

Research on the Application and Prospect Analysis of Digital Twins in the Full Life Cycle Management of Medical Buildings

Ruonan Li 

School of Management, Wanjiang University of Technology, Ma'anshan, China
Email: 19055408680@163.com

How to cite this paper: Li, R.N. (2026) Research on the Application and Prospect Analysis of Digital Twins in the Full Life Cycle Management of Medical Buildings. *World Journal of Engineering and Technology*, **14**, 511-519.
<https://doi.org/10.4236/wjet.2026.143030>

Received: April 18, 2026

Accepted: June 23, 2026

Published: June 26, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Currently, China is further advancing the construction of new-type infrastructure and the digital transformation of the construction industry. As a key enabling technology, Digital Twin has provided a new approach for the construction sector. Characterized by high safety requirements, high operational continuity, and high complexity, medical buildings are plagued with pain points in engineering management, such as frequent design changes, poor construction collaboration, disconnection between different construction phases, and low management and control efficiency. Against this backdrop, this paper establishes a Digital Twin framework integrating BIM, IoT, HIS, and BAS, and realizes closed-loop full-life-cycle management of medical buildings via unified semantics and spatio-temporal indexing. In the pilot hospital project, virtual prototypes and simulations adopted in the design phase cut the number of design revisions from 5 to 2 and shortened the design cycle by 30%. In the construction phase, the combination of 4D progress management and on-site perception reduced the schedule deviation rate from 8% to 3%. During the operation and maintenance phase, with fault diagnosis and strategy engine technologies, the fault response time was shortened from 2 hours to 30 minutes, annual energy consumption was lowered by 12%, and the daily turnover rate of consulting rooms rose from 4.5 times to 6.0 times. Furthermore, this framework enables cross-phase knowledge transfer and parameter inheritance to support the continuous optimization of medical buildings. Its integration with artificial intelligence, edge computing, and other technologies can further extend its application to scenarios such as emergency deduction.

Keywords

Digital Twin, Medical Buildings, Full Life Cycle Management, Integration of BIM and IoT

1. Introduction

Against the trend of digitalization and informatization development in China's construction industry, new-generation information technologies represented by digital twins have shown enormous potential and broad development prospects in achieving in-depth integration with the construction sector, and their value is particularly prominent in the specialized field of medical buildings [1]. Medical buildings feature high safety standards, high operational continuity, and high complexity [2] [3]. They must comply with rigid constraints, including infection prevention and control, separation of clean and polluted flows, and environmental compliance, while ensuring smooth operational processes and controllable energy consumption under limited resources. Traditional methods relying on static drawings and empirical judgment fail to address practical challenges such as fragmented cross-stage data, cross-system coupling [4], and rapid iterative updates. Parameters and strategies cannot be effectively transmitted across design, construction, and operation phases, resulting in frequent rework, potential risks, and low efficiency. Based on data-driven virtual-real mapping and supported by two-way data links and closed-loop decision-making [5] [6], digital twins can integrate BIM, the Internet of Things, hospital information systems, and building automation systems under unified semantics and spatio-temporal indexes. This enables the synchronous evolution of facility status and operational strategies, and further establishes a linked management mechanism oriented to space-time dimensions, events, and strategies [7] [8]. This paper constructs a full-life-cycle framework for medical buildings based on three core elements: observability (real-time perception of building geometry, equipment status, flow of people, environment, etc), controllability (control instructions and adjustment strategies are issued based on data) and evolvability (continuous iteration of model and strategy, knowledge inheritance), and verifies the framework in the new campus of a real hospital. It aims to provide reusable methodologies and data foundations for multi-stage collaborative work, risk pre-control, and optimal resource allocation, as well as deliver practical engineering solutions for smart hospital construction, energy conservation, and carbon emission reduction.

2. Project Description

This project is a comprehensive medical technology building project in the new hospital area of a comprehensive tertiary hospital in East China. The total construction area is 15680.45 m². There are four floors on the ground, local equipment interlayers, and no basement. The functions cover general outpatient clinics, specialist clinics, medical imaging, inspection centers, central pharmacies, infusion halls, and supporting medical technology rooms. It is one of the core buildings in the new hospital area. The implementation scope of digital twin covers the whole life cycle, and the BIM model and medical process flow are collected in the design stage. Collect 4D progress and on-site perception data during the construction phase; the operation and maintenance phase collects the operation data of BAS (Building Automation System), HIS (Hospital Information System), and IoT (In-

ternet of Things) devices to form a cross-stage unified data set.

3. Application Practice of Digital Twins in All Stages of the Whole Life Cycle of Medical Buildings

3.1. Practical Application of Digital Twins in the Design Phase of Medical Buildings

During the design stage of the outpatient and medical technology complex building for the new campus of this tertiary hospital, the project team adopted digital twins as virtual design prototypes for detailed design. By integrating BIM geometric information, medical process specifications, and equipment parameters, a unified semantic model was established to realize collaborative simulation of spatial layout, medical treatment procedures, and equipment configuration under a unified coordinate system. Taking the operating room tower (BIM-ID: EQ01) → energy consumption point (BAS-1008) → vibration sensor (IoT-021) → asset number (HIS-0005) as an example, cross-system data mapping and fusion can be realized at this stage. The performance indicators are based on the year before the implementation of the project, and the implementation cycle is 18 months. The application results show that the number of program modifications is reduced from 5 times to 2 times, and the design cycle can be shortened by 30%. In view of the high sensitivity of the operation department and the intensive care unit (ICU) to clean-sewage diversion and emergency transport, the design side uses agent-based human flow simulation. This method conforms to the complex and dynamic characteristics of medical human flow, and can set path cost functions for medical staff, patients, and logistics personnel, and incorporates constraints such as elevator capacity, buffer room layout, and gradient of barrier-free ramps. On this basis, quantitative evaluation was conducted on the key routes of postoperative patient transfer to ICU, congestion degree at intersection points, and potential exposure time of cross-infection risks.

In the design stage, the airflow simulation method (CFD) can be used for ventilation and pressure difference design [9], which can meet the high precision requirements of clean rooms. Through the simulation analysis of the layout of the supply and return air and the gradient of the pressure difference, the air flow organization effect of the negative pressure ward and the clean operating room is checked by using the air age, pollutant dilution efficiency, and other indicators. The maintenance and inspection envelopes of large imaging equipment and surgical ceiling towers often conflict with comprehensive pipelines. By means of collision detection and accessibility analysis, the project team can determine in advance within a virtual scenario the width of maintenance passages, the rotating radius for disassembly and assembly, and the requirements for hoisting routes imposed by equipment weight.

3.2. Practical Application of Digital Twins in the Construction Stage of Medical Buildings

In the construction organization of the new campus of this Grade A tertiary hos-

pital in East China, the project team takes digital twins as the core of on-site command and data hub. It integrates 4D progress models, WBS task lists, and material arrival schedules into a unified semantic base, and aligns them with sensing data such as UWB tags, RTK positioning, tower crane weighing, and video recognition. In this way, the statuses of component hoisting, installation, acceptance, and other processes are synchronously mapped in the virtual scenario.

Targeting the characteristics of medical buildings, such as numerous overlapping construction procedures and concentrated hoisting operations, the system can automatically identify delay risks based on deviations between planned and actual progress, and optimize tower crane operation schedules and team deployment plans. In the project record, the progress deviation rate converges from 8% of the baseline to 3%, and the progress adjustment is more forward-looking. Meanwhile, it links material arrival schedules, yard layout, and hoisting frequency scheduling, and organizes construction via three-day rolling plans and visual dashboards to reduce work stoppages caused by mismatched materials.

In terms of quality management, the system matches and compares BIM component information with laser point cloud and photogrammetry data to verify the installation accuracy of key parts, including air ducts, medical gas pipelines, clean ceilings, and door and window openings, and generates visual deviation cloud maps. It can keep the installation error of key components within the threshold of 5 to 10 millimeters, automatically issue rectification orders for non-compliant items, clarify responsible persons, re-inspection time, and acceptance procedures, and improve the precision of construction quality control.

3.3. Practical Application of Digital Twin in the Operation and Maintenance Stage of Medical Buildings

During the operation and management phase of the new campus of this Grade A Tertiary Hospital, the project team takes the digital twin platform as a cross-system business hub, and coordinates data and management strategies focusing on three main lines: equipment operation, energy management, and space efficiency (see **Figure 1**). The platform integrates BIM geometry data, BAS building automation data, HIS business data, and IoT perception data under unified semantics and spatiotemporal indexes, establishes full-dimensional ledgers and event streams for equipment instances, and embeds state estimation and rule engines into the closed-loop control links. In view of the high requirements of HVAC and medical gas systems for continuity and safety, the platform deploys an FDD fault detection and diagnosis model [10]. This model can adapt to the high reliability requirements of medical equipment, and point to abnormal pattern recognition and root cause location. The threshold crossing, feature mutation, and health attenuation are linked to mobile terminal alarm, work order, and spare parts check, so that the equipment fault response time is compressed from baseline 2 h to 30 min, and the data are derived from the equipment operation log statistics.

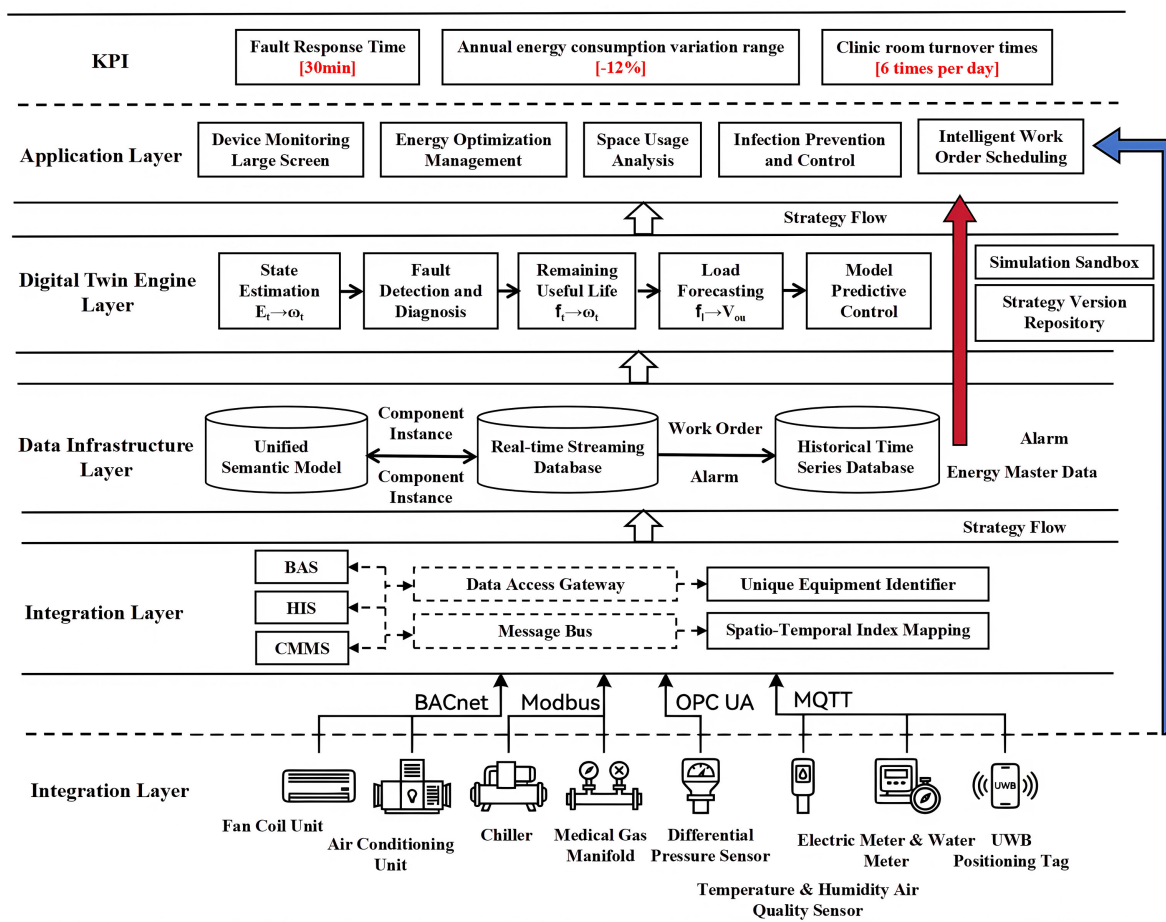


Figure 1. Architecture diagram of digital twin operation and maintenance management platform for medical buildings.

Driven by load forecasting and equipment health assessment, the strategy engine verifies the group control of chillers as well as target values of supply air temperature, humidity, and pressure difference via online simulation, and then distributes them to the control end, cutting annual energy consumption by 12% compared with the baseline. In terms of space management, the platform aligns access control statistics and positioning data with HIS scheduling information to build time-period profiles of consultation room turnover rate and peak-valley waiting flow. The turnover rate of the clinic increased from 4.5 times/day at the baseline to 6.0 times/day, and the data were derived from the statistics of HIS medical records. It is worth noting that the boundary parameters of pressure difference and air age in intensive care units and negative pressure wards have been solidified into a parameter library during the design phase. In the operation and maintenance stage, real-time environmental monitoring data are compared with the parameter library online. Once the values approach critical thresholds, linkage strategy adjustments for bypass air valves, fan speeds, and access control will be activated to balance isolation protection performance and ward passage efficiency. Accordingly, knowledge transfer and parameter inheritance are integrated into daily management procedures, enabling the continuous iteration of the closed-loop optimization.

tion system covering equipment health management, energy consumption control and space efficiency improvement within a unified model.

4. Prospect Outlook of Digital Twins in the Full Life Cycle Management of Medical Buildings

This section focuses on the prospect of digital twins in the whole life cycle management of medical buildings. The content involved is the direction that future research needs to focus on, and has not yet been implemented, which can be further explored and verified by subsequent scholars.

4.1. Application Expansion Directions under Technological Integration

Against the compound demands for safety, continuity, and timeliness in the operation of medical buildings, digital twins will be further integrated with emerging technologies such as artificial intelligence, the Internet of Things, and 5G in the future, achieving collaborative linkage at the model layer, data layer, and control layer. For equipment health management and operating condition optimization, operation and maintenance teams can adopt self-supervised models combined with knowledge graphs to jointly model time series data and event streams. Pattern constraints are applied to improve the reliability of anomaly identification and service life prediction, as well as fault detection and diagnosis results are connected to the strategy engine, which is expected to raise the accuracy of failure prediction for key rotating equipment to 95%. Meanwhile, online adaptive calibration for chilled water plant group control and differential pressure targets can be realized via strategy learning methods with safety constraints.

5G network slicing and edge computing enable the collection, fusion, and distribution of high-concurrency data to be shifted to the equipment end to realize end-edge-cloud collaboration, with latency controlled within 10 milliseconds. This effectively supports rapid in-day closed-loop management for differential pressure maintenance in negative-pressure wards, airflow organization in operating departments, and linkage control of medical gases. In wards with high-density mobile entities, edge nodes can conduct rolling calculation for path planning of disinfection robots and logistics fleets, so as to reduce instantaneous exposure risks caused by cross-contamination between clean and polluted areas.

If the IoT layer adopts a device-oriented unified semantic and protocol stack, aligning the OPC UA device information model with the FHIR medical data standard to a unified identification system, it can integrate device instances, ward processes, and environmental states under the same spatio-temporal index. This provides a stable knowledge base for cross-system rule engines and state estimation. Derived from this, the construction of digital twin smart hospitals can further expand emergency drills into computable virtual sandboxes in the future. By virtue of multi-agent simulation, scenarios such as infectious disease outbreaks, power outage switching, and fire smoke diffusion can be simulated online, and the link-

age verification of access control, air dampers, and personnel scheduling strategies can be completed in the simulation. The verified management and control logic is then mapped and deployed to the physical hospital system in a safe and controllable manner. Meanwhile, XR-based teaching and on-the-job training can be further embedded into this sandbox, enabling new employees to familiarize themselves with strategies and identify risks in dynamic processes close to real scenarios, forming a closed-loop transfer path from cognition to execution.

4.2. Key Challenges and Countermeasures for Industrial Implementation

In view of the operational characteristics of medical buildings, digital twin platforms are required to realize cross-system coupling and maintain highly reliable continuous operation. Accordingly, multiple constraints still exist in the industrial implementation and popularization of such platforms. Fragmented data standards hinder semantic mutual recognition among BIM, BAS, HIS, and IoT systems. The lack of unified equipment identification and spatio-temporal indexes increases the costs of asset mapping and event traceability. Renovation of existing buildings is restricted by closed-source interfaces and insufficient data collection capacity, making it difficult to build a high-quality data foundation. Digital security and privacy compliance raise barriers to data sharing. The mismatch between investment cycles and return cycles leads to heavy upfront capital expenditure pressure. In addition, the shortage of interdisciplinary talents and ambiguous service delivery scopes easily result in idle operation of platforms, all of which undermine the practical application effect of digital twins.

In response to the above challenges, priority should be given to establishing unified data specifications. Centering on equipment instances, it is essential to unify asset coding, spatial hierarchy, and event vocabulary, and align BIM models, control points, process parameters, and HIS master data within a consistent identification system. At the interface layer, semantic gateways shall be built with scalable information models and medical data standards adopted, so as to precipitate facility entities and rule bases into reusable components and form a parameter inheritance chain covering the whole process from design to operation and maintenance. In terms of cost management, a tripartite cooperation mechanism among governments, enterprises, and hospitals can be explored. The basic platforms can be incorporated into regional new infrastructure construction or energy-saving renovation special projects. Investment can be shared via performance-based payment and energy management contracting modes, and system expansion can be implemented in phases through modular components. From the governance perspective, digital security and privacy protection shall be integrated into the full life cycle of medical buildings, with hierarchical domain management and zero-trust architecture adopted to form a closed-loop mechanism for outbound data approval and log auditing. For capacity building, dedicated operation posts and standardized training systems need to be established to link parameter databases and knowledge bases into a self-learning iterative mechanism.

5. Conclusion

This paper proposes a digital twin methodology and implementation path for the full life cycle of medical buildings. It connects BIM, the Internet of Things, hospital information systems, and control platforms via a unified semantic database, embeds knowledge transfer and parameter inheritance into governance processes with the support of spatio-temporal indexes and rule engines, and thereby forms a continuously evolving management closed loop covering design to operation and maintenance. Practice proves that this framework can achieve synergistic advantages in scheme deduction, construction collaboration, and operation and maintenance optimization, and presents systematic characteristics that take observation as the foundation, control as the means, and evolution as the goal. The research can provide references for the digital lean construction, integrated project management, and full-life-cycle value improvement of medical buildings. In the future, digital twin will be further integrated with artificial intelligence, edge computing, and other technologies to build computable emergency sandboxes and training spaces, so as to support online deduction and strategy verification of complex scenarios.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] Hu, H., Wang, M., Lei, Q., *et al.* (2024) Digital Twin Hospitals: Transforming the Future of Healthcare. *Journal of Biomedical Engineering*, **41**, 376-382. (In Chinese)
- [2] Wanigarathna, N., Sherratt, F., Price, A. and Austin, S. (2019) Design Re-Use: Critical Application of Healthcare Building Design Evidence. *Engineering, Construction and Architectural Management*, **26**, 350-366. <https://doi.org/10.1108/ecam-07-2017-0118>
- [3] Peng, Y., Zhang, M., Yu, F., Xu, J. and Gao, S. (2020) Digital Twin Hospital Buildings: An Exemplary Case Study through Continuous Lifecycle Integration. *Advances in Civil Engineering*, **2020**, Article ID: 8846667. <https://doi.org/10.1155/2020/8846667>
- [4] Hosamo, H.H., Nielsen, H.K., Kraniotis, D., Svennevig, P.R. and Svidt, K. (2023) Digital Twin Framework for Automated Fault Source Detection and Prediction for Comfort Performance Evaluation of Existing Non-Residential Norwegian Buildings. *Energy and Buildings*, **281**, Article ID: 112732. <https://doi.org/10.1016/j.enbuild.2022.112732>
- [5] Pedral Sampaio, R., Aguiar Costa, A. and Flores-Colen, I. (2023) A Discussion of Digital Transition Impact on Facility Management of Hospital Buildings. *Facilities*, **41**, 389-406. <https://doi.org/10.1108/f-07-2022-0092>
- [6] Fang, J., Wu, Z., Yang, R., Lian, Y., Li, X., Chu, T.J., *et al.* (2025) Dynamic Object Mapping Generation Method of Digital Twin Construction Scene. *Buildings*, **15**, Article No. 2942. <https://doi.org/10.3390/buildings15162942>
- [7] Alavi, H., Gordo-Gregorio, P., Forcada, N., Bayramova, A. and Edwards, D.J. (2024) AI-Driven BIM Integration for Optimizing Healthcare Facility Design. *Buildings*, **14**, Article No. 2354. <https://doi.org/10.3390/buildings14082354>
- [8] Han, Y.L., Li, Y.B., Li, Y.K., *et al.* (2023) Digital Twinning for Smart Hospital Operations: Framework and Proof of Concept. *Technology in Society*, **74**, Article ID: 102317. <https://doi.org/10.1016/j.techsoc.2023.102317>

- [9] Massarotti, N., Mauro, A., Sainas, D., Marinetti, S. and Rossetti, A. (2019) A Novel Procedure for Validation of Flow Simulations in Operating Theaters. *Science and Technology for the Built Environment*, **25**, 629-642. <https://doi.org/10.1080/23744731.2018.1556053>
- [10] Chen, Z., O'Neill, Z., Wen, J., Pradhan, O., Yang, T., Lu, X., *et al.* (2023) A Review of Data-Driven Fault Detection and Diagnostics for Building HVAC Systems. *Applied Energy*, **339**, Article ID: 121030. <https://doi.org/10.1016/j.apenergy.2023.121030>