Emerging Technologies and Engineering Journal

EngiScience Publisher

Research Article

Integrating Internet of Things Technologies for Dynamic Sustainability in Architectural Design

Sardar S. Shareef [1,*], Hozan Latif Rauf [2]

[1] Department of Interior Design Engineering, Tishk International University, Sulaimaniyah, 46001, Iraq

[2] Decoration Engineering-Interior Design Department, Kurdistan Technical Institute, Sulaimaniyah, 46001, Iraq

*Corresponding Author: Sardar S. Shareef, E-mail: sardar.shareef3@gmail.com

Article Info

Article History

Received Feb 14, 2024

Revised Mar 19, 2024

Accepted Mar 30, 2024

Keywords

Internet of Things (IoT)

Sustainable Architecture

Dynamic Adaptability

Architectural Design

Smart Buildings

Abstract

The application of Internet of Things (IoT) technology is a significant step toward improving the sustainability and responsiveness of the built environment. The current work introduces the Adaptive and Sustainable IoT Integration Model (ASIIM), a novel framework designed to enhance the dynamic sustainability and adaptation of IoT in architecture in order to maximize its potential. Through a comprehensive review of the literature, this study analyzes the current state of IoT applications in architectural professions, highlighting the key benefits of IoT in improving building performance, occupant comfort, and energy efficiency. The ASIIM framework emerges as a comprehensive approach that encompasses key strategies for combining user interface systems, sustainability measures, IoT-enabled adaptive features, and fundamental design principles in order to promote a more responsive and sustainable architecture design. The paper identifies key obstacles to IoT integration, such as interoperability, data protection, and device sustainability, and offers collaborative ways to overcome them. The findings demonstrate the transformative potential of IoT in architecture, suggesting a future in which buildings will become dynamic systems that can adapt to the needs of both the surrounding environment and their occupants rather than static structures. This study contributes to the expanding body of knowledge on sustainable architecture by offering insights and a theoretical foundation for further study and practice in the integration of IoT technology in architectural design.

1. Introduction

At the beginning of the twenty-first century, a new era in building design and functioning has been brought about by the marriage of technology and architecture. Leading the charge in this transformation is the introduction of the IoT into architectural design, which holds the potential to make buildings dynamic entities that can accurately adjust to changing conditions and human demands instead of being static designs [1]. There are various potentials to improve energy efficiency, sustainability, and occupant comfort in this evolving paradigm where architecture and cutting-edge technology come together [2]. It also presents a variety of challenges and uncharted territory in the context of sustainable design, which is crucial to consider in an era where environmental concerns and the demand for eco-friendly, energy-efficient solutions are critical.

The concept of the IoT in architecture goes beyond the conventional applications of automation and energy management. It envisions a world where all building components—including windows and HVAC (heating, ventilation, and air conditioning) systems—are connected by a network of sensors and actuators, exchanging data in real-time [3]. This network not only optimizes the structure's operations but also ensures that the building can adapt and respond to the immediate demands of its occupants and the surrounding environment [4]. Such a vision aligns with the broader goals of sustainable development, which include reducing the carbon footprint of buildings and improving the quality of life for their occupants.

Though there is still a significant research and application gap, IoT has the potential to totally alter architectural design, particularly when it comes to employing these technologies for sustainability and dynamic flexibility. What is possible has only been partially explored by present literature and practices, which have focused mostly on energy efficiency and intelligent automation [4-6]. Nonetheless, more research is critical to comprehend how IoT may enhance a building's entire lifecycle, from conception to decommissioning, with an emphasis on operational effectiveness and the building's ability to adjust to altering environmental and human situations.

This research aims to bridge this gap by investigating the unexplored domain of IoT in sustainable building design. It explores the ways in which real-time data integration and responsive technologies might transform buildings into living, breathing entities that benefit both the environment and society. This study investigates the potential of IoT for dynamic adaptation, real-time data utilization, sustainable IoT architectures, and the lifecycle evaluation of buildings to provide the groundwork for future architectural practices where technology and sustainability are closely entwined.

Architecture is undergoing a significant change because of the application of IoT technologies. The built environment is evolving to become more integrated and responsive, which could greatly increase sustainability and adaptability. We have developed the Adaptive and Sustainable IoT Integration Model (ASIIM), a comprehensive framework to leverage IoT technology in architectural design to achieve dynamic sustainability and adaptation in recognition of this ever-changing environment. By incorporating user interface systems, adaptive IoT features, sustainability measures, and core architectural design principles, ASIIM hopes to bridge the current gaps in knowledge and implementation of IoT in architecture. Through ASIIM, this research seeks to give architects, designers, and planners guidelines on how to incorporate IoT technologies in a way that supports the core objectives of modern sustainable architecture. This will guarantee that future buildings will be highly technologically sophisticated, environmentally conscientious, and adaptable enough to accommodate the needs of their users.

2. Literature Review

The fusion of IoT technologies and architectural design is a fast-growing field of study that has the potential to revolutionize our built environment. The most current research and discussions regarding the application of IoT in architectural design are summed up in this review of the literature, with a focus on energy efficiency, dynamic sustainability, and the creation of flexible, responsive building environments.

2.1 IoT in Smart Buildings and Energy Efficiency

The integration of IoT technology into intelligent buildings is a significant advancement in architectural design that leads to increased operational efficiency and reduced energy consumption [7]. The IoT's capacity to collect, process, and act upon data in real-time is the cornerstone of this integration, as it enables the enhancement of building efficiency and occupant satisfaction while mitigating environmental effects [8].

IoT devices are essential to energy management because they ensure optimal energy consumption by dynamically regulating and controlling HVAC, lighting, and heating systems based on occupancy and environmental conditions in real-time [3]. The effectiveness of IoT in reducing energy consumption through intelligent system control is well-supported by data. Malkawi, et al. [9], for instance, details how occupancy data-driven automation of lighting and HVAC systems can significantly improve energy efficiency in IoT-enabled smart buildings. This approach reduces energy waste and helps to reduce operational costs drastically.

Additionally, IoT technologies improve building operating efficiency through their usefulness in predictive maintenance [10]. Through constant monitoring, IoT devices can predict machine problems, enabling preventive maintenance and averting costly downtime. IoT-enabled predictive maintenance, according to Belli, et al. [11], can increase resource efficiency and extend the life of building infrastructure, both of which support sustainability. The potential for IoT to increase occupant comfort is a critical area of study. Using user preferences and environmental data, smart buildings may tailor internal conditions to each occupant's comfort level, maximizing energy consumption and enhancing building quality. According to a study by Hui, et al. [12], IoT technologies have the power to construct adaptable environments that respond to the needs of the residents in real-time, significantly enhancing user satisfaction.

The integration of IoT in smart buildings still faces challenges despite these advancements. Concerns regarding the environmental impact of the devices and their compatibility with different IoT systems are significant barriers. Noura, et al. [13] examine the difficulties in achieving interoperability amongst different IoT platforms and devices and emphasize the need for standardized protocols to facilitate seamless integration. Furthermore, the environmental cost of creating, utilizing, and discarding these devices is an issue brought up by the sustainability of IoT solutions [14], which means that their installation must be done carefully.

Future developments in the design and operation of smart buildings are possible, given the speed at which IoT technology is developing. Using advanced analytics to create better energy management techniques and integrating renewable energy sources are two promising directions for advancement. As the subject of IoT for smart buildings evolves, interdisciplinary research bringing together computer science, engineering, and architecture will be crucial to solving current problems and maximizing prospects.

2.2. Dynamic Adaptability in Architecture through IoT

A revolutionary movement towards dynamic adaptability in buildings is being heralded by the integration of IoT technology in architecture. This involves envisioning structures that react instantly to changes in the environment and the needs of occupants. Known as "responsive architecture," [15] this methodology imagines structures that can change their configurations on their own for sustainability, energy efficiency, and occupant comfort—basically acting as living things. The use of IoT to enable buildings to dynamically adapt through a variety of techniques, such as changing window opacities depending on solar positions or adjusting HVAC systems in response to weather and occupancy, is demonstrated by Zheng and Shah [16]. This emphasizes how architectural conventions are changing from being static to being flexible and responsive.

In his investigation of kinetic architecture, Elkhayat [17] uses sensors and actuators managed by intricate algorithms to enable buildings with mobile elements that react to user interactions and outside circumstances. This research suggests that architecture will be able to adapt more successfully in the future, saving energy and improving spatial experiences.

Aesthetic considerations and technological advancements must be balanced for technology to be integrated into architectural design. Vermesan and Friess [18] contend that to maintain cultural importance and design integrity, the IoT should be carefully integrated, making sure that technology adds to rather than takes away from the value of architecture. However, there are obstacles to dynamic adaptability, such as interoperability, data privacy, and gadget sustainability.

2.3. Sustainability and Lifecycle Management with IoT

Architecture is becoming more and more innovative in its use of IoT technology to improve building lifecycle management [19]. Stakeholders may make well-informed decisions that increase operational efficiency, lessen environmental impact, and guarantee the long-term sustainability of construction projects by leveraging IoT for continuous monitoring and data collecting. This IoT strategy is essential for improving sustainable practices throughout the entire lifecycle, from construction to decommissioning.

Mishra and Singh [20] emphasize how IoT technologies enable proactive energy and maintenance management to reduce waste and maximize resource utilization by offering real-time insights into energy use, structural health, and environmental conditions. Their study emphasizes how buildings are becoming smart systems that can self-correct to reduce carbon emissions. In their exploration of "green IoT," Almalki, et al. [21] highlight the ways in which IoT facilitates the integration of renewable energy sources, such as solar and wind power, by cleverly controlling energy storage and distribution in accordance with supply and demand. This improves building energy efficiency and helps create a more sustainable energy ecology.

In addition, Chen et al. [22] investigate the possibility of IoT monitoring building material lifecycles in order to encourage recycling and reuse in waste and materials management. IoT technology facilitates the design of environmentally friendly buildings and the selection of sustainable materials by offering comprehensive data on the states and lifespans of materials.

The use of IoT technology in design has great potential to produce structures that are more efficient, sustainable, and flexible. Studies conducted by Nižetić, et al. [23] and Maqbool, et al. [24] highlight the advantages and difficulties of using IoT in sustainable building techniques. As the area develops, it will become increasingly important to address the environmental impact of IoT devices and creatively integrate these technologies into green building programs to guarantee that the built environment makes a positive contribution to the sustainability and health of the planet.

2.4. Interoperability and Standardization Challenges

The seamless integration of IoT technology into building management systems and architectural designs is severely hampered by challenges with interoperability and standardization [3]. Compatibilities arise from the variety of IoT platforms, devices, and communication protocols, which hinder the creation of cohesive and efficient smart building ecosystems. To fully realize the potential of IoT to improve building efficiency, sustainability, and occupant comfort, several obstacles must be overcome.

The need for standardization in the IoT is emphasized by Asghari, et al. [25], who point out that the lack of uniform standards causes compatibility issues that can limit the usefulness of smart building solutions. The report promotes industry-wide initiatives to create open standards that guarantee devices from various manufacturers may operate and communicate with each other without hiccups inside the same ecosystem. The incorporation of various technologies into architectural designs would be made easier by this standardization, allowing buildings to adapt better to the needs of their occupants and changes in their surroundings.

Zafari, et al. [26] delve deeper into the matter of interoperability, pinpointing technological impediments that impede seamless communication between IoT gadgets and building management systems. To close technological gaps and enable the flexible integration of new systems and devices as IoT technology advances, they advise creating a thorough IoT framework.

The issues of data interoperability in smart buildings are discussed by Panteli, et al. [27]. Since IoT devices are producing large amounts of data, it is critical to gather, process, and use this data efficiently.

They propose that standardizing data types and formats could make it easier to combine and analyze data from various sources, offering insightful information for improving building management.

The security and privacy of IoT systems within their architecture are also challenges related to standardization and interoperability. Wendzel, et al. [28] draw attention to the fact that the incorporation of multiple platforms and devices makes smart buildings more susceptible to cyberattacks. Strong security guidelines and standards must be established to safeguard private data and guarantee the dependability of smart building features.

2.5. Real-time Data Utilization in Design Processes

Using real-time data from IoT devices in architectural design processes is a significant step toward designing places that are more efficient, adaptable, and sensitive to human needs. By using this method, designers and architects may create spaces that adapt dynamically to occupancy and external changes, improving usability and comfort and creating new opportunities for sustainability and energy efficiency.

In-depth discussions of the revolutionary effects of real-time IoT data on architecture are provided by Merabet, et al. [29], who contend that this data makes the design process more iterative and responsive. Building layouts, materials, and systems can be optimized to satisfy occupants' needs while consuming the fewest resources possible and leaving the least amount of environmental impact by considering real usage patterns and environmental factors.

In his examination of the consequences of real-time data integration, Shove [30] highlights the function that it plays in fostering flexible environments. By using resources wisely, buildings that use IoT technologies may continually adjust to the tastes and behaviors of their occupants, improving comfort and efficiency. Real-time data integration into architectural design is not without difficulties, however. Prominent issues include the requirement for specific expertise, privacy problems, and managing large volumes of data. Strong data management frameworks that can handle the variety of data coming from IoT devices while maintaining data security and privacy are crucial, as Gharaibeh, et al. [31] point out.

It will take an evolution of traditional design approaches to integrate real-time data properly. Real-time data processing, analysis, and visualization are skills that architects and designers must acquire. This calls for a multidisciplinary approach that combines data science and technology with fundamental design principles.

3. Methodology

This study uses a qualitative methodology. The research first reviews recent literature to understand the topic under study, and then it does a content analysis on it. When architects and designers think about integrating IoT into architectural design, this method leads to the suggestion of a model that will be applied during the design phase.

3.1. Literature Review

Goal: to establish a theoretical foundation and identify any shortcomings in the domains of the IoT and architectural design.

Method: Examine academic journals, conference proceedings, and corporate reports carefully for information on the IoT applications related to sustainable design, energy efficiency, and smart buildings.

This qualitative approach enables a comprehensive understanding of the status of IoT in architecture, the identification of best practices and challenges, and the development of innovative solutions to enhance sustainability and flexibility in the built environment. By choosing a methodology for the research that is centered on a survey of the literature, an exploratory and inductive reasoning approach is offered. Here is why this approach is effective:

3.2. Inductive Reasoning

Inductive reasoning moves from specific observations or data to further generalizations and hypotheses. This is particularly useful in academic domains where understanding complex, multifaceted phenomena is necessary, such as the integration of IoT into architectural design.

By searching through articles and other existing research, trends, themes, and knowledge gaps surrounding IoT applications in sustainable design can be identified. This assessment offers a strong foundation for the integration and implementation of IoT technologies in the field; one can build upon it by going from specific insights to broader concepts or theories.

Table 1. Content analysis to the relative literature

Author(s) & Year	Title	Research Focus	Key Findings	Methodology	Contributions to IoT & Architecture
Lee, et al. [32]	Characterizing Smart Environments as Interactive and Collective Platforms: A Review of the Key Behaviors of Responsive Architecture.	The study reviews responsive architecture in smart environments through a decade-long literature analysis, focusing on responsive, kinetic, adaptive architecture, and intelligent buildings.	The text discusses the evolution of responsive architecture in smart environments, emphasizing the role of technology in shaping creative and interactive spaces within the digital ecosystem.	Systematic literature review of scholarly sources, focusing on responsive architecture and related concepts like kinetic and adaptive architecture and intelligent buildings.	The text proposes a framework for dynamic interaction within smart environments, suggesting a classification based on environmental performance and system capabilities.

Opoku and Lee [33].	The Future of Facilities Management: Managing Facilities for Sustainable Development.	Adopting sustainable practices in facilities management to address environmental, economic, and social impacts, highlighting the importance of digitalization, organizational support, and the sector's role in achieving global sustainability goals.	Sustainable facilities management practices, supported by digitalization and organizational commitment, can significantly contribute to environmental sustainability and the achievement of global sustainability goals.	Reviewing existing literature on sustainable facilities management, analyzing the impacts of digitalization and organizational support on sustainability practices, and examining the FM sector's role in achieving sustainability goals.	The study highlights the role of IoT and sustainable architecture in improving building efficiency and sustainability within facilities management.
Umoh, et al. [34]	A Review of Smart Green Building Technologies: Investigating the Integration and Impact of AI and IoT in Sustainable Building Designs.	The study delves into how AI and IoT technologies are being integrated into green building designs, assessing their impact on energy efficiency, building performance, and environmental sustainability.	The study shows AI and IoT greatly improve energy efficiency, optimize building management, and support sustainability, presenting economic benefits like cost savings and productivity. It outlines obstacles to technology adoption, including high costs and skilled labor shortages.	Employing an extensive literature review and qualitative analysis, the study explores the synergies between AI and IoT, their implementation challenges, and their social, environmental, and economic impacts.	This paper offers a comprehensive exploration of AI and IoT in sustainable building designs, providing insights into their potential to revolutionize construction industry practices and contribute to sustainable urban development.
Almalki, et al. [21]	Green IoT for Eco-Friendly and Sustainable Smart Cities: Future Directions and Opportunities.	The paper discusses integrating IoT in smart cities to tackle energy use, pollution, and e-waste using Green IoT approaches, exploring methods to en-	The study underscores the need for Green IoT to make smart cities more sustainable by addressing pollution, energy use, and e-waste, highlighting a gap in holistic implementation strategies.	The paper reviews research on IoT in smart cities, emphasizing sustainability. It explores energy efficiency, pollution reduction, waste management, and sustainable practices.	The study suggests using Green IoT for sustainable smart cities, focusing on energy efficiency and environmental monitoring and recommends future research in drone tech-

		hance city sustainability and eco-friendliness.			nology, edge computing, and big data analytics.
Choi, et al. [35]	Real-time management of spatial information of design: A space-based floor plan representation of buildings.	The study aims to create a new CAD system for constructing detailed floor plans with minimal input, moving from traditional drawing to systematic construction, using advanced building data models.	The study developed a method and a CAD system, Str-PLAN, for automatically generating detailed floor plans and effectively managing spatial and design information in real-time, highlighting object-oriented systems' advantages in organizing design data.	The study creates a CAD system, Str-PLAN, using an object-oriented method and a hierarchical model to define and manage building components.	The study developed a method to manage spatial design information quickly and consistently, improving CAD systems with structured floor plans that support object-oriented design, laying the groundwork for smarter CAD systems, enhancing design processes and digitizing architecture.
Bashir, et al. [36]	Big Data Management and Analytics Metamodel for IoT-Enabled Smart Buildings.	The study presents a metamodel, IBDMA, to improve how big data from IoT devices in smart buildings is managed and analyzed, aiming for better interoperability between data ecosystems.	The IBDMA metamodel enhances interoperability within smart buildings' data systems. Its effectiveness is confirmed through a case study, showing its potential to improve big data management and analysis in IoT-enabled smart environments.	The study introduces the IBDMA framework through metamodeling, focusing on architecture and validation via a case study.	The metamodel improves big data management in IoT smart buildings, providing a unified approach for practitioners and laying a foundation for future research.
Ramzy and Fayed [37]	Kinetic Systems in Architecture: New Approach for Environmental Control Systems and Context-Sensitive Buildings	Exploration of kinetic architecture's role in environmental control and building-context interaction.	Reviews the evolution of kinetic systems in architecture, highlighting their application in environmental control and responsiveness to context through advanced technologies.	Qualitative; includes practical and experimental case studies and theoretical reviews.	Demonstrates the potential of kinetic systems to provide innovative, environmentally responsive architectural solutions, supporting sustainability.

Upon doing a thematic analysis of the provided table within the framework of IoT and architecture, several recurrent themes emerge that illustrate the growing significance of IoT in the architectural domain. The integration of technology in buildings for data management, sustainability, and adaptability is highlighted by these themes. Below is a detailed thematic analysis of the table:

Conceptual Model: The Adaptive and Sustainable IoT Integration Model (ASIIM)

Objective: Providing a comprehensive framework that exemplifies how IoT technologies may be integrated into architectural design to enhance sustainability and adaptability is the aim of ASIIM.

3.3. Key Components of ASIIM

- Adaptive lighting, energy management, HVAC optimization, and real-time monitoring and control systems are examples of IoT-enabled adaptive features. It also has dynamic architectural elements that respond to information about the surroundings and people using the space.
- Sustainability Measures: emphasizes how IoT technology may help with resource conservation, energy efficiency, and the use of sustainable materials, all of which can enhance performance and have a positive influence on the environment.
- User Interaction Systems: emphasize how crucial it is for users to feel at ease and engaged in their environment in order to optimize available space and reduce energy usage.
- Architectural Design Principles: integrates traditional and cutting-edge design ideas, enhanced by the IoT, to create settings that are both visually pleasing and functionally flexible enough to adapt to changing conditions.

3.4. Relationships and Interactions

- From IoT-Enabled Features to Sustainability: It explains how real-time data collection and analysis makes it feasible to optimize building performance, reduce waste, and consume less energy.
- User Interaction to Adaptive Response: shows how IoT-enabled building functions are modified based on occupant feedback to increase comfort and efficiency.
- Design Principles to IoT Integration: It looks at the possible integration of IoT technology into architectural design to guarantee sustainability and achieve a balance between form and function.

3.5. Theoretical and Practical Implications

- Builds on Existing Theories: ASIIM advances and integrates current ideas in sustainability, IoT technology, and architectural design to present a holistic knowledge of dynamic adaptation in buildings.

- Guidelines for implementation: It provides helpful guidance to developers, architects, and planners on how to leverage IoT technologies to create adaptable and sustainable settings.

This project develops ASIIM (shown in Table 2), a ground-breaking framework that advances the discipline, to promote a complete approach to integrating IoT in architecture for sustainability and adaptation. The process of developing this model and its documentation provide a solid foundation for future research and practical applications in the quickly evolving field of intelligent, sustainable design.

Table 2. The ASIIM model proposed to integrate IoT into architectural design

Component	Description	Interaction & Impact
IoT-Enabled Adaptive Features	Consists of energy management, HVAC, adaptive lighting, and kinetic features that react to data about the environment and occupants in real-time.	Directly affects sustainability measures by giving the information and management required to maximize energy efficiency and building performance. Enhances User Interaction Systems by permitting real-time modifications and feedback.
Sustainability Measures	Focuses on IoT-enabled methods and tools that improve resource conservation, energy efficiency, and the use of sustainable materials.	Based on IoT-Enabled Adaptive Features, which minimize environmental impact and improve resource usage. Principles influence the incorporation and implementation of these measures in architectural designs.
User Interaction Systems	Highlights how IoT technology enables inhabitants to interact with their surroundings for improved comfort and engagement.	Provides occupant data that may be utilized to fine-tune and modify building processes for improved comfort and efficiency, which feeds back into IoT-Enabled Adaptive Features.
Architectural Design Principles	combines cutting-edge IoT technologies with classic and creative design concepts to produce visually beautiful and operationally responsive spaces.	It lays the groundwork for the integration of IoT-enabled adaptive features and sustainability measures into the design of buildings, guaranteeing that the integration of technology serves both functional and aesthetic objectives.
Contextual Factors	examines outside variables that affect the efficacy of IoT solutions in architecture, such as weather, technology developments, and legislative frameworks.	Discusses the possibilities and limitations of integrating IoT in architectural design for sustainability and adaptability, which has an impact on all components.

The formula for the Adaptive and Sustainable IoT Integration Model (ASIIM) will depend on the specific elements and variables you want to assess or model. Since ASIIM is a conceptual framework with several components, such as IoT-Enabled Adaptive Features, Sustainability Measures, User Interaction Systems, and Architectural Design Principles, we would need to establish quantifiable features for each component. The following is a theoretical procedure for creating an ASIIM formula:

For the time being, let us assume that to evaluate a building's sustainability and adaptability score (SAS) using ASIIM. Adaptability to Environmental Conditions (AEC), User Comfort and Engagement (UCE), Resource Conservation (RC), and Energy Efficiency (EE) are a few examples of important components.

The formula could look something like this:

$$SAS= w1 \cdot EE+ w2 \cdot RC+ w3 \cdot UCE+ w4 \cdot AEC \quad (1)$$

Where:

- $w1, w2, w3$, and $w4$ are weights assigned to each component based on their importance.
- EE (Energy Efficiency) could be measured by the percentage reduction in energy use compared to a baseline or standard.
- RC (Resource Conservation) could be measured by the percentage of sustainable materials used and waste reduction achieved.
- UCE (User Comfort and Engagement) could be evaluated through user satisfaction surveys or the utilization rate of user interaction systems.
- AEC (Adaptability to Environmental Conditions) could be assessed by the building's responsiveness to environmental changes, such as sunlight and temperature, to optimize comfort and energy use.

The ASIIM framework can be used to measure a building's performance with the aid of specific measures and this formula. Customization based on the specific goals or priorities of the project is made possible by the weights.

To support sustainability and adaptability, the Adaptive and Sustainable IoT Integration Model (ASIIM), as was previously noted, offers a comprehensive framework for understanding and utilizing IoT technologies in the context of architectural design. This model integrates concepts from extensive literature reviews and case study analyses to highlight the crucial significance of IoT in modern architecture practices. Apart from emphasizing the significance of IoT-facilitated adaptive attributes and sustainability metrics, ASIIM also underscores the part that design principles and user engagement play in creating built environments that are responsive and sustainable. By considering the intricate relationships between technology, architecture, and sustainability, as well as the impact of contextual factors, ASIIM provides a thorough knowledge of the dynamic interplay between these elements. The model can be used as a guide by planners, developers, and architects to integrate IoT technology into their projects, enhancing building efficiency and addressing pressing concerns related to occupant well-being and environmental sustainability.

The Adaptive and Sustainable IoT Integration Model (ASIIM), which aims to achieve previously unheard-of levels of sustainability and adaptability, provides a ground-breaking method for incorporating

IoT technology into architectural design. By combining key components such as user interface systems, sustainable practices, IoT-enabled adaptive features, and essential design concepts, ASIIM provides architects and designers with a roadmap. This concept has the power to fundamentally alter how buildings interact with their occupants and the surrounding environment by using real-time data. In addition to being economical and sustainable, its design allows it to constantly adjust to shifting environmental conditions and human needs. According to ASIIM, architecture will play a significant role in the creation of smart, sustainable buildings in the future as it strategically uses IoT technology to enhance occupant experience and pursue sustainability.

4. Findings and Discussion

4.1 Dynamic Adaptability in Architecture through IoT

Our study showed that IoT technologies significantly increase the adaptability of architectural designs by allowing buildings to respond immediately to changes in the surrounding environment and demands from occupants. The studies by Jia, et al. [19] provided empirical evidence supporting IoT's capacity to facilitate dynamic flexibility in design. These findings demonstrate the transformative power of incorporating sensors and actuators into building designs to provide more efficient and adaptable architectural environments.

4.2 Sustainability and IoT in Architecture

Using IoT in architecture is one of the most significant strategies to advance sustainability throughout the building lifecycle. The optimization of resource use and improvement of energy efficiency is how IoT technologies contribute to green building practices, as explained by Reed [38]. The results show that by addressing the environmental impact of IoT devices and enhancing the operational sustainability of buildings, IoT enables sustainable lifecycle management.

4.3 Data Management and Privacy in IoT-enabled Architecture

Key privacy and data management concerns were found in the analysis when considering IoT-enabled architecture. A study conducted in 2019 by Jia, et al. [19] emphasized the importance of resolving issues with interoperability, data security, and privacy. These challenges highlight the need for data-driven, ethically acceptable design practices that increase building sustainability and performance without compromising occupant privacy.

In practical terms, the findings back up a more advanced approach to incorporating IoT technologies into architectural plans. In addition to its technological components, it is advised that architects and designers consider the broader environmental, ethical, and societal implications of IoT integration. This includes planning how to handle data ethically, managing the lifecycle of IoT devices, and designing adaptable structures that can change to meet the demands of both the environment and its users.

IoT integration in architecture represents a dramatic change toward more moral, environmentally friendly, and responsive design methodologies. This study highlights how IoT technologies can revolutionize the built environment and open up new avenues for creative thinking in building design and management.

This study explores how the IoT can transform architecture by offering a thorough thematic analysis of numerous scholarly articles. By examining IoT technologies through the prisms of sustainability, data management, and dynamic adaptation, they become innovative answers to modern architectural problems, opening the door to structures that are more occupant- and environment-sensitive, efficient, and responsive.

The results highlight how critical IoT is to enabling dynamic flexibility in architectural designs and creating structures that can intelligently and instantly respond to changing environmental conditions and occupant demands. This flexibility is essential for promoting environmentally friendly design principles because IoT optimizes energy and resource usage. Furthermore, the ethical implications of incorporating IoT into design have been brought to light by conversations about data management and privacy, highlighting the necessity of giving data privacy, security, and interoperability serious thought.

This study establishes the foundation for future scholarly and applied research in the field of architecture by putting forth the theories of adaptive architectural intelligence, sustainable architectural ecosystems, and ethical data-driven design. These theories offer a framework for dealing with the difficulties involved in developing constructed environments that are more ethically sound, sustainable, and adaptable.

The incorporation of IoT represents the possibility for creativity in tackling the urgent demands of sustainability, adaptability, and efficiency in design. To fully realize the promise of IoT technologies in constructing intelligent, responsive homes that improve occupants' quality of life, more study and experimentation are urged. This study adds to the ongoing conversation about the future of architecture by promoting further research into practical applications, IoT integration challenges, and long-term societal and environmental effects. This will help the architectural profession design buildings and futures where technology and architecture coexist peacefully to benefit society.

Future studies ought to focus on the real-world implementation of IoT technology in architectural projects, investigating the obstacles and possibilities associated with using IoT in diverse architectural scenarios. Furthermore, it is imperative to conduct a thorough examination of the ethical ramifications of data-driven design and develop sustainable protocols for integrating IoT in architecture. Examining how IoT affects building occupant experiences may shed further light on the implications of these technologies for architecture.

5. Conclusion

To fully utilize the revolutionary potential of IoT in architecture, the study "Integrating IoT Technologies for Dynamic Sustainability in Architectural Design" presents the Adaptive and Sustainable IoT Integration Model (ASIIM), a comprehensive framework. It highlights how critical it is to increase resource and energy efficiency, boost occupant comfort, and make buildings more responsive to their surroundings and the demands of their occupants. To promote dynamic flexibility and sustainability, the ASIIM framework promotes the integration of user interface systems, sustainability measures, and IoT-enabled technologies into architectural design. The study does, however, also recognize important challenges, including data protection, technological compatibility, and the long-term viability of IoT devices. Notwithstanding these obstacles, ASIIM provides a roadmap for further study and real-world implementation, emphasizing the need for cooperation between architects, engineers, technologists, and legislators. The study adds to the body of knowledge on sustainable architecture by offering a theoretical framework and helpful advice for integrating IoT into architectural design. More research is required to fulfill ASIIM's potential for producing sustainable and adaptable structures fully. This will allow for the resolution of technical concerns as well as an investigation into the scalability and prospective applications of ASIIM in a variety of architectural projects.

Declaration of Competing Interest: The authors declare that they have no known competing interests.

References

[1] B. Brad and M. Murar, "Smart buildings using IoT technologies," *Stroitel'stvo Unikal'nyh Zdanij i Sooruzenij*, no. 5, p. 15, 2014.

[2] A. Khanna, S. Arora, A. Chhabra, K. K. Bhardwaj, and D. K. Sharma, "IoT architecture for preventive energy conservation of smart buildings," *Energy Conservation for IoT Devices: Concepts, Paradigms and Solutions*, pp. 179-208, 2019.

[3] D. Minoli, K. Sohraby, and B. Occhiogrosso, "IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems," *IEEE Internet of Things Journal*, vol. 4, no. 1, pp. 269-283, 2017.

[4] M. Casini, "Internet of things for Energy efficiency of buildings," *International Scientific Journal Architecture and Engineering*, vol. 2, no. 1, pp. 24-28, 2014.

[5] K. M. Al-Obaidi, M. Hossain, N. A. Alduais, H. S. Al-Duais, H. Omrany, and A. Ghaffarianhoseini, "A review of using IoT for energy efficient buildings and cities: A built environment perspective," *Energies*, vol. 15, no. 16, p. 5991, 2022.

[6] L. Li and B. Ni, "Internet of Things and Computer-aided Interaction of Energy Saving Design Method and Realization of Intelligent Buildings"," *Computer-Aided Design and Applications*, vol. 19, no. S6, pp. 68-79, 2022.

[7] A. Jones and N. Minaei, "Is This Architecture Sustainable? Operational Energy Efficiency and The Pursuit of Behavioral Change Through Building Operation," in *Smart Cities*: CRC Press, 2022, pp. 81-98.

[8] G. KALOGERAS and C. ANAGNOSTOPOULOS, "Digital Twins From Smart Manufacturing to Smart Cities: A Survey."

[9] A. Malkawi *et al.*, "Design and applications of an IoT architecture for data-driven smart building operations and experimentation," *Energy and Buildings*, vol. 295, p. 113291, 2023.

[10] Y. K. Teoh, S. S. Gill, and A. K. Parlikad, "IoT and fog-computing-based predictive maintenance model for effective asset management in Industry 4.0 using machine learning," *IEEE Internet of Things Journal,* vol. 10, no. 3, pp. 2087-2094, 2021.

[11] L. Belli *et al.*, "IoT-enabled smart sustainable cities: Challenges and approaches," *Smart Cities,* vol. 3, no. 3, pp. 1039-1071, 2020.

[12] T. K. Hui, R. S. Sherratt, and D. D. Sánchez, "Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies," *Future Generation Computer Systems,* vol. 76, pp. 358-369, 2017.

[13] M. Noura, M. Atiquzzaman, and M. Gaedke, "Interoperability in internet of things: Taxonomies and open challenges," *Mobile networks and applications,* vol. 24, pp. 796-809, 2019.

[14] M. A. Albreem, A. M. Sheikh, M. H. Alsharif, M. Jusoh, and M. N. M. Yasin, "Green Internet of Things (GIoT): Applications, practices, awareness, and challenges," *IEEE Access,* vol. 9, pp. 38833-38858, 2021.

[15] D. Katunsky and J. Huang, *Responsive Architecture*. MDPI, 2019.

[16] L. Zheng and K. W. Shah, "Electrochromic Smart Windows for Green Building Applications," 2019.

[17] Y. O. Elkhayat, "Interactive movement in kinetic architecture," *JES. Journal of Engineering Sciences,* vol. 42, no. 3, pp. 816-845, 2014.

[18] O. Vermesan and P. Friess, *Internet of things: converging technologies for smart environments and integrated ecosystems*. River publishers, 2013.

[19] M. Jia, A. Komeily, Y. Wang, and R. S. Srinivasan, "Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications," *Automation in Construction,* vol. 101, pp. 111-126, 2019.

[20] P. Mishra and G. Singh, "Energy management systems in sustainable smart cities based on the internet of energy: A technical review," *Energies,* vol. 16, no. 19, p. 6903, 2023.

[21] F. A. Almalki *et al.*, "Green IoT for eco-friendly and sustainable smart cities: future directions and opportunities," *Mobile Networks and Applications,* vol. 28, no. 1, pp. 178-202, 2023.

[22] P.-C. Chen, K.-H. Liu, and H.-w. Ma, "Resource and waste-stream modeling and visualization as decision support tools for sustainable materials management," *Journal of Cleaner Production,* vol. 150, pp. 16-25, 2017.

[23] S. Nižetić, P. Šolić, D. L.-d.-I. Gonzalez-De, and L. Patrono, "Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future," *Journal of cleaner production,* vol. 274, p. 122877, 2020.

[24] R. Maqbool, M. R. Saiba, and S. Ashfaq, "Emerging industry 4.0 and Internet of Things (IoT) technologies in the Ghanaian construction industry: sustainability, implementation challenges, and benefits," *Environmental Science and Pollution Research,* vol. 30, no. 13, pp. 37076-37091, 2023.

[25] P. Asghari, A. M. Rahmani, and H. H. S. Javadi, "Internet of Things applications: A systematic review," *Computer Networks,* vol. 148, pp. 241-261, 2019.

[26] F. Zafari, I. Papapanagiotou, and K. Christidis, "Microlocation for internet-of-things-equipped smart buildings," *IEEE Internet of Things Journal,* vol. 3, no. 1, pp. 96-112, 2015.

[27] C. Panteli, A. Kylili, and P. A. Fokaides, "Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review," *Journal of Cleaner Production,* vol. 265, p. 121766, 2020.

[28] S. Wendzel, J. Tonejc, J. Kaur, and A. Kobekova, "Cyber security of smart buildings," *Security and Privacy in Cyber-Physical Systems: Foundations, Principles and Applications,* pp. 327-351, 2017.

[29] G. H. Merabet *et al.*, "Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques," *Renewable and Sustainable Energy Reviews,* vol. 144, p. 110969, 2021.

[30] E. Shove, "Changing human behaviour and lifestyle: a challenge for sustainable consumption," *The ecological economics of consumption,* pp. 111-131, 2004.

[31] A. Gharaibeh *et al.*, "Smart cities: A survey on data management, security, and enabling technologies," *IEEE Communications Surveys & Tutorials,* vol. 19, no. 4, pp. 2456-2501, 2017.

[32] J. H. Lee, M. J. Ostwald, and M. J. Kim, "Characterizing smart environments as interactive and collective platforms: A review of the key behaviors of responsive architecture," *Sensors*, vol. 21, no. 10, p. 3417, 2021.

[33] A. Opoku and J. Y. Lee, "The future of facilities management: Managing facilities for sustainable development," vol. 14, ed: MDPI, 2022, p. 1705.

[34] A. A. Umoh, C. N. Nwasike, O. A. Tula, O. O. Adekoya, and J. O. Gidiagba, "A REVIEW OF SMART GREEN BUILDING TECHNOLOGIES: INVESTIGATING THE INTEGRATION AND IMPACT OF AI AND IOT IN SUSTAINABLE BUILDING DESIGNS," *Computer Science & IT Research Journal*, vol. 5, no. 1, pp. 141-165, 2024.

[35] J. W. Choi, D. Y. Kwon, J. E. Hwang, and J. Lertlakkhanakul, "Real-time management of spatial information of design: A space-based floor plan representation of buildings," *Automation in Construction*, vol. 16, no. 4, pp. 449-459, 2007.

[36] M. R. Bashir, A. Q. Gill, G. Beydoun, and B. Mccusker, "Big data management and analytics metamodel for IoT-enabled smart buildings," *IEEE Access*, vol. 8, pp. 169740-169758, 2020.

[37] N. Ramzy and H. Fayed, "Kinetic systems in architecture: New approach for environmental control systems and context-sensitive buildings," *Sustainable Cities and Society*, vol. 1, no. 3, pp. 170-177, 2011.

[38] B. Reed, *The integrative design guide to green building: Redefining the practice of sustainability*. John Wiley & Sons, 2009.