Original Research Article

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Digital Twin-Driven Intelligent Hotel BIM Operation and Maintenance System: A Case Study of Holiday Inn

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Abstract: The rapid development of smart buildings requires efficient and data-driven hotel facility management. Despite the potential of building information modelling (BIM) and digital twins, empirical studies addressing heterogeneous data fusion and intelligent diagnostics in real hotel environments are limited. This study developed an integrated digital twin framework that combines BIM, IoT sensing, and semantic modelling based on the BRICK Schema to enable unified data representation and real-time operational mapping. A digital twin operation and maintenance (O&M) system was implemented and validated at the Holiday Inn Hotel. The system supports real-time equipment monitoring, predictive fault diagnosis, and dynamic emergency simulations. During a three-month pilot deployment, the system reduced the fault localization time from 120 ± 40 min to 15 ± 10 min ($p < 0.001$), improved inspection efficiency by 140% ($p < 0.001$), and yielded an estimated annual reduction of 18% in maintenance costs and 12% in energy consumption. The results demonstrate the effectiveness of digital twin-enabled facility management and provide a replicable methodological reference for extending BIM values across the building lifecycle.

Keywords: BIM; Digital Twin; Case Study; Semantic Modelling; Data Fusion; Facility Management; Predictive Maintenance

Introduction

The building industry continues to face persistent challenges related to fragmented information flow and data discontinuity during the O&M stage of buildings. Although BIM has been widely adopted in design and construction, its value is often underutilized in O&M, where BIM models frequently become static archives that fail to support real-time operational decision making. Digital twins, enabled by real-time sensing and bidirectional mapping between physical and virtual assets, offer a promising means to overcome these limitations. BIM provides high-fidelity geometric and semantic information for initializing digital twins, whereas digital twins extend the value of BIM across the building lifecycle, forming the foundation for intelligent facility management[1-2].

Hotel operations require exceptionally high levels of timeliness and reliability in facility management. However, traditional practices rely heavily on manual inspections and reactive alarm-based responses, often resulting in delayed fault handling, elevated O&M costs, and persistent information silos. Existing studies have largely focused on conceptual frameworks or

isolated system implementations, while empirical research that deeply integrates BIM geometric models, real-time operational data, and ontology-based semantic representation, and validates such integration in a real hotel environment remains scarce.

To address these gaps, this study developed a digital twin–driven intelligent O&M system for a Holiday Inn hotel by integrating BIM, IoT sensing, and ontology-based semantic modelling. This study addresses three key questions:

(1) How can a unified digital twin architecture be constructed to overcome data heterogeneity and interoperability challenges in hotel facility management?

(2) To what extent can such a system improve operational efficiency and reduce O&M costs in real hotel scenarios?

(3) What methodological and practical insights can be generalized to support the digital transformation of similar building types?

1. Research Design and System Framework

1.1 Research Design and Data Collection Process

This study adopts the design science research paradigm, following an iterative path of "problem identification—solution design—system implementation—field validation—evaluation and optimization," and undergoes two rounds of development cycles to refine the system functionality. The data were sourced from four sources.

(1) Interviews and questionnaires: Semi-structured interviews were conducted with 15 members of the hotel facility management team, engineers, and maintenance personnel, and 15 valid usability questionnaires (5-minute Likert scale) were collected to clarify requirements and assess the user experience.

(2) BIM model: Based on the as-built drawings and on-site verification, a level-of-detail (LOD) 400 precision model was built using Revit, and lightweight processing was performed using Navisworks, ultimately optimizing the number of model faces from 120 million to 8 million to ensure smooth loading on the web-based platform.

(3) Operational and sensor data: Real-time collection of building management system (BMS) and sensor data (temperature, humidity, energy consumption, and vibration) was achieved through IoT gateways and APIs with quality control measures such as timestamp standardization, outlier filtering, and missing value imputation.

(4) Maintenance and work order data: A total of 148 maintenance records were extracted from the computerized maintenance management system (CMMS) over the past 12 months to establish a performance baseline.

1.2 Overall System Framework

As shown in **Figure 1**, the overall system architecture comprises five layers:
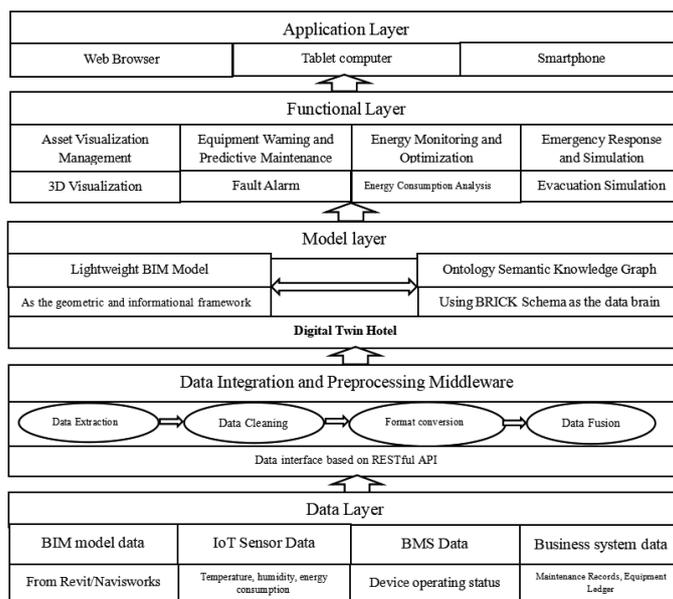

Figure 1.

Data Layer: Integrates BIM, IoT sensors, BMS operational status, and business system data to form the data foundation for the digital twin.

Data Processing Middleware Layer: RESTful APIs are used to extract, clean, transform, and fuse multisource heterogeneous data to provide standardized data streams for the upper layers.

Model Layer: Integrates lightweight BIM models and semantic knowledge graphs based on the BRICK Schema, forming digital twin representations mapped to physical entities[3].

Function Layer: Provides four core functions: asset visualization management, equipment warning and predictive maintenance, energy monitoring and optimization, and emergency response simulation[4].

Application Layer: Adopts a browser/server architecture to support multi-terminal and cross-platform access.

2. Key Technologies for System Implementation

2.1 BIM Model Construction and Lightweight

Processing

Model construction follows the "Building Information Modelling Design Delivery Standard" GB/T51301-2018. To ensure smooth performance on the web, the original model is lightweight, and geometric simplification is performed using Navisworks, removing internal structures that hold no value for operations and maintenance. Repeated components are rendered using instancing to reduce memory usage, and LOD techniques are applied to achieve dynamic loading of the model. After optimization, the loading time of the model was maintained within 3 s under standard network conditions[5].

2.2 Multi-source Data Integration and Semantic Modelling Process

As shown in **Figure 2**. Multisource data integration is at the core of high-quality digital twins[6]. By customizing the data middleware, heterogeneous data [Figure
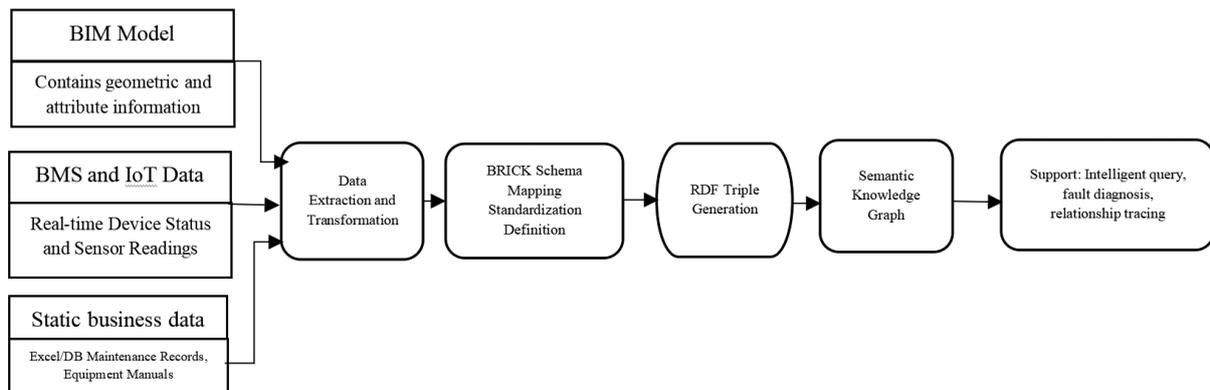

Figure 2.

from BIM, BMS, IoT, and CMMS were integrated and standardized. Therefore, the BRICK Schema was adopted as the top-level ontology for semantic mapping, unifying equipment identifiers from different systems into RDF triples, and effectively resolving the data silo issue caused by inconsistent naming conventions. The accuracy rate of semantic mapping reached 98% after the manual verification of 100 key devices. The constructed semantic knowledge graph supports complex queries and relationship tracing using SPARQL, thereby providing a unified logical foundation for advanced intelligent applications.

2.3 Visualization System Development and Function Implementation

The system frontend uses the Three.js engine for 3D rendering, whereas the backend is built using the Spring Boot Framework. Three core functions were implemented.

Asset Visualization and Management: Supports hierarchical drill-down queries from "building-floor-room-device." Asset information retrieval responds within sub-second timeframes.

Equipment warning and predictive maintenance: The QR codes of the device were integrated. The warning mechanism is based on a rule engine and statistical

process control model, which can automatically generate and dispatch maintenance work orders. As shown in **Figure 3**.
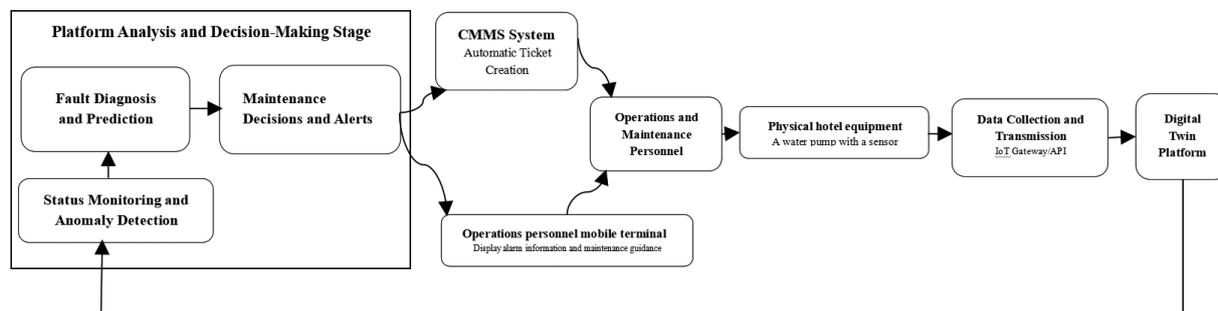

Figure 3.

Emergency Simulation Module in the Platform Analysis and Decision-Making Phase: Integrates BIM geometric models with Pathfinder evacuation simulation to achieve dynamic simulation and route optimization for incidents such as fires, with results visualized in a three-dimensional environment.

3. Case Applications and Effectiveness Analysis

3.1 System Deployment and Verification

The system completed a three-month pilot deployment in a hotel. To comprehensively validate the effectiveness of the system, three main categories comprising 21 typical operation and maintenance scenarios were designed for testing.

Equipment fault early warning (nine scenarios): Situations such as refrigerant leakage in the air-conditioning unit, pump bearing overheating, and elevator entrapment were simulated.

Energy anomaly diagnosis (seven scenarios): Scenarios such as high energy consumption in the banquet hall outside business hours and failure to turn off public area lighting on time were created.

Emergency simulation and response (five scenarios): dynamic simulation of evacuation routes and emergency equipment locations in fire scenarios.

Fifteen valid user feedback forms showed an overall system satisfaction rating of 4.47±0.52 (on a 5-point scale). Notably, "convenience of asset information inquiry" (4.6±0.51 points) and "timeliness of fault early warning" (4.5±0.63 points) received the highest ratings.

3.2 Quantitative Effectiveness Analysis

compared the key performance indicators of the pilot and baseline periods using appropriate statistical methods to test the significance of the differences. The results are presented in **Table 1**. The findings indicate that after the system was implemented, both the fault-location time and inspection efficiency improved significantly ($p < 0.001$). The reduction in maintenance costs and energy consumption further demonstrates its potential economic benefits and green operation.

Table 1.

Indicator	Baseline	Pilot period	Rate of change (%)	Statistical Test Results	Explanation
Fault location time (minutes)	120±40(N = 148)	15±10(N = 21)	−87.5%	$t(167) = 11.95, p < 0.001$	Event Log
Inspection efficiency (area/person/day)	5±1.2	12±1.5	+140%	$t(373) = 42.87, p < 0.001$	Inspection Record
Average Annual Maintenance Cost (1,000 CNY)	500	410	−18%	N/A	Avoided 3 unplanned shutdowns
Annual energy consumption (1,000 kilowatt-hours)	1000	880	−12%	N/A	Estimated based on pilot data

Conclusion

This study developed a digital twin system that integrates BIM, IoT, and ontology semantics, effectively addressing the challenges of data integration

and inefficiency in hotel facility management. The empirical results show that the system enables deep fusion and interoperability of multisource data and achieves significant improvements in key operation and maintenance metrics. The fault location time was reduced by 87.5%, and the inspection efficiency increased by 140%. This validates the effectiveness of a data-driven intelligent operation and maintenance model in shifting hotel asset management from passive response to proactive prediction.

The main outcomes of this study reflect three key aspects. First, it proposes and validates a technical framework that integrates lightweight BIM, semantic modelling, and real-time data connectivity, thereby providing a comprehensive solution to the issue of data heterogeneity during the operations and maintenance phases. Second, through rigorous case studies, it quantitatively assesses the tangible benefits of digital twin technology in improving operational efficiency and reducing the costs. Finally, it summarizes a set of replicable and scalable methods and practical experiences, offering valuable references for the digital transformation of similar buildings.

As an in-depth case study, the applicability of this framework to a broader range of building types requires further validation. Currently, the intelligent diagnostic capability of the system mainly relies on a rule engine, and integrating machine learning algorithms in the future will be key to enhancing its predictive power. In summary, this study not only demonstrates the practical value of digital twins in hotel operations and maintenance but also lays a theoretical and practical foundation for extending BIM applications across the entire building lifecycle and promoting intelligent transformation in building operations.

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