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Design and Research of Digital Twin Construction Platform Based on Xiazhuang Inverted Siphon Project

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ABSTRACT

In order to ensure the safe construction of the Xiazhuang inverted siphon project, this paper is based on this project, focusing on the centre of safe construction, using digital twin technology, designing and constructing an intelligent control construction platform through Mockplus and Unity3D software. This platform can monitor the construction site in an all-round way, provide real-time feedback and timely control, and correct and optimise the construction plan through data interaction, so as to improve the quality and efficiency of building construction, reduce the potential safety hazards during the construction, and achieve the purpose of intelligent construction and safe building.

1. INTRODUCTION

The central region of Yunnan Province is one of three major arid zones in China's Yangtze River Basin, and the problem of water shortage has seriously affected the economic development of the region for a long time. The Central Yunnan Water Diversion Project is a national strategic infrastructure project to solve this problem [1], which can not only solve the problem of water shortage in the region, but also has good economic and ecological benefits. The Xiazhuang inverted siphon (XZ-IS) project is one of the important buildings of the Project, and its safe construction is related to the success or failure of the Project [2]. The XZ-IS is a typical mass concrete heterogeneous structure. As an important water conservancy project, the complexity and challenge of its construction determine that traditional construction management methods can no longer meet the needs of construction. However, the rapidly evolving digital twin technology provides a new solution.

As early as in 2003, Professor Michael Grieves of the University of Michigan introduced a concept of "digital equivalents of physical products", which is widely regarded as the first use of a term "digital twin" (DT) [3]. With the rapid development of science and technology, DT technology has been applied in many industries. In recent years, construction industry has also employed DT technology to serve it and achieved good results. Jiang et al. [4] used DT technology to establish an effective model to simulate and measure the safety of lifting on the construction site, thus reducing the occurrence of safety accidents. Du [5] put forward a digital twin construction theory prototype, and built a building management platform model and applied it to real projects with good results, and finally put forward her personal prediction and outlook on the future development of green and intelligent buildings. Xia et al. [6] established a digital twin of construction unit and constructed a cement engineering construction digital twin system in order to realise project visualisation and collaboration and improve construction efficiency. Digital twin-based intelligent management platform for dam construction proposed by Deng et al. [7] showed great advantages. Sun and Liu [8] proposed a new hybrid model based on DT technology and Building Information Modeling (BIM) in their research work. They established and applied an intelligent dispatching management system platform through this modeling, and the resource management and deployment of construction projects were greatly improved by employing the platform. Omrany et al. [9] provided a comprehensive analysis of the development of DT in construction industry through a systematic study of more than one hundred publications, which summarised the application of DT in eight major areas, while pointing out the challenges faced by DT. The results showed that DT technology has greatly benefited these construction areas, improving construction quality and efficiency, and significantly advancing the industry.

In view of these, according to the basic theory of DT, this paper applies the DT technology to the actual project of XZ-IS. Mockplus software was used to design and create the prototype system architecture, and combined with Unity3D platform to design and build the XZ-IS DT construction platform. With the help of this platform, comprehensive monitoring and optimisation of engineering construction could be carried out, for example, the site situation could be viewed in real time, the construction progress could be controlled, the safety risks could be found, the safe construction could be ensured, and the resource coordination and scheduling could be carried out, etc., with a view to introducing new theories and ideas for the building construction industry. At the same time, under the operation of the platform, the simulation, monitoring and optimisation of the construction process are realised, so as to reduce the construction risk, guarantee the construction safety and improve the construction efficiency and quality.

2. PROJECT OVERVIEW AND OVERALL DESIGN CONCEPT

XZ-IS project is an important part of the water transfer line of Dali II section of Central Yunnan Water Diversion Project, with a total length of 4460.423 metres, and every 15 metres is a standard construction section. Inverted siphon selects C30 reinforced concrete pipe with pipe diameter D=4.9m, single pipe length 4.3km, three pipes and one joint arrangement, adopting buried pipe type, with design flow rate 120m³/s, and its base is located in the lake sedimentary soil layer, with low bearing capacity and high construction difficulty, and it is the largest inverted siphon diversion project in the whole line. The model of XZ-IS is shown in Figure 1.

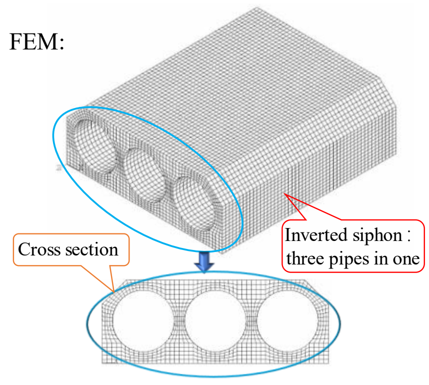

Figure 1. XZ-IS finite element model

XZ-IS is a complex structure involving a variety of sectional forms, which covers construction features such as structural complexity, high technical requirements, and big construction difficulty. Therefore, the design and research of DT construction platform is very necessary. In terms of theory, it can promote the development of technical theories in the industry and provide reference for similar projects. In practice, it can ensure the safe construction of the project, reduce the safety hazards and improve the efficiency. Overall steps of research and design of DT construction platform can be seen in Figure 2.

(1) Demand analysis: A detailed analysis and understanding of the construction process and requirements for XZ-IS project.

(2) Data acquisition and modeling: During the development process of DT platform, a large number of data collection is required, which includes many parameters and information related to engineering construction. These collected data was used to build a digital model of XZ-IS project.

(3) Simulation and emulation: Mockplus software was used to design the system architecture and built a 3D model to simulate the construction process of XZ-IS project. Through simulation, safety hazards were detected and construction safety conditions were evaluated, etc.

(4) Real-time monitoring and control: The construction platform designed and created a real-time monitoring and control systems to capture real-time construction site data.

(5) Optimization and decision: Through Unity3D engine to build a visual construction platform, design and add various optimization tools, according to simulation and analysis of model, amend and optimize the construction plan to improve efficiency and safety of construction.

(6) Verification and evaluation: The platform was applied to the actual construction process of XZ-IS project, and performance and effectiveness of the platform were verified and evaluated.

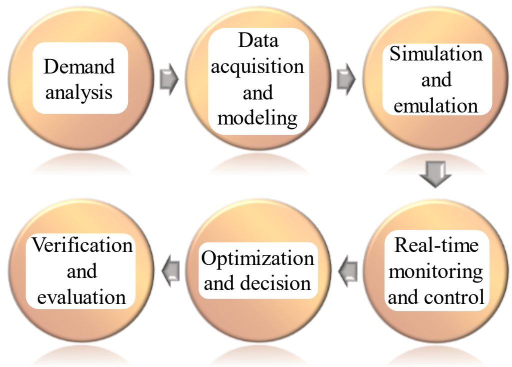

Figure 2. Overall design flow of the platform

3. PROTOTYPE DESIGN OF PLATFORM SYSTEM

3.1 Functional requirements analysis of the platform

The purpose of establishing DT construction platform was to improve construction management efficiency, reduce project risks and optimise construction quality through the application of science and technology. According to the characteristics of XZ-IS project, the DT construction platform had the following six main functional requirements, as shown in Figure 3.

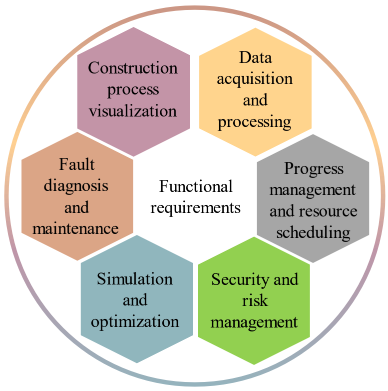

Figure 3. Functional requirements of the platform

Specifically:

(1) Data acquisition and processing: The platform should be able to connect with various types of sensors and monitoring equipment to achieve real-time acquisition of construction data.

(2) Construction process visualization: The platform shall have the function of visualisation, which intuitively presents real-time condition of the construction site through the

interaction between DT model and the actual construction situation.

(3) Simulation and optimisation: The platform should have the functions of simulation and emulation, and be able to use DT model to simulate construction plan, assess the effects and risks of different plans, and optimise construction.

(4) Security and risk management: The platform should include a safety management module to help users carry out safety control, predict potential risks and take timely measures.

(5) Progress management and resource scheduling: The platform should have the function of progress management to help users track construction progress, set up planned tasks and deploy resources.

(6) Fault diagnosis and maintenance: The platform should have functions of fault diagnosis and maintenance management to help users quickly identify and locate equipment faults and provide corresponding maintenance solutions.

3.2 Theoretical basis of DT technology

DT technology is an advanced technology for real-time interaction and information exchange with the real world through digital models. It combines many technologies such as physical system modeling, sensor data acquisition, big data analytics, and artificial intelligence to simulate, analyze, and optimize the operational state and performance of physical systems in real time [10]. Figure 4 shows theoretical basis of DT technology.

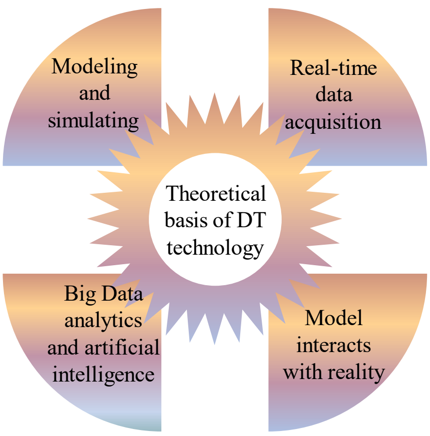

Figure 4. Theoretical basis of DT technology

Specifically:

(1) Modeling and simulating: DT technology is based on digital modeling of physical system, which in turn leads to simulation and analysis of the system.

(2) Real-time data acquisition: DT technology relies on the real-time acquisition and transmission of data from physical systems, and requires a large amount of real-time data to reflect the state and performance of actual system.

(3) Big data analytics and artificial intelligence: DT technology utilizes big data analytics and artificial intelligence technology to process and analyze the collected data. Artificial intelligence algorithms could be applied to DT model to automate decision making and optimization to improve performance and efficiency of the system [11].

(4) Model interacts with reality: DT model obtains the state information of the system in real time by exchanging data with actual system, and analyzes and predicts it.

3.3 Platform architecture design

In 2017, Tao et al. [12] put forward the concept of DT workshop by introducing DT concept into the manufacturing workshop and created a five-dimensional model of digital twin [13]. This paper drew on this model to establish system architecture of the platform shown in Figure 5 using Mockplus software based on the construction characteristics and process requirements of XZ-IS project.

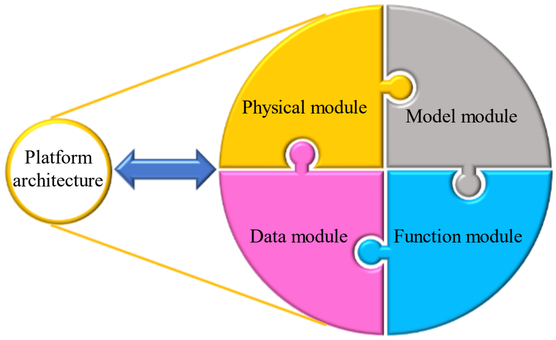

Figure 5. Platform architecture design

(1) Physical module: Including the basic hardware and software facilities of the digital twin platform, both types of equipment need to be designed to ensure feasibility, accuracy and timeliness.

(2) Data module: Responsible for data acquisition, storage and management, it includes data acquisition system, database and data processing system.

(3) Model module: It was the core of digital model of XZ-IS project, which includes building information model (BIM), inverted siphon project model, construction process model, etc.

(4) Function module: It provides various functions and tools of DT platform for simulation, data analysis, optimization adjustment and decision support. Functional division of the platform is shown in Figure 6.

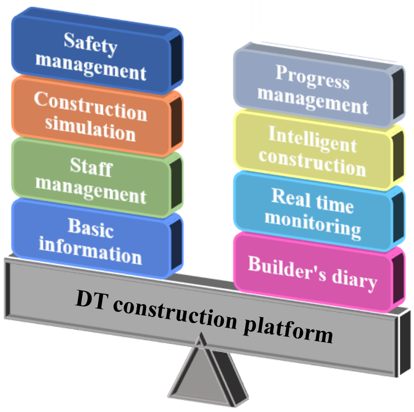

Figure 6. DT platform functional partition

3.4 Prototype design of the system

Prototype mainly refers to the initial design concepts and patterns, which is a visual presentation of an idea based on actual things, and mainly expresses the system architecture, content, functions and interaction mode [14, 15]. Mockplus is a simple and fast design software, which provides a large number of UI component libraries and interaction design functions to quickly create system architectures, and can well express designer's ideas. Therefore, this paper utilized this software to design the functions and interfaces of construction platform, and then creates an interactive prototype of XZ-IS DT construction platform. Specific prototyping steps are shown in Figure 7.

(1) Creating project: Created a new project in Mockplus.

(2) Desktop design: Created various corresponding pages in the project and add each component.

(3) Interactive design: Used Mockplus' interaction design features to add interactive behavior to page elements.

(4) Navigation design: Added a navigation menu that makes it possible to navigate and switch between different pages.

(5) Data display: Added relevant data presentation components to the prototype based on the needs of construction platform.

(6) Optimization and evaluation: Tested the model and optimized the details.

(7) Sharing and presentation: Exported prototypes as presentable files to share with team members.

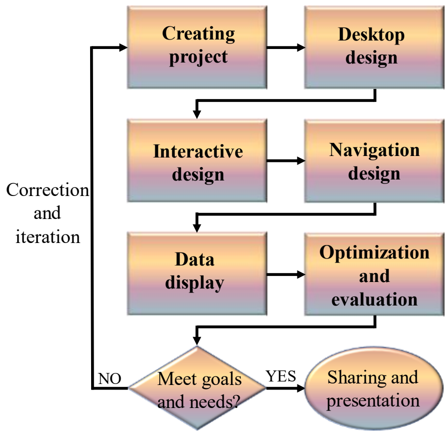

Figure 7. Steps in prototype design

3.5 Design results

Based on DT theory, this paper utilized the mature Mockplus software to design and create the prototype of platform system according to the objectives and requirements, and functional partitions. Main menu interface is shown in Figure 8, which consists of five parts: weather, functional area, project progress, warning information, and notification. In functional area, the details of each functional module can be viewed. For example, Figure 9 shows the intelligent temperature control of concrete in intelligent construction function module.

Figure 8. System's main menu

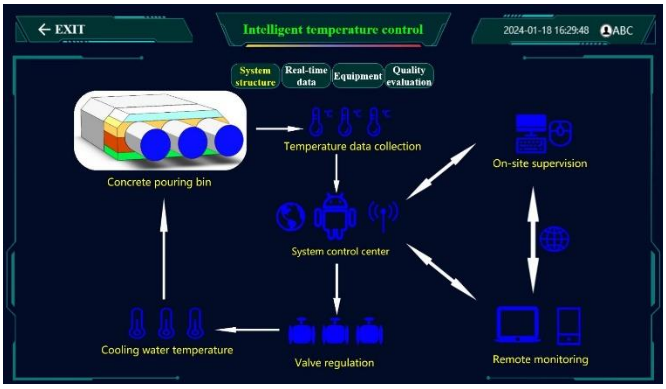

Figure 9. Intelligent temperature control system

4. UNITY3D VISUALIZATION PLATFORM BUILDING

4.1 Building steps

In order to further visualize the DT construction platform, Unity3D was adopted to build a visualization platform for DT construction platform of XZ-IS. Unity3D is a powerful development platform with good graphic rendering capabilities, multi-platform support, flexible interactivity, and various functional extensions. Using it to build a construction platform can achieve the design goals well and provide good visualization effects. The main steps of DT construction platform visualization of XZ-IS are shown in Figure 10 [16].

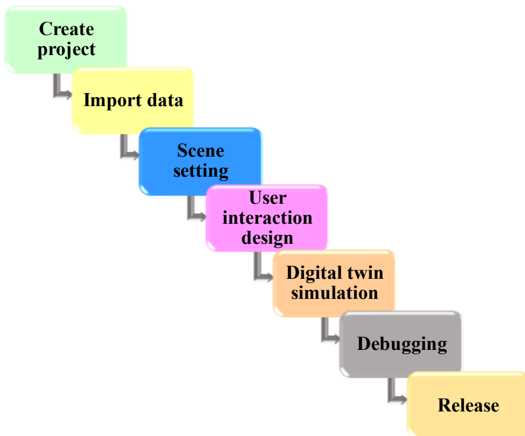

Figure 10. Visualization platform building steps

Specifically:

(1) Create project: Created a new project, named it, and confirmed to use a 3D project template.

(2) Import data: Imported all the data (including 3D model files of the project) into the Unity editor.

(3) Scene setting: Set up the model layout and environment conditions.

(4) User interaction design: Used the user interface (UI) system of Unity3D to carry out design and layout of UI elements.

(5) Digital twin simulation: Wrote simulation code for engineering construction using Unity scripting language.

(6) Debugging: Performed adjustments and testing of system functionality to ensure proper functioning.

(7) Release: Released the construction platform as an executable file.

4.2 Core technology and achievements

4.2.1 3D modeling and optimization

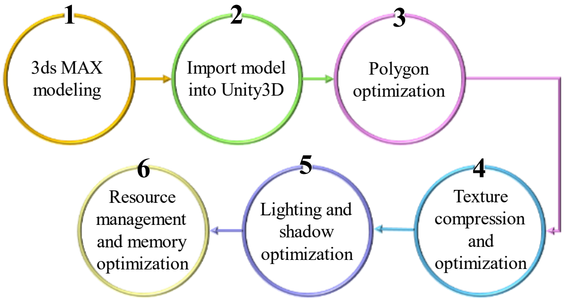

Figure 11. 3D modeling & optimization steps

Figure 11 specifically:

(1) 3ds MAX modeling: 3D modeling software (3ds Max) was used to obtain and create a 3D model of XZ-IS, and entering the appropriate material parameters.

(2) Import model into Unity3D: Importing a 3D model into Unity, allowed you to use Unity3D's import tools to handle the model's import settings and fine-tune the model.

(3) Polygon optimization: Using the polygon optimization tools to remove unnecessary details and optimize model performance and rendering effect of model.

(4) Texture compression and optimization: Using appropriate texture compression and optimization techniques on models to reduce texture file size and improve rendering performance.

(5) Lighting and shadow optimization: Improving scene rendering by using Unity's dynamic lighting and real-time shading techniques.

(6) Resource management and memory optimization: Managed resources in scenes wisely to optimize memory usage and loading speed.

Through all above steps, the 3D modeling and optimization of XZ-IS construction model were completed, specific results can be seen in Figure 12.

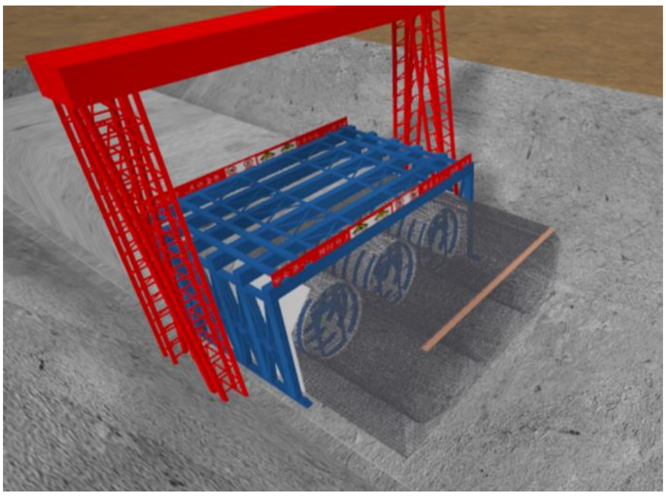

Figure 12. 3D construction model

4.2.2 Scene interaction development

Figure 13 specifically:

(1) Unity3D user input: Using Unity's input system to respond to operator's actions.

(2) Object selection and manipulation: Realized operations such as selection, movement, and scaling of objects.

(3) Develop camera control scripts: Developed camera control scripts to enable switching and roaming of live viewpoints.

(4) Establish user interface (UI) interactions: Designed and created UI elements that are easy to manipulate.

(5) Collision detection: Use Unity's collider components for collision detection and object interaction effects.

(6) Implement gesture recognition: Gesture recognition function was implemented by using Unity's gesture recognition library.

(7) Data interaction and update: Interacted actual construction data with DT platform data to update the model status in real time.

(8) Create virtual buttons and triggers: Created virtual buttons and triggers in the scene to make it easy to click or trigger specific events or actions.

(9) Add animations and special effects: Used Unity's animation system and effects capabilities to add animations and special effects to models to increase the visual impact of interactions.

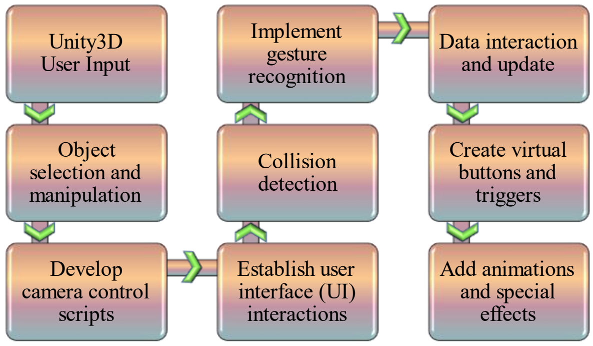

Figure 13. Scene interaction development steps

Through the reasonable use of all above technologies, the scene interaction function of XZ-IS DT construction platform could be realized, and an easy-to-operate visualization platform could be obtained, as shown in Figure 14, and the simulation, control and visualization of construction process could be realized.

Figure 14. Visualisation platform home

5. CONCLUSION

Based on the actual project of XZ-IS, this paper used DT technology and Unity3D to design and build the DT construction platform of XZ-IS, providing comprehensive digital management and intelligent control for the construction of XZ-IS project. During the design process, the project characteristics and construction requirements were analyzed in detail, and a fully functional construction platform was designed. Through operation of the platform, the managers can carry out comprehensive monitoring and control of project construction, and the visualization page can well display actual construction situations and conveniently find out the construction problems, and then take corresponding measures in time to ensure the safety of building construction. In short, the platform can help the safe construction of the project, improve the construction efficiency and ensure the quality of the construction, and at the same time, it also provides certain reference for similar projects.

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