



# Preliminary Study on Intelligent Hydropower Plant Construction Based on Digital Twinning

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**Abstract.** Digital twin technology can promote the deep integration of industrialization and informatization, further improving the management efficiency and level of intelligent hydropower plants. This article conducts preliminary research on the overall architecture, data base, twin platform, and twin application of digital twin intelligent hydropower plants. It constructs the digital twin architecture of intelligent hydropower plants, defines and standardizes the expression of information models and various object digital twin expressions, and forms an application mode of intelligent hydropower plants based on digital twin technology, providing methodological references for promoting the practical application of digital twin technology in intelligent hydropower plants.

**Keywords:** digital twins; intelligent hydropower plant; data base; twin platform; twin application

## 1 Introduction

With the rapid development of information and digital technology, the intelligent construction of hydropower plants has entered a new stage. On the one hand, a comprehensive integrated platform has been built to achieve data sharing and unified management. On the other hand, through digitization and networking, interconnectivity has been achieved, and more comprehensive device status information has been obtained [1]. In order to further improve management efficiency and level, the construction management mode of traditional hydropower projects is also constantly innovating [2], and digital twin technology is gradually being used in the construction and management operation of hydropower plants [3-5].

The construction of intelligent hydropower plants only requires three-dimensional digital modeling of buildings and mechanical and electrical equipment, as well as three-dimensional visualization and simulation of some equipment operating conditions. There is still a big gap between the requirements of twin interaction and digital twin technology, mainly reflected in three aspects: firstly, the construction of the local perception system is not yet perfect, and the collection of environmental and operating condition information that affects the operation and management of hydropower plants in engineering and river basins needs to be further supplemented; Secondly, the

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expression of intelligent hydropower plants based on digital twin technology is not mature, and there is no standardized method for expressing massive multi-source data using digital twin technology; Thirdly, the integration of digital twin technology with business applications is insufficient, posing challenges to application functionality and interaction methods[6-7]. Therefore, based on the framework of intelligent hydropower plants and general deployment methods, this article preliminarily constructs the digital twin architecture of intelligent hydropower plants, defines and standardizes the expression of information models and various object digital twin expressions, constructs a digital twin scene editor, and forms an application mode based on digital twin technology, providing technical support for promoting the widespread application of digital twin technology in intelligent hydropower plants.

## 2 Overall Architecture

The intelligent hydropower plant technology architecture based on digital twin is divided into five parts: the foundation support layer, the data interaction layer, the digital twin base, the digital twin platform, and the digital twin application, as shown in Figure 1. Among them, the foundation support layer provides data sources for twin modeling and operation, including a digitized perception system and infrastructure system composed of water structures, hydropower plant equipment, and intelligent sensors. The data interaction layer is responsible for data collection, transmission, and processing, and uses a mixed networking method in multiple ways to build a communication network for hydropower plants, providing a high-quality basic communication network for digitalization and realizing bi-directional data interaction between the twin hydropower plant and the physical hydropower plant. The digital twin base is mainly composed of physical perception data, GIS spatial information, and BIM models, on which various spatial data (such as vector data, terrain data, image data, oblique photography data, and laser point cloud data) and business data (such as image data, attribute data, and monitoring data) are fused according to their precision and source, to construct a seamless visualization scene of data resource layer hierarchy conversion and data and terrain construction, to meet the requirements of engineering data level browsing applications. The digital twin platform includes a two-three-dimensional GIS platform and a three-dimensional real-time simulation engine (generally using a game engine). Based on the digital twin platform, various scene visualizations, business application simulations, equipment operation simulation training and maintenance, and full life cycle management are carried out according to application requirements, through digital twin interactive design and business implementation[8-10].

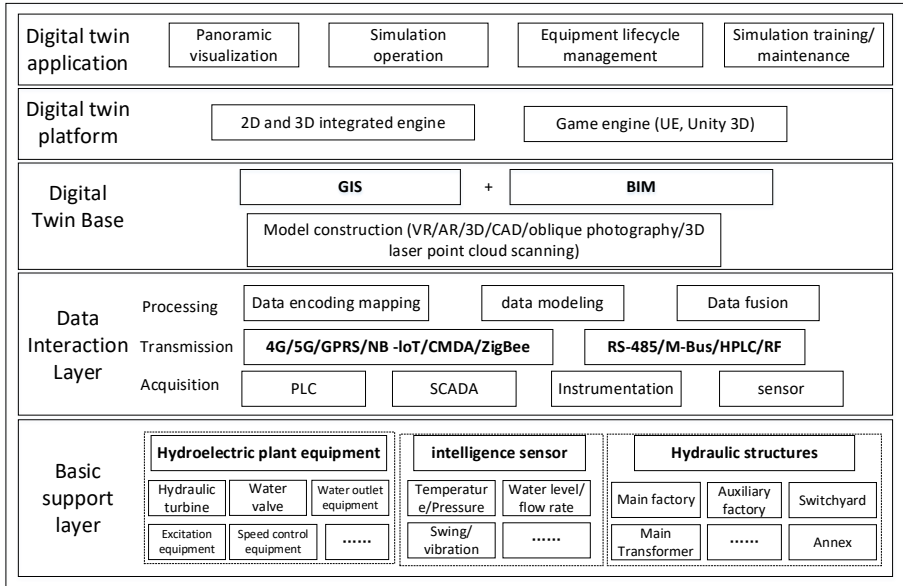


Fig. 1. Schematic diagram of technical architecture

### 3 Digital Twin Base

GIS+BIM is used to build the digital twin base, converting the BIM model into a format compatible with GIS data standards and displaying BIM and GIS information in the same scene. According to the "Technical Guidelines for Digital Twin Water Conservancy Projects", model data of different levels are created. At the same time, the perception system data is connected and fused with the entities in the scene in a twin manner.

#### 3.1 Improvement of Perception System

The current construction of the perception system for intelligent hydropower plants mainly focuses on data acquisition of site conditions of mechanical and electrical equipment, hub engineering safety, and basin rainfall. The data collected are all point data, lacking data acquisition of hierarchical data, such as river cross-sections, basin rainfall distribution, and soil moisture distribution. With the development of satellite remote sensing, unmanned aerial vehicle monitoring, underwater measurement, internet of things communication, and other technologies, the perception system for intelligent hydropower plants needs to be further improved under the technology of digital twin, which has the ability of three-dimensional expression. Therefore, this paper needs to use advanced technologies such as satellite remote sensing to construct a complete "Sky-Earth Integration" perception system, supplementing the perception

means for the construction, operation, and management of hydropower plants from multiple scales and dimensions.

### 3.2 Unified Information Modeling

Through standardized information modeling and unified equipment coding, as shown in Fig. 2, digital descriptions of on-site equipment and information systems are completed, solving problems such as insufficient perception of on-site information and non-standard descriptions, and breaking through the business information silos of hydropower plants.

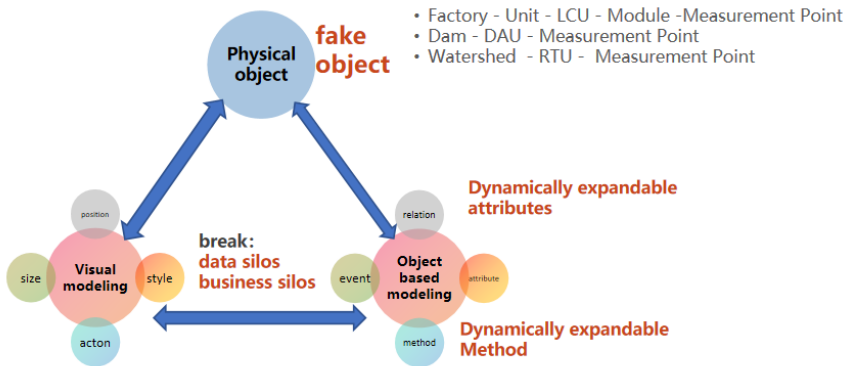


Fig. 2. Schematic diagram of information modeling

### 3.3 Geographic Spatial Data

**L1 Data.** Construct a spatial geographic data base for the watershed using lower precision DOM data (resolution better than 2m) and 30m grid precision DEM data and perform three-dimensional slicing on basin images and terrain data, and merge DOM data, DEM data, and basin boundary line layers, water system line layers, and other layers to form L1 level data map services. Supporting the HTTP protocol, providing network map services (WMS), and returning map formats include PNG, GIF, JPEG, TIF, raster forms, or SVG, vector forms.

**L2 Data.** On the basis of L1 level data base map, overlay high-precision aerial images, ground elevation data, and underwater terrain data of hydropower plants and their surroundings, such as DOM data with a resolution better than 1m and DEM data with a grid accuracy better than 15m, to form L2 level geographic spatial data. Processed maps are converted into layered tile formats or caching including pictures and data. Dynamic map acquisition is achieved through JavaScript and XMLHttpRequest API.

**L3 Data.** Based on the L1 and L2 data maps, using high-precision digital orthophoto images and ground elevation data, airborne oblique photography of the hydropower plant area, BIM data on major water conservancy facilities and critical mechanical and electrical equipment, L3 geographic spatial data maps are constructed.

**Oblique photography real-time three-dimensional model:** Use oblique photography technology to obtain downward-facing image ground oblique images, produce ground oblique photography models, and perform individualized processing on important buildings. Specialized software is used for image data sorting, control point measurement, model refinement, and model splicing. The oblique photography accuracy resolution is better than 8cm for major water conservancy buildings and better than 3cm for water conservancy buildings, and lightweight processing is performed in the on-line processing phase.

**BIM model:** Collect design drawings of medium and large-scale dams in the basin, and combine them with texture images and texture production obtained through field collection to build scene facility and equipment models, such as mechanical, hydraulic devices, electric devices, oil, water, gas pipelines, etc., strictly according to the product manual and drawings to achieve 1:1 full-size three-dimensional construction, with scene layout consistent with the on-site layout. Regarding the modeling accuracy of BIM, the "Water Conservancy and Hydropower Engineering Design Information Model Delivery Standard T/CWHIDA 0006-2019" has corresponding regulations. The accuracy of hydropower plant civil model, indoor model, water turbine model, sensor model, etc. should not be lower than the accuracy standards specified in this standard, and the model accuracy standards are shown in the following table 1:

**Table 1.** Definition of LOD in CWHIDA006-2019

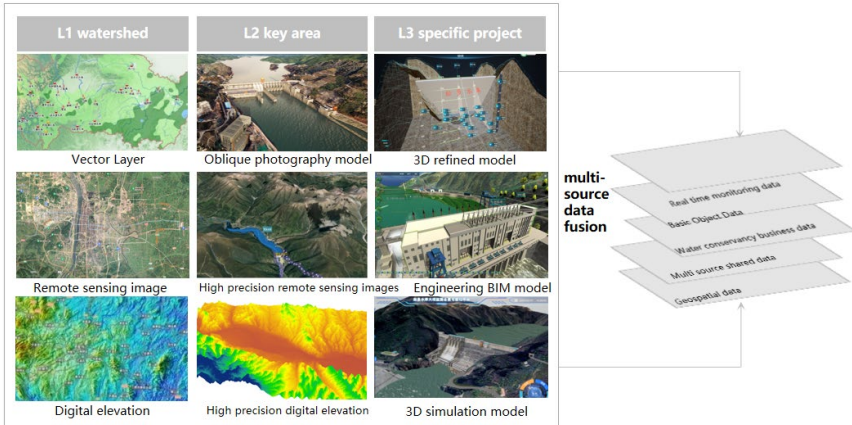
Grade	Abbreviation	Smallest Unit Model Included
Level of model definition 1.0	LOD1.0	Project-level model unit
Level of model definition 2.0	LOD2.0	Function-level model unit
Level of model definition 3.0	LOD3.0	Component-level model unit
Level of model definition 4.0	LOD4.0	Part-level model unit

Choose mainstream modeling software such as Solidworks, 3ds Max, Blender, etc., to build 3D models with various precision suitable for different scenarios based on methods such as BIM modeling of buildings from CAD drawings, 3D laser point cloud scanning, oblique photography, and manual modeling. The model files are compatible with mainstream formats (rvt, ifc, fbx), forming a consistent lightweight data structure. Large BIM files can be divided into sub-packages, with a sub-package data structure formulated to build the relationships and reassembly strategies with geometry in different sub-packages.

### 3.4 Data Fusion

Standardize and map geospatial data, 3D model data, monitoring data, document data, audio and video data, etc., to establish connection relationships between spatial enti-

ties and business objects, as shown in Fig. 3. Through standardized interface specifications and indexing technology, achieve the fusion and application of business data, satisfying the graphical interaction application of entity objects and business data in digital twin applications. Support real-time data rendering, comprehensive data queries, spatial analysis applications, and multi-dimensional statistical analysis functions by annotating the main technical parameters (such as water head, pressure, flow, size, weight, material, etc. ) of 3D models, maintenance electronic files, manufacturer information, and more.



**Fig. 3.** Schematic diagram of data fusion

The integrated data formats include:

- (1) DEM, DOM related geographic information system formats, including Shapefile, KML, GeoJSON, etc;
- (2) Vector data formats such as digital line drawing maps, including KML, SHP, GeoJSON, TopJSON, etc;
- (3) 3D model data formats such as oblique photography data, including OSGB, glTF, 3DTiles, etc;
- (4) Image and texture data formats, including JPEG, PNG, etc;
- (5) Business data formats, including XML, JSON, CSV, etc.

## 4 Digital Twin Platform

### 4.1 Digital Twin Engine

The digital twin platform mainly relies on the digital twin engine to integrate various data based on the digital twin base. Depending on the application focus, a two-three dimensional integrated GIS and game engine, or a combination of both, can be used. Combining GIS with WebGL (Web Graphics Library) to establish a three-dimensional virtual scene, featuring GIS service publication, management, aggregation, mul-

ti-level expansion, as well as the addition of feature modeling, real-time interaction with terrain and models, etc. The integration of GIS technology with high-fidelity engine technology such as UE (Unreal Engine) and Unity 3D ensures efficient visualization of GIS and model data.

**Scene Editor.** Build a scene editor for configuring interactive real-time rendering of 3D scene effects, including scene effect design, scene service debugging, scene service publishing, etc. Quickly build or update the scene by dragging and dropping elements such as the base plate, model, and interaction, as is shown in Fig. 4.

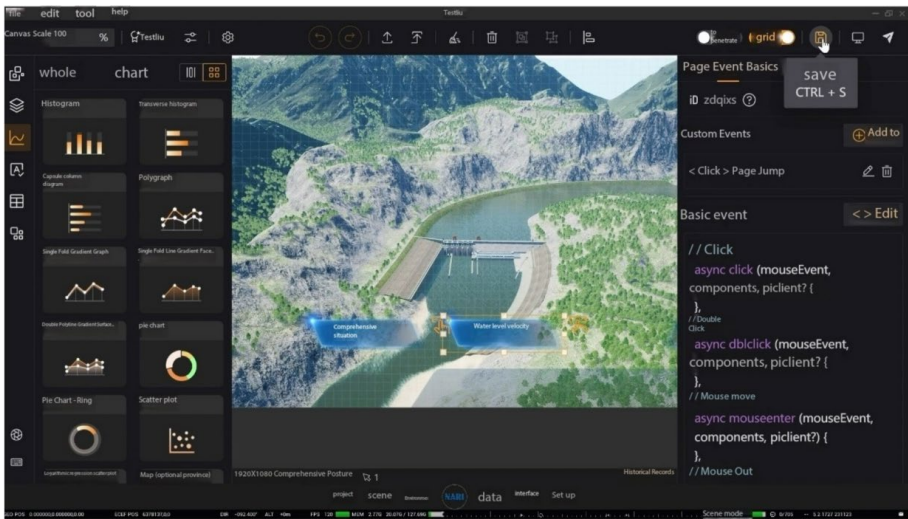


Fig. 4. Schematic diagram of twin scene construction

**Engine Fusion.** By utilizing integrated streaming technology and developing a streaming protocol based on WebRTC, the rendering results of the high simulation engine are pushed in real-time to the GIS engine for display, fully utilizing the spatial analysis capabilities of the GIS engine and the visual effects of the high simulation engine.

## 4.2 Various Object Digital Twin Expression Methods

Data acquired at different levels in the digital twin base are mainly divided into three types of objects: point, linear, and planar. The way they are expressed varies at different levels, requiring the definition and standardization of how different types of objects are expressed at different levels. For example, rainfall stations can be expressed with point objects at the L1 and L2 levels, but with planar enclosures and local linear expressions at the L3 level; the expression of electromechanical equipment is similar. Engineering hubs at the L1 level can be expressed with planar or sim-

ple planar enclosures, but at L2 and L3 levels, planar enclosures are used (L2 and L3 levels use 3D models of different precision, all rendered in real-time with triangular faces), as shown in Table 2. Additionally, newly added data such as satellite remote sensing and underwater surveys in this document also need to standardize their expressions. Satellite remote sensing and satellite cloud images use texture and terrain fitting to express spatial planar information, while large cross-sections of underwater survey river channels use polygonal surfaces (essentially composed of triangular faces).

**Table 2.** Definition of Object Expression

Object	L1	L2	L3
rainfall station	point-figure	point-figure	area-figure, line-figure(part)
electromechanical equipment	point	point	planar, linear(part)
engineering hub	planar	planar	planar
satellite remote sensing data	texture, terrain	texture, terrain	texture, terrain
underwater measurement data	polygon	polygon	polygon

### 4.3 Twin Scene Construction

Based on spatial data and relevant models of hydraulic structures, a full element scene floor is constructed, which involves four levels: watershed level, engineering level, facility level, and part level. When designing scenarios, fully consider the data scale, as the data size varies greatly between different scenarios. For the same watershed level scenario, the initial information content of DOM data with a resolution better than 1m is more than 6 times that of DOM data with a resolution of 2m. The accuracy of the 3cm oblique photography model is about 100G per 1km<sup>2</sup>. The model data for 18 single point projects with a single BIM model size (LOD300 accuracy) is approximately 200G.

(1) The watershed level can reflect the situation within the relevant watershed where the hydropower station is located, and its main functions include watershed flood control.

(2) Engineering level can reflect the situation within the scope of the hydropower station itself, and its main functions include simulation operation, virtual inspection, etc.

(3) The facility level can reflect the situation of key equipment and facilities such as electrical equipment inside the hydropower station, and the main functions it carries include the entire life cycle of the equipment.

(4) The part level can reflect the component situation of key equipment in hydropower stations, complete the part level disassembly of key necessary equipment, and mainly carry out functions such as equipment disassembly and assembly, equipment maintenance and inspection.

#### **4.4 Visual Rendering and Interaction**

Based on a visualization engine, twin scenes are rendered and performance improved using techniques such as visibility removal, multi-resolution model simplification, image-based rendering and acceleration, texture optimization, multi CPU parallel or PC cluster, collaboration between CPU and GPU and graphics card programmable rendering acceleration. For example, based on a high simulation engine, using geometric representation methods such as triangular stripes and triangular fans to accelerate 3D scene rendering, the average frame rate is increased by more than 2 times, greatly improving rendering efficiency.

Realize the interaction between users and graphics in the scene, automatically obtain spatial coordinate information, model attribute information, etc., and drive three-dimensional interactive operations, including dynamic display of models, three-dimensional interactive positioning, and spatial attribute queries.

### **5 Digital Twin Applications**

Through the use of digital twin technologies such as 3D GIS, BIM digital modeling, visual rendering, and lightweight technology, dynamic and high-performance loading and rendering of different levels of scenes is achieved, supporting the simulation functions of digital twins. This meets the various business application needs of hydropower plants, enabling data-driven scenarios and simulation optimization iterations through bidirectional interaction.

#### **5.1 Roaming of River Basins and Hydropower Plants**

By integrating basin DOM data, DEM data, vector layers, oblique photography data, BIM model data, etc., and through parameter settings, customized flights of the basin and hydropower plants can be realized. This allows for a macro control of the basin and project as a whole, while providing interactive scene support for basin flood control and disaster reduction, and digital hydropower management.

#### **5.2 Simulation Operation of Hydropower Plants**

By binding to various intelligent sensor monitoring points, simulation operation of hydropower plants can be realized in the digital twin of the hydropower plant. This includes real-time simulation of changes in water levels, gate openings and closings, turbine operations, etc., driven by business data models to achieve synchronous simulation operation of physical and digital twin hydropower plants. The digital twin can also optimally allocate load for economic operation considering multiple objectives like water consumption and power generation benefits and implement load linkage adjustment strategies with other stations.

### **5.3 Application of Flood Control about “prediction-warning-rehearsal-plan”**

Building hydrodynamic models, reservoir dispatch models, safety monitoring models, water quality safety models, and other water conservancy and hydropower professional models helps streamline the business logic of hydropower plants. It organizes and reconstructs massive data in a structured manner, building a knowledge base and establishing a "prediction-warning-rehearsal-plan" digital twin application. This, combined with real-time operational status, water conservancy model predictions, artificial intelligence analysis results, etc., allows for visual rehearsals, iterative optimization and formation of the best plans in the hydropower plant digital twin.

### **5.4 Full Lifecycle Management of Equipment**

BIM models established strictly according to the position, size, and structure of the equipment can clearly display the location and structure of the equipment, associating equipment operation parameters, drawing materials, maintenance data, and maintenance information. Equipment information can be displayed in real-time, and warnings for abnormal operating statuses and over-lifespan service can be issued and displayed prominently, forming full lifecycle management of hydropower plant equipment and facilities. This effectively addresses sudden equipment failures.

### **5.5 Virtual Inspection**

Based on 3D modeling and augmented reality (AR) technology, customized inspection tasks for different scenarios like turbine generator sets, underground plants, and corridors can be realized. Path planning can be customized, and walking routes can be drawn in a 3D scene, with points of interest manually added along the route. Virtual inspections automatically record inspection routes, equipment parameters, monitoring data, etc., generating inspection logs. Fast inspections for critical, alarm, and faulty equipment can be achieved, enhancing the inspection range and frequency and improving inspection work efficiency in combination with manual inspections.

### **5.6 Maintenance Training Simulation**

Using virtual reality (VR) technology, interactive maintenance simulations are formed through visual, auditory, and tactile simulation, further improving maintenance management levels and the ability of employees to handle accidents and faults. Simulation objects include main equipment like turbines, turbine generators, and governors, and 3D models of partial and overall assemblies are established according to maintenance procedures, operational guides, and equipment drawings. Key technologies like quick focusing, optical spatial positioning, inertial motion capture, and 2D to 3D linkage are applied to accurately position maintenance personnel and objects in 3D space and capture their motion states.

## 5.7 Digital Panoramic Screen

Using screen configuration, HTML5, Hybrid, data resource pooling, lightweight technology, visual rendering, cloud rendering, and other technologies are comprehensively applied to build a digital panoramic screen. Based on the data twin foundation, massive data aggregation and analysis, and visual data applications for multi-terminal scenarios are achieved, enhancing intelligence levels.

## 6 Conclusion

This article preliminarily constructs the digital twin architecture of intelligent hydropower plants, defines and standardizes the expression of information models and various object digital twin expressions, forms an application mode based on digital twin technology, and provides methodological references for promoting the practical application of digital twin technology in intelligent hydropower plants. Further research on simulation mechanism models will continue, utilizing artificial intelligence, big data analysis, and other technologies to improve the digital simulation level for understanding, prediction, and optimization of the physical system's performance. This provides stronger technical support for the operation and management of intelligent hydropower plants, enhancing the operational management level and socio-economic benefits, and promoting the deeper development of intelligent hydropower plants.

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