Reengineering of organizational and technological processes of NPP construction

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Abstract. Nuclear power construction is characterized by high capital costs, a significant number of participants in the design and construction processes. One of the most significant factors of the efficiency of NPP projects implementation is the adopted technology for the construction. An analysis of the Soviet and modern experience in the NPPs construction allows to assert that the piece reinforcing application leads to an increase in the project implementation time. The technology of large-block assembling of NPP structures and equipment have been widely used by the world leaders in NPPs construction, but the implementation of this technology required significant costs for the organization of the necessary infrastructure. In the context of the rapid development of computing systems, instrumentation and mechanical engineering, it is proposed to fundamentally rethink the processes of NPP construction. It is proposed to return to the technologies of large-block installation of NPP structures by switching from rail lifting mechanisms to pneumatic wheels, by robotizing the processes of enlargement and installation of structures and equipment. The functions of managing and making organizational and technological decisions can be partially transferred to a specially developed neural network that has access to an array of data on previously implemented projects. This approach allows us to consider the NPP construction project as a cyber-physical system and opens the way to a whole range of areas of fundamental and applied research in the field of technology, organization and management of the construction of NPP.

1. Introduction
The construction of objects using nuclear power (OUNP) is a complex process in which dozens of survey, design, construction, installation and commissioning organizations can simultaneously participate in only one project. The long period of project implementation, high capital costs, significant technological complexity of the work performed determine the urgent need for systematic accumulation, systematization, and analysis of the historical and current experience of the construction of the OUNP. This experience, transferred within the framework of organizations and enterprises, labor collectives, enclosed in the archive of design and working documentation can and should be used in the development of new space-planning, design, organizational and technological solutions.

The stagnation of nuclear power construction in the 90s and early 2000s inevitably led to the loss of some of the experience gained in the Soviet era in the construction of nuclear power plants (NPPs), which was clearly demonstrated in the construction of modern Russian NPPs in Novovoronezh and Sosnovy Bor. The two-block Novovoronezh NPP-2 and Leningrad NPP-2 are power plants of the «NPP-2006» project and they were conceived as transitional to the VVER-SOI project (Standard, Optimized
and Informatized), which demonstrates a steady trend towards the full-scale introduction of advanced information technologies, methods and forms of work organization and execution into the NPP construction process.

2. Materials and methods
The organizational and technological specifics of the construction of the OUNP can be clearly demonstrated in the analysis context of the approaches development to the construction of nuclear generation facilities in the USSR and in the world.

Due to lack of development of engineering and transport systems in the building structures construction, the first domestic NPPs was used primarily piece (elementwise) installation of fittings or used flat reinforcement cages, nets and small-panel removable formwork. Numerous embedded parts and sinkholes were installed directly on the construction site. However, already in the first years of construction, the key shortcomings of this approach were identified: insufficient accuracy and quality of construction work (CW), excessive saturation of the work front with labor resources.

To solve these problems and reduce total labor costs in the NPP construction since the early 70s of XX century in the construction process have been actively promoted pre-assembly of reinforcement and formwork elements as well as embedded parts in the units on special stands construction base (CB). However, the disadvantage of this scheme was the increased metal consumption (by about 15 %), which is necessary to ensure the transport and installation rigidity of the elements [1].

A further development of the approach of block installation of NPP structures was the creation of a generating center at the preparatory stage of construction, in addition to the developed CB, a complex of construction industry enterprises that were focused on the production of large-sized heavy blocks of building structures of high factory readiness. Vivid examples of the long preparatory phase with a wide CB development transport infrastructure and construction the construction industry enterprises are the projects Balakovo and Zaporozhye NPP [2].

During project implementation the Balakovo NPP, the high complexity of works on the reactor building construction has been partially solved using super large blocks collected on specially designed and manufactured mobile Plaza jigs, moving along the rail with CB in the area of the unique lifting mechanism, crane K2x190. The use of this lifting mechanism allowed to installate the elements weighing up to 380 tons.

The use of large-block volumetric installation of structures, and other technological and engineering innovations made it possible to organize a flow-through method of construction power units at the Balakovo NPP, which significantly reduced the construction time [3, 4]. The brigades, specialized organizations and divisions, having completed their scope of work on one power unit, lost no time in moving to the construction of another, where they again performed the already well-mastered operations. The first power unit of the Balakovo NPP became a kind of testing ground, where a new technology for the construction of a high-tech facility was developed, the personnel potential was formed, and shortcomings in the project documentation were identified and eliminated.

A large-scale involvement the most creative and progressive layers of society - students, has become very important for all domestic experience in the construction of NPP. The announcement of the Balakovo NPP as an All-Union Komsomol Shock construction site made it a place of attraction for highly motivated and qualified representatives of the Student Construction Brigades (SCB) movement. The student’s participation in the implementation process of important economic facilities of the USSR allowed to compensate for the labor shortage in the construction industry and also significantly contributed to the implementation of innovative activities. At the same time, the SCB movement itself was in the process of developing, constantly improving and transforming its own organizational structure [5, 6], as well as ensuring the formation of the personnel potential of the construction industry [7].

No less significant example of systematic improving the construction processes of unique construction objects was the Zaporozhye NPP construction. The advantage of choosing the site for the construction of this power plant was the presence of a developed CB and transport infrastructure, created
earlier during the construction of the Zaporozhye NPP. The construction of the NPP was carried out by the flow-rate method, which allowed to reduce the time of construction work at the main facilities. The step of putting power units into operation was one or two years (in 1985, the first power unit was put into operation, power unit #2 - in 1986, power unit #3 - in 1987, power unit #4 - in 1988, power unit #5 - in 1989), which was a good indicator for that period.

At the CB itself, the equipment and structures were enlarged into large-sized heavy-weight blocks. To implement the installation of large-sized blocks, the corresponding scheme of construction mechanization of the main building was designed. During the construction of the Zaporozhye NPP, a powerful CB was formed, reinforced by a complex of construction industry enterprises that produce metal and reinforced concrete products and structures. Large-scale assembly of armometallic blocks of design cutting into assembly blocks was carried out at the CB landfill with gantry cranes.

After the Chernobyl accident, society, including under pressure from environmental organizations, began to form a negative attitude to the construction of new NPP and nuclear energy in general. The large-scale disaster forced experts around the world to reconsider the problem of NPP safety and to think about the need for international cooperation in order to improve the safety of high-tech facilities.

In the following years, the development of projects for a new NPP generation with increased safety began, both from the point of view of improving the control and NPP management, and from the point of view of localization the possible consequences of severe accidents. In Russia, further improvement of safety systems is reflected in the «NPP-2006» projects [8].

In the «NPP-2006» project, the power unit is equipped with two protective shells with a ventilated space between them, the inner protective shell ensures the tightness of the volume where the reactor plant is located, the outer shell is able to withstand natural (earthquakes, floods, hurricanes, tornadoes) and man-made (plane crash, external explosions) impacts on a high-tech object. Also in this project, a system of passive removal of residual heat is used, which provides long-term heat removal from the reactor core in the absence of all power sources. A passive filtration system is provided between the outer and inner protective shells of the NPP power unit, which makes it possible to exclude the release of radioactive products into the environment through the outer protective shell in any situations associated with the failure of the active special ventilation system. A melt localization device located under the reactor vessel was installed [9].

The new technological systems created to meet the safety requirements significantly complicated the project and led to an increase in the construction volume of the reactor building, which is clearly seen in figure 1.

![Figure 1. Superimposition of plans and sections of the reactor building of the old and new generation NPPs: black - the unified project of the NPP with VVER-1000; gray - the project «NPP-2006» of the new generation.](image)

The «NPP-2006» project implementation involved the construction of two-block Novovoronezh NPP-2 and Leningrad NPP-2. The construction of these power plants was based mainly on the use of piece reinforcement and element-by-element installation of structures and equipment, which in practice
led to a significant increase in the established construction time and estimated cost. In part, this approach was justified in the context of parallel design and the lack of sufficient experience in implementing similar projects in modern Russia, but already in the process of implementing the CW, the issue of improving the concept of constructing the main structures of NPPs became acute.

In addition to the chosen construction technology, the duration of the construction of Novovoronezh NPP-2 was influenced by a short preparatory period (about 15 months) and the creation of a minimum CB [10]. In practice, this led to an increase in the duration of the construction of the NPP due to the inability to fully use the worn-out funds of the Novovoronezh NPP production base, as well as the technological complexity, significant labor intensity and duration of work on the construction of monolithic structures of the reactor building. Based on the analysis of the implementation of the Novovoronezh NPP-2 project, it was decided to partially return to the use of a longer and more capital-intensive stage of preparation for construction production in the NPP construction project, which is extremely important in the implementation of modern NPP projects.

The existing experience of the Leningrad NPP-2 construction also demonstrated the problems associated with the project implementation. By analogy with the Novovoronezh NPP, a large number of contractors and subcontractors were involved in the project. At the same time, most of them did not have sufficient organizational and technological experience, due to the previously mentioned stagnation of nuclear power construction in previous decades. In practice, this led to a series of accidents on the construction site. In 2011, the reinforcement frame section collapsed in central hall of the first power unit of the NPP. In 2015, another incident occurred, which led to an adjustment of the planned project implementation dates and an increase in the cost of the Leningrad NPP-2 construction. From a height of 20 meters, a block of protective pipes of a nuclear reactor weighing 70 tons fell, which was completely disabled as a result of the impact. Also, due to the fall of the protective tube block, the spent nuclear fuel holding pool was damaged.

It should be noted that a number of the adopted design decisions of the modern power units of Novovoronezh NPP-2 and Leningrad NPP-2 had to be revised after the start of construction. It was clearly demonstrated that the piece reinforcement technology of reinforced concrete structures and the use of traditional formwork lead to high labor costs on the site and, as a result, to an increase in the duration of construction. The construction period of Novovoronezh NPP-2 power unit #1 was 98 months, and power unit #2 - 118 months. The construction of power unit #1 of the Leningrad NPP-2 took almost 113 months, and power unit #2 - 126 months. Historically, the shorter construction time was demonstrated by the method of constructing a power unit using enlarged reinforced formwork blocks. For example, the construction of power units #1, #2 and #3 of the Balakovo NPP took 61, 75 and 74 months, respectively. The terms of construction of power units #1 - #5 of the Zaporozhye NPP did not exceed 60 months. In less than 45 months, power units #1 and #2 of the Japanese NPP (Kashiwazaki-Kariwa) were built. These indicators are impressive even if we take into account the significant complexity of modern NPP projects relative to their predecessors.

Initially, the technology of piece reinforcement used at Novovoronezh NPP-2, when the reinforcement is knitted manually on site, assumed a reduction in the total area of all CB sites and was supposed to be about 25 hectares. The relatively small size of the above CB was explained by a number of reasons:

- the construction was carried out in-situ reinforced concrete, and not in precast, as had been the case, therefore, the project lacked shop, polygons for the production of concrete slabs encasement connecting metal trusses, platforms for the assembly of wall unit-cells, etc.;
- theoretically, there was no need for a large number of powerful lifting cranes focused on pre-installation enlargement of structures;
- the planned delivery of almost all embedded elements, sinkholes was supposed to be from centralized plants without mandatory temporary storage at the CB.

For comparison, in the NPP construction with VVER-1000 reactors square CB traditionally made of 60 hectares (60% of the area occupied strengthening and assembling area building structures and technological equipment, 20% are warehouses, the rest area was occupied by the workshops).
However, the actual area of the Novovoronezh NPP-2 CB turned out to be much larger than planned, since the piece reinforcement technology led to increased labor costs at the construction site, and was changed during the project implementation. It was decided to perform part of the work on the construction of the reactor containment area using massive armometallic structures and non-removable steel formwork-lining, which led to the need to increase the production area at the CB.

During the Novovoronezh NPP-2 and Leningrad NPP-2 construction, it was revealed that the installation of piece fittings in massive structures of high-tech objects (the foundation plate of the reactor building) takes much time, so it would be advisable to automate this process. The experience of constructing 6-7 power units of the Japanese Kashiwazaki-Kariwa NPP is an example of this approach. As part of the construction of the 6th power unit of this project, an automatic machine for lifting scaffolding and horizontal reinforcement feeding was developed and used, which significantly reduced the labor costs for piece reinforcement and increased the accuracy of positioning the penetrations [11].

Improved based on the experience of the 6-th unit construction of the automatic machine for assembly of reinforcement cages allowed to collect rebar into blocks by automated operations in accordance with the data about the location of the valves, which were loaded in the memory of the machine from the developed information model. This machine was used at the 7th power unit of the Japanese Kashiwazaki-Kariwa NPP in order to increase the efficiency of assembling large volumes of valves by factory manufacturing. One of such machines was used to meet all the needs of the NPP construction site. This machine was able to double the capacity of the valve assembly and thereby reduce the construction time of the NPP [12].

The projects of modern NPPs include a huge number of welded joints, both structural components and components of sealed systems, most of which are performed manually. High-quality welding is crucial and requires a long time, so increasing the level of automation of this process contains a significant reserve for reducing the construction time of high-tech facilities.

Methods for increasing the deposition rate of the seam metal while maintaining high quality through automation can help to reduce the construction time. It should be understood that automation of welding processes can be effective only if high-quality preparation of factory products and their accurate pre-assembly. Excess edges, the presence of notches, inaccurate joint lines can negate all efforts to optimize the work of the welding site.

Automatic welding equipment was used to weld pipelines during the Kashiwazaki-Kariwa Unit 7 of the Japanese NPP construction. This equipment facilitated welding in narrow spaces and thus shortened the construction time of the NPP. In order to ensure the correct use of advanced welding technologies, a systematic review of the use of automatic welding equipment was carried out during the entire period of construction of the Japanese NPP. The inspectors who were selected to carry out all the inspection activities during the construction of the NPP were properly trained and trained [13].

In addition to the automation of construction work is an important aspect in reducing the construction time of high-tech facilities is the multidimensional design technology, which allows you to determine and work out the sequence of operations during construction, which makes it possible to adjust the time schedule of work and reduces the construction time of NPPs.

The technology of multidimensional modeling allows us to get an idea of the production process and provide high-quality management of the construction of high-tech objects (the method of visual planning) [14]. This technology has a number of advantages, since it provides a visual representation of the mutual placement and linking of various elements of equipment, linking them to walls and ceilings, which in turn reduces the time of work on finalizing project documentation and reduces the number of collisions that occur on the construction site [15].

According to [16], the volume of work on correcting the working documentation without the use of multidimensional modeling can reach 12 % of design work in total, and thanks to clarity and early identification of possible collisions, this figure can be reduced to 2 %.

Usually, there is a real-time connection between the drawings and the multidimensional model, and all changes made to the model are automatically updated in the drawings and vice versa, which is a significant advantage of this technology.
All multidimensional models have the necessary information (size, weight, design position, etc.) in a single database, which is also available for manufacturers. This database allows you to automatically compile lists of material costs, select and specify equipment, which significantly increases efficiency by providing all routine processes to electronic computers and thereby reduces the likelihood of errors that can affect the timing and cost of construction of NPPs [17].

3. Results
This is the first step towards creating a neural network for the construction of high-tech objects. Electronic computers of the USSR in the 70s - 80s of the XX century did not have sufficient speed to process existing and emerging data arrays in real time. This did not allow us to work out the entire possible variety of simulated situations during the construction of NPPs, but now this obstacle has been overcome and favorable conditions are being formed for large-scale digitalization of the design and construction of NPPs.

Over the past decades, scientists, engineers, and programmers, drawing on the experience of their predecessors, have overcome the barriers of computing power and presented the world with new technological wonders of incredible power [18].

The introduction of existing technologies in the construction production of NPPs is necessary, since these technologies make it possible to process large amounts of data at high speed and predict the output parameters of simulated situations with a high degree of probability, taking into account the risk assessment and optimization of the flows of basic resources [19]. This is achievable due to the ability of neural networks to generalize and identify hidden dependencies between input and output data, which will take a significant amount of time for a person and the probability of error when processing a large amount of data is quite high.

The most important stage of creating a neural network for the construction of a NPP is its training, and the prospects for its practical implementation depend on the successful completion of this stage. Training is based on the downloaded data, which is why it is so important to provide the available information (experience in the construction of NPPs) to neural networks.

After training, the neural network is transformed into a highly effective tool that can predict and provide optimal solutions for the implementation of new NPP projects based on the experience of constructing high-tech facilities. Also, in real time, the neural network is able to predict the results according to the selected criteria or their combination based on the incoming information about the state of the main organizational, technological and managerial situations at high-tech facilities under construction.

Thus, it becomes possible to instantly process incoming data from the object under construction, which accelerates and facilitates the process of making organizational, technological and managerial decisions both at the planning stage of the construction process and during its production [20]. This solution will in the future reduce the financial costs of building a NPP by reducing the number of employees who carry out technical supervision and support decision-making [21].

The use of modern technologies in the NPP construction in order to automate processes and reduce the construction time of high-tech facilities is a necessary task. Processes such as the introduction of multi-dimensional models in the database, pre-assembly of cutting units design in the assembly and erection of blocks in the design position using lifting devices can be linked into a single network of information interaction.

For example, at the Balakovo NPP, a K2x190 gantry crane was used on a track with a lifting capacity of 380 tons, but the key problem of this crane was the rail tracks that blocked the entrances to the power unit under construction. This crane was in test mode and was specially created for the construction of the Balakovo NPP.

The power of modern technology and development of pneumatic construction equipment it is possible to create the same unique K2x190 gantry crane gantry crane on rubber-the-go with its connection to a single network information interaction, which in theory would increase the speed of construction of NPPs [22]. This solution will allow you to automatically assemble the design cutting
blocks into assembly blocks according to multidimensional models, which will be uploaded to the database with all the necessary information (the characteristics of the blocks and their design position). After that, it is possible to automatically perform the installation of the assembled blocks in the design position, which will provide the probability of minimizing the role of a person in this construction process. In this case, a person will be assigned the role of an observer and controller of the process of building an NPP.

4. Conclusion

Large-scale digitalization and informatization of all construction subsystems can rightfully be a significant driver for the development of nuclear power construction. Reengineering of the Soviet, modern Russian and world experience in the construction of NPP, carried out with a full-scale involvement of advanced information technologies, will transform the existing conservative concepts of design, manufacture, transportation, installation of building structures and equipment for nuclear facilities. The robotization of the construction process will fundamentally transform the role of a person in the construction of high-tech facilities, reduce the proportion of manual labor, provide a condition for the full-scale application of the hybrid-block method of assembling structural elements and NPP equipment, and increase the quality and speed of CW. Linking a single information system of logistics processes and robotic construction of the main NPP structures will reduce the overstocking of warehouse space, balance material flows, simplify the process of communication between customers and suppliers, and positively affect the reliability of individual participants and the entire investment and construction project as a whole [23].

Summarizing all above, it can be argued that currently there are objective prerequisites for considering the NPP construction project as a cyber-physical construction system [24]. The accumulated statistical data on the implementation of analog projects and prototypes form the basis for working with big data. The concept of the Internet of Things, implemented by equipping NPP structures and equipment with means and technologies of interaction with each other and the external environment, significantly reduces the involvement of a person in a few routine technological processes, and will free up significant labor resources. Cloud computing, multidimensional modeling, robotization of construction processes, the introduction of additive technologies, which have proven their effectiveness in various sectors of the economy, are relevant and popular tools for the implementation of projects for the construction of high-tech construction facilities, including NPP.

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