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Actual problems of the full-scale digital twins technology for the complex engineering object life cycle management

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Abstract. This article discusses the problems that arise with the widespread digital twin technology introduction for complex engineering objects. Based on the nuclear power experience, various classes of problems are considered. They are related to the different information models and data demand structures and for life-cycle at different stages. As part of the industrial technologies transformation during the Fourth Industrial Revolution, information model & digital twin concepts have fundamental importance. Target effects and actual problems of the technology are analyzed. The enlarged stages of the life cycle, such as design, construction, operation, and decommissioning are considered. The focus of the technology analysis is selected large objects of the Rosatom Corporation. Possible trends in the full life cycle digital twins technology are considered development. The problems of preserving large volumes of structured digital data for long periods at many decades are discussed. The problem of changing the competencies of engineering and management personnel in connection with the digital transformation of the economy and industry during the Fourth Industrial Revolution is considered. It is predicted that it is necessary to increase the costs of implementing digital technologies to achieve the target effects of the digital transformation of the industry and economy.

1. Introduction

Within the industrial technologies transformation framework in the Fourth Industrial Revolution course that is taking place before our eyes, the concepts of the information model of a complex engineering object (CEnO) and its digital counterpart are of fundamental importance [1-2]. The information model of this paper will be understood as a structured system that describes the types of heterogeneous digital information about the modeling object. Such information includes:

- Multidimensional digital object models, potentially decomposable into systems and components;
- A list of attributes related to the object as a whole, as well as its complex components, structural blocks, and individual components. Attributes can be described by different data types (numerical values in the units defined in the systems, qualitative characteristics - both free and selected from closed lists, and others);
- Integral documents, or their links, or documents fragments can act as elements of information models;
- Information models can include descriptions of the behavior of the objects under consideration specified in a certain way (in the form of a relationship between external and internal

parameters specified by formulas, graphs, tables, algebraic or differential equations). These dependencies can be both deterministic and probabilistic.

- Other data types related to the essential characteristics of the simulated object..

2. Materials and methods

It is important to understand that the information model should provide an adequate description of the various situations and stages of the object under consideration, the dynamics of its parameters, and configuration throughout the entire life cycle from design to disposal. At the same time, the information model determines the structure of information about the object, the relationships of the essential parameters (including the external environment parameters in which the object is immersed). An adequate description of a complex engineering object is implemented through a complex of physical, technical, economic, and other data. At the same time, the data values themselves about the instantaneous object situations are not fixed by the information model. In fact, the set of these instantaneous values is a digital shadow of the simulated object at a specific time. The more accurately the digital shadow describes the current state of the simulated CEnO, the more information model adequate that generates it. At the same time, the information model adequacy is meant not so much the parameters volume is taken into account, but rather the essential nature of the regularities laid down in it for this CEnO.

Actually, it is reasonable to understand that the real-time digital twin is the dynamic set of digitized data listed above and accumulated in the format of time series. It is data sets tied to certain points on the time axis [3-4]. For functioning digital twins, the last current point on the time axis, to which data about the object is linked, characterizes its state at present. At the same time, it is important to understand that the real object and its digital twin exist in fundamentally different spaces. They are physical space/time and digital information space. An interesting feature is that a physical object exists only instantaneously in the present. It is fundamentally impossible to go back in time to measure its parameters. A digital twin can be scrolled repeatedly in the dynamics, "stopped" at a random time point, and analyzed in it. That is, the digital double simultaneously exists throughout the time during which information was collected up to the current present. The next digital twin feature is the ability to change the basic information model structure without changing the physical object itself. If we decide that it is necessary to fix some additional parameters, we can change the information model. We can fill the digital twin with new parameter values set from the moment of making the decision. Such a necessity may arise both due to logical reasons (analytically identified information model inadequacy), and due to changes in the physical object, for example, adding new components or subsystems to it

Currently, the entire global industry is at the transition stage to the use of digital twins as CEnO interaction tools. So far, the full scenarios range for such interaction is not fully clear. Digital twins are created by various organizations. They can be large corporations or small high-tech startups [5]. Accordingly, the accumulated effectiveness statistics of the digital twins usage in various situations is not yet sufficient. In general, the three digital twin technology application sectors can be considered. They are the complex engineering object digital twin, a market product digital twin, and a large series of specific engineering product digital twin [6]. For general reasons, the use of the CEnO digital twin should have significant engineering and economic efficiency. Experimental data in this area were obtained for several facilities in the field of nuclear energy, energy, and oil refining [7-8]. In many cases, there is an observed efficiency increase when using digital twin technology at the construction stage of the CEnO lifecycle [9]. The large-scale use of this technology actually began in the world about 10 years ago. The CEnO construction time duration is some years (till 10) as a rule. Significant experience for analysis has been accumulated so far only for the first stage of the life cycle. It is the construction of objects and their commissioning. At this stage, the digital twins creation basis were the technologies of BIM-design, network schedules based project management, and supply management systems. JSC IC “Atomstroyexport” is one of the industry leaders in the digital twins usage at the CEnO construction stage in Russia. It is GC Rosatom the engineering division. JSC EC “Atomstroyexport” developed Multi-D technology. This product designs technology-based BIM digital twins and time/ resource/ personnel digital management. During the construction of nuclear power units in Russia and abroad, Multi-D technology is widely used. It really makes it possible to significantly increase the rhythm and efficiency of the nuclear power facilities construction [10]. Similar data seem to be observed in the traditional energy sector, as well as in the construction of simpler facilities, such as modern office centers, as well as in complex centralized residential development. These conclusions are confirmed by the high rates of implementation of BIM-design systems in Russia and the world

At the same time, we observe certain contradictions with the thesis of high efficiency of the use of digital twins technology for all stages of the complex engineering objects life cycle. There is a tendency to include in contracts for the construction of CEnO conditions for the transfer of the information model and digital shadow of the object to the Customer at the time of its commissioning. Currently, such an approach is practically becoming the standard of contractual practice and is even included in the requirements of the national legislation of developed countries and in the recommendations of the IAEA. Some experience has already been gained in meeting these requirements of Atomstroyexport Company. However, it turns out that the obtained information models and data - filled digital shadows of objects at the time of commissioning are poorly used in the further operation of these SPI (at least in the energy sector) [11]. It seems necessary to analyze the reasons for this gap at least qualitatively. The first, most obvious reason is the different structure of the required information model of the CEnO for the construction and operation stages. At the construction stage, the most significant parameters are described by the implemented Multi-D model. It is during construction that the spatial configuration of the CEnO changes most rapidly. The integral target parameters of this stage are the fulfillment of the project deadlines, quality and cost of construction, equipment installation and commissioning. The final digital shadow of the CEnO includes, from the point of view of the contractor of the construction stage, a three-dimensional model, a list and installation schemes of equipment, the final cost of the object (determined on the basis of acceptance documents for the object). The modern format for presenting this data is a comprehensive BIM project (can be transmitted as a digital copy or generated output forms) and accounting data for transferred fixed assets. Thus, at the operation stage the most dynamic parameters of the information model are data on technological modes of operation of the entire engineering complex, its individual systems and pieces of equipment, the consumption of material resources during the operation of CEnO and commodity products, as well as the economic parameters of the operational business enterprise, including personnel costs and staff efficiency. It is obvious that the detailed information model of the object at the life cycle previous stage corresponds to the required digital twin information structure at the operational stage only as initial conditions that practically do not change during operation. At the same time, the information models of the object as a whole, technological systems, equipment units and engineering communications received from the contractor are described by designers, builders and installers from the point of view of their own needs in the first place [12]. Attributes and parameters that are essential for operators, technologists and repairmen are often simply unknown to designers and are not elementary laid down by them in the information model structure [13]. The opposite is also true. Data structures for the information model at the stage of construction of the object, including the BIM model of the entire production complex, are poorly demanded and used by operational personnel in their daily activities. A separate difficulty is presented by the features of the software for BIM modeling. This software is quite complex and expensive. In addition, it requires a high and specific qualification of users, even if they do not participate in the development of the project, but only work with already created solutions. Although the BIM model can be useful for certain operational tasks, today in practice they are only used if the operation and construction are carried out by the same organization. Naturally, this leads to the loss of relevance of the developed BIM models, and also often leads to the loss of digital data as unclaimed, despite the fact that data storage requires certain, albeit small costs.

We also note one more risk that accompanies the modern approach to engineering design data digitization. "Hard" (paper) copies of documentation are human-readable almost indefinitely. But versions of electronic document formats tend to change quickly. The versions of high-tech engineering software themselves also change with high frequency. At the same time, leading manufacturers guarantee compatibility of software versions with data formats to a small depth. It is no more than a few years as a rule. At the same time, even simple structures rarely have a service life of fewer than 25 years. Complex and responsible objects, such as nuclear power plants, dams, bridges, and engineering infrastructure of cities have a lifecycle period of one hundred years or more. During this time, there is a change and reorganization of project operating organizations, deep retraining of their personnel. To recompile the digital information models and twins for a complex engineering object in a software new version, at least error-free data loading in previous forms, updating the format, and uploading updated data files are required. At the same time, the failures and collision occurrence is not excluded. Their identification and elimination will require the intervention of qualified personnel. As a result, model relevance maintaining at a many decades time distance is not yet a proven task. It is necessary to plan resources and monitor the progress of this implementation.

3. Results

The object digital shadow is extremely popular during the transition to the stages of its decommissioning, deep modernization and reconstruction, and repurposing. In the event of loss of data from the digital twin of building structures, engineering networks, general and technological equipment, these sets of operations will require, in fact, a full-scale reverse BIM redesign. This is especially important when decommissioning particularly dangerous facilities, for example, radiation-hazardous facilities, as well as production facilities contaminated with toxic components [14]. The cost of time and resources for design, in this case, will significantly exceed the cost of maintaining and updating the BIM model throughout the operation.

In general, the stages of reconstruction, deep modernization, and decommissioning according to the information model structure requirements should strongly correlate with the life cycle first stage picture. Accordingly, the economic and engineering efficiency of these stages should increase in a certain way when using end-to-end digital twins. Thus, the costs of maintaining digital twins in the end-to-end full life cycle of the CEnO can be justified. However, to date, such data is clearly insufficient, and decision-making depends entirely on the information and skills of management, the strategic nature of its thinking. At the same time, of course, full life cycle digital twins will be created for specific industries. In particular, such a task is set in the Rosatom State Corporation. The task is made relevant by the requirements of safe operation and the very expensive process of decommissioning power units and other nuclear energy facilities that are currently unfolding [15]. It is also known that large oil, energy, chemical, and metallurgical companies are beginning to work with digital twins on the full life cycle of the CEnO. We can expect confirmation of the engineering and economic feasibility of the technology from large-scale users, development of the main algorithms for its use. It will be a replication for most of the created SPIs in the coming years.

4. Discussion

We will focus separately on the decommissioning nuclear power facilities task. In this case, digital engineering technologies for working with complex digital twin are logically integrated into the standard classical action plan-starting from planning and performing a comprehensive engineering radiation survey, continuing with planning decontamination and dismantling of equipment, engineering communications, buildings and structures, performing this complex of works and carrying out final control of the state of the dismantled (or deeply reconstructed object). The stages of the program can be designed, modeled and controlled using a object digital twin, which includes accumulated data from both the initial design stage and the entire operation experience. Naturally, in the course of work, the digital twin is continuously changing based on the received data [16]. At the same time, it is possible to perform predictive analysis of the consequences of decisions made by modeling in the framework of a digital double at any time. Digital tools of this technology are being developed both by a number of Rosatom’s subsidiary companies and by external contractors. The

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tasks of nuclear power facilities decommissioning arise and will continue to arise in the coming years both in the Russian Federation and in all countries where Russian-designed nuclear power plants were operated. In most cases, these are the countries of Western Europe, where the requirements for information modeling of engineering processes are actively included in national legislation. Therefore, the development of the technology of working with digital twins of radiation-hazardous SIO is not just an economic advantage, but a necessary condition for Rosatom's subsidiary companies to enter the world markets.

Today, the world is certainly facing a technological gap. All large-scale industry enterprises (nuclear industry enterprises and other fields) that are being decommissioned today were built many decades ago. At that time, of course, digital modeling technologies were absent. Design data, as well as data on the course of operation, are available in an unstructured form without a digital model. Design data is presented in the form of paper drawings. Even for Rosatom enterprises that did not survive the change of ownership and engineering and technological collapse after the USSR's destruction. Some design data may be lost. For the described tasks that require the construction of digital information models and digital twins, it is necessary to perform reverse engineering design procedures. It is the translation of design and operational documentation from paper to digital form. To date, this task is most acute for the above-mentioned reasons for Rosatom State Corporation. The result of its successful solution will be a number of consequences. First, safety will be improved and the costs of the nuclear power facilities decommissioning in the Russian Federation will be optimized. Equally important may be the technologically leading position of enterprises and/or contractors of Rosatom Group in the field of creating digital twins of the historically accumulated industrial and infrastructural heritage of previous stages of economic development [17]. At the same time, it is obvious that it will be necessary to use both the technology of working with complete or almost complete sets of paper design project documentation, as well as full-scale surveys and engineering analysis for CEnO partially or even completely lost data and documents. Such competencies are currently in short supply in the field of digital engineering, not only in Russia but also in the world. The acquisition of these competencies can allow their future owners to capture large regional and global markets of the booming Industry 4.0 economy. In this situation, companies that organize the future modernization, reconstruction, and decommissioning of complex engineering facilities need to acquire a fairly wide range of new competencies (by their forces or through contractors) and select available data sources in all formats. To date, these events have been deploying until sufficient wide class of software, adequate facilities for storage and processing, staff training, and allocation of resources for its operation are not provided in the estimates even in Rosatom State Company. Thus, the digital twins method for the decommissioning stage has not yet been widely implemented, although it is actively discussed. And before its implementation, it is possible to justify engineering, technological and economic effects only speculatively and qualitatively.

A separate problem for the digital twins technology implementation to the CEnO end-to-end life cycle management is the problem of the lack of appropriate personnel at all levels. In the first approximation, we can distinguish three levels. They are the level of managers of an organization or large projects, the level of heads of specialized departments and leading specialists, and the level of line personnel who directly build digital models and fill digital twins data. It is important to understand that each level corresponds to its competence and motivation. Because of the extremely rapid development of technology, the actual course of the next industrial revolution, even conceptual understandings change before our eyes, in a few years. The system of education in all forms has not yet been adjusted-from basic bachelor's degree programs, through specialized master's and postgraduate programs, to the system of additional professional education for middle-and senior-level specialists of high-tech organizations. Naturally, at the same time, competencies, knowledge, and skills at all these stages should be specific, set up to achieve the goals of sufficiency and demand for acquired competencies at a specific level, at certain workplaces and areas of responsibility. So, for young professionals, it is important to know the primary tools for designing information models and digital twins, as well as effective methods for filing them with real data. At the level of mid-level specialists, it is important to have the ability to build criteria for building the structure of information model and digital twin, knowledge of the limits of the possibility of modern methods, achievable results, as well as the ability to assess the time and resource costs to achieve them. Managers need to give a concept of those integral effects in the field of efficiency, manufacturability, and economy, which the CIP full life cycle end-to-end digital twins technology on the allow to achieve.

5. Conclusion

In conclusion, it should be noted that the digital twin technology development as one of the basic elements of the fourth Industrial Revolution is inevitable. It is necessary to carry out a large amount of work to eliminate the already identified problems for full-scale implementation and the manifestation of target effects. It can be predicted that the large number and complexity of tasks will be increased in the future. Howev-er, as a result of their successful solution, we will have a full-scale digital transfor-mation of all spheres of life. One of the most important and popular areas of such transformation is digital transformation management of the life cycle of complex engineering objects.

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