International Journal of Management and Marketing Intelligence	*International Journal of Management and Marketing Intelligence, 2(1), 26-38.*	
	Volume: 2	http://ijmmi.com
	Issue: 1	ISSN:
	Received: February 21, 2025.	Accepted: March 15, 2025
	Citation: Ahmad, A. & Alshurideh, M. (2025). Digitization and IoT-Driven Transformation of Smart Buildings, International Journal of Management and Marketing Intelligence, 2(1), 26-38.	

Digitization and IoT-Driven Transformation of Smart Buildings

Ala'a Ahmad[1] and Muhammad Alshurideh[1]

[1]Department of Management, College of Business Administration, University of Sharjah, UAE.

ARTICLE DETAILS

Article History
Published Online: March 2025

Keywords
IoT
Smart Buildings
Building Automation
Energy Efficiency
Cybersecurity
Digital Twin
Building Automation

JEL Codes:
C61, C63, O33 & Q55

Corresponding Author
Email: u19106242@sharjah.ac.ae

ABSTRACT

The digitization of building management systems (BMS) via the Internet of Things (IoT) is transforming urban infrastructure by improving energy efficiency, sustainability, and operational resilience. In response to increasing energy demands and the necessity for carbon emission reduction, IoT-enabled smart buildings to have emerged as a pivotal technological advancement, incorporating real-time monitoring, automated control, and data-driven decision-making to enhance building performance. This study analyzes the transformation of traditional building control systems into intelligent infrastructures, highlighting the Internet of Things' contribution to optimizing facilities management, predictive maintenance, and efficient energy use. A thorough literature review and case study analysis indicate that IoT-driven automation markedly enhances energy saving, occupant comfort, and cost efficiency, hence advancing sustainable urbanization objectives. Notwithstanding these advantages, the implementation of IoT in smart buildings encounters obstacles, such as interoperability hurdles, cybersecurity risks, and data privacy issues, requiring comprehensive legislative frameworks and secure design. The successful execution of IoT ecosystems in building automation necessitates compliance with open communication standards, incorporation of AI-driven analytics, and investment in secure cloud-edge computing infrastructures. Moreover, regulatory measures including government incentives, revised building rules, and smart grid integration might expedite IoT-driven modernization of current infrastructures. This study concludes by offering strategic recommendations for policymakers, engineers, and business leaders to facilitate scalable IoT adoption, strengthen cybersecurity resilience, and foster interoperability in smart building environments, thereby ensuring a sustainable, efficient, and intelligent future for the built environment.

1. INTRODUCTION

Buildings are essential to the urban landscape, as city dwellers spend a considerable amount of time indoors. Efficient and insightful building management is essential for attaining sustainability goals, such as minimizing energy use and improving quality of life (Ahmad & Alshurideh, 2023a; Ghaffarianhoseini et al., 2018). Intelligent buildings employ integrated technology to autonomously manage, control, and optimize building efficiency (Jia et al., 2019). In contrast to conventional structures reliant on manual or standalone controls, smart buildings utilize information and communication technologies (ICT), especially IoT devices and sensors, to dynamically respond to occupant needs and environmental conditions (Buckman, Mayfield, & BM Beck, 2014; Lavrinovica et al., 2024; Taboada-Orozco et al., 2024). In addition, with the rise of urbanization, communities must develop strategies to regulate energy consumption, enhance operational efficiency, and ensure occupant comfort (Jia et al., 2019). Smart buildings are essential in this shift, employing automated control systems for HVAC, lighting, security, and energy management, therefore minimizing waste and enhancing efficiency (Risteska et al., 2017). Research indicates that intelligent building automation can save energy usage by as much as 30%, while enhancing indoor air quality and overall occupant satisfaction (Ahmad, Assad, & Alshurideh, 2023; Ghaffarianhoseini et al., 2018). Additionally, in recent decades, the term of intelligent building has progressed from rudimentary "intelligent buildings" with minimal automation to contemporary "smart" structures that integrate advanced, adaptable technology (Buckman et al., 2014). Buckman et al. (2014) characterize smart buildings as systems that "integrate and account for intelligence, enterprise, control, and materials and construction as a cohesive building system, with adaptability, rather than reactivity, at its core" to attain goals such as energy efficiency, durability, and occupant satisfaction. A smart building integrates building automation with IoT connectivity, facilitating real-time data sharing across HVAC, lighting, security, and other subsystems to enhance performance (Jia et al., 2019; Anaam et al., 2023). The outcome is a fusion of the physical and digital realms, converting static structures into dynamic ecosystems (Taboada-Orozco et al., 2024). Further, updating legacy systems with IoT is essential for the advancement of smart cities (Jia et al., 2019; Ozturk, 2024). Numerous older structures continue to utilize obsolete Building Management Systems (BMSs) or independent controls that lack interoperability and remote monitoring functionalities (Taboada-Orozco et al., 2024). IoT ecosystems comprising distributed sensors, actuators, cloud platforms, and data analytics can revitalize these antiquated facilities without necessitating a comprehensive infrastructure renovation (Stojkoska & Trivodaliev, 2017; Alshurideh et al., 2023). Retrofitting historical equipment with IoT sensors and network connectivity enables building managers to digitize formerly analog processes, thereby creating new opportunities for energy conservation, predictive maintenance, and enhanced occupant services (Buckman et al., 2014; Taboada-Orozco et al., 2024). This modification presents difficulties, especially with integration complexity, cybersecurity threats, and data privacy issues (Ghaffarianhoseini et al., 2018; Vasudevan, 2024). As intelligent buildings evolve towards more data-centricity, ensuring secure and efficient data transmission between IoT devices and central management systems is imperative (Stojkoska & Trivodaliev, 2017). This research examines the role of IoT technologies in the digitalization of building management, namely in converting traditional systems into contemporary smart buildings (Taboada-Orozco et al., 2024). The document is organized in the following manner:

We initially examine the concept of smart buildings and the impact of IoT on enhancing building operations. We then evaluate the significant contributions of IoT in enhancing legacy control systems and analyze the obstacles and solutions faced during implementation. We then examine case studies that illustrate effective IoT implementations and their advantages in sustainability, energy efficiency, and cost savings. We examine cybersecurity and data management challenges in IoT-enabled environments, emphasizing the necessity of security frameworks to protect digital ecosystems. The research finishes with specific recommendations for legislators, engineers, and corporate leaders to enhance IoT integration within current infrastructures. This work seeks to elucidate the potential and practical implications of IoT-enabled smart building transformation using a comprehensive methodology (Buckman et al., 2014; Jia et al., 2019; Taboada-Orozco et al., 2024).

2. LITERATURE REVIEW

2.1. Smart building and IOT concepts and significances

The concept of smart buildings has emerged as a significant development in modern urban infrastructure, including advanced digital technologies to enhance building efficiency and occupant contentment. A smart building is defined as a structure equipped with sensors and interconnected devices that form an intelligent network, enabling real-time monitoring and adaptive control of various environmental parameters (Jia et al., 2019). The integration of Internet of Things (IoT) technology into building management systems enables automatic responses to fluctuating circumstances like as occupancy, lighting, temperature, and air quality, thereby minimizing energy consumption and improving operational efficiency (Antouz et al., 2023; Taboada-Orozco et al., 2024). The increasing urbanization and growing energy demand of buildings highlight the necessity of transitioning to smart infrastructure. In industrialized nations, structures constitute more than 30% of national energy consumption due to operational demands, making them vital to sustainability efforts (Stojkoska & Trivodaliev, 2017). IoT-enabled smart buildings address these challenges by employing sophisticated energy management systems that optimize heating, ventilation, air conditioning (HVAC), lighting, and security through real-time data analysis (Jia et al., 2019). Moreover, intelligent buildings facilitate the transition to a more robust and sustainable urban environment by integrating with smart grids, allowing for dynamic energy load distribution and encouraging the utilization of renewable energy sources such as solar and wind power (Buckman et al., 2014). Besides energy savings, smart buildings impact overall sustainability and occupant well-being. Intelligent buildings enhance occupant health and productivity by consistently assessing indoor environmental quality to provide appropriate air circulation, thermal comfort, and lighting conditions (Ghaffarianhoseini et al., 2018). The ability to adjust building operations in real-time based on occupancy and environmental data represents a significant shift from traditional reactive approaches to proactive and predictive facility management (Taleb et al., 2023; Alshurideh, 2024).

The historical evolution of building automation systems laid the groundwork for modern smart buildings. Traditional Building Management Systems (BMSs) have been utilized for decades to control HVAC, lighting, and security systems in large commercial and industrial facilities. However, these systems often employ proprietary protocols that demonstrate restricted interoperability, requiring significant manual intervention for system adjustments and diagnostics (Stojkoska & Trivodaliev, 2017). The advent of IoT has transformed this field by employing cloud-connected sensors, machine learning algorithms, and distributed computing, enabling seamless integration across various building subsystems (Jia et al., 2019). Unlike conventional Building Administration Systems, IoT-enabled smart buildings utilize open communication protocols and cloud analytics, enabling effective data exchange and remote management (Taboada-Orozco et al., 2024). To add more, a key differentiating characteristic of smart buildings is their adaptability. Traditional control techniques rely on pre-established schedules or rigid automation, whereas IoT-based systems employ adaptive responses guided by sensor data and artificial intelligence. Ventilation rates may be adjusted in real-time according to carbon dioxide levels, so ensuring ideal indoor air quality and minimizing unnecessary energy use (Buckman et al., 2014). Similarly, adaptive lighting systems adjust brightness based on sunlight availability and occupancy, therefore reducing energy consumption while maintaining visual comfort (Ghaffarianhoseini et al., 2018). These intelligent technologies represent a significant shift from automated, static responses to highly flexible building environments that continuously enhance operations depending on contextual data (Ahmad & Alshurideh, 2023a; Ahmad & Alshurideh, 2023b; Ahmad et al., 2024; Amponsah, 2024).

The development of smart buildings requires a comprehensive approach, incorporating advancements in both hardware and software. IoT-driven building automation relies on a network of sensors, actuators, infrastructure, and cloud platforms to analyze and react to real-time data (Hanaysha & Alzoubi, 2022; Zahra, 2024). The amalgamation of IoT and artificial intelligence has improved the capabilities of smart buildings, enabling predictive analytics for issue identification, occupancy-driven energy efficiency, and self-governing decision-making in facility management (Jia et al., 2019; Ghazal et al., 2023). The integration of human-centric design elements ensures that technological advancements align with occupant preferences and behaviors, hence improving overall user satisfaction and operational efficiency (Taboada-Orozco et al., 2024). Despite the numerous advantages of IoT-enabled smart buildings, challenges remain in their widespread implementation. Legacy infrastructure sometimes demonstrates incompatibility with modern IoT platforms, necessitating the deployment of intermediary solutions such as IoT gateways and cloud-based middleware (Stojkoska & Trivodaliev, 2017). Furthermore, cybersecurity challenges must be addressed to protect smart buildings from potential cyberattacks and illegal access to critical operational data (Buckman et al., 2014; Sukkari, 2024). Comprehensive data governance legislation and regulatory structures are essential for the secure and ethical utilization of IoT technology in the constructed environment. Keep in mind that the integration of IoT technology into smart buildings represents a transformative shift in modern design and facilities management. Smart buildings are redefining the relationship between urban infrastructure and environmental stewardship by enhancing energy efficiency, fostering tenant well-being, and advancing broader sustainability goals. The continuous progress of IoT-enabled building automation will be crucial for the development of resilient, flexible, and efficient smart cities in the future.

2.2. IoT technologies enabling building digitization

The Internet of Things (IoT) infrastructure in a smart building consists of interconnected devices and platforms that collaborate to enhance operational efficiency and occupant comfort (Ghazal et al., 2021; Poyyamozhi et al., 2024a). Smart building ecosystems utilize an array of sensors to monitor environmental and structural parameters, such as temperature and humidity sensors, light sensors, motion and occupancy detectors, air quality monitors evaluating CO_2 levels and volatile organic compounds, and smart meters for utilities including electricity and water. Spachos & Hatzinakos (2016) created a real-time cognitive wireless sensor network system for indoor CO_2 monitoring, improving air quality management and ventilation optimization in intricate interior settings. The use of IoT sensors in smart buildings has transformed real-time data acquisition, automation, and energy efficiency (Verma et al., 2021). In contrast to conventional Building Management Systems (BMS) that depend on fixed schedules and manual modifications, IoT-based frameworks like SenseRT facilitate low-latency data processing, permitting dynamic regulation of HVAC, lighting, and security systems in accordance with real-time occupancy and environmental factors. This adaptive strategy mitigates energy waste, improves operational efficiency, and enables predictive maintenance by identifying equipment inefficiencies prior to their escalation, hence reducing downtime and repair expenses. The scalability of IoT sensor networks facilitates seamless connection with legacy systems, minimizing the necessity for costly infrastructure renovations. Furthermore, edge computing improves real-time decision-making by minimizing latency and bandwidth limitations, especially in security applications that necessitate immediate threat detection. Notwithstanding these developments, issues regarding data privacy and security persist, requiring stringent encryption, access control measures, and data anonymization approaches to safeguard occupant information (Verma et al., 2021). Utilizing real-time IoT streaming frameworks, smart buildings may enhance sustainability, operational efficiency, and security, thereby fostering more resilient, adaptive, and intelligent urban settings.

Actuators and controllers interpret sensor data to implement necessary modifications. An actuator can regulate a damper in an air duct, adjust a thermostat setting, enhance lighting intensity, or trigger an alarm system (Djehaiche et al., 2019). IoT devices utilize wired and wireless networks for communication, utilizing protocols such as Ethernet, Wi-Fi, Zigbee, Z-Wave, LoRaWAN, Modern wireless IoT technologies provide substantial benefits for upgrading antiquated structures, as they obviate the necessity for major rewiring, therefore diminishing installation expenses and system inactivity. Wireless ambient light sensors can dynamically regulate artificial lighting according to natural light availability, thereby improving energy efficiency without requiring invasive installations (Krebs, 2023). This flexibility facilitates cost-effective and minimally invasive enhancements to outdated structures, accelerating the digital transition of older systems (Poyyamozhi et al., 2024a).

The IoT platform or middleware is an essential component of an IoT-enabled structure. In building automation systems (BAS), a centralized platform, whether a local building management system or a cloud-based service, is crucial for gathering data from diverse linked devices, doing analytics, and providing interfaces for facility managers. This integration facilitates effective oversight and management of building operations, improving energy efficiency and occupant comfort. The University of Central Florida's Building Automation System Specification highlights the necessity of a cohesive platform that adheres to ANSI/ASHRAE Standard 135 (BACnet) to facilitate uninterrupted communication between devices and systems. It often uses communication protocols like as BACnet/IP, KNX, or MQTT to interface with various smart devices. The integration of devices through a unified platform resolves a major limitation of obsolete systems: interoperability challenges (Djehaiche et al., 2019). Traditional building control systems sometimes utilize proprietary protocols, obstructing easy data exchange.

IoT gateways and protocol translators enable the integration of older systems, such as HVAC controllers using Modbus or proprietary languages, into the IoT network to address compatibility issues (Spachos, Papapanagiotou, & Plataniotis, 2018). This hybrid approach preserves existing infrastructure while augmenting it with IoT technologies, enabling a progressive digitalization strategy (Poyyamozhi et al., 2024a). Consequently, older buildings may incrementally improve their management systems by integrating new automation capabilities without requiring extensive system renovations (Le et al., 2023). Previous studies indicate that IoT technology enhances building management through automation, energy optimization, and real-time monitoring (Jia et al., 2019). Jia et al., (2019) contend that IoT sensors, wireless networks, cloud computing, and mobile/web applications are fundamental components of the smart building ecosystem. The integration of these technologies facilitates what the authors refer to as the "smartization" of buildings, transforming static infrastructure into dynamic, data-driven systems. Also, Cloud-based analytics can evaluate real-time sensor data to identify trends in energy use and system efficacy (Quinn et al., 2022). For instance, advanced analytics may detect inefficiencies in HVAC systems or anomalies in lighting patterns, leading to automatic adjustments that improve energy efficiency. The capacity to detect equipment problems using IoT-based fault detection enables predictive maintenance strategies, hence reducing the probability of unexpected failures and costly downtime (Milenkovic, 2022). Additionally, the Internet of Things (IoT) enhances user-centric control, allowing building occupants to interact with their environment through mobile applications or feedback interfaces. Intelligent lighting systems may be adjusted based on occupancy and user preferences, while automated HVAC controls provide suitable indoor climate conditions (Jia et al., 2019). Additionally, residents may report maintenance issues in real time, with IoT platforms efficiently monitoring and addressing these requests. Further, a vital component of IoT-driven building digitization is real-time monitoring and control. Traditional facilities management generally relies on scheduled inspections and reactive maintenance, leading to delays in identifying operational inefficiencies (Quinn et al., 2022). In contrast, IoT-enabled buildings continuously monitor critical systems, detecting issues before they intensify. IoT water sensors can identify leaks, triggering automated alerts that facilitate immediate intervention, hence mitigating water damage and resource wastage (Milenkovic, 2022). Likewise, IoT-based energy metering provides detailed insights into the consumption of power, water, and gas, enabling data-driven strategies for energy optimization (Jia et al., 2019). A Versatile Sensor Data Acquisition System (VSDACS) was employed in a study to collect real-time data on electricity, water, gas, ventilation, and solar energy generation, enabling prompt anomaly detection, including unexpected energy spikes or inefficiencies (Quinn et al., 2022). Moreover, the availability of precise, real-time data significantly enhances decision-making for building managers, enabling a shift from reactive maintenance to proactive, efficiency-focused operations. For instance, Ambasht, (2023) emphasized that real-time data integration and analytics empower organizations to harness data effectively, leading to improved operational efficiency and informed decision-making. Similarly, the study by (Kumar, Chandra, & Agarwal, 2024) presents a real-time approach for smart building operations prediction, highlighting the role of continuous data monitoring in optimizing building performance.

In summary, IoT technologies constitute the digital infrastructure for modern smart buildings, enabling extensive sensing, astute management, and integrated communication. The Internet of Things (IoT) enhances building automation by connecting conventional building systems to modern smart city infrastructures through cloud-based data integration and artificial intelligence-driven automation (Milenkovic, 2022). Research indicates that IoT-enabled building management systems lead to significant energy savings, improved occupant comfort, and heightened operational efficiency (Jia et al., 2019). Moreover, emerging functionalities such as mobile application remote control, voice assistant integration, and building-to-grid services indicate the impending progress in the development of IoT-based smart buildings (Quinn et al., 2022). However, issues related to cybersecurity and data governance must also be examined, which will be discussed in the next sections.

3. METHODOLOGY

This study employs a comprehensive examination of scholarly literature and practical case studies pertaining to the application of Internet of Things (IoT) technologies in smart buildings. A systematic method was utilized to ensure a thorough analysis of existing information and emerging advancements in IoT-based building management. A comprehensive search was conducted in Scopus-indexed journals and conference proceedings to identify relevant publications on smart buildings, IoT applications, and the modernization of legacy systems. The search was improved using specific keywords including “smart building,” “IoT,” “building automation,” “legacy systems,” “energy efficiency,” and “facilities management”. Research included in esteemed journals such as Automation in Construction, Energy and Buildings, Sustainable Cities and Society, and the IEEE Internet of Things Journal was recognized for its scientific rigor and pertinence (Ghaffarianhoseini et al., 2018). Articles focusing on IoT applications in building management or the transition from traditional to smart systems were selected from an initial pool. The selected literature was analyzed and categorized into thematic classifications based on the principal objectives of this study. Encompassed themes:

- Conceptualizing Smart Buildings: Examining definitions and significance of intelligent infrastructure in modern urban settings.
- Improvements to Legacy Systems via IoT: Analyzing the integration of IoT technology to modernize existing building management systems (BMS) challenges to IoT Implementation by Identifying technological, economic, and societal barriers to the widespread adoption of IoT in building automation.

- Case Study Analysis: Analyzing real-world examples of successful IoT implementation, emphasizing improvements in energy efficiency, operating costs, and occupant satisfaction. Assessing the impact of IoT-enabled smart buildings on reducing energy consumption and carbon emissions.
- Cybersecurity and Data Considerations: Examining concerns related to data security, privacy, and regulatory compliance in IoT-integrated building management systems.
- Qualitative data derived from these sources included articulated benefits, technical challenges, and best practices (Stojkoska & Trivodaliev, 2017). Quantitative data, encompassing energy savings percentages and performance metrics from case studies, were employed to validate conclusions (Ghaffarianhoseini et al., 2018).

The research examined documented case studies of IoT implementations in buildings to validate theoretical conclusions with real-world applications (Jia et al., 2019). The sources included academic case studies, pilot projects published in peer-reviewed journals, and actual smart buildings recorded in industry white papers and technical reports (Buckman et al., 2014). Each case study was assessed based on building type (commercial, residential, industrial, mixed-use) based on:

- Current legacy systems (traditional HVAC, lighting, security).
- Deployment of IoT solutions (wireless sensors, cloud analytics, automation platforms).
- Key outcomes (improvements in energy efficiency, cost savings, occupant satisfaction)

IoT retrofitting was highlighted as a viable method for modernizing existing infrastructure while minimizing capital expenditure (Stojkoska & Trivodaliev, 2017). A comparative methodology was utilized to synthesize information from multiple sources, ensuring that the results were rigorously analyzed (Jia et al., 2019). Convergent data, encompassing common benefits and challenges, were identified to formulate generalized findings (Buckman et al., 2014). Divergent viewpoints or contradictory outcomes were also analyzed to ensure a balanced perspective (Taboada-Orozco et al., 2024). Significant focus was placed on the correlation between technical enhancements and operational outcomes, particularly how IoT integration improves energy efficiency and reduces maintenance costs (Stojkoska & Trivodaliev, 2017). The discussion on cybersecurity emphasized risk mitigation strategies including encryption, network segmentation, and IoT security frameworks (Ghaffarianhoseini et al., 2018). This technique provides a comprehensive understanding of the evolution of building management by integrating data from various IoT ecosystem sources (Jia et al., 2019). It enables an analysis of technological and managerial aspects, including implementation challenges, operational efficiency, and sustainability outcomes (Taboada-Orozco et al., 2024).

4. FINDINGS

4.1. IoT driven modernization of legacy building systems

The incorporation of Internet of Things (IoT) technologies into legacy Building Management Systems (BMS) markedly improves and expands their functionalities, converting conventional infrastructures into contemporary smart building networks. This method enables current systems to function harmoniously without requiring a total reconstruction. Legacy systems frequently exhibit compartmentalized operations for diverse building functions, including HVAC, lighting, and security, characterized by restricted remote access and data analytics capabilities. The use of IoT sensors and controllers integrates these varied systems, facilitating centralized oversight and management. IoT gateways are essential in this integration, converting obsolete communication protocols into modern, internet-enabled formats, thus linking ancient equipment to current IoT systems. This technique allows firms to upgrade gradually, integrating current systems with new technology to circumvent the significant expenses linked to total system replacements. Also, the enhancement of conventional BMS with IoT enables real-time monitoring and accurate control that were before unachievable. Sabit & Tun (2024) created a prototype that incorporates an IoT subsystem into a pre-existing BMS, yielding a reliable smart building management system. This integrated system can identify sensor malfunctions and adjust accordingly, preventing HVAC and lighting systems from functioning under defective conditions-a prevalent problem that results in energy waste in outdated systems. Their research indicated a notable enhancement in energy efficiency and dependability, with simulations and empirical case studies revealing an average hourly power savings of roughly 36.8 kW during particular failure situations. This example demonstrates how the integration of IoT sensors and alternative communication channels can enhance legacy controls and reduce inefficiencies resulting from undetected failures in outdated systems.

A significant benefit of IoT integration is the consolidated visibility of data across previously isolated systems. Facility managers can utilize a consolidated dashboard that presents real-time information on temperature, humidity, occupancy, energy usage, security notifications, and many metrics across the entire building. Such extensive insight was uncommon in prior systems, which often offered only aggregated data, such as monthly energy consumption. The Internet of Things enables constant data transmission from all rooms and devices, facilitating advanced analytics to detect trends and abnormalities. A rapid surge in energy usage in a particular location may indicate an HVAC fault or an open window; IoT monitoring facilitates prompt identification of these issues, whereas conventional systems may fail to identify them. Managing the extensive data produced by IoT sensors is intricate and requires resilient solutions. Thus, IoT modernization frequently entails the implementation of cloud data storage and analytics platforms, or the adoption of edge computing solutions for real-time on-site data processing capable of managing huge data (Sabit & Tun, 2024). Furthermore, The integration of the Internet of Things (IoT) into building management systems markedly improves responsiveness and user engagement. Occupants and facility staff receive prompt messages on their mobile devices on incidents such as air quality alarms or security breaches identified by intelligent cameras. This real-time surveillance facilitates immediate reactions to anticipated problems, thus enhancing safety and operational efficacy. Moreover, IoT facilitates the remote management of building systems; engineers can modify settings via mobile applications while offsite, and tenants can control room temperatures before their arrival. This degree of involvement signifies a significant transition from conventional systems that necessitated on-site manual intervention or programming at a control panel. The integration of IoT and smartphone connectivity improves the efficiency and convenience of building management, resulting in more effective and user-focused operations (Ahmed et al., 2022).

In conclusion, IoT technologies act as accelerators for the digitization of legacy structures. Older buildings can attain performance levels akin to modern smart buildings with planned IoT retrofits, without requiring major renovation. Literature and case studies demonstrate that IoT-enhanced legacy systems surpass traditional configurations in multiple aspects: they diminish energy waste, facilitate condition-based maintenance, and improve experiences for occupants and operators. These innovations directly tackle limitations inherent in legacy structures, like the lack of feedback mechanisms and difficulties in optimizing intricate construction dynamics. Nonetheless, IoT integration has obstacles, such as establishing interoperability between legacy and contemporary components and preserving fail-safety to ensure buildings remain operational even if the IoT network experiences faults that require competent management. The following section will examine the distinct advantages achieved, especially in terms of sustainability and cost reduction, along with the problems and solutions related to the implementation of IoT in building automation.

4.2. Energy efficiency improvements

A prominently recognized benefit of IoT-enabled smart buildings is their substantial energy efficiency. IoT devices provide precise management of building systems, reducing waste and enhancing performance (Jia et al., 2019). IoT-based occupancy sensors can automatically turn off lighting and HVAC systems in empty spaces, while smart thermostats can modify setpoints dynamically according to real-time occupancy patterns and weather conditions (Sabit & Tun, 2024). Empirical research substantiates the efficacy of IoT-enabled energy management systems. A commercial building in the UK that implemented IoT sensors and smart controls for HVAC and lighting realized an annual energy consumption reduction of 38% relative to its baseline operation (Onuh, Feng, Chen, & Soto, 2022). This enhancement demonstrates the cumulative advantages of IoT-driven optimizations, including lowering lights when sunshine is adequate and decreasing airflow in unoccupied areas. Moreover, IoT-enabled Building Management Systems (BMS) facilitate real-time monitoring and energy consumption modifications, thereby averting superfluous heating, cooling, or lighting activities (Milenkovic, 2022). Intelligent buildings can engage in demand-response initiatives, dynamically modifying HVAC and lighting loads to save electricity expenses during peak grid periods while ensuring occupant comfort (Jia et al., 2019). Moreover, IoT-integrated renewable energy technologies, including battery storage and solar panels, can be improved using real-time grid data, hence augmenting sustainability and energy resilience (Quinn et al., 2022). Through the constant monitoring of equipment performance, IoT sensors can identify HVAC inefficiencies such as contaminated filters or suboptimal components thereby facilitating early maintenance prior to the escalation of failures (Quinn et al., 2022). This predictive maintenance strategy conserves energy and prolongs equipment lifespan, hence indirectly decreasing maintenance and replacement expenses (Milenkovic, 2022).

4.3. Sustainability and carbon footprint reduction

The energy efficiency advantages of IoT significantly enhance urban sustainability initiatives by diminishing greenhouse gas emissions linked to building energy consumption (Quinn et al., 2022). Retrofitting historical structures with IoT-based energy management systems can reduce energy usage by 20–30%, so substantially affecting municipal energy demand and carbon emissions (Onuh et al., 2022). Nevertheless, although IoT-enabled buildings reduce operational emissions, research indicates that the embodied carbon footprint of IoT devices must also be taken into account. Onuh et al., (2022) determined that the production and installation of IoT sensors augmented a building's embodied carbon emissions by roughly 7% per annum (nearly 2-kilogram CO_2 per square meter annually). Nonetheless, the rise in carbon emissions is counterbalanced by substantial decreases in operational energy use, indicating that IoT-driven efficiency rapidly mitigates its initial environmental effects (Onuh et al., 2022). In addition to energy, IoT technologies provide comprehensive resource management. IoT-enabled water meters and leak detection systems facilitate the prompt detection of plumbing inefficiencies, hence reducing water waste and maintenance expenses (Milenkovic, 2022). IoT-enabled smart waste management systems enhance collection routes and recycling through sensor data, hence increasing garbage disposal efficiency and minimizing logistical carbon footprints (Jia et al., 2019). The benefits of long-term sustainability are enhanced when IoT-enabled smart buildings incorporate real-time renewable energy management. Structures that integrate solar energy, battery storage, and intelligent networks can emphasize the utilization of renewable energy, hence diminishing reliance on fossil fuel-derived electricity (Quinn et al., 2022). This facilitates net-zero carbon objectives by diminishing peak energy requirements and optimizing self-produced renewable energy (Onuh et al., 2022).

4.4. Operational cost reduction

In addition to energy efficiency, IoT-enabled smart buildings generate significant reductions in operational costs via automation and predictive maintenance (Jia et al., 2019). Research demonstrates that a 30% decrease in energy consumption can result in annual savings of to tens or even hundreds of thousands of dollars for major commercial edifices (Onuh et al., 2022). IoT-enabled predictive maintenance decreases operational costs by identifying anomalies in equipment performance, enabling facility managers to conduct repair alone when required instead of according to predetermined maintenance plans (Milenkovic, 2022). This mitigates unforeseen equipment malfunctions, avoids operational interruptions, and prolongs asset longevity, hence averting costly emergency repairs and replacements (Quinn et al., 2022). Furthermore, IoT-based space utilization monitoring enhances building management through the analysis of occupancy patterns (Jia et al., 2019). Organizations can consolidate underutilized spaces, decrease HVAC demand in unoccupied areas, and dynamically modify ventilation schedules (Onuh et al., 2022). A smart building may identify that a certain office wing is hardly used in the morning and postpone HVAC activation in that section until actual occupancy rises, so minimizing superfluous heating and cooling costs (Milenkovic, 2022). Significantly, these efficiency-oriented cost reductions do not undermine occupant comfort; rather, they augment it. IoT-driven systems enhance ventilation, lighting, and thermal comfort by dynamically modifying indoor conditions in response to occupancy and air quality (Jia et al., 2019). In a case study, IoT ventilation optimization enhanced employee comfort and decreased HVAC energy consumption (Quinn et al., 2022). Likewise, intelligent lighting systems that harmonize natural and artificial illumination have been associated with enhanced occupant productivity and well-being (Onuh et al., 2022). The research strongly indicates that IoT-driven smart building initiatives yield quantifiable enhancements in energy efficiency, sustainability, and operational cost-effectiveness (Jia et al., 2019). Research demonstrates that IoT-augmented building management systems can realize energy savings of 20–40%, markedly decreasing carbon emissions and improving building resilience (Onuh et al., 2022). The interrelated advantages establish a compelling economic rationale for IoT implementation, allowing building proprietors and facility administrators to decrease expenses while improving building intelligence (Milenkovic, 2022). Successful IoT implementation necessitates strategic planning, resolution of interoperability issues, mitigation of cybersecurity concerns, and management of data governance constraints (Quinn et al., 2022). The proliferation of IoT in smart buildings will increasingly contribute to global sustainability and energy efficiency objectives (Jia et al., 2019).

4.5. Challenges in IoT adoptions for building automation

To facilitate the adoption of IoT in legacy buildings and ensure a successful transition to smart building management, a comprehensive strategy is required, integrating technological, regulatory, and operational measures. Policymakers and regulators play a crucial role in shaping the adoption landscape by introducing financial incentives such as grants, tax credits, and low-interest loans to encourage IoT-based energy efficiency retrofits. Updating building codes to be "smart-ready" by requiring sub-metering and open protocol wiring can further support integration (Dosumu & Uwayo, 2023). Ensuring interoperability is another critical aspect, requiring collaboration between government bodies and industry stakeholders to establish open data standards that prevent vendor lock-in and facilitate seamless integration of IoT systems across different platforms. Strengthening cybersecurity regulations and privacy frameworks is equally important, as secure IoT deployment requires mandatory encryption, routine security audits, and compliance with privacy regulations to safeguard occupant data (Poyyamozhi et al., 2024a). Further, from an operational perspective, building owners and developers can take an incremental approach by initiating pilot IoT projects in specific areas, such as HVAC or lighting systems, to assess their benefits and build internal expertise. Pilot projects can generate empirical data that supports a broader business case for IoT deployment, helping to justify return on investment through energy savings and maintenance cost reductions (Dosumu & Uwayo, 2023). Given the complexity of IoT implementations, organizations should invest in workforce development by training personnel in smart building technologies and forming partnerships with IoT integrators and energy service companies. Facility managers and engineers should focus on adopting modular, scalable IoT architectures that support future expansion and integration with multiple vendors, ensuring long-term system compatibility (Poyyamozhi et al., 2024a). Moreover, the success of IoT in smart buildings depends on a data-driven approach to management, leveraging real-time analytics to optimize energy usage, detect anomalies, and enhance operational efficiency. Transparent communication with occupants regarding smart building features can increase acceptance and improve participation in energy-saving initiatives.

Cybersecurity considerations should be integrated from the early design phase, with robust measures such as network segmentation, device authentication, and proactive threat monitoring ensuring the security of building automation systems (Dosumu & Uwayo, 2023). Edge computing can complement cloud-based IoT infrastructure by processing sensitive data locally, reducing bandwidth constraints, and enhancing security. In addition, regulatory frameworks should mandate clear data governance policies to protect user privacy, including anonymization techniques and transparent data collection disclosures (Poyyamozhi et al., 2024a). Policymakers can accelerate IoT adoption by incorporating smart building technologies into national climate action plans, providing regulatory clarity, and incentivizing the integration of demand-response programs that allow buildings to interact dynamically with the power grid. Establishing performance benchmarks and certification programs for IoT-enabled energy efficiency, similar to existing green building standards like LEED and BREEAM, can further motivate investment in smart infrastructure. Ultimately, the modernization of legacy buildings into smart, IoT-enabled structures requires a multidisciplinary approach that aligns technological advancements with sound policy, workforce readiness, and strong cybersecurity measures. By strategically addressing these challenges, stakeholders can unlock the full potential of IoT in transforming the built environment into a more sustainable, efficient, and intelligent ecosystem that benefits property owners, occupants, and society at large (Dosumu & Uwayo, 2023).

5. DISCUSSION

The incorporation of Internet of Things (IoT) technologies into building management systems has become a crucial approach for improving operational efficiency and sustainability in existing buildings. This discourse integrates contemporary research and case studies to clarify the extensive ramifications of IoT implementation in retrofitting legacy structures, highlighting sustainability, occupant welfare, cybersecurity, and policy factors. Also, retrofitting existing buildings with IoT technologies provides significant environmental advantages. Structures represent over 34% of worldwide energy usage and 37% of CO_2 emissions, highlighting the urgent necessity for energy-efficient measures (Poyyamozhi et al., 2024b). Implementing IoT-based energy management systems can result in substantial decreases in energy use. Integrating IoT devices into traditional Building Management Systems (BMS) has resulted in energy consumption reductions of up to 36% in specific situations (VEXO, 2023). These retrofits save operational expenses and advance sustainability objectives by lowering the carbon footprint of urban facilities. In addition to energy savings, IoT-augmented smart buildings can boost Indoor Environmental Quality (IEQ), hence affecting occupant health and productivity. Advanced air quality sensors provide real-time surveillance and regulation of environmental variables including temperature, humidity, illumination, and air quality. Optimal indoor environmental quality (IEQ) is associated with enhanced worker productivity and diminished absenteeism (Poyyamozhi et al., 2024a). Furthermore, individualized environmental controls enabled by IoT technologies can improve occupant comfort, resulting in increased happiness and well-being. Also, the increase of IoT devices in building management systems has greatly enlarged the attack surface, making smart buildings more vulnerable to cyber assaults. Flaws in these interconnected devices may result in illegal access and control over essential building activities, endangering both infrastructure integrity and occupant safety. To alleviate these dangers, it is essential to enforce rigorous security measures, such as network segmentation, strong authentication mechanisms, and ongoing monitoring. Moreover, implementing open data governance standards and engaging tenants in decision-making processes are crucial measures to mitigate privacy issues related to large data collecting in smart buildings (Dos Santos et al., 2021).

Policy interventions are essential for promoting the implementation of IoT technology in building retrofits, aiding initiatives to improve energy efficiency, operational effectiveness, and smart infrastructure (Poyyamozhi et al., 2024a). Governments can facilitate IoT adoption via subsidies, tax incentives, and the implementation of smart building certification schemes (Dosumu & Uwayo, 2023). Offering financial incentives, including grants and tax credits, motivates property owners and developers to engage in IoT-driven energy saving solutions. Numerous international initiatives, including Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM), have integrated IoT-driven smart building technologies as essential criteria for certification, thereby promoting their implementation in urban settings (U.S. Green Building Council, 2021). Moreover, revising building standards and regulatory rules to facilitate IoT-driven building automation guarantees that outdated infrastructures can evolve into contemporary energy-efficient systems (Naderpour, Rafiean, & Fakharian, 2018). Updated building codes have to require open communication protocols for building management systems (BMS), guaranteeing interoperability across IoT solutions and traditional systems to avert vendor lock-in (Alreshidi, Mourshed, & Rezgui, 2017). Furthermore, instituting cybersecurity and data protection legislation is essential for alleviating security issues linked to IoT implementation in smart buildings. Governments ought to implement frequent security assessments, standards for data encryption, and frameworks for privacy protection to strengthen the resilience of IoT-enabled infrastructure (Abu Bakar et al., 2024). So, through the implementation of focused policy interventions, governments can provide a regulatory framework that promotes innovation, improves energy efficiency, and stimulates investments in smart buildings. Integrating IoT-based building management systems with climate action policies and sustainability frameworks can expedite digital transformation and provide a resilient, future-proof urban infrastructure (Poyyamozhi et al., 2024a).

6. RECOMMENDATIONS

6.1. Solutions and strategies for IoT adoption

The obstacles related to IoT implementation in building automation are considerable; yet research and industry practices have produced numerous solutions to address them. Essential solutions focus on technology standardization, project management methodologies, security frameworks, and policy interventions to enable IoT-based smart building implementations. Moreover, interoperability through Standards and Open Protocols where a major impediment to IoT adoption is system compatibility. The adoption of open standards and universal communication protocols is crucial for seamless integration. Many smart building initiatives are presently transitioning to standardized IoT protocols, such as MQTT for data messaging and REST/HTTP APIs for device communication. Moreover, established building automation protocols like BACnet, Modbus TCP, KNX, and works enhance cross-device compatibility, hence advancing IoT ecosystem integration. To address integration challenges, employing middleware platforms that translate legacy Building Management System (BMS) protocols into modern IoT networks can link outdated building automation systems with cloud-based IoT infrastructure. Furthermore, semantic interoperability frameworks such as Project Haystack and Brick Schema create standardized naming conventions and data models to ensure consistent interactions among IoT devices, hence reducing integration mistakes and enhancing cross-system communication. Wireless IoT technology offer an economical approach for modernizing antiquated buildings. Wireless sensors can be deployed without rewiring existing infrastructure, hence reducing installation costs and preventing disruptions. Studies indicate that the amalgamation of IoT technologies with existing Building Management technologies (BMSs) can markedly improve energy efficiency in smart buildings (Poyyamozhi et al., 2024a).

Cost mitigation and demonstrating Return of Investment (ROI) is an important elements of any deployment of IoT in smart buildings requires substantial upfront investment, including costs for sensors, networking devices, and software systems. To mitigate financial apprehensions, companies may use IoT gradually, first with pilot projects in industries where the highest return on investment (ROI) can be demonstrated. Implementing an energy monitoring system helps identify inefficiencies, and these first discoveries can aid in subsequent deployment. Energy Service Companies (ESCOs) offer performance contracting frameworks, financing IoT retrofits and recovering costs through a share of the energy savings. This method reduces cost barriers, making IoT adoption more feasible. Governments and legislators are recognizing the benefits of IoT-based energy management. Many nations already provide grants and tax incentives for smart building features, particularly those enhancing energy efficiency and demand-response capabilities. Initiatives such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) encourage IoT integration by awarding certification credits for features including automated fault detection, advanced energy metering, and demand-response participation. Assessing post-implementation energy savings and operational cost reductions is essential to substantiate IoT expenditures. Case studies indicate that IoT-augmented smart buildings can significantly reduce energy consumption, often achieving full ROI within a few years (Poyyamozhi et al., 2024a).

The knowledge gap concerning IoT is a significant barrier to the implementation of smart buildings. Organizations are increasingly dedicating resources to workforce training, ensuring that facilities management staff are proficient in IoT device management, cybersecurity protocols, and data analytics. Some companies are establishing specialized roles, such as IoT systems managers and energy analysts, to oversee IoT initiatives and improve efficiency. Moreover, collaborations with system integrators and IoT service providers are becoming more common in the industry, since outsourcing IoT management to specialist organizations streamlines complex connections. Best practices suggest that early stakeholder involvement can improve the outcomes of IoT projects. Engaging IT and facilities management teams at every phase of smart building implementation from design and planning to commissioning and operations ensures seamless integration. The integration of IoT management into corporate IT infrastructures enhances security and long-term maintenance strategies (Baharetha et al., 2023).

Cybersecurity is a paramount issue in the implementation of IoT for intelligent buildings. Adopting essential cyber hygiene measures, including altering default passwords, requiring robust authentication, and maintaining current firmware, might avert various security breaches. Moreover, network segmentation, which partitions a network into distinct pieces, guarantees the isolation of building control systems from corporate IT networks, thus averting illegal access. This method improves security by restricting potential attack vectors and confining breaches to designated network areas. Consult the paper for an exhaustive investigation of cybersecurity in smart buildings. by Rondon et al. (2020), It analyzes vulnerabilities in Enterprise Internet of Things (EIoT) systems and suggests solutions to mitigate related risks. Additionally, governments and organizations are progressively adopting IoT cybersecurity protocols to protect linked devices. The National Institute of Standards and Technology (NIST) has created extensive frameworks, including the Cybersecurity for the Internet of Things (IoT) program, which facilitates the development and implementation of standards, guidelines, and associated tools to enhance the cybersecurity of IoT systems and their deployment environments (Rondon et al., 2020). Alongside compliance with stated requirements, certain building owners are actively performing cybersecurity audits to detect and address vulnerabilities in their IoT-based automation systems. These audits entail evaluating the security status of IoT devices and networks, confirming adherence to best practices, and instituting requisite protections to mitigate any threats. To add more, Blockchain technology has surfaced as an innovative security option for smart buildings. Blockchain improves the security of IoT transactions and device interactions through the use of distributed ledgers, hence prohibiting data modification and unauthorized access. The decentralized characteristic of blockchain guarantees that data remains irreversible and transparent, therefore enhancing trust in the integrity of building management systems (Almarri & Aljughaiman, 2024). Also, governments can expedite IoT adoption by revising building codes to promote the integration of smart infrastructure. Policymakers can set standards for cybersecurity in smart buildings, interoperability, and energy performance, thereby assuring uniform regulatory regimes. Collaborative partnerships, including utility-driven incentives for IoT-enabled demand response, can enhance investment in smart building systems. Despite the hurdles associated with IoT integration in building automation, strategic technical solutions, cybersecurity protocols, workforce development, and legislative advocacy are facilitating advancements in smart building technology.

6.2. Expedite IoT adoption in legacy buildings

A multi-stakeholder approach is essential to expedite IoT adoption in legacy buildings and guarantee smooth integration into smart building management. Policymakers, building proprietors, engineers, and IT specialists must cooperate to overcome technological, regulatory, and financial obstacles while emphasizing interoperability, cybersecurity, and sustainability (Dosumu & Uwayo, 2023; Poyyamozhi et al., 2024a). The subsequent recommendations offer strategic direction for main stakeholder groups.

6.2.1. For policymakers and regulators

Governments are essential in promoting IoT use in smart buildings through the establishment of incentives, regulatory frameworks, and interoperability standards (Alreshidi et al., 2017). Monetary incentives, including grants, tax credits, and low-interest loans, might motivate property owners to adopt IoT-driven energy efficiency initiatives. Furthermore, building codes must be revised to be "smart-ready," mandating sub-metering, open protocol wiring, and IoT-enabled infrastructure to provide scalability and future enhancements (Dosumu & Uwayo, 2023). Facilitating interoperability is crucial to avert vendor lock-in and support sustained investments in IoT technologies. Governments ought to partner with business associations and IoT standardization entities to establish open data standards that provide interoperability between legacy and contemporary systems (Poyyamozhi et al., 2024a). Furthermore, enhancing cybersecurity rules is essential for safeguarding IoT-enabled smart buildings. Implementing encryption standards, conducting regular security audits, and enforcing stringent access controls can safeguard building automation systems from cyber threats (Bakar et al., 2024). Furthermore, governments ought to implement privacy legislation that secure occupant data, assuring adherence to data protection frameworks while fostering transparent data governance practices (Dosumu & Uwayo, 2023).

6.2.2. For building owners, developers, and business leaders

Landlords and corporate executives should adopt a gradual strategy for IoT implementation, commencing with pilot initiatives in certain systems such as HVAC, lighting, or security (Dosumu & Uwayo, 2023). These minor projects enable enterprises to quantify energy savings, decrease operational costs, and enhance maintenance efficiencies, so reinforcing the justification for substantial IoT expenditures. Furthermore, collaborating with IoT integrators and energy service companies (ESCOs) can facilitate the management of intricate IoT implementations while enhancing long-term return on investment (Poyyamozhi et al., 2024a). Further, to mitigate the technological skills deficit, enterprises ought to allocate resources towards workforce training and partner with educational institutions to cultivate proficiency in IoT management, cybersecurity, and data analytics (Dosumu & Uwayo, 2023). Additionally, an incremental retrofit plan should be implemented, emphasizing low-disruption technologies such as wireless IoT sensors, cloud-based analytics, and edge computing solutions that integrate effortlessly with current building systems (Alreshidi et al., 2017). Data-driven decision-making is essential in IoT-enabled building management; monitoring energy consumption, performance trends, and predictive maintenance insights using real-time dashboards and AI-powered analytics can optimize efficiency and reduce costs (Bakar et al., 2024).

6.2.3. For engineers, designers, and facility managers

Incorporating cybersecurity best practices into IoT system design is essential for safeguarding smart building infrastructures against cyber threats (Dosumu & Uwayo, 2023). Principles of secure-by-design, such as robust authentication mechanisms, encrypted communication channels, and network segmentation, ought to be integrated into request-for-proposal (RFP) forms and procurement procedures (Bakar et al., 2024). Regular penetration testing, intrusion detection, and firmware updates must be performed to improve the resilience of IoT systems. Additionally, engineers must prioritize open architectures and modular systems by choosing IoT devices and Building Management System (BMS) platforms that conform to widely recognized interoperability standards (Alreshidi et al., 2017). Employing middleware solutions to connect ancient BMS protocols (BACnet, Modbus) with contemporary IoT networks guarantees interoperability between outdated and modern technology (Poyyamozhi et al., 2024b).

It is essential to design IoT retrofits with a focus on simplicity and operator usability. Facility managers want cohesive, user-friendly management interfaces for the real-time monitoring and automation of HVAC, lighting, and security systems (Dosumu & Uwayo, 2023)Failsafe procedures, including local overrides for HVAC controls during network failures, must be established to maintain building functionality amid connectivity disruptions (Bakar et al., 2024). Also. data protection remains a key concern, requiring robust data governance frameworks. Best practices include implementing edge computing solutions to minimize sensitive data transmission, using compression techniques to optimize storage, and anonymizing occupancy and personal data to comply with data privacy laws (Poyyamozhi et al., 2024b). By strategically implementing IoT technologies in legacy buildings, stakeholders can overcome adoption barriers and drive sustainable innovation. Policymakers must create a regulatory framework that incentivizes smart building technologies, while business leaders and facility managers must focus on practical IoT integration, cybersecurity resilience, and workforce development. Engineers must design scalable, interoperable, and secure IoT systems, ensuring long-term reliability and efficient building operations. The transformation of legacy infrastructure into smart, data-driven ecosystems represents a multidisciplinary effort, aligning technological advancements with environmental, operational, and economic sustainability goals (Dosumu & Uwayo, 2023; Poyyamozhi et al., 2024b).

7. CONCLUSION

The digitization and transformation of smart buildings via IoT ecosystems is revolutionizing facilities management and building operations. With the rapid pace of urbanization, IoT-enabled smart buildings are becoming fundamental to sustainable infrastructure by optimizing energy efficiency, minimizing operational costs, and improving occupant comfort and security (Dosumu & Uwayo, 2023; Poyyamozhi et al., 2024a). The incorporation of real-time monitoring, adaptive automation, and predictive analytics in smart buildings surpasses the functionalities of conventional building management systems, facilitating data-driven decision-making to improve building performance and resilience against climate and operational challenges (Jia et al., 2019). Additionally, empirical research confirms that IoT-enabled smart buildings provide significant advantages across various dimensions. Case studies indicate energy savings of 20–40%, decreases in carbon emissions, and enhancements in load balancing and grid interaction (Onuh et al., 2022). Furthermore, predictive maintenance of IoT data has resulted in diminished equipment failure rates, hence decreasing unanticipated downtime and maintenance costs (Milenkovic, 2022). These developments serve the financial interests of building owners while also aligning with overarching societal sustainability objectives, especially in urban resilience planning (Poyyamozhi et al., 2024b). Smart buildings are essential for meeting climate goals by minimizing energy usage, incorporating renewable energy sources, and facilitating smart grid infrastructure (Quinn et al., 2022). Furthermore, optimizing indoor environmental quality (IEQ) via dynamic HVAC and lighting control allows IoT-enabled buildings to improve occupant health, well-being, and productivity, which is increasingly acknowledged as a competitive advantage in workplace strategy and real estate valuation (Le et al., 2023).

The move from traditional buildings to fully IoT-integrated smart environments is intricate and requires deliberate navigation. Primary hurdles encompass technology interoperability, substantial initial expenditures, ambiguity regarding return on investment, deficiencies in facilities management expertise, and considerable cybersecurity and data privacy threats (Bakar et al., 2024). In the absence of a systematic strategy to tackle these problems, the implementation of IoT in smart buildings may encounter obstacles to scalability and efficacy (Dosumu & Uwayo, 2023). Fortunately, solutions are arising to address these challenges: the implementation of open IoT standards, protocol gateways for legacy system integration, and phased IoT deployment via performance-based finance models can alleviate technical and financial impediments (Poyyamozhi et al., 2024b). Similarly, cybersecurity best practices such as network segmentation, encryption, and ongoing security monitoring can enhance the resilience of IoT systems, safeguarding buildings against potential cyber threats (Dos

Santos et al., 2021). Establishing open data governance principles, anonymizing tenant data, and adhering to privacy legislation will be crucial for sustaining public trust in smart building programs (Bakar et al., 2024).

In conclusion, the Internet of Things (IoT) serves as a disruptive catalyst in the modernization of building management, integrating technological innovation with sustainability and operational efficiency. Legacy buildings that incorporate IoT technologies will enhance their long-term efficiency and interoperability with smart city initiatives, while those that resist IoT integration may face obsolescence regarding functionality, energy management, and occupant satisfaction To maximize the potential of IoT, stakeholders comprising government regulators, corporate executives, and engineers must actively interact with smart technology solutions, prioritizing interoperability, cybersecurity, and human-centered design. As technology progress accelerates and legal frameworks adjust, the obstacles to IoT adoption will persistently decrease, promoting the development of more intelligent, sustainable, and adaptive urban infrastructure.

References

Abu Bakar, A., Yussof, S., Abdul Ghapar, A., Syarmila Sameon, S., & Nørregaard Jørgensen, B. (2024). A Review of Privacy Concerns in Energy-Efficient Smart Buildings: Risks, Rights, and Regulations. *Mdpi.ComAA Bakar, S Yussof, AA Ghapar, SS Sameon, BN JørgensenEnergies, 2024•mdpi.Com*, 17(5), 1-17. Retrieved 19 February 2025 from https://doi.org/10.3390/en17050977

Ahmad, A. Y., Assad, N. F., & Alshurideh, M. T. (2023). Running Head: Impact of Smart Buildings on Accounting and Management Control. *Studies in Computational Intelligence*, 1056, 1795–1806. Retrieved 20 February 2025 from https://doi.org/10.1007/978-3-031-12382-5_98

Ahmad, Ala'a, & Alshurideh, M. (2023a). Digital Twin in Facility Management Operational Decision Making and Predictive Maintenance. Lecture Notes on Data Engineering and Communications Technologies, 152, 437–448. Retrieved 20 February 2025 from https://doi.org/10.1007/978-3-031-20601-6_38

Ahmad, Alaa, & Alshurideh, M. T. (2023b). Adoption Factors of Digitize Facilities: A Management Review. Studies in Computational Intelligence, 1056, 781–792. Retrieved 20 February 2025 from https://doi.org/10.1007/978-3-031-12382-5_42

Ahmed, M. A., Chavez, S. A., Eltamaly, A. M., Garces, H. O., Rojas, A. J., & Kim, Y. C. (2022). Toward an Intelligent Campus: IoT Platform for Remote Monitoring and Control of Smart Buildings. Sensors (Basel, Switzerland), 22(23), 1-23, 9045. Retrieved 19 February 2025 from https://doi.org/10.3390/S22239045

Ahmad, A. A., Nuseir, M. T., Alzoubi, H. M., Al Kurdi, B., Alshurideh, M. T., & Al-Hamad, A. (2024). Impact of the internet of things (IoT) on the E-supply chain with the mediating role of information technology capabilities: An empirical evidence from the UAE automotive manufacturing industry. In Cyber Security Impact on Digitalization and Business Intelligence: Big Cyber Security for Information Management: Opportunities and Challenges (pp. 409-429). Cham: Springer International Publishing.

Almarri, S., & Aljughaiman, A. (2024). Blockchain Technology for IoT Security and Trust: A Comprehensive SLR. Sustainability 2024, Vol. 16, Page 10177, 16(23), 1-35. Retrieved 19 February 2025 from https://doi.org/10.3390/SU162310177

Alreshidi, E., Mourshed, M., & Rezgui, Y. (2017). Factors for effective BIM governance. *Journal of Building Engineering*, 10, 89–101. Retrieved 19 February 2025 from https://doi.org/10.1016/J.JOBE.2017.02.006

Alshurideh, M. (2024). Utilize internet of things (IOTs) on customer relationship marketing (CRM): An empirical study. International Journal of Management and Marketing Intelligence, 1(1), 11-19.

Alshurideh, M. T., Al Kurdi, B., Saleh, S., Massoud, K., & Osama, A. (2023). IoT applications in business and marketing during the coronavirus pandemic. In The Effect of Information Technology on Business and Marketing Intelligence Systems (pp. 2541-2551). Cham: Springer International Publishing.

Ambasht, A. (2023). Real-Time Data Integration and Analytics: Empowering Data-Driven Decision Making. *International Journal of Computer Trends and Technology*, 71(7), 8–14. Retrieved 19 February 2025 from https://doi.org/10.14445/22312803/IJCTT-V71I7P102

Amponsah, C. (2024). The Effects of Pros and Cons of Applying Big Data Analytics to Enhance Consumers' Responses. International Journal of Management and Marketing Intelligence, 1(3), 1-8.

Anaam, E., Hasan, M. K., Ghazal, T. M., Haw, S. C., Alzoubi, H. M., & Alshurideh, M. T. (2023, February). How private blockchain technology secure iot data record. In 2023 IEEE 2nd International Conference on AI in Cybersecurity (ICAIC) (pp. 1-6). IEEE.

Antouz, Y. A., Akour, I. A., Alshurideh, M. T., Alzoubi, H. M., & Alquqa, E. K. (2023, March). The impact of internet of things (IoT) and logistics activities on digital operations. In 2023 International Conference on Business Analytics for Technology and Security (ICBATS) (pp. 1-5). IEEE.

Baharetha, S., Soliman, A. M., Hassanain, M. A., Alshibani, A., & Ezz, M. S. (2023). Assessment of the challenges influencing the adoption of smart building technologies. Frontiers in Built Environment, 9, 1-16, 1334005. Retrieved 19 February 2025 from https://doi.org/10.3389/FBUIL.2023.1334005/BIBTEX

Bakar, A. A., Yussof, S., Ghapar, A. A., Sameon, S. S., & Jørgensen, B. N. (2024). A Review of Privacy Concerns in Energy-Efficient Smart Buildings: Risks, Rights, and Regulations. *Energies*, 17(5), 1-17.

Buckman, A. H., Mayfield, M., & BM Beck, S. (2014). What is a smart building? *Smart and Sustainable Built Environment*, 3(2), 92–109.

Djehaiche, R., Aidel, S., Sawalmeh, A., Saeed, N., & Alenezi, A. H. (2023). Adaptive control of IoT/M2M devices in smart buildings using heterogeneous wireless networks. IEEE Sensors Journal, 23(7), 7836-7849.

Dos *Santos*, D. R., Dagrada, M., & Costante, E. (2021). Leveraging operational technology and the Internet of things to attack smart buildings. *Journal of Computer Virology and Hacking Techniques*, 17(1), 1-20. Retrieved 19 February 2025 from https://doi.org/10.1007/S11416-020-00358-8

Dosumu, O. S., & Uwayo, S. M. (2023). Modelling the adoption of Internet of things (IoT) for sustainable construction in a developing economy. *Built Environment Project and Asset Management*, 13(3), 394–411. Retrieved 19 February 2025 from https://doi.org/10.1108/BEPAM-08-2022-0123/FULL/HTML

Ghaffarianhoseini, A., Clements-Croome, D., Raahemifar, U., & Tookey, K. (2018). Intelligent or smart cities and buildings: a critical exposition and a way forward. *Taylor & FrancisA Ghaffarianhoseini, H AlWaer, A Ghaffarianhoseini, D Clements-Croome, U BerardiIntelligent Buildings International, 2018•Taylor & Francis*, 10(2), 122–129. Retrieved 19 February 2025 from https://doi.org/10.1080/17508975.2017.1394810

Ghazal, T. M., Alshurideh, M. T., & Alzoubi, H. M. (2021). Blockchain-enabled internet of things (IoT) platforms for pharmaceutical and biomedical research. In The International Conference on Artificial Intelligence and Computer Vision (pp. 589-600). Cham: Springer International Publishing.

Ghazal, T. M., Al-Dmour, N. A., Said, R. A., Omidvar, A., Khan, U. Y., Soomro, T. R., ... & Ali, L. (2023). DDoS intrusion detection with ensemble stream mining for IoT smart sensing devices. In The Effect of Information Technology on Business and Marketing Intelligence Systems (pp. 1987-2012). Cham: Springer International Publishing.

Hanaysha, J. R., & Alzoubi, H. M. (2022). Investigating the impact of benefits and challenges of IOT adoption on supply chain performance and organizational performance: An empirical study in Malaysia. Uncertain Supply Chain Management, 10(2), 537-550.

Jia, M., Komeily, A., Wang, Y., & Srinivasan, R. S. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction*, 101, 111–126. Retrieved 19 February 2025 from https://doi.org/10.1016/J.AUTCON.2019.01.023

Krebs, J. (2023). How to Bring the IoT to Older Buildings with Automation Technology. Retrieved 19 February 2025 from www.ti.com

Kumar, S. S., Chandra, R., & Agarwal, S. (2024). A real-time approach for smart building operations prediction using rule-based complex event processing and SPARQL query. Journal of Supercomputing, 80(15), 21569–21591. Retrieved 19 February 2025 from https://doi.org/10.1007/S11227-024-06276-6

Lavrinovica, I., Judvaitis, J., Laksis, D., Skromule, M., & Ozols, K. (2024). A Comprehensive Review of Sensor-Based Smart Building Monitoring and Data Gathering Techniques. *Applied Sciences (Switzerland)*, 14(21), 1-17. Retrieved 19 February 2025 from https://doi.org/10.3390/APP142110057

Le, T., Wang, A., Yao, Y., Feng, Y., Heydarian, A., Sadeh, N., & Tian, Y. (2023). Exploring Smart Commercial Building Occupants' Perceptions and Notification Preferences of Internet of Things Data Collection in the United States. *Proceedings - 8th IEEE European Symposium on Security and Privacy, Euro S and P 2023*, 1030–1046. Retrieved 19 February 2025 from https://doi.org/10.1109/EUROSP57164.2023.00064

Milenkovic, M. (2022). IoT System Case Study: Personal Office Energy Monitor (POEM). 1-20. Retrieved 19 February 2025 from http://arxiv.org/abs/2210.17356

Naderpour, H., Rafiean, A. H., & Fakharian, P. (2018). Compressive strength prediction of environmentally friendly concrete using artificial neural networks. *Journal of Building Engineering*, 16, 213–219. Retrieved 19 February 2025 from https://doi.org/10.1016/J.JOBE.2018.01.007

Onuh, A. O., Feng, H., Chen, Q., & Soto, B. G. de. (2022). Investigating energy savings when using iot devices in buildings: a case study in the uk. *Proceedings of the European Conference on Computing in Construction*, 3, 1–8. Retrieved 19 February 2025 from https://doi.org/10.35490/EC3.2022.179

Ozturk, I. (2024). Factors influencing the use of the Internet of Things (IoT) to enhance customer relations and customer experience. International Journal of Management and Marketing Intelligence, 1(2), 1-9.

Poyyamozhi, M., Murugesan, B., Rajamanickam, N., Shorfuzzaman, M., & Aboelmagd, Y. (2024a). IoT—A Promising Solution to Energy Management in Smart Buildings: A Systematic Review, Applications, Barriers, and Future Scope. *Buildings*, 14(11), 1-31.

Poyyamozhi, M., Murugesan, B., Rajamanickam, N., Shorfuzzaman, M., & Aboelmagd, Y. (2024b). IoT—A Promising Solution to Energy Management in Smart Buildings: A Systematic Review, Applications, Barriers, and Future Scope. *Buildings*, 14(11), 1-31. Retrieved 19 February 2025 from https://doi.org/10.3390/BUILDINGS14113446

Quinn, C., Shabestari, A. Z., Gilani, S., Misic, T., Litoiu, M., & Mcarthur, J. J. (2022). Building Automation System Data Integration with BIM: Data Structure and Supporting Case Study. 118, 1-16. Retrieved 19 February 2025 from https://doi.org/10.1016/j.autcon.2020.103257

Risteska Stojkoska, B. L., & Trivodaliev, K. V. (2017). A review of Internet of Things for smart home: Challenges and solutions. *Journal of Cleaner Production*, 140, 1454–1464. Retrieved 19 February 2025 from https://doi.org/10.1016/J.JCLEPRO.2016.10.006

Rondon, L. P., Babun, L., Aris, A., Akkaya, K., & Uluagac, A. S. (2020). PoisonIvy: (In)secure Practices of Enterprise IoT Systems in Smart Buildings. *BuildSys 2020 - Proceedings of the 7th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation*, 130–139. Retrieved 19 February 2025 from https://doi.org/10.1145/3408308.3427606

Sabit, H., & Tun, T. (2024). IoT Integration of Failsafe Smart Building Management System. *IoT 2024*, 5(4), 801–815. Retrieved 19 February 2025 from https://doi.org/10.3390/IOT5040036

Spachos, P., & Hatzinakos, D. (2016). Real-Time Indoor Carbon Dioxide Monitoring Through Cognitive Wireless Sensor Networks. *IEEE Sensors Journal*, 16(2), 506–514. Retrieved 19 February 2025 from https://doi.org/10.1109/JSEN.2015.2479647

Spachos, P., Papapanagiotou, I., & Plataniotis, K. N. (2018). Microlocation for Smart Buildings in the Era of the Internet of Things: A Survey of Technologies, Techniques, and Approaches. *IEEE Signal Processing Magazine*, 35(5), 140–152. Retrieved 19 February 2025 from https://doi.org/10.1109/MSP.2018.2846804

Sukkari, L. (2024). The impact of big data analytics on customers' online buying. International Journal of Management and Marketing Intelligence, 1(2), 10-19.

Taboada-Orozco, A., … K. Y.-S. (Basel, & 2024, undefined. (2024). Smart Buildings: A Comprehensive Systematic Literature Review on Data-Driven Building Management Systems. *Pmc.Ncbi.Nlm.Nih.GovA Taboada-Orozco, K Yetongnon, C NicolleSensors (Basel, Switzerland), 2024•pmc.Ncbi.Nlm.Nih.Gov*, 24(13), 1-32. Retrieved 19 February 2025 from https://doi.org/10.3390/s24134405

Taleb, N., Al-Dmour, N. A., Issa, G. F., Abdellatif, T. M., Alzoubi, H. M., Alshurideh, M., & Salahat, M. (2023). Analysis of Issues Affecting IoT, AI, and Blockchain Convergence. In The Effect of Information Technology on Business and Marketing Intelligence Systems (pp. 2055-2066). Cham: Springer International Publishing.

Vasudevan, A. (2024). Cyber Security: A Customer Perspective on Emerging Technologies. International Journal of Management and Marketing Intelligence, 1(4), 1-7.

Verma, R., Brazauskas, J., Safronov, V., Danish, M., Merino, J., Xie, X., … Mortier, R. (2021). SenseRT: A Streaming Architecture for Smart Building Sensors. Retrieved 19 February 2025 from https://arxiv.org/abs/2103.09169v1

Zahra, A. (2024). Using intelligent information systems to enhance customers’ knowledge. International Journal of Management and Marketing Intelligence, 1(3), 9-16.