this context, in our opinion, the understanding of “asset management” proposed by the ISO 55000 standard [7], which defines asset management as a coordinated activity to extract value from assets, is more appropriate. Under the general concept of “asset management” can be meant management of the value of enterprises, its shares and management of the value of the portfolio of real estate [8].

Normally, the income of the owner of a real estate asset depends on the time of delivery or use of the asset. At the same time, there are both fixed and variable costs depending on the time of delivery or use. Prompt decision making and forecasting operating costs play a key role for the owner or management company.

It is proposed to consider the following basic approaches to organizing the lifecycle management of complex technical systems, production and production infrastructures in the context of global digitalization:

- The introduction of BIM technologies not only at the design or construction stage, where this technology has already proven itself well but also in the operation of existing facilities, industries, and production structures (O&M phase) created before the advent of BIM technologies.
- Involving the potential owner of the asset (investor) and the organization operating the facility in the process of creating and designing the facility.
- The BIM model becomes the basis for the formation of a digital asset created on the basis of a digital twin of an object or a complex technical system.

According to current paradigm (using CAD systems), designed production infrastructure, buildings and structures, and the actually created object often do not correspond to each other [9]. The same applies to production, which is planned to be located within the existing production infrastructure. As a result, a mismatch arises between the actual production and the infrastructure, since losses and distortions occur during the transformation from the design stage to the O&M stage at the stages of the lifecycle. Figure 1 illustrates the increasing degree of the gap between manufacturing and manufacturing infrastructure.

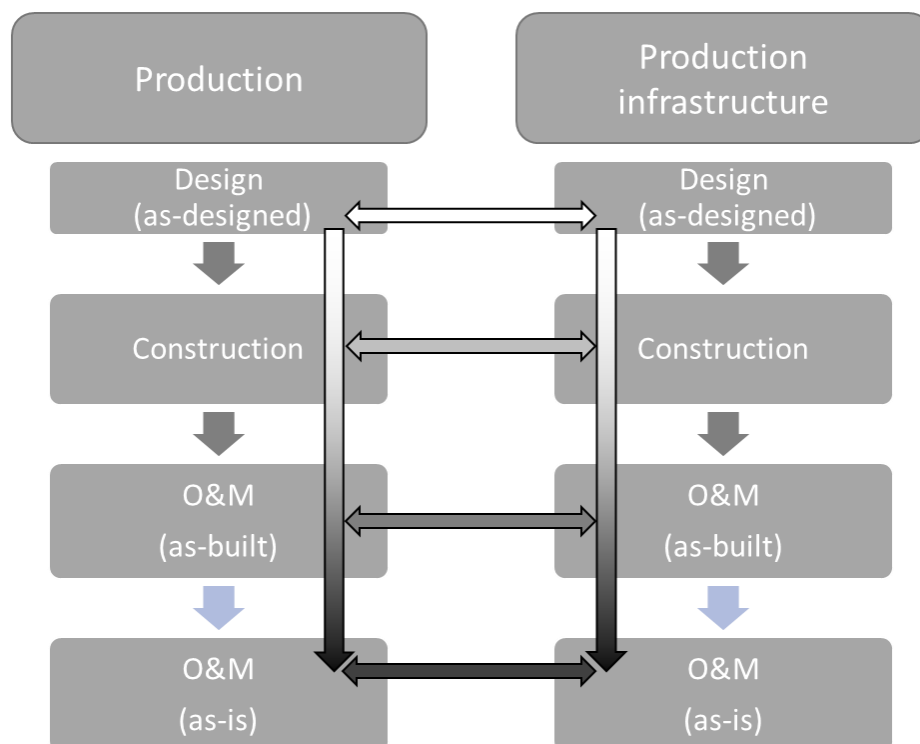


Figure 1. The gap in the coherence between production and production infrastructure during the lifecycle of the facility.

The key consequence of this gap is the “trial operation” stage, which takes time, the greater the increase in operating costs, the more significant and critical the errors and inconsistencies of as-built production and production infrastructure. During this stage, the so-called “childhood diseases” of the object are identified and eliminated [10].

Another significant problem that occurs in the current paradigm of managing the lifecycle of an object is the large role of the human factor [11]. Currently, the future owner of the asset or the operating organization is not sufficiently involved in the design process of the tangible and digital asset (the concept of a digital asset is disclosed later in the Results section). Nevertheless, it is the operating organization that should play a key role in the design of the facility, since it has to maintain it, manage the lifecycle and its cost, 80% of which falls on the operational stage [12]. In the case when the operating organization acquires a complex technical object containing the know-how of the developer, there may be cases of deliberate introduction of restrictions into the supplied documentation. The equipment manufacturer is often not interested in disclosing information about the features of his work.

The use of digital twins in the design and creation of products, in production, as well as in the production infrastructure (in the form of BIM-models of buildings and structures included in its composition) is becoming more widespread [13]. In this case, the key task is the matching of all the listed technologies in the process of managing the lifecycle of the created facility or a complex technical system.

A significant barrier to the digitalization of the lifecycle of an object is insufficient practical evidence of the payback of implementing information technologies in asset management. Real examples of implementation with real indicators are rarely found in the literature, which once again confirms the relevance of this study and the lack of real implementation of information technology in the process of managing the lifecycle of an object. Nevertheless, there are vivid examples of savings due to BIM not only during the design and construction period [14], but also during the O&M period [15]. One of the needs for further research is the study of practical examples of implementing information technology in enterprise asset management to generalize and formalize methods for creating and managing digital twins of asset (digital assets).

2. Methods

For real estate, in particular industrial facilities, thanks to the development of digital technologies today there is the possibility of creating an information model of the object. By an information model of an object, we mean a digital 3D model of the object, presented in the form of combined information about the geometric parameters of the object, and its qualitative characteristics, characteristics of materials, and other constant and variable parameters, their relationship. The information model of the object allows predicting a change in the state of the object depending on external factors and decisions made. This model is not a “digital twin” of the object, rather its “digital shadow” Whereas regarding the implementation of information technologies in real estate asset management, the key concept today is building information modeling of buildings (BIM) [16], in the field of digital automatic control systems (ACS), a definition such as SIM (system information modeling) is used. Both of these concepts are closely related to the management of information about an object, and it is of particular interest how these two approaches can be integrated into the process of managing complex technical objects both from a technological point of view, and from the point of view of economics, and operational cost management.

The current paradigm of creating an object or a complex technical system involves two initial stages: design and “trial operation”. The harmonized digitalization of production and production infrastructure makes possible the transition to a new paradigm: design and trial digital operation together in the first stage. In this case, it is supposed to conduct virtual experiments, adjust project documentation based on the needs of the stages of construction and operation with the direct participation of the construction and O&M organizations in the design process.

In developed under the guidance of A.I. Borovkov [17] the new paradigm of digital design and modeling of globally competitive products of the new generation (Fig. 2) presents matrix of target indicators and resource constraints, presented in a short report by the Competence Center of the NTI SPbPU “New Production Technologies” on the topic of digital twins in the high-tech industry [18]. Production experience can be used for digitalization of built environment.

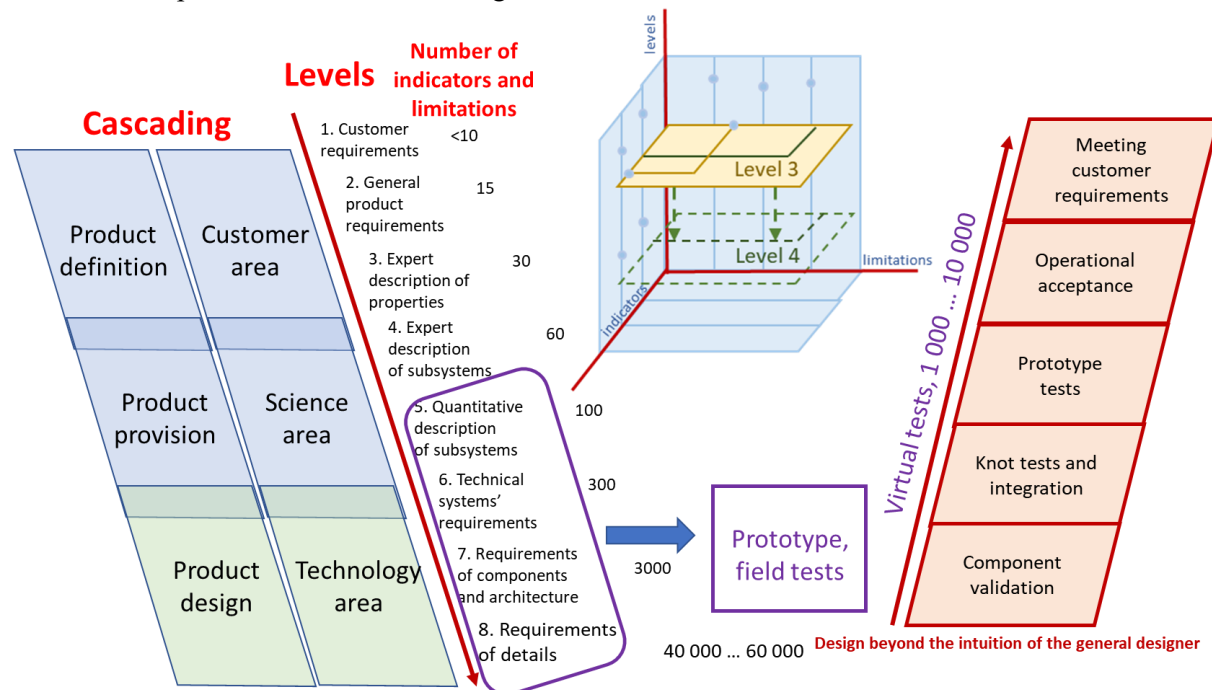


Figure 2. Matrix of target indicators and resource constraints [18].

3. Results

If we consider asset management in the context of the lifecycle [19], then the introduction of information technologies will significantly reduce the costs for the owner throughout the entire lifecycle of the facility, concentrate consideration of all possible risks and costs at the design stage, and minimize possible additional costs at the production (construction) stages and operation [20]. In other words, the owner of the asset using information technology receives tools for managing the value of his asset even at the stage of designing the object [21] with sufficient elaboration of the digital model, it becomes possible to predict the consequences of any decision with high accuracy. The digital information model of an object actually becomes a digital asset model, since it allows to simulate and predict the consequences of decisions. In this regard, the information model of the asset can be considered as a resource controlled by the company and capable of bringing economic benefits in the future, which means the digital model of the object itself acts as a digital asset. Digitalization of the economy leads to an increasing spread of the lifecycle contract both in real estate management [22] and in asset management in general. At the same time, there is a conflict between the desire of the company of the designer and builder of the facility to reduce the time of design and manufacturing and, accordingly, the cost of production on the one hand, and operating costs for maintaining and operating the facility on the other hand [23]. Digital technologies, introduced at all stages of the lifecycle, increase the transparency of the stages of design, production and operation, encouraging process participants to interact in an “open-book” system.

As already described above, digitalization is a tool for reducing the time of real trial operation (tends to zero with an improvement in the degree of elaboration of the design stage and modeling of operating processes).

The components of a complex technical system should be worked out at the design stage so that only simplified models with the necessary input / output data are used in the future. Accordingly, it is assumed to develop resource-intensive design of components, subsequently, the creation of a “smart” system.

There are a number of barriers to the implementation of information technology in the organization’s asset management process. One of them is the definition and formalization of information necessary for the creation, updating and use of an asset management model [24]. As in the case of the digital twin of an industrial facility, a digital asset can often be filled to a large extent with redundant data that is not of practical importance in the management process [17]. Digitalization of asset management should be aimed at creating highly intelligent management systems that use only the necessary information about the asset and its components.

Based on the foregoing, a transition from modeling to using an optimized database of simulation results is assumed. That is, a simplified model as part of a digital asset should be able to interact with the ERP-system (Enterprise Resource Planning), transferring to it the information necessary for decision-making at the operational and strategic management levels [25,26].

The described technique is actually applied in practice. The positive experience was illustrated by the authors in publications, including the description of laser scanning algorithms [27], generation of information models based on laser scanning data [28], strain monitoring [29] in existing objects, hybrid processing of laser scanning data [30], and so on. Globally, all developed technologies can be applied to create digital as-built assets that correspond to the real state of an object and change over time (as-is information models).

4. Conclusions

Thus, the following basic approaches to organizing the lifecycle management of complex technical systems, production and production infrastructures in the context of global digitalization are proposed:

- Implementation of BIM technologies not only at the design or construction stage, where this technology has already proved itself, but in the process of operating existing facilities, industries and production structures created before the advent of BIM technologies (O&M stage).
- Involving the potential owner of the asset (investor) and the organization operating the facility in the design process.
- The BIM model becomes the basis for the formation of a digital asset created on the basis of a digital twin of an object or a complex technical system.

A technological breakthrough will be possible when the formation and updating of a digital asset becomes natural as the asset itself is designed, built and operated. At the moment, there are requirements for the operational model reflected in GOST [4], but in reality they are not respected. The information model issued by the designer, not only does not reach the operation process, but also becomes irrelevant during the construction process, since the actual work projects are adjusted to the contractors, adjust the initial data and move away from the original information model. The intermediate step towards the technological breakthrough may be the widespread implementation of the following rule: construction and operating organizations are required to update the information model, which is actually a digital asset, in accordance with the adjustments and changes that occur during construction and operation.

Based on this study, the development of asset management methods by combining economic approaches and information technologies in the field of BIM and SIM, introducing a digital asset at all stages of the lifecycle of an object, including design, construction and operation, is of particular relevance in the future directions.

There are few examples of the practical application of asset digitalization and calculating the savings due to this, in connection with which there is a need to implement real projects for creating industrial and civil facilities based on digital technologies and formulating methods for assessing the economic efficiency of introducing digital technologies in asset management. Also of practical interest

is the analysis of changes in the trial operation time depending on the degree of implementation and development of a digital asset at all stages of the lifecycle.

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