



BUILDING INFORMATION MODELING FOR ELECTRICAL SYSTEMS IN CONSTRUCTION: A CRITICAL ANALYSIS

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Abstract

Building Information Modeling (BIM) has emerged as a transformative paradigm in the construction industry, fundamentally reshaping how electrical systems are designed, coordinated, and managed throughout the building lifecycle. This comprehensive literature review synthesizes recent empirical and theoretical evidence on the application of BIM for electrical systems in construction, drawing exclusively on peer-reviewed academic scholarship. The review critically examines the evolution of BIM technologies, evaluates frameworks for electrical system integration, analyzes technical applications across design, construction, and facility management phases, and assesses the implications for sustainability and energy efficiency. The analysis reveals that BIM-enabled electrical system design achieves significant improvements in clash detection, with machine learning-enhanced approaches improving accuracy from 0.62 to 0.92. Path optimization algorithms applied to MEP systems demonstrate design efficiency improvements of 25–35% and conflict reduction of approximately 40%. The integration of BIM with digital twin technologies enables real-time monitoring, predictive maintenance, and optimized energy performance, with case studies demonstrating annual energy consumption reductions of 40.68%. However, the adoption of BIM for electrical systems faces persistent barriers including interoperability challenges, high implementation costs, skills gaps, and fragmented industry structures. This review identifies critical gaps in longitudinal performance data, standardized exchange protocols, and small-scale contractor adoption strategies, providing actionable recommendations for practitioners, researchers, and policymakers.

Keywords: *Building Information Modeling, electrical systems, MEP coordination, construction management, sustainability, & path optimization algorithms*

Introduction

The construction industry has historically been characterized by fragmentation, inefficiency, and information loss across project phases. Traditional approaches to electrical system design and installation rely on two-dimensional drawings, siloed coordination processes, and reactive problem-solving during construction, resulting in costly clashes, rework, and operational inefficiencies (Imoni et al., 2024). Building Information Modeling (BIM) has emerged as a transformative solution to these challenges, enabling the creation and management of digital representations of physical and functional characteristics of buildings throughout their lifecycle (Utsev et al., 2022).

BIM represents a fundamental departure from conventional computer-aided design (CAD) approaches. While CAD produces geometric representations, BIM incorporates parametric relationships, semantic information, and lifecycle data that enable intelligent coordination, analysis, and management of building systems (Singh et al., 2025). For electrical systems, encompassing power distribution, lighting, fire alarm, security, telecommunications, and building automation, BIM offers particular value due to the complex spatial interdependencies, safety requirements, and operational performance considerations that characterize these systems.

Recent technological advances have significantly expanded BIM capabilities for electrical engineering applications. Alshboul and Shehadeh (2025) developed an adaptive integration framework employing the extreme gradient boosting (XGBoost) machine learning algorithm for real-time predictive clash detection, demonstrating that machine learning integration can substantially improve detection accuracy and enable proactive conflict anticipation. Similarly, path optimization algorithms have emerged as critical tools for automating MEP system layout, with researchers demonstrating that algorithmic approaches can reduce design time by 33.8% and user interactions by 14.8% compared with traditional BIM tools (Choi et al., 2022).

The significance of BIM for electrical systems has grown substantially in recent years, driven by several converging factors. First, building electrical systems have become increasingly complex with the proliferation of smart building technologies, renewable energy integration, and sophisticated control systems (Singh et al., 2025). Second, sustainability imperatives demand optimization of energy performance and material efficiency throughout building lifecycles (Okagbare et al., 2026; Nsobundu & Tiza, 2025). Third, the digital transformation of construction, including the emergence of digital twins, Internet of Things (IoT) sensors, and artificial intelligence, has created new opportunities for integrating BIM with operational technologies (Di Leo et al., 2024; Siv, 2025).

This review aims to provide a comprehensive and critical synthesis of recent evidence on the application of BIM for electrical systems in construction. Drawing exclusively on peer-reviewed academic scholarship published between 2020 and 2026, the review addresses six core questions: (1) What is the evolution and current state of BIM technologies for electrical systems? (2) What frameworks and standards guide BIM-enabled electrical system design and coordination? (3) What empirical evidence exists on the benefits and challenges of BIM for electrical systems? (4) How does BIM integration with sustainability and energy efficiency goals manifest in electrical system design? (5) What role do emerging technologies such as digital twins, path optimization algorithms, and machine learning play in advancing BIM for electrical systems? and (6) What implications do the findings have for practice, policy, and future research?

Evolution and Foundations of BIM for Electrical Systems

Historical Development of BIM Technologies

The evolution of BIM for electrical systems can be traced through several technological generations. Imoni et al. (2024) provide a comprehensive overview of BIM's trajectory in the construction industry, noting that while the conceptual foundations of BIM emerged in the 1970s with the development of object-oriented modeling, widespread adoption accelerated following the release of Industry Foundation Classes (IFC) standards in the 1990s and the establishment of national BIM mandates in the 2000s and 2010s. Utsev et al. (2022) contextualize BIM within the broader sustainability transformation of civil engineering and construction, noting that BIM capabilities have evolved from simple 3D visualization to encompass time (4D), cost (5D), sustainability (6D), and facility management (7D) dimensions. For electrical systems, this evolution has enabled increasingly sophisticated coordination, analysis, and lifecycle management capabilities.

The transition from legacy analog plans to digital BIM models represents a significant challenge for the industry. Urbietta et al. (2026) highlighted that a vast number of analog building plans remain archived by public entities managing urban development, and manually converting these plans into digital models is prohibitively expensive. Their work introduced an end-to-end machine learning approach for converting raster-based electrical floor plans into BIM models using the IFC standard, addressing the critical challenge of converting legacy documentation into digital formats. Table 1 presents the evolution of Building Information Modelling (BIM) dimensions and their corresponding applications in electrical systems within the construction industry. The table highlights how BIM has progressed from basic geometric modeling to advanced lifecycle management functionalities.

Table 1. *Evolution of BIM Dimensions and Applications for Electrical Systems*

BIM Dimension	Definition	Electrical System Applications	Maturity Level
3D (Geometric)	Spatial representation of components	Visual placement of conduits, panels, lighting fixtures; clash detection	Widespread
4D (Time)	Scheduling and sequencing	Construction sequencing; prefabrication scheduling; phased installations	Growing
5D (Cost)	Cost estimation and budgeting	Quantity takeoffs; material cost tracking; life-cycle cost analysis	Moderate
6D (Sustainability)	Energy and environmental analysis	Lighting analysis; energy modeling; embodied carbon assessment	Emerging
7D (Facility Management)	Operations and maintenance	Asset tracking; maintenance scheduling; system performance monitoring	Emerging

BIM Software Platforms for Electrical Systems

The market for BIM software platforms has matured considerably, with several platforms offering specialized capabilities for electrical system design and coordination. Toni (2025) conducted a comprehensive study on BIM implementation in electrical projects, utilizing Autodesk Revit for modeling and Navisworks for analysis, demonstrating that this combination enables early detection of clashes and automated material take-offs.

The integration of BIM with specialized electrical planning tools has advanced significantly. buildingSMART International and Siemens AG (2025) published standardized openBIM use cases for electrical distribution systems, addressing the integration of medium-voltage and low-voltage electrical distribution systems into building models. These use cases, documented as UC 2.06 and UC 2.07, enable collision detection, space verification, and early planning coordination using IFC 4.3 export functionality. Table 2 provides a comparative overview of BIM software platforms used for electrical system design, focusing on their capabilities, interoperability standards, strengths, and limitations.

Table 2. *Comparison of BIM Software Platforms for Electrical Systems*

Platform	Electrical System Capabilities	Interoperability Standards	Strengths	Limitations	Representative References
Autodesk Revit	Integrated electrical design, panel schedules, lighting calculations, circuit routing	IFC, DXF, DWG, COBie	Comprehensive tools; large user base; extensive content libraries	High cost; steep learning curve	Imoni et al. (2024); Toni (2025)
Navisworks	Clash detection; model federation; coordination review	IFC, NWD, DWF	Real-time clash detection; multi-discipline coordination	Analysis-focused; limited modeling	Toni (2025); Alshboul & Shehadeh (2025)
Siemens SIMARIS	MV and LV power distribution design; IFC 4.3 export	IFC 4.3	Electrical system specialization; seamless BIM integration	Limited to electrical domain	buildingSMART & Siemens (2025)
MagiCAD	Revit/AutoCAD plugin; advanced electrical calculations	IFC, DXF, DWG	Specialized electrical calculations; extensive product libraries	Requires base platform; additional cost	Singh et al. (2025)

Path Optimization Algorithms for MEP Electrical Systems

Algorithmic Approaches to Electrical System Layout

The design of electrical system layouts, including conduit routing, cable tray placement, and panel positioning, represents a complex optimization problem requiring consideration of spatial constraints, material costs, energy efficiency, and maintainability. A comprehensive review by Guo et al. (2025) systematically examined path optimization algorithms for MEP systems, establishing a structured classification of optimization algorithms based on their suitability for BIM-integrated applications.

The authors introduced a hybrid optimization framework combining the global search capability of Ant Colony Optimization (ACO) with the local refinement efficiency of the A* algorithm, enhanced by dynamic weight adjustment and context-aware mechanisms. Simulation experiments based on a hospital BIM model demonstrated that this approach improves design efficiency by approximately 25–35% and reduces conflict incidence by around 40% (Guo et al., 2025). Table 3 presents an overview of path optimization algorithms applied in electrical system design, highlighting their mechanisms, applications, performance benefits, and limitations. These algorithms play a critical role in improving the efficiency and accuracy of routing electrical components, such as cables, conduits, and wiring systems, within BIM environments.

Table 3. *Path Optimization Algorithms for Electrical System Design*

Algorithm	Mechanism	Electrical System Applications	Performance Benefits	Limitations	Representative References
Ant Colony Optimization (ACO)	Pheromone-based path selection inspired by ant foraging	Electrical pre-embedding wiring; cable routing	Reduced total wiring length by 37% in high-rise buildings	Parameter sensitivity; computational intensity	Guo et al. (2025); Yuan Bao et al. (in Guo et al., 2025)
A	Heuristic graph search with cost and heuristic functions	MEP pipe routing; conduit pathfinding	33.8% design time reduction; 14.8% fewer user interactions	Local optimum susceptibility	Choi et al. (2022); Guo et al. (2025)
Genetic Algorithm (GA)	Evolutionary optimization with crossover and mutation	Pipeline layout; system partitioning	15% improvement in layout efficiency; 10% construction time reduction	Encoding complexity; computational cost	Guo et al. (2025)
Simulated Annealing (SA)	Probabilistic search with temperature-based acceptance	Electrical circuit layout; component placement	30-day to 20-day iteration cycle reduction; 90% error reduction	Cooling schedule sensitivity	Guo et al. (2025); Hsu et al. (in Guo et al., 2025)

Multi-Objective Optimization in Electrical Design

Contemporary research has increasingly focused on multi-objective optimization approaches that balance competing design criteria. Guo et al. (2025) identified that well-optimized pipeline layouts can significantly reduce material consumption, minimize energy loss, and lower carbon emissions, meeting sustainability goals and certification standards such as LEED. The integration of Building Information Modeling with path optimization algorithms enables the simultaneous optimization of multiple objectives, including reduction in conduit length and fitting quantities, minimization of electrical losses through optimized conductor routing, efficient use of ceiling plenum and shaft spaces, and design for accessibility and future modifications. Yuan Bao et al. (as cited in Guo et al., 2025) developed an improved ACO-based method for electrical pre-embedding wiring in high-rise buildings. By calculating electrical loads and incorporating parallel wiring, wall-mounted wiring, and stress acceleration strategies, this method was applied to engineering projects, demonstrating a 37% reduction in total wiring length.

Generative Design and Machine Learning Integration

The convergence of generative design with BIM has opened new frontiers for electrical system optimization. Xu et al. (2025) offered a comprehensive overview of BIM-based generative design focusing on five cardinal domains, including mechanical, electrical, and plumbing (MEP) system design. Their analysis reveals that generative design methods have the capability to autonomously generate a multitude of design alternatives that adhere to specific design criteria and constraints. The integration of machine learning with path optimization represents a significant advancement. Guo et al. (2025) explored the potential of generative artificial intelligence, such as Generative Adversarial Networks (GANs) and diffusion models—for generating initial pipeline layouts and enhancing spatial adaptability. These approaches can learn from large-scale datasets of building pipeline configurations to enable the construction of semantically informed initial solutions.

Clash Detection and Coordination in Electrical Systems

Traditional Clash Detection Methods

Clash detection represents one of the most critical applications of BIM for electrical systems, given the complex spatial interdependencies between electrical conduits, structural elements, mechanical ducts, and plumbing pipes. Traditional clash detection methods, while valuable, remain largely reactive, identifying conflicts after they have been modeled rather than anticipating them proactively (Alshboul & Shehadeh, 2025). Toni (2025) demonstrated that implementing a federated model and Common Data Environment (CDE) using Autodesk Revit and Navisworks resulted in improved coordination between teams, real-time updates, and decision traceability. This approach consolidates greater efficiency and reliability by enabling early detection of clashes before they manifest in the field.

Machine Learning-Enhanced Clash Detection

The integration of machine learning with clash detection workflows has significantly advanced the state of practice. Alshboul and Shehadeh (2025) presented an adaptive integration framework employing the XGBoost machine learning algorithm for real-time predictive clash detection in MEP systems. Through direct interfacing with BIM models, their system offers dynamic updates and proactive conflict anticipation, allowing for instant corrective actions. Performance evaluation across diverse BIM projects demonstrated that the XGBoost-enhanced framework substantially

improved detection metrics: increased from 0.62 to 0.92; increased from 0.65 to 0.93; and enabled anticipation of potential clashes before full modeling completion.

The framework's ability to predict clashes in real time represents a significant advancement over traditional reactive approaches, which typically identify conflicts only after modeling is complete, leading to costly delays and rework. Table 4 presents a comparison of clash detection approaches used in BIM-based electrical system design, focusing on detection timing, accuracy, advantages, and limitations. The table highlights the traditional rule-based approach as a widely used method in current practice.

Table 4. *Comparison of Clash Detection Approaches*

Approach	Detection Timing	Accuracy	Key Advantages	Limitations	Representative References
Traditional Rule-Based	Post-modeling	0.60–0.70	Well-established; predictable	Reactive; labor-intensive review	Alshboul & Shehadeh (2025)
Federated Model Coordination	During coordination reviews	0.70–0.80	Multi-discipline integration; traceable decisions	Requires structured workflows	Toni (2025)
XGBoost-Enhanced	Real-time predictive	0.92	Proactive; instant corrective actions; adaptive	Requires training data; implementation complexity	Alshboul & Shehadeh (2025)
Rule-Based + Supervised Learning	Hybrid detection	0.80–0.90	Filters irrelevant clashes; prioritizes critical conflicts	Two-stage process	Lin & Huang (2019)

Interoperability and Open Standards

Interoperability remains a critical challenge for effective clash detection across disciplines. Building SMART International and Siemens AG (2025) addressed this challenge by publishing standardized open BIM use cases for electrical distribution systems using IFC 4.3. These use cases provide comprehensive implementation guidance, enabling reliable data exchange between systems and increasing compatibility with BIM coordination tools. The IFC 4.3 standard significantly enhanced electrical system data exchange capabilities, enabling representation of circuit connectivity and hierarchical relationships, panel schedules and load calculations, conduit and cable tray routing, and lighting fixture specifications and control systems. Jang and Collinge (2020) systematically investigated BIM asset integration challenges from a mechanical and electrical contractor perspective, identifying 15 key issues classified under four broad themes: Informational, Technological, Organisational, and Industrial. Their case study analysis verified that despite BIM asset integration processes reaching globally recognized standards, systemic characteristics of the industry result in persisting problems that impact the BIM-FM asset management journey.

Digital Twin Integration for Electrical System Management

BIM as Foundation for Digital Twins

Digital twin technology extends BIM capabilities by creating dynamic, real-time digital representations of physical assets that continuously synchronize with operational data. Siv (2025) proposed a comprehensive framework for scalable digital twin deployment in smart campus buildings, integrating 3D laser scanning, BIM modeling, and IoT-enabled data visualization to support facility operations and maintenance.

The methodology developed by Siv (2025) includes reality capture using terrestrial laser scanning and structured point-cloud processing; development of an enriched BIM model incorporating architectural, mechanical, electrical, plumbing, conveying, and sensor systems; creation of a digital-twin environment linking equipment metadata, maintenance policies, and simulated IoT data. A case study of the Price Gilbert Building at Georgia Tech demonstrated the implementation of this workflow, with 509 equipment items modeled and embedded with OmniClass classifications into the digital twin. Ten interactive dashboards were developed to visualize system performance, enabling centralized asset documentation, improved system visibility, and enhanced preventive and reactive maintenance workflows.

Digital Twin Applications for Electrical Systems

Di Leo et al. (2024) presented a comprehensive investigation of BIM and digital twin technologies for electrical systems in industrial buildings. Their case study demonstrated that a BIM-based digital twin prototype can bring several benefits, including centralized access to equipment specifications, maintenance histories, and operational parameters; analysis of illuminance levels and energy consumption under various operational scenarios; real-time load analysis and capacity planning; proactive identification of spatial conflicts during design and operations; and schedule optimization based on equipment condition and operational requirements.

The authors also explored the potential of Extended Reality (XR) technologies for the design and management of electrical systems, noting that XR integration enables increased training and skill development opportunities for facility management personnel. Table 5 presents key digital twin capabilities for electrical system management, focusing on functionalities, associated benefits, implementation requirements, and supporting literature. The table emphasizes real-time monitoring as a fundamental capability in digital twin applications for smart buildings and infrastructure.

Table 5. *Digital Twin Capabilities for Electrical System Management*

Capability	Description	Benefits	Implementation Requirements	Representative References
Real-Time Monitoring	Continuous tracking of electrical parameters	Proactive fault detection; optimized performance	IoT sensors; data integration platform	Siv (2025); Di Leo et al. (2024)
Predictive Maintenance	AI-driven failure prediction based	Reduced downtime; extended equipment life	Machine learning models; historical data	Yang et al. (2025)

	on operational data			
Energy Optimization	Real-time energy consumption analysis and control	Reduced operating costs; carbon footprint reduction	Energy meters; control systems	Dai & Yang (2025)
Asset Management	Centralized equipment metadata and documentation	Improved maintenance efficiency; regulatory compliance	BIM model; asset tagging	Siv (2025); Jang & Collinge (2020)
Visualization Dashboards	Interactive display system performance	Enhanced decision-making; stakeholder communication	Data visualization platform	Siv (2025)

Predictive Analytics and Machine Learning Integration

The integration of machine learning with digital twin environments enables advanced predictive capabilities for electrical systems. Yang et al. (2025) proposed an Integrated Design Decision Support System (IDDSS) combining BIM for real-time facility modeling with Big Data analytics for improved decision-making. Using Graph Neural Networks (GNNs), the system contemplates the multifaceted connections between energy components to accurately predict energy demand, renewable energy generation, and perform predictive maintenance. Performance indicators demonstrated system effectiveness thus, Energy Efficiency Ratio (EER): 0.85; Load Factor (LF): 75%; Power Loss Reduction (PLR): 20%; Renewable Energy Penetration (REP): 60%; and Grid Reliability (Availability Factor): 99.5%. These results substantiate the system's capacity to increase both sustainability and efficiency in electrical systems for power energy facilities and buildings.

Sustainability and Energy Efficiency Integration

BIM-Enabled Energy Optimization

The integration of BIM with energy analysis tools enables comprehensive optimization of electrical system performance. Dai and Yang (2025) conducted a case analysis on a retrofitted primary school building in Guangdong, China, utilizing BIM-based energy simulations, material optimization, and solar technology integration. The outcomes revealed that the BIM-driven design approach reduced annual energy consumption by 40.68%, with lighting energy use decreasing by 36.59%.

A rooftop photovoltaic system demonstrated a payback period of 7.46 years while powering environmental sensors autonomously. The hardware system integrated sensors and an ARDUINO-based controller to detect environmental factors including rainfall, temperature, and air quality, powered by a 6W solar panel and a 2200 mAh/7.4 V lithium battery. Nsobundu and Tiza (2025) provided a comprehensive evaluation of sustainable construction practices, emphasizing the role of BIM in facilitating material optimization and waste reduction in electrical system installations. Similarly, Okagbare et al. (2026) examined sustainable concrete practices in the construction industry, noting that BIM coordination reduces material waste by enabling precise quantity takeoffs and prefabrication planning.

Low-Carbon Design Through Path Optimization

Path optimization algorithms contribute directly to sustainability goals by minimizing material consumption and energy losses. Guo et al. (2025) emphasized that well-optimized pipeline layouts can significantly reduce material consumption, minimize energy loss, and lower carbon emissions, meeting sustainability goals and certification standards such as LEED. The multi-objective optimization framework proposed by the authors enables designers to balance: reduced conduit length and fitting quantities decrease embodied carbon; optimized routing minimizes electrical losses and improves system efficiency; and prefabrication based on optimized layouts reduces on-site waste.

Renewable Energy Integration

The integration of renewable energy systems with BIM-enabled design represents an emerging frontier. Yang et al. (2025) demonstrated that BIM-based systems can optimize Renewable Energy Systems (RES) integration by accurately predicting energy demand and renewable energy generation using Graph Neural Networks. The system contemplates the multifaceted connections between energy components, addressing the challenges of fluctuations in renewable electricity sources, inadequate energy consumption, and inefficient integration of Energy Storage Systems (ESS) that can cause unforeseen grid fluctuations and high operating expenses.

Barriers and Challenges to BIM Adoption for Electrical Systems

Informational and Technological Barriers

Jang and Collinge (2020) systematically identified barriers to BIM asset integration from a mechanical and electrical contractor perspective, classifying 15 key issues under four broad themes. Informational barriers include deficiencies in BIM regulations and standards, inaccurate information exchanges, and unclear requirement definitions that ultimately result in higher project costs and poorer operational efficiencies.

Technological barriers encompass software interoperability issues, the fragmentation of digital platforms, and the challenge of maintaining data consistency across project phases. Alshboul and Shehadeh (2025) noted that while machine learning-enhanced clash detection offers significant benefits, implementation complexity and training data requirements remain barriers for smaller contractors. Table 6 outlines the key barriers to BIM adoption for electrical systems, categorizing them based on their nature, impacts on project delivery, and possible mitigation strategies. The table specifically highlights informational barriers as a critical challenge affecting effective BIM implementation.

Table 6. *Barriers to BIM Adoption for Electrical Systems*

Barrier Category	Specific Barriers	Impact	Mitigation Strategies	Representative References
Informational	Deficient BIM standards; unclear requirements; inaccurate exchanges	Higher project costs; operational inefficiencies	Standardized protocols; clear contract requirements	Jang & Collinge (2020)

Technological	Interoperability issues; platform fragmentation; data consistency	Coordination challenges; data loss	openBIM standards; IFC 4.3 adoption	buildingSMART & Siemens (2025); Jang & Collinge (2020)
Organisational	Skills gaps; training requirements; resistance to change	Implementation delays; suboptimal use	Investment in training; change management	Imoni et al. (2024)
Industrial	Fragmented supply chain; inconsistent practices; contractual issues	Limited collaboration; information silos	Integrated project delivery; collaborative contracts	Jang & Collinge (2020); Toni (2025)

Skills and Organizational Capacity

The effective implementation of BIM for electrical systems requires specialized skills that are not uniformly distributed across the industry. Imoni et al. (2024) noted that the steep learning curve associated with BIM platforms such as Autodesk Revit represents a significant barrier to adoption, particularly for smaller electrical contracting firms. Organizational capacity extends beyond individual skills to encompass process adaptation, workflow integration, and cultural change. Toni (2025) emphasized that BIM adoption represents not merely technological innovation but a paradigm shift in information management and collaboration in the construction sector.

Small and Medium Enterprise Adoption Challenges

While large engineering firms have made substantial investments in BIM capabilities, small and medium enterprises (SMEs) face particular challenges in BIM adoption. Jang and Collinge (2020) noted that the costs associated with software licensing, hardware infrastructure, and staff training can be prohibitive for smaller electrical contractors, potentially exacerbating fragmentation in the industry.

Vision for the Future of Research

Algorithmic Scalability and Dynamic Constraints

Guo et al. (2025) identified several research gaps requiring future investigation, including algorithmic scalability for complex building environments, dynamic constraint modeling that adapts to changing design conditions, and improved handling of multi-objective trade-offs in path optimization. The authors specifically highlighted the need for diameter-aware layout optimization that accounts for varying conduit and cable tray dimensions, as well as BIM-driven multi-scale generative modeling that integrates design decisions across multiple levels of detail.

Quantum Heuristic Algorithms

At the technological frontier, Guo et al. (2025) explored the potential of quantum heuristic algorithms for MEP design. Owing to their high parallelism and global search capabilities in solving nonlinear and multi-objective problems, quantum approaches have been preliminarily applied to

address node conflict issues in high-density pipeline layouts. However, this line of research remains in its infancy and lacks empirical validation within the context of building MEP systems.

Generative Design and AI Integration

Xu et al. (2025) called for further development of generative design methodologies that align with widely accepted standards such as IFC and seamlessly integrate with BIM protocols. The authors proposed an integrative framework covering all application domains of BIM-based generative design, aiming to drive advancements for research and practice. Future research directions identified by Xu et al. (2025) include integration of Transformer networks and diffusion models for chromosome encoding; development of semantically informed initial solutions from large-scale building configuration datasets; and enhanced interoperability between generative design tools and BIM platforms

Digital Twin Maturity and Real-Time Analytics

Siv (2025) noted that while the proposed digital twin framework validated the feasibility of scalable digital twin deployment for facility management, most IoT data in the case study were simulated due to limited existing sensor infrastructure. Future research should focus on real-time sensor integration, analytics integration, and the development of autonomous building operations capabilities.

Conclusion

The paper examined recent empirical and theoretical evidence on the application of Building Information Modeling (BIM) for electrical systems in construction. The synthesis of peer-reviewed academic scholarship published between 2020 and 2026 reveals that BIM technologies have fundamentally transformed electrical system design, coordination, and management across the building lifecycle. The evidence demonstrates that BIM-enabled electrical system design achieves significant improvements through multiple technological pathways. Path optimization algorithms applied to MEP systems, including Ant Colony Optimization, A, Genetic Algorithms, and Simulated Annealing, demonstrate design efficiency improvements of 25–35% and conflict reduction of approximately 40%. Machine learning-enhanced clash detection using XGBoost algorithms improves accuracy from 0.62 to 0.92, enabling proactive conflict anticipation and instant corrective actions. Digital twin integration enables real-time monitoring, predictive maintenance, and optimized energy performance, with case studies demonstrating annual energy consumption reductions of 40.68%. However, the adoption of BIM for electrical systems faces persistent barriers. Jang and Collinge (2020) identified informational, technological, organisational, and industrial barriers that continue to impede seamless BIM integration. Interoperability challenges, high implementation costs, skills gaps, and fragmented industry structures remain significant obstacles, particularly for small and medium enterprises.

The evidence reviewed has important implications for practitioners, researchers, and policymakers. For practitioners, the findings underscore the value of investing in BIM capabilities, adopting openBIM standards such as IFC 4.3, and integrating machine learning-enhanced clash detection into coordination workflows. For researchers, the review identifies critical gaps in algorithmic scalability, quantum heuristic approaches, generative design integration, and digital twin maturity. For policymakers, the evidence supports the development of standardized protocols, investment in training infrastructure, and policies that promote interoperability through open standards.

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