Proceedings of CONF-CIAP 2026 Symposium: International Conference on Atomic Magnetometer and Applications
DOI: 10.54254/2753-8818/2026.HZ29623

BIM for Safe Hospital Operations and Maintenance

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Abstract. Hospital buildings have complex spaces, dense systems, and peak traffic, and traditional operations face challenges such as fragmented information, slow response, high energy consumption, and weak emergency capabilities. Using a BIM platform for operations and maintenance can extend the lifespan of critical equipment by 15%, reduce labor costs for operations by 20%, cut energy consumption by more than 10%, and significantly improve the collaboration efficiency among medical engineering, logistics, and clinical departments, providing a replicable model for low-cost, resilient, and sustainable smart hospital operations. Based on the advantages of BIM (Building Information Modeling) 3D visualization and full lifecycle data integration, this paper proposes a "BIM IoT IBMS" integrated framework, constructing three core modules: equipment and facility management, safety and emergency response, and pipeline inspection, achieving second-level fault localization, preventive maintenance, and dynamic energy consumption control. Through this study, BIM has significant implications for hospital safety management. Whether in enhancing safety assurance or improving efficiency, it is evident that BIM hospital operations and maintenance will be the major development trend for future hospitals. However, there are still some cost issues at present.

Keywords: BIM, Hospital building, Operations and Maintenance

1. Introduction

Under the dual impetus of “Healthy China 2030” and the “New Infrastructure” strategy, modern hospital construction is steadily evolving toward intelligent, human-centric, and highly refined operations. As one of the most functionally complex, densely populated and system-intensive public buildings, a hospital incorporates dozens of specialized subsystems: Heating, Ventilation, and Air Conditioning (HVAC), water supply and drainage, medical gases, logistics and pneumatic-tube transport, clean-room engineering, radiological systems, etc., whose crowded pipelines fight for space in extremely tight shafts and ceilings. Across the hospital’s full life-cycle, its managers must therefore guarantee safe, efficient, low-carbon and green performance.

Hospitals are also hubs of massive human and material traffic. By the end of 2024, China recorded 10.11 billion outpatient visits [1]; the comparable figures for 2021-2023 were 8.53, 8.42 and 9.56 billion, respectively, showing a fluctuating upward trend. Fifty-five percent of patients arrive between 08:00-11:30, another 25 % between 14:00-16:30, and only 6 % at night. Thus, more than 60 % of the daily census is compressed into a 3.5-hour window, producing instantaneous

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densities of 6-8 persons/m², far above the 2.5 persons/m² recommended by the Code for Design of General Hospitals.

The operation & maintenance (O&M) phase accounts for the longest duration and the greatest share of life-cycle cost. Traditional O&M still relies on 2-D drawings, paper archives and personal experience, resulting in severe information silos, low emergency-response efficiency, outdated asset-management tools, and chaotic energy and space management.

The adoption of a Building Information Modelling (BIM) platform could fundamentally change this situation. BIM is a life-cycle collaborative management system built on 3-D digital technology; its essence is to integrate multi-dimensional data, geometric, physical, functional and temporal, so that design, construction and operation can be digitally coordinated and optimized [2]. Because the model can carry information for the entire life-cycle, BIM has revolutionary potential to refine, intelligentize and visualize hospital operation and maintenance [3]. With BIM, the problems created by complex spaces, numerous building systems and dense human/logistics flows can be mitigated, while the traditional shortcomings, information silos, low efficiency, slow emergency response and coarse energy management can be overcome. Consequently, BIM is critical for keeping hospitals safe and efficient, reducing whole-life costs and improving the patient and staff experience.

This paper examines the contribution of BIM to hospital O&M in three areas: equipment and facility management, safety and emergency response, and pipeline inspection. Although considerable research already exists on space and equipment management, safety management during the operational phase remains relatively unexplored; safety/emergency response and pipeline inspection constitute the principal focus of the present study [4].

2. The necessity of integrating BIM with hospital operation and maintenance systems

Traditional hospital O&M is inefficient: most data maintenance still relies on direct database connections that force staff to correct records manually, seriously reducing their ability to pinpoint and solve problems accurately. To eliminate this slow, error-prone process the conventional management model must be replaced. BIM, a 3-D digital life-cycle platform, offers parametric modelling, visualization and full information integration. Acting as the single data source for the entire life-cycle, it allows staff to query information visually and down to room-level detail, department name, floor area, use category (clinical, diagnostic, teaching, research, administration, etc.) and security classification. This visual capability of BIM thus greatly improves both the intuitiveness of O&M work and the speed of locating assets or incidents.

Moreover, the “7 × 24 h non-stop” nature of a large general hospital makes its O&M requirements fundamentally different from those of office towers or industrial plants. The four core needs are:

(1) Asset & medical-equipment management

(2) Space & facility management

(3) Safety & emergency management

(4) Information-system management

Both clinical staff and patients are demanding ever-greater functionality and convenience from IT systems, placing heavier burdens on hospital information departments. The way in which information-system O&M requirements are managed directly determines the speed and quality of hospital digitalization; these systems must be continuously strengthened and expanded as the hospital grows and medical management standards rise [5].

Traditional O&M performs poorly in this context. A BIM-based platform, by contrast, supplies a single gateway for operations: menus are organized by business domain and access rights are

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granted to the system owners of each discipline. This solves the long-standing problem of managing buildings whose functions differ drastically from zone to zone, an issue that directly affects the efficiency of hospital-wide safety management. To guarantee rapid and effective emergency response, integrating BIM with the hospital O&M system is therefore essential.

Conventional HVAC design can rarely react promptly or accurately to the dynamic changes that characterize a complex healthcare environment. Within a BIM framework, however, the rational layout of functional zones and the optimization of air-flow paths are determined and calculated in advance, cutting computation time by 90 % and increasing response speed by 38.20–53.24 %, while delivering a cleaner hospital environment [6].

3. Establishing a hospital operation and maintenance system based on BIM

(1) Whole-life management of equipment & facilities

Through a tightly-integrated information platform, hospital executives can monitor and analyze the real-time utilization of every resource: staff, money and materials [7]. Each asset carries a "digital ID" that links its model, technical parameters, manufacturer, warranty terms and operating manual to the database. On this basis, the system performs predictive maintenance: work orders are created automatically from the maintenance schedule and pushed to the responsible technicians. Every repair record and parts replacement is stored in the same database, building a fully traceable electronic history for the asset.

(2) Safety & Emergency Management

1) Fire-fighting Emergency

Using real-time fire-dynamic simulation, the O&M team generates a 3-D visual map of hazard zones and, by coupling it with occupant-evacuation algorithms, produces the shortest yet safest escape routes, raising evacuation efficiency by 25 %. When the smoke-control system is re-optimized around these routes, the fire-safety performance of the building is further enhanced [8].

The moment a fire-alarm signal is triggered, the IBMS pushes the exact alarm coordinates to the BIM platform. Within three seconds, the source floor is located and flashes red; the system calculates the shortest evacuation path, overlays it with animated green arrows, and pops up the IDs of the nearest hydrants, extinguishers and smoke-extraction outlets together with live CCTV feeds. Duty staff can execute the entire response without leaving the BIM interface.

In the First Affiliated Hospital of Xiamen University project, BIM + IoT integration enables real-time monitoring of all fire-equipment assets. Critical-device fault response time has been cut to 3 minutes and alarm-handling efficiency improved by 30% [9].

2) Medical Emergency Response

Under conventional O&M, nurses and clerks must question patients individually, so information moves slowly; patients may wander undetected and create unnecessary risk, while zones exposed to contagious cases cannot be located and sealed quickly. BIM eliminates these gaps: enter the suspected case's ID card number and the platform instantly retrieves canteen payments and access-card swirls to reconstruct the patient's 3-D path through outpatient areas, lifts and wards, automatically highlighting every zone where he/she lingered 15 min or longer. One click dispatches the cleaning team and temporarily locks the affected departments via the access-control interface. Rapid isolation and disinfection protect the hospital's real-time hygiene and raise janitorial productivity.

(3) Pipeline Inspection and Clash Detection

In traditional O&M, 2-D drawings make it almost impossible to spot every pipe clash early; conflicts are often discovered only after walls are opened, forcing costly re-work and schedule slips.

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BIM turns the entire piping network into an instantly navigable 3-D model. Administrators can run real-time clash-detection scripts directly on the platform: any hard or clearance conflict between HVAC, water, medical-gas, electrical or data ducts is highlighted in red the moment it appears. The design team then zooms to the root clash, exports the exact coordinates, drafts an optimized routing proposal and issues a targeted revision, all before a single bracket is installed. This proactive cycle eliminates field surprises, shortens construction duration and prevents the heavy economic losses that typically follow late-stage pipe rerouting [10].

4. Case study on the application of BIM in hospital operation and maintenance systems

Under the traditional O&M model, equipment repairs are slow and duplicate work orders are common. For example, within six months in 2022 the same model of infusion pump at Zhongshan People's Hospital (Guangdong) was reported for "mother-board replacement" 38 times; post-event investigation showed that 31 of these calls were actually caused by a loose power cable. The hospital's annual re-repair rate for medical devices was 23.4 %, double the 11 % provincial average for similar institutions. The root cause: failure records for 3,300 devices were kept in an Excel file on a shared drive, so on-site technicians could not look up history on their phones [11].

To solve this, Shanghai East Hospital embedded the mechanical–electrical logic into its BIM platform. When an alarm occurs the system automatically calculates the impact zone and pushes the exact location, root cause and optimum repair procedure to the technician's mobile phone; the rate of sudden failures has since fallen by 12 % [12].

A 1,200-bed Grade-A tertiary hospital in Beijing entered all 1,967 valves and 8,412 m of water-supply/ drainage pipes into BIM and linked them to pressure/flow sensors. The platform's algorithm detects anomalies in real time and, within 30 s, pinpoints the affected pipe segment. Between 2021 and 2022, the hospital pre-empted 11 potential bursts and recorded zero flooding-related closures [13].

These cases show that BIM's advantages in hospital O&M are already substantial: it fills the information gaps left by design and handover, makes pipeline inspection faster and more accurate, and plays a critical role in safety and emergency response.

5. Conclusion

In short, by two-way integration with IoT and FM/IBMS, BIM turns a static 3-D model into a real-time digital-twin hospital. It delivers second-level fault location, live energy diagnostics, one-click space-and-asset enquiries, cuts operating cost and raises efficiency. A fire alarm immediately produces a 3-D hazard map and the shortest safe evacuation route; a single swipe-trace generates a 3-D infection path and locks down the affected ward in one click to stop cross-infection. Pipeline clashes that used to plague maintenance are now detected and corrected on the BIM canvas before work starts.

Over the last decade, BIM practice in healthcare has become multi-dimensional, deeper and more specialized. Yet most studies still describe pilot schemes of six months or less; longitudinal data covering three-plus years in general hospitals, specialty hospitals and retrofitted old campuses are scarce, and medical-outcome indicators: failure rates, nosocomial events, patient satisfaction are rarely linked. The evidence is therefore too thin and too narrow.

The next step is to create a multi-centre, long-term, open-API evidence platform with third-party evaluation, moving BIM O&M from "visible & usable" to "measurable & provable" and ultimately into national standards for hospital construction and smart management. At the same time, higher

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model accuracy, lower software cost and a pipeline of trained BIM specialists must be tackled if the technology is to fulfil its promise in hospital operations.

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