Proceedings of the 3rd International Conference on Green Energy, Environment and Sustainable Development (GEESD2022), X. Zhang et al. (Eds.)

doi:10.3233/ATDE220276

Intelligent Design and Construction Coordination of Nuclear Power Based on Digital Twin

Chao GUO[1], Xinwei XU, Jiakun HU, Jie ZHANG and Zhigang ZHOU
State Key Laboratory of Nuclear Power Safety Monitoring Technology and Equipment, Design Institute, China Nuclear Power Engineering Company Ltd., Shenzhen, Guangdong Province, PR China

Abstract. Digital twin is a computer informational transformation technology of "combination of virtual and real", it is accelerating the implementation in various fields. Based on the digital twin technology, relying on 3D design model of nuclear power plant. To use the method of modular design, this paper combed the relationship between the three-dimensional model and construction progress, established the corresponding relationship of model granularity at different levels, and used VR/AR technology for simulation to construct the 4D nuclear power plant model realizing the collaborative design and construction of nuclear power project. This paper has studied and adopted artificial intelligence algorithm and developed the software of intelligent layout of nuclear island pipelines in nuclear power plant, which has realized the intelligent layout design of nuclear power to a certain degree. On the basis of the above research and application, aiming at the cost of the design and construction of nuclear power plant, this paper expands the 3D and 4D models of nuclear power project to 5D model, and further studies the 6D model of nuclear power project based on the technology of digital twin, so as to meet the needs of operation and maintenance, simulation test and asset management after the completion and handover of nuclear power plant. Because of the development of chip, sensor, internet of things, software algorithm, machine learning and other technologies, digital twin will have more imagination space for application.

Keywords. Digital twin, nuclear power, artificial intelligence, virtual reality, augmented reality, building information modeling, design and construction coordination

1. Introduction

The engineering design of nuclear power project has long developed from traditional two-dimensional drawing design to three-dimensional digital design. The 3D design has the characteristics of visualization, multi professional collaborative design and digital model handover. Nowadays, the three-dimensional model has further developed to the 4D model. The 4D model is the concept of 3D model plus time sequence of nuclear power plant. It includes the sequence of each design discipline in system design and

[1] Corresponding Author, Chao GUO, State Key Laboratory of Nuclear Power Safety Monitoring Technology and Equipment, Design Institute, China Nuclear Power Engineering Company Ltd., Shenzhen, Guangdong, PR China; Email: charlesguothu@126.com.

layout design, as well as the schedule and correlation of nuclear power project construction. In essence, it is a 3D model plus time dimension attribute.

Visual construction is a hot research and application direction recently. It is mainly to add the construction related attributes to the object data in the 3D model, so that various equipment, bulk materials and other items can be connected with the installation work package with time attributes, so as to realize the 3D model from layout design and push it to guide the on-site construction. The introduction of building information model (BIM) technology and platform has the characteristics of visualization, parameterization and fast information transmission. Combined with virtual reality (VR) and augmented reality (AR) technology, the designed 3D model and the construction WBS (Work Breakdown Structure) work package can be used to realize 4D model simulation and guide construction [1]. It can improve work efficiency and cut down operation errors.

Digital twin, also known as digital mapping and digital image, refers to simulating physical entities, processes or systems in the information platform. It is the twin of entity systems in the information platform [2]. With the help of digital twin method, we can understand the status of physical entities on the information platform, and even control the predefined interface components in physical entities, so as to help company monitor work progresses, perform predictive repairation and improve technological process. For different real objects, the focus and purpose of digital twin model construction are different. For the digital twin of enterprise organization project entities, more emphasis is placed on the aggregation and integration of wide area data, and efforts are made to optimize global decision-making and strengthen collaboration through simulation, which has attracted more and more attention of enterprise management.

2. Difference between Digital Twin and BIM

In essence, digital twin method is a functional system composed of physical substance and twin information model, which can optimize continuous process. Digital twin is a technology to settle the bottleneck problem of the interaction, integration of data space and physical space. Digital twin method is being applied to product design, production line operation and maintenance and production line planning. The development of digital twin system helps enterprises accelerate the time to market of new products, optimize the operation efficiency of production line, improve production deficiencies, develop new business models, and then improve the revenue.

BIM method is a data driven model which has applications of engineering design, construction, commissioning, and administration [3]. In the process of data integration and information modelling, information carrying and passing are carried out in the process of building plan, work action and repairation. It make engineers and workers can understand their tasks. Thus they answer and take actions efficiently. It also offers services to engineering teams. And it includes the objects to install and units to take action.

In fact, digital twinning is a emulation method. It applies the entity, transducer information and other data. And it combines various disciplinary and probability, and finishes the corresponding objects in virtual information world. So it imitates the entire life cycling actions of homologous physical objects [4]. The field of engineering construction is the most deeply applied in China, and the field of intelligent manufacturing has the highest attention and the hottest research [5].

BIM manages the planning, design, construction and execution of buildings, but BIM models and data are not real-time. Digital twinning method is regarded by most researchers be worthy the architectural technological method. It is a real-time map of the architectural environment. Digital twins can provide information about the current state of the construction subsystem and how they will affect operation and maintenance when assets such as HVAC or lighting fail to work.

The development of digital twinning method can provide information beyond assets in the application, including the digital twin model of the whole facility, project or organization, which means that people, processes. Actions shall become significant information origins to provide more background information about the building environment for digital twin, so as to provide decision support for the work of managers.

3. Overview of Digital Twin Technology

Essence of digital twinning method is information modeling, which aims to build a completely consistent digital model for entity objects of physical space and in the digital space [6]. However, information modeling involved in digital twin is no longer based on the traditional bottom information transmission format, but an overall abstract description of the external form, internal mechanism and operation relationship of entity objects, which is reflected in multiple transformations of digital twin technology, and to build digital models in different forms according to different uses and scenes.

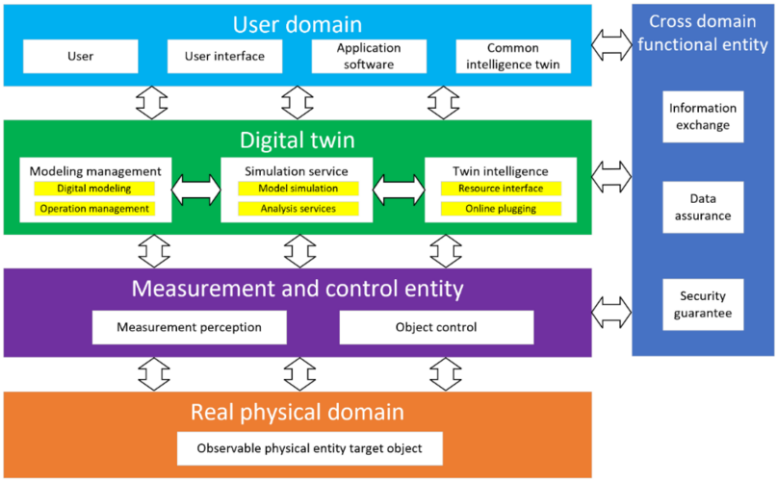

Figure 1. Logical structure diagram of digital twin technology.

Digital twin connects buildings and their space with their design objectives and purposes, and regards digital twin as the digital replica of buildings for its management from the perspective of data-driven. The intelligent building that generates data inputs it into the digital twin, which can be used by managers and decision makers for more intelligent supervision. Figure 1 is logical structure diagram of digital twin Technology.

To map the following physical elements like composition, status, action, function and effects of complicate objects. It includes manufactured goods, industry systems and building facilities to the virtual world is what digital twinning mainly does [7].

Digital twin technology has four features.

(1) Virtual physical mapping: Digital twin technology requires the construction of digital representation of physical objects in digital space. Physical objects in physical space and twins in digital space can realize two-way mapping, data connection and state interaction;

(2) Real time synchronization: Based on the acquisition of multiple data such as real-time sensing, twins can comprehensively, accurately and dynamically reflect the state changes of physical objects, including appearance, performance, position, abnormality, and etc.;

(3) Symbiotic evolution: In an ideal state, the mapping and synchronization state realized by digital twin should include whole life time of twin entities from engineering, production, operation to scrapping, and the twins should evolve and update with the life cycle process of twin objects;

(4) Closed loop optimization: The ultimate purpose of establishing twins is to describe the internal mechanism of physical entities, analyze laws and insight into trends, and form optimization instructions or strategies for the physical world based on analysis and simulation, so as to realize the closed-loop decision-making and optimization function of physical entities.

4. Digital Twin in Design and Construction Coordination

Our company has made great progress in informatization and digital design since its establishment. The professional 3D digital design has been at the forefront of domestic design institutes, and the company's business information system platform is developing in the direction of intelligence and multi-business collaboration.

4.1. Key Elements of Design and Construction Coordination

The company uses the PDMS software of Aveva company to carry out 3D modeling of nuclear power plant. In exploration of intelligent design and collaborative applying of engineering and construction in nuclear power project, the company faces two tasks: the integration of design specifications and artificial intelligence algorithms, and the all-round coordination of design and construction based on data and model. For intelligent design, we sort out the design constraint rules, summarize the engineering design experience, to build the digital model of nuclear power project. We mainly study intelligent three-dimensional design algorithm according to knowledge engineering and artificial intelligence, and realize the intelligent 3D layout design by integrating layout design constraints. For design and construction coordination, we adopt the method of integrating design and construction coordination data with digital twin concept [8], and combined with the 3D model of nuclear power based on digital twin technology to study process scheme simulation, duration optimization, resource allocation and other contents, so as to achieve dynamic administration of construction operation [9].

Key elements of intelligent layout design and design and construction coordination of nuclear power plant are shown in Figure 2. (1) Based on standards, constraints, status and engineering experience, 3D intelligent layout algorithm is adopted to establish the three-dimensional model of nuclear power project to meet the internal cooperation needs of different design disciplines, such as mutual information presenting between nuclear power design disciplines, etc. (2) Based on the designed 3D model and data, using the

construction simulation technology of VR/AR, the construction business department can simulate and predict the installation operation and arrange the construction plan according to the correct logic, so as to reduce the rework of construction operation, ensure the safety of construction personnel. It improves the construction quality of nuclear power project.

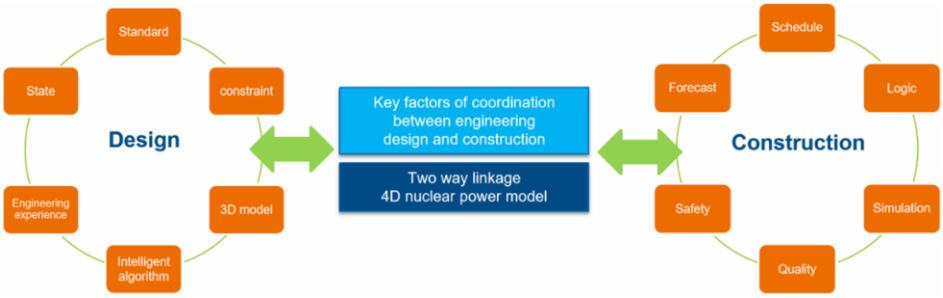

Figure 2. Key elements of digital twin application.

It is worth noting that the model with key elements of design and construction coordination mentioned in Figure 2 is a two-way linkage 4D nuclear power project model according to digital twin method. For items designed and built by the nuclear power plant, it contains not only the spatial attribute of three-dimensional layout, but also the time dimension attribute of each item.

4.2. Digital Twin Enabling Design and Construction Coordination

To apply digital twin technology in nuclear power plant engineering and construction cooperation, one important works is to create the mapping relations between model object and construction object. Relying on PDMS, the company establishes the three-dimensional engineering model of nuclear power project [10], and constructs the object of the whole life time according to digital twin technology. The data is applied cooperatively among different departments through digital twin model, so as to promote the transformation of construction to the working mode of visualization and two-way feedback.

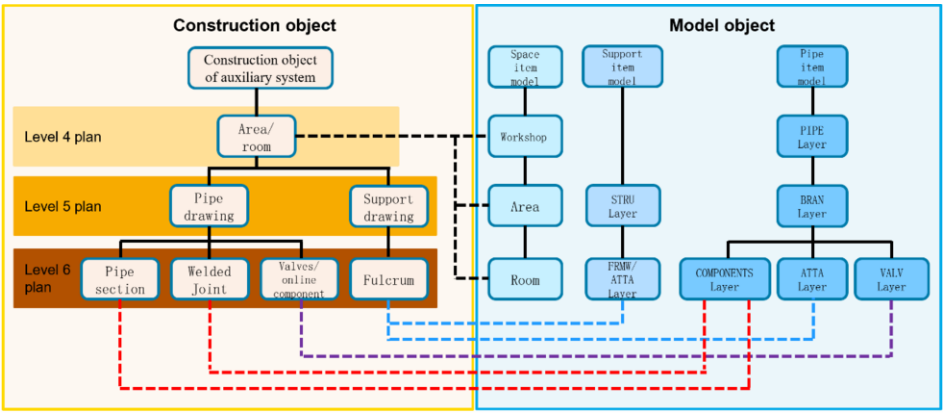

Figure 3. Association diagram of construction object and model object.

As is shown in Figure 3, we sorted out the information in the pipeline drawing and support drawing of nuclear power plant design. First we clarified the logical relationship between the construction item object and the design model object, and then established the mapping relationship between the model object and the construction object. As shown in Figure 3, the physical object of construction and the virtual object of design model are associated through information such as area, room and location, so as to meet the preconditions for EC (engineering design and construction) data connectivity and serve to be the base for the creation and applying of digital twin model.

We summarize the 3D model, data status and the relationship with construction operations, study how to use the installation work package to link the construction materials with the WBS to form progress breakdown structure, and add the time dimension attribute to the 3D model, so as to obtain the dynamic construction guidance of 4D nuclear power plant. By studying the integrated design and construction coordination mechanism based on 3D layout design model [11], we have compiled the EC data flow rule program using digital twin technology, constructed the integrated design and construction coordination platform, and achieved the effect of visualization work at both design and construction levels.

5. Deepening Application of Digital Twin Technology

Through the progress of science and technology, more and more new high technologies are taken into applications. It has played a big role to increase the modernization of all industries. Especially for the construction industry, the applying of digital twin technology in construction optimization and dynamic management promote the scientificity and rationality of the construction scheme. And it can further improve the project quality.

Due to the particularity of nuclear power, the safety and quality requirements for design and construction are very high. At present, in engineering and constructing of nuclear power projects, the effective applying of digital twin technology isn't fully realized. At this stage, China is the main force of nuclear power construction globally. The study on the synergy of digital twin method in engineering and constructing of nuclear power projects and the applying of other expanded fields will further reduce costs and increase efficiency for the development of the company, and play a huge demonstration and leading role in other construction industries.

5.1. Digital Twin Model from 3D to ND

Based on the 3D engineering design model, we studied and applied digital twin method to achieve the coordination of design and constructing of 4D nuclear power plant. We sorted out the layout design requirements, determined more comprehensive design constraints, including process constraints, physical constraints, economic constraints, installation constraints, safety constraints and operation and maintenance constraints, established layout rules for pipelines, supports and hangers and various equipment in the nuclear island. Then we used path finding algorithms (such as LEE algorithm, A* algorithm, SPFA algorithm, etc.), Intelligently generated the 3D layout model of the

pipeline, and further automatically arrange the corresponding equipment at each node when the shape, size and weight of various equipment are determined.

When the designed nuclear power equipment is manufactured in the supplier's factory, the digital twin data can be added to the model of nuclear power project under engineering and constructing, and the process is gradual. Each nuclear power professional completes the system function design of the equipment on the basis of mutual supporting. After the functional attributes of the nuclear power equipment are determined, the designer will provide them to the supplier for manufacturing as required. After manufacturing, the supplier will return the three-dimensional layout information and time schedule of the equipment to the designer and add it to the digital twin model. 5D model refers to the model including equipment item cost and construction operation cost, which is used for project budget analysis and cost control. It will control the factors causing cost changes in real time and accurately in the whole process of project design and construction. 6D model refers to each item of nuclear power plant with design attribute, procurement attribute, manufacturing attribute, construction attribute and commissioning attribute. After the project is completed and handed over for operation, various test simulations can be carried out, such as wind pressure resistance performance analysis, seismic performance analysis, air tightness analysis, water tightness performance analysis and thermal energy saving analysis.

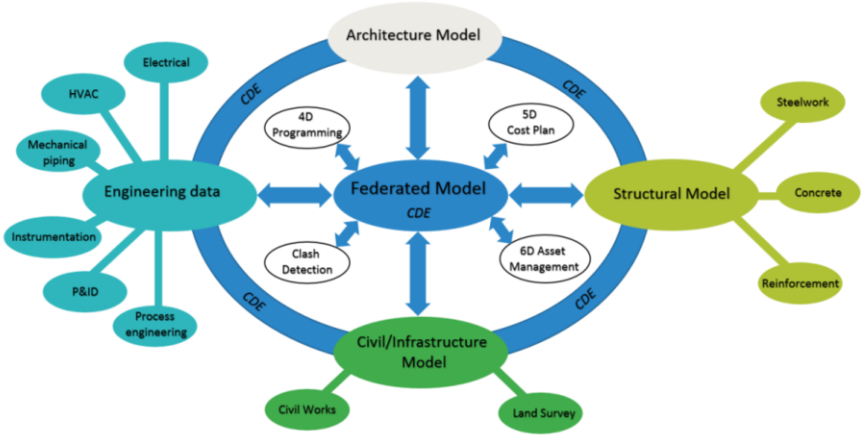

Figure 4. Joint model using digital twin.

Figure 4 is a joint model using digital twin method. It includes various data information from 3D to 4D, 5D and 6D. Engineering data includes electrical, HVAC, mechanical piping, instrumentation, P&ID, process engineering and other items, structural model includes steelwork, concrete, reinforcement and other structures, and infrastructure model includes civil works, land survey and other information.

5.2. Digital Twin Technology System

From the perspective of technology, the digital twin technology system is very huge. Its perception, calculation and modeling process cover many technical fields such as perception control, data integration, model construction, model interoperability, business

integration, human-computer interaction and so on [12]. Figure 5 is a schematic diagram of digital twin technology system.

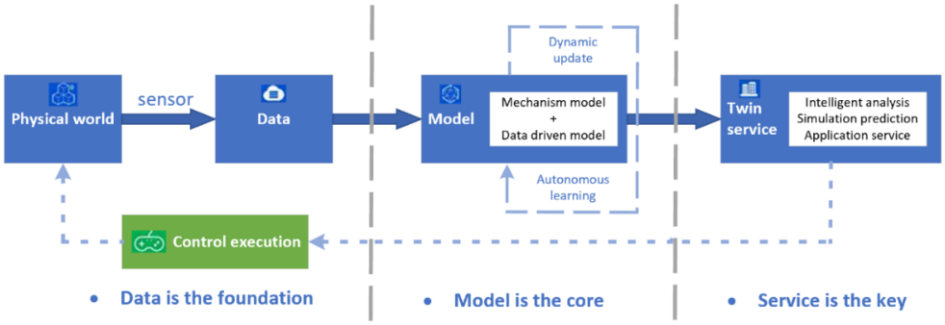

Figure 5. Digital twin technology system.

In architecture, the applying of digital twin technology can truly simulate the internal appearance of buildings. Although nuclear power plants are much more complex than ordinary buildings, the basic principles of application are the same. Digital twin provides three main functions: modeling, simulation and management. Information modeling is how to provide services to complete the design and construction of buildings. The simulation allows the project leader to plan changes and adjustments with the insight of data support. The management through digital twin can be space management, asset management and labor management, all of which are managed with aggregated data.

We can compare a digital twin constructing to the creating of a virtual man, the most important action is skeleton construction. Data collection, data management are the muscles of man. Data flow between digital space and virtual space is man's blood. Through multi-dimensional modeling, digital twin realizes the real-time analysis of business data by establishing a multi-dimensional model of enterprise entity business. It predicts business results in real time based on business drivers, warns and adjusts risks in time, and realizes the real-time integration of data collection, modeling and simulation, analysis and warning, decision support and etc.

6. The Value and Challenge of Digital Twin

Construction of digital twin model is not the goal, but a means. People hope to improve the performance of its corresponding phenomenon objects with analysis of virtual twin modelling. The digital twin of physical entities can improve the benefits of industrial products in entire time cycle of R&D, manufacture and maintaining. The digital twin with enterprise organizational entities as the object can greatly improve the overall digital and intelligent operation level of enterprises and realize cost reduction and efficiency increase. Digital twin technology is gradually being applied in a wider range of fields to help enterprises develop to a higher level of informatization and intelligence [13].

6.1. Application Value of Digital Twin

Digital twin technology makes enterprises control work performance, put forward predictive maintaining, and give insightful decisions easier. Overall, digital twin technology has 5 substantial advantages:

(1) Speed up risk assessment. Digital twin method helps organizations conduct virtual testing & verification of products' functions before they come out. Engineers can use them to determine process failures.

(2) Predictive maintaining. Enterprises use digital twin method to actively control equipment & system in order to arrange maintaining in the early stage.

(3) Remote monitoring on time. Managers can remotely monitor the products, systems and projects.

(4) Better teamwork. Process automation and access to system information 7 days 24 hours. Round the clock access allows technicians to focus more on collaboration.

(5) Better decisions. Through integration of data analysis, enterprises can do better decisions and make faster adjustment.

6.2. Challenges Faced by Digital Twin

The realization of digital twin technology depends on development and high integrating of many new technologies. Digital twin modeling technology has experienced the development from physical component assembly modeling to deep fusion modeling of complicated objects. Since massive database and big data mining exists, digital twin technology faces a great challenge on the storage and computing power.

Moreover, digital twins put forward requirements for processing chips, data computers mainly in the following three aspects:

(1) The model and data scale of digital twins is very large. It includes the data and modelling of all elements, all businesses and all processes which are updated in the entire time cycle of the modeling object, which requires the huge processing capacity of computer hardware.

(2) Digital twins have real-time demands for the efficiency of model simulation and information analysis and data processing. It requires strong calculating power of computing equipment or hardware.

(3) Digital twins need more active and large terminal equipment. It requires bigger data transmission capacity and demonstrating tech of equipment.

7. Conclusion

Digital twin is not only a technology, but also a series of management methodology. It is a life-cycle management method according to architectural engineering, constructing administration and collaboration. In the past, design, procurement, construction, operation and other links were connected in series. Now all departments work together, and everyone's work is recorded and shared. All information such as design, processing, construction and project management are integrated into a unified database to meet the work requirements of upstream and downstream business departments.

Based on the new information technology (especially IOT, VR/AR, big data, machine learning, etc.), we have preliminarily established the model framework and business application platform of virtual nuclear power plant by using digital twin, which

not only achieves the digital delivery of results from design to construction, but also achieves the digital coordination of the process of design and construction. We even plan to apply digital twin technology to the digital power grid [14]. After the nuclear power plant is completed and handed over for operation, the problems encountered will be fed back to the upstream engineering and construction department through experience, so as to help make improvements in the next nuclear power project.

Last, we plan to focus our work to study the intelligent design algorithm suitable for more nuclear power design disciplines on the basis of realizing the intelligent engineering of nuclear island pipes in nuclear power plants, so as to promote the coverage of automatic layout design of nuclear power plants and improve the effectiveness of intelligent design results for construction. In addition, we will further study how to expand the digital twin model of nuclear power plant from 3D (three-dimensional layout model), 4D (time process model), to 5D (cost budget model), 6D (asset management model), that is able to realize the engineering and construction coordination of nuclear power project, and meet the work needs of departments such as business planning and finance. Finally the digital twin model is handed over after the completion of nuclear power plant, and it can meet the requirements of business departments such as operation, maintenance and asset management.

References

[1] Sun L, Sha JQ, Xie HP, Ling YC, Miao Y, Jiang LC. Research on refined management of project cost based on 4D-BIM. Journal of Xiangtan University (Natural Science Edition). 2020 Aug;42(4):104-10.
[2] Tao F, Zhang CY, Zhang H, Cheng JF, Zou XF, Xu H, Wang Y, Xie BB. Future equipment exploration: digital twin equipment. Computer Integrated Manufacturing Systems. 2022 Jan;28(1):1-16.
[3] Chen Q, Liu GY, Wang J, Sun PY, Dai JS. Research on the application of BIM technology in the construction stage. Engineering Construction. 2022;(2):69-73.
[4] Yu Y, Fan ST, Peng GW, Dai S, Zhao G. Study on application of digital twin model in product configuration management. Aeronautical Manufacturing Technology. 2017;(7):41-45.
[5] Liu J, Zhao YL, Zhang XS, Miao FX, Shi KY. Smart factory construction based on digital twins. Modern Manufacturing Engineering. 2019;(9):68-75.
[6] Diao SF, Li SQ, Wu XH. On the virtual epistemology based on digital twins. Journal of Foshan University (Social Science Edition). 2022 Jan;40(1):5-13.
[7] Liu J, Shi KY, Song XW, Zhao YL, Zhang XS. Survey on virtual factory application. Group Technology & Production Modernization. 2019;36(2):17-23.
[8] Liu L. Application exploration on BIM technology in construction management. Engineering Construction. 2022;5(1):98-100.
[9] Li J. Application of BIM technology in construction schedule control. Construction & Design for Engineering. 2022;(2):193-195.
[10] Zou J. Construction and design of PDMS three-dimensional model based on thermal power engineering. Scientific and Technological Innovation. 2021;(29):54-56.
[11] Zhang SR, Jiang PQ, Wu ZQ. Advances in research of lean construction technology of integrated design and construction for hydropower projects: exploration of digital twin application mode. Journal of Hydroelectric Engineering. 2021 Jan;40(1):1-12.
[12] Lin ZC. Digital twins technology framework and its applications in manufacturing industry. Industrial Control Computer. 2020;33(6):129-131,133.
[13] Liu Q, Liu B, Wang G, Zhang C, Liang ZX, Zhang P. Research on digital twin: Model, problem and progress. Journal of Hebei University of Science and Technology. 2019 Feb;40(1):68-78.
[14] Zhang ZL. Application of digital twin technology in digital power grid. Technology Innovation and Application. 2022;(8):155-157.