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Review Article

Reviewing the Green Building Concepts Along With the Applications of AI and IoT for Environmental Monitoring and Designing Sustainable Infrastructures

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Abstract. This academic article explores the ever-evolving field of smart green building technologies, with a particular emphasis on the ways in which artificial intelligence (AI) and Internet of Things (IoT) are integrated into and affect sustainable architecture. The study is based on background of changing green building principles, which are highlighted by rapid development of smart technologies that are changing face of contemporary architecture. With goal of comprehending how AI and IoT might improve building performance and sustainability with simultaneous reduction in carbon footprints, the study takes a methodological approach that is based on a thorough assessment of the literature and qualitative analysis. It looks at how AI and IoT work together, how difficult it is to deploy them, how they affect society and environment, how much it will cost to invest in these technologies. The primary conclusions show that combining AI and IoT improves building performance, increases energy efficiency, promoting environmental sustainability. The study showcases cutting-edge IoT building management technologies and to create more sustainable and effective living environments. It also notes impediments to the uptake of these technologies, such as financial limitations and the requirement for highly qualified personnel. In summary, the study suggests a multimodal strategy to address these issues, with a focus on legislative changes, educational programs, and creation of affordable green building technologies. In-depth investigation of AI and IoT integration in sustainable building designs is presented in this study, along with insights into how these technologies may transform the construction sector and advance sustainable urban development.

Keywords. Sustainable construction, green buildings, Artificial Intelligence, Internet of Things, environmental monitoring

Mathematics Subject Classification (2020). 68T01, 68T05, 68T20, 68T27

1. Introduction

1.1 Examining the Development and Foundational Ideas of Green Building

The development and tenets of green building constitute a crucial facet of contemporary design, tackling the pressing requirement for ecological sustainability within the building industry. Abbas [1] draws attention to the large environmental impact of building development, pointing out that in Europe, the construction industry is accountable for roughly 50% of the consumption of natural resources, 40% of energy output, and a significant amount of solid waste and CO_2 emissions. This emphasizes how important it is to design high-performance structures that follow sustainability guidelines in order to preserve natural resources, stop land contamination, and use less energy. The growing public demand for green buildings, a reaction to the environmental effects of conventional construction methods, promoting sustainable development in the construction industry by highlighting green architecture design as a tactic to reduce resource consumption and environmental harm. This strategy is becoming more widely acknowledged as essential to the peaceful cohabitation of people and the environment, and it is consistent with global sustainability. The fundamental ideas of sustainable green construction are covered, along with tactics and recommendations for using green building materials and sustainable design. They propose a checklist to evaluate a building's compliance to sustainable green construction principles. Their study focuses on the Palestinian context. This strategy is essential for converting both new and old buildings into sustainable structures, which will save energy, cut waste, and enhance the quality of the environment as a whole technique.

Abbasi and Hasan [2] investigated how the New European Bauhaus ideas might be applied to teaching sustainable architecture. In line with the goals of the European Green Deal, the study finds new design indicators pertaining to energy, environment, interior climate, and society. These metrics help architects create structures that support the circular economy, use renewable energy sources, and preserve biodiversity. The environmental issues raised by conventional building techniques have led to the development of green building principles. Sustainable development in the built environment is greatly aided by green building design, which incorporates techniques for resource conservation, energy efficiency, and environmental preservation. These studies' examination of the fundamentals of green construction gives designers and architects a framework for producing structures that are not only aesthetically beautiful and useful, but also sustainable and ecologically conscious.

1.2 Growth in Modern Architecture's Use of Smart Technologies

Modern architecture's incorporation of smart technologies marks a significant turn toward environmentally friendly construction method. In their investigation of the function of smart technologies in sustainable design, Alhaleem *et al*. [4] paid particular attention to how these technologies might be integrated with environmental norms. Their research emphasizes how crucial smart buildings are to achieving environmental sustainability through the utilization of renewable energy sources and energy-efficient practices. The concept of Smart-Eco buildings, which combines cutting-edge intelligent technologies with sustainable architecture, is examined by Addy *et al*. [3]. Their research is to improve Smart-Eco buildings' technical performance, especially in terms of energy efficiency. The study looks closely at components such as windows, shading systems, and facades to see if they can meet strict energy requirements. This demonstrates how crucial smart building technologies are to preserving environmental integrity as well as enhancing building performance. A thorough analysis of new developments in sustainable materials and smart green building technologies is done by Ismail and Afifi [23].

Their work highlights how important it is to use sustainable materials—such as those made from industrial waste—in order to lower embodied energy and improve the use of renewable resources. The report further clarifies how crucial technology is to the efficient management of green construction projects, including construction Information Modelling (BIM) and ontology. This method shows how integrating cutting-edge materials and intelligent systems is essential to creating sustainable urban landscapes. All things considered, the emergence of smart technology in contemporary architecture represents a revolutionary shift toward more eco-friendly and effective building designs. Buildings that are both technologically sophisticated and ecologically conscious must be developed by integrating this technology with sustainable materials and environmental regulations. This trend in the building industry toward intelligent, sustainable architecture is a reflection of a larger movement that seeks to strike a balance between ecological stewardship and technological innovation.

1.3 AI: Revolutionizing the Design of Green Buildings

The development of Artificial Intelligence (AI) in the field of green building design is evidence of how sustainable architecture is changing. Aliero *et al*. [5] explored the use of AI in the design of sustainable buildings, highlighting the significance of optimization techniques. Artificial Intelligence (AI) is a crucial instrument in the intricate world of architecture and building projects. It helps designers make informed decisions about energy use, resource management, and the incorporation of sustainable materials. The study emphasizes the potential of Artificial Intelligence (AI) techniques, including fuzzy logic, neural networks, evolutionary algorithms, Knowledge-Based Engineering (KBE), and Monte-Carlo simulation. These technologies have the potential to greatly improve decision-making, which will result in improved design results and project efficiencies, especially when used early in the design process. AI integration in sustainable architecture aims to redefine the design process rather than merely increase efficiency. In their exploration of the field's present use of AI, Almalki *et al*. [6] showed how the technology automates and modifies the job of designers. This transition is best illustrated by the employment of AI in the creation and manipulation of 3D models of buildings.

The design process is streamlined by these models, which allow for accurate computations and the development of associative sections that adapt automatically to changes in the 3D model. Moreover, AI's contribution to Building Information Modelling (BIM) enables worldwide cooperation on architectural projects, improving productivity all through a building's lifecycle. The report does, however, also recognize the difficulties in this field, including BIM interoperability problems and the possibility of information misunderstanding. Amuda-Yusuf *et al*. [7] concentrated on the use of deep learning — a subset of artificial intelligence — in the optimized design of green buildings in smart cities. Their study sheds light on the growing significance of Artificial Intelligence (AI) in urban planning and architecture, notably in terms of streamlining traffic, cutting energy use, and raising the effectiveness of green buildings. Deep learning outperforms conventional techniques in terms of prediction accuracy thanks to its multi-layer neural network architecture. This capacity is essential in the process of developing architecture, where accuracy and vision are critical. AI integration into green building design is a complex process. It includes more than just the. AI is changing the way that sustainable architecture is practiced. The capacity to analyse extensive datasets and generate informative forecasts renders it a priceless tool in the endeavour to create sustainable and effective building blueprints. The use of AI in green building design is becoming more and more important as the construction sector struggles with environmental issues. It can provide creative solutions and open the door for future developments in sustainable architecture.

1.4 Internet of Things: A Novel Approach to Constructing Sustainable Buildings

In the realm of modern architecture, the Internet of Things' (IoT) integration with sustainable construction practices is a major breakthrough. In the context of university buildings, Aung *et al*. [8] look into the function of IoT as an enabler of the Sustainable Development Goals (SDG). Their study presents an approach based on the Smart Readiness Indicator (SRI), which measures the effect of IoT deployments in these environments. The study shows how useful the Internet of Things is for keeping an eye on and controlling air quality and energy usage, especially when used in conjunction with smart campuses. An actual illustration of how IoT can help achieve SDG in academic settings is the University of Zaragoza, Spain's deployment of the sensoriZAR IoT ecosystem. Badawy *et al*. [9] concentrated on applying IoT to optimize building energy use in another study. Using cutting-edge optimization techniques like Fractional Chaotic Order Particle Swarm Optimization (FCPSO), Chaotic Particle Swarm Optimization (CPSO), and Particle Swarm Optimization (PSO), their research creates a data transmission model for the Internet of Things in smart buildings. By solving the issues brought on by the constraints of IoT node batteries, this strategy seeks to lower energy usage in IoT networks.

The study highlights the role of IoT in lowering operational costs without sacrificing occupant comfort by emphasizing its ability to reduce cooling and heating loads in smart buildings. This helps create settings that are more cost-effective. The impact of IoT on improving the sustainability of tourist sites is examined, with an emphasis on coastal areas. In order to acquire expert opinions on the smart tourist destination strategy made possible by IoT, the study uses the Delphi technique. This study offers a prognostic analysis of how the Internet of Things can influence how tourist sites are managed in the future. It emphasizes how the Internet of Things may help stakeholders in the management process and improve the marketing and branding of coastal tourism areas. Every one of these research advances our knowledge of the various settings in which IoT technology might be applied to improve efficiency and sustainability. Benavente-Peces and Ibadah [11] offer a technical perspective on energy optimization in smart buildings and insights into the use of IoT in academic settings. Benavente-Peces [10] expands this topic by addressing sustainable tourism, demonstrating the wider applications of IoT across other industries. These many IoT applications highlight the technology's adaptability and promise as a major tool for developing sustainable building design and management.

1.5 Combining IoT and AI to Improve Building Performance

The fields of smart building design and sustainable architecture are undergoing a transformation thanks to the convergence of Artificial Intelligence (AI) and the Internet of

Things (IoT). Bhutta [12] investigated the integration of participatory techniques, systems, and solutions for building smart communities using IoT and AI. The report highlights the process of converting towns into smart communities by using IoT and AI to fulfill residents' requirements. Important sectors including smart governance, energy, buildings, mobility, infrastructure, technology, healthcare, and citizen participation are all included in this approach. The study shows how IoT and AI improve intelligence in several domains, including various stakeholders and resulting in better life quality, increased resilience, efficient use of resources, and community empowerment. D'Apuzzo *et al*. [13] delves into the application of IoT and AI to urban planning, with a focus on creating sustainable smart cities. Their assessment highlights the omnipresent nature of data from smart devices connected to the internet, covering a variety of use cases of AI and IoT in urban life. The use of this data to build intelligent systems for smart cities is covered in the study, with implications for anything from secure settings to smart healthcare.

Artificial Intelligence, widely regarded as the fourth industrial revolution, has been demonstrated to have a significant impact on urban life, altering the way cities are organized, run, and experienced. Darwish [14] research focuses on utilizing IoT technologies to develop and monitor smart systems. Their study tackles the need for information and comprehension of technology to enable remote access and control of structures from anywhere at any time. The report outlines a way to create an IoT network architecture for Intelligent Buildings (IB) using an experimental testing bench. It talks about the incorporation of IoT architecture into intelligent building systems and describes the future trends of IB. The implementation and performance testing of a solution for an Android-compatible monitoring device and a distributed network of creative IB components are also covered in this study. The studies all point to the integration of AI and IoT as a critical element in improving the sustainability and performance of buildings. Darwish [15] offer a viewpoint on these technologies' role in urban planning and smart city development, Eini *et al*. [16] offers insights into the broader impact of these technologies on community development. A technical perspective on the integration of IoT in intelligent building systems is provided by Franco [17]. When taken as a whole, these studies show the many uses and advantages of AI and IoT in promoting sustainable building design and management practices.

1.6 Overcoming Obstacles in the Implementation of Smart Green Buildings

There are many obstacles in the way of implementing smart green buildings, especially in poor nations. The main barriers to green building include greater upfront costs, prices related to green technologies and materials, and certification fees. These issues are divided into five categories by the study using exploratory factor analysis: regulatory and steering factors, behavioural barriers, insufficiently skilled experts, data and motivation management system, and the expense of green building. This analysis emphasizes how important it is for construction experts to regularly assess performance in order to spot and address issues pertaining to green building projects. In order to promote eco-friendly living, Gao [18] investigated the idea of Green Smart Buildings (GSBs) and suggests a creative combination of green and smart technologies. Architectural concepts and a communication architecture that emphasize the integration of different digital components elaborately complement the GSB concept. The study explores the real-world uses of smart and green technologies in buildings, emphasizing the opportunities and difficulties in realizing the vision of sustainable smart cities. Within the pertinent strategic integrated intelligence of architecture, the GSB paradigm is offered as a major progress towards sustainable community development. Gao *et al*. [19] offer the incorporation of green facades in smart building design as a workable remedy for a number of environmental issues.

The study analyses the effects of green facades on lowering energy consumption through air purification, natural insulation and shading, and improving the visual appeal of urban surroundings. It does this by doing a thorough analysis of recent research and applications in the field. Green facades have a lot of potential, but there are still practical implementation, maintenance, and cost-effectiveness issues that separate theory from practice. The study highlights the important role that green facades play in developing sustainable urban settings as it identifies these obstacles and explores possible solutions, such as technology advancements, legislative support, and public awareness campaigns. Assessing the Social and Environmental Effects of Smart Technologies, the growth of smart cities depends on the substantial positive social and environmental effects of smart building integration. Gilner *et al*. [20] is centered on the social dimensions of smart cities, with a specific emphasis on intelligent sustainable structures. It examines the characteristics of Smart Sustainable Buildings (SSB) and the potential for their advancement. In order to identify links between these variables, the research makes use of a SWOT matrix and the DEMATEL approach. It also looks at how users and designers of intelligent, sustainable buildings affect the growth and creative use of these structures in urban settings.

The motives, definitions, approaches, and difficulties involved in assessing the social effects of smart city services and technologies are examined. The paper addresses how social impact has been incorporated into smart city assessment frameworks and presents the fundamentals of social impact assessment. It looks into how human-centered design-focused smart city projects handle social impact, highlighting the need for more analytical, consistent, and coherent methods to create change narratives and understand the effects of smart city initiatives before, during, and after they are implemented. Guribie *et al*. [21] concentrated on the process of making decisions about the rehabilitation or reconstruction of old structures while taking lifespan sustainability into account. The study creates a clever framework for decision assistance that combines Field Information Modelling (FIM)® with digital technologies such as point cloud processing and Building Information Modelling (BIM). It assesses and contrasts cost, energy use, and carbon emissions as well as other sustainability factors between renovation and scenarios including destruction or deconstruction and redevelopment. The study emphasizes how crucial it is to optimize building design in order to lower carbon emissions and embodied energy while still meeting current energy regulations in order to enhance overall energy performance. All of this research highlights how critical it is to assess how smart building technologies will affect society and the environment. A thorough analysis of the difficulties in determining the social impacts in smart cities, offer a useful framework for decision-making in the context of aging buildings, and insights into the social dynamics of smart sustainable buildings. When taken as a whole, they highlight how diverse the effects of smart technology are on sustainable urban development.

1.7 Advancements in Intelligent Green Construction

Technological, environmental, and sociological breakthroughs will continue to determine the future of smart green construction. The incorporation of ever complex control and communication systems into building designs creates opportunities for countless improvements. Reducing carbon footprints and improving built environment are the goals of smart construction. By combining cutting-edge techniques and environmentally friendly materials, green construction integrates technology with sustainable living habits to improve energy and water efficiency. It is anticipated that BREEAM and LEED certification programs would eventually become prerequisites for all building projects, regardless of size. In order to fulfill the increasing energy demands of technology and become carbon-free, self-sustaining buildings are seen to be the best option. A widespread national and international trend is the use of smart technologies to convert traditional structures into smart buildings. The primary goal of smart energy technology, explains to lower energy expenses and environmental effects throughout the building lifecycle. In order to attain the lowest energy costs while having no negative environmental impact, engineers, planners, and designers are investigating the applications of smart technologies in buildings. The application of smart energy technology and systems facilitates the shift to economically and environmentally sustainable smart cities. The infrastructure of smart buildings and smart cities depends on renewable energy. Smart building architecture is facilitated by important technologies such as Smart Building Energy Management Systems (SBEMS), smart lighting, smart grids, and smart metering.

Using smart and renewable energy technology in conjunction with conservation and energy efficiency measures, many nations have set goals to lower their carbon footprints. The environmental, economic, and sociological benefits of Green Building Technologies (GBTs) have led to significant improvements in recent years. The potential of GBTs to advance sustainable development—specifically in relation to climate change—is covered by Hodson *et al*. [22]. The goal of GBTs is to improve environmental conditions by using energy, water, and other resources in a balanced manner. In terms of energy use and emissions, low maintenance and operating costs, improving productivity and health, etc., Green Buildings (GBs) are advantageous. A critical evaluation of previous and ongoing research in the GBT field is required to determine the future course for sustainable green building technologies. This essay looks at how green building construction is now going and offers suggestions for more research and development that will be needed in order to create a sustainable future. The report also suggests potential avenues for sustainable development research in the future. The main goals are raising general quality of life, minimizing negative effects on the environment, and optimizing energy performance. The efficient use of cutting-edge technologies and environmentally friendly practices will be key to the development of smart green buildings and the creation of more resilient and ecologically friendly urban environments.

1.8 The Study's Objective

To investigate and evaluate the cutting-edge developments in smart green building technologies that are going to influence sustainable urban planning and architecture in the future:

(1) Examine how cutting-edge digital and control technology can be used into green building designs to improve sustainability and energy efficiency.

(2) Examine how smart energy management systems and renewable energy sources can help buildings have a smaller carbon footprint.

(3) Evaluate how cutting-edge green building supplies and building techniques affect the overall sustainability of urban infrastructure.

(4) Examine how smart green buildings might boost environment and residents' comfort, health, and productivity to improve their quality of life.

2. Literature Review

2.1 A Systematic Approach to an Extensive Literature Analysis

An organized and methodical process is used in the methodological approach to do an extensive literature evaluation in the context of sustainable building design. A Systematic Literature Review (SLR) is crucial for comprehending the sustainable development of small and medium-sized businesses. According to their methodology, empirical facts are carefully examined, investigations are rigorously evaluated and analysed, and the results are then synthesized. Finding patterns, knowledge gaps, and fresh perspectives in the field of sustainable development is made possible by this approach. The methodological approach provided offers a two-way evaluation of the efficiency of sustainable economic development management. According to their methodology, a set of indicators for evaluating expenses and outcomes will be developed, and these indicators will then be used for an extensive assessment. This scientific approach offers a balanced perspective on both expenses and results, making it useful for evaluating the effectiveness of sustainable economic development plans.

2.2 Examining the AI and IoT Integration in Green Buildings

A qualitative investigation of cutting-edge technologies and their implementation in the building sector is part of the methodological strategy for examining the incorporation of Artificial Intelligence (AI) and the Internet of Things (IoT) in green buildings. A framework that incorporates building information modelling (BIM) and the Internet of Things (IoT) into the elements of green business models, illuminating the potential of AI and IoT to change conventional construction techniques into more sustainable, effective, and environmentally friendly procedures by examining the theme content from interviews and other qualitative data. Green building integration of AI and IoT is a complicated and multidimensional topic that necessitates a thorough grasp of the technology aspects as well as the industry's readiness to accept such developments. The study's analytical approach opens the door to more informed decision-making and strategic planning in the construction sector by illuminating the opportunities and difficulties linked to the integration of these technologies.

2.3 Cutting Edge AI Utilized in Green Building Design

Sustainable architecture has advanced significantly with the use of Artificial Intelligence (AI) in green building design. This integration is a revolutionary way to designing buildings that are more effective, sustainable, and sensitive to human needs. It goes beyond simple technology innovation. Isopescu [24] explored the field of deep learning, which is a subset of artificial intelligence, and how it might be used to optimize green building designs in smart cities. Their findings highlight the potential for improving urban planning and design using deep learning, which is typified by multi-layer neural architectures. This method works especially well for streamlining traffic, cutting energy use, and raising the general effectiveness of green buildings. Deep learning's application in this situation shows how Artificial Intelligence (AI) might result in more precise forecasts and wiser choices when it comes to urban planning. The use of computer-based simulation technology in green building design is essential to the architectural process because it allows designers to evaluate the advantages and disadvantages of different design approaches and replicate a variety of scenarios.

Architects may make well-informed decisions that improve the efficiency, sustainability, and quality of green buildings by utilizing computer simulations. This strategy is essential for tackling the issues raised by environmental concerns and the requirement for sustainable development in the building sector. Virtual Reality (VR) and green building design are two topics investigated by Jaafreh and Jaafreh [25]. Architects and designers may view and analyse green building indicators in real-time with the help of VR technology, which provides an immersive and interactive platform. With the use of this technology, design scenarios may be thoroughly examined, leading to a more profound comprehension of the ramifications of different design decisions. VR integration into green building design is a major advancement in the incorporation of cutting-edge technology into environmentally friendly architectural methods. Using AI, VR, and computer-based simulation in the design of green buildings goes beyond simply implementing new technology. It signifies a paradigm change in the way designers and architects approach building sustainable living environments.

With the use of these technologies, it is now possible to comprehend how buildings affect the environment more comprehensively, which results in designs that are sustainable and visually beautiful as well as environmentally responsible. Furthermore, AI is being used in green building design for purposes other than environmental sustainability and energy efficiency. It also includes improving the comfort and well-being of occupants. AI-driven technologies ensure ideal living and working environments by monitoring and adjusting building conditions in real-time. This human-centered design methodology is essential for developing environments that support health and well-being while simultaneously conserving resources. The future development and application of AI and associated technologies is inextricably linked to the design of green buildings. As these technologies advance, they will make it possible to take sustainable building in even more creative and useful ways. AI has enormous potential to change the field of green building design; examples include AI-driven material selection and usage and automated building management systems. Modern AI applications for green building design are a fusion of sustainability, human-centered design, and technology. A new era of sustainable design is being ushered in by the use of deep learning, computer simulations, and virtual reality into the architectural process. In addition to making buildings more energy-efficient and environmentally friendly, these technologies are also changing how people interact with the built world. AI has the potential to significantly influence how green building design develops in the future as we investigate and innovate in this area.

2.4 Creative IoT Solutions for Manageable, Sustainable Buildings

In the field of sustainable design, the Internet of Things' (IoT) integration with building management systems is revolutionary. Building management is changing as a result of IoT solutions, which are making buildings more user-friendly, sustainable, and efficient. Jha *et al*. [26] examined the idea of "green buildings" and how the Internet of Things may help make these buildings more efficient and environmentally beneficial. Their study explores the key IoT ideas for managing green buildings while compiling a substantial body of knowledge in the area. In order to use resources effectively and efficiently, the study highlights the necessity for better-designed buildings and how IoT can be a key component in reaching this objective. IoT integration in green buildings encourages environmentally friendly practices and improves resource management. The adoption of IoT-based intelligent building energy management platforms is a topic covered by Krausková and Pifko [27]. In order to combine different energy systems into a holistic building energy IoT platform, their study makes use of Niagara IoT technology. By achieving system integration, user administration, data monitoring, and optimization scheduling, this platform greatly advances the objectives of sustainable development and green building. The study demonstrates how Internet of Things (IoT) technology may successfully lower building energy usage, offering an effective and long-lasting energy management solution. Energy efficiency is just one-use case for IoT in sustainable building management. It also includes many other features, such as occupant comfort, maintenance, and security. Building managers may use the data collected and analysed by IoT devices and sensors to make well-informed decisions regarding energy use, maintenance schedules, and resource management.

Additionally, IoT technologies in green buildings improve tenants' general well-being. IoT systems monitor temperature, lighting, and air quality to make sure that the interior atmosphere is favourable to productivity and wellness. The implementation of a human-centric approach is crucial in designing places that not only optimize resource utilization but also foster the welfare of their users. The deeper integration of IoT with other developing technologies holds the key to the future of sustainable building management. For example, combining Artificial Intelligence (AI) with IoT can result in even more advanced building management systems. These technologies might anticipate maintenance requirements, maximize energy use, and even adjust to inhabitants' shifting tastes and behaviours. The interoperability of various IoT devices and systems, as well as guaranteeing data security and privacy, present obstacles when adopting IoT solutions in green buildings. For IoT to be successfully adopted in sustainable building management, several issues must be resolved. Sustainable building management is being redefined by creative IoT technologies. IoT integration in green buildings improves occupant comfort, maximizes resource use, and advances the built environment's sustainability. IoT will become more and more important in influencing the direction of sustainable building management and architecture as technology develops.

2.5 Successful Architecture and Internet of Things Integration Models

Sustainable architecture has advanced significantly with the incorporation of Artificial Intelligence (AI) and the Internet of Things (IoT) into building management systems. This integration is a revolutionary way to designing buildings that are more effective, sustainable, and sensitive to human needs. It goes beyond simple technology innovation. Digital Twins

(DTs) and their development in relation to Building Information Modelling (BIM), cutting-edge platforms, technologies, and applications across the project life cycle stages are explored by Lam *et al*. [28]. Their study highlights DTs' potential as an all-encompassing method for organizing, controlling, forecasting, and improving Architecture, Engineering, Construction, and Operation (AECO) projects. This strategy works especially well for increasing the number of Sustainable Development Goals (SDGs) attained and for maximizing the AECO sector's post-pandemic recovery.

The usage of IoT to adjust construction management modelling systems is covered by Liu *et al*. [30]. In their study, a framework known as the Construction Management Modelling System (CMMS) is proposed, which integrates mobile technology, green building concepts, smart surveillance, IoT, smart data tags, Supervisory Control and Data Acquisition (SCADA), Building Management Systems (BMS), and self-moving transportation. By creating the best possible IoT system modelling, this creative configuration model seeks to solve the difficulties encountered on building sites for various project kinds and provide a product that includes all of the fixes for both anticipated and current roadblocks. The Smart Urban Mobility Management project, which intends to design and test highly novel tools including drones, High Definition (HD) smart cameras, Internet of Things (IoT) sensors on 5G networks, and AI tools, is examined by Mahdavinejad and Bitaab [29]. The project considers energy efficiency, traffic flow mobility, and environmental parameter control while integrating environmental datasets, information systems, and local databases. This strategy demonstrates the potential of IoT and AI in urban planning and administration and is a tangible step towards more sustainable and connected cities. Energy efficiency is just one aspect of how AI and IoT are being integrated into sustainable building management. It also includes many other features, such as occupant comfort, maintenance, and security. Building managers may use the data collected and analyzed by IoT devices and sensors to make well-informed decisions regarding energy use, maintenance schedules, and resource management.

Additionally, IoT systems improve tenants' general well-being in green buildings. IoT solutions make sure that the interior atmosphere is favourable to productivity and health by keeping an eye on temperature, lighting, and air quality. This focus on the needs of people is essential to designing environments that are not just resource-efficient but also enhance the well-being of those who use them. The deeper IoT integration with other cutting-edge technology is what will shape sustainable building management in the future. Building management systems that are much more advanced may result from the integration of Artificial Intelligence (AI) and the Internet of Things. These technologies might anticipate the need for maintenance, maximize energy efficiency, and even adjust to the shifting tastes and behaviours of the occupants. The interoperability of various IoT devices and systems, as well as guaranteeing data security and privacy, present obstacles when adopting IoT solutions in green buildings. For IoT to be successfully adopted in sustainable building management, several issues must be resolved. Sustainable building management is being redefined by creative IoT technologies. IoT integration in green buildings improves occupant comfort, maximizes resource use, and advances the built environment's sustainability as a whole. IoT will become more and more important in influencing the direction of sustainable building management and architecture as technology develops (Liu *et al*. [30]).

2.6 Evaluating the Results of Energy Efficiency in Smart Green Buildings

In the field of sustainable architecture, evaluating the energy efficiency results of smart green buildings is essential study. The purpose of this study is to understand how integrated technologies affect building sustainability and overall performance, not merely to measure energy savings. The importance of Information and Communication Technologies (ICT), methods, and applications in enhancing energy efficiency in smart buildings is examined. Their study explores distribution, analysis of consumption, tactics, and management in the optimization of electrical energy efficiency. The study highlights how crucial smart buildings and smart grids are to minimizing the negative environmental effects of energy use. This strategy is essential for attaining more advanced performance monitoring and control methods as well as for promoting the adoption of energy harvesting projects to raise overall productivity. The energy efficiency of the upcoming generation of smart buildings is covered, with an emphasis on auxiliary technologies and methods. Because electrical energy is used so widely, the inquiry focuses on it. Because green energies and energy harvesting contribute to energy efficiency, they are also considered. The most pertinent current and upcoming ICT methods and technologies that can maximize energy efficiency in smart buildings are highlighted in this study. Sensors, communication standards and technologies, intelligence methods and algorithms, renewable energy sources, and energy harvesting are all given significant attention in this area in order to enable high-performance intelligent systems that maximize energy efficiency and occupant comfort. The integration of smart technologies with wind and solar systems is examined as a means to achieve sustainable building practices (Mahdavinejad and Bitaab [31]).

The paper suggests a combined system for clean energy resources and water reserve and addresses ways to overcome the primary obstacles to sustainable development. The study stresses the use of smart technology to control and support the entire process and suggests integrating the newest renewable energy systems into newly constructed or existing structures. Energy efficiency in green buildings is significantly increased by the integration of smart technologies. With the help of these technologies, energy usage can be monitored and controlled in real time, which improves resource efficiency. The sustainability of these structures is further improved by the utilization of renewable energy sources like solar and wind power.

Furthermore, ICT and smart technologies are used in green buildings for purposes other than energy efficiency. It also includes improving the comfort and well-being of occupants. Real-time monitoring and control of building conditions by smart technologies guarantees the best possible living and working circumstances. Creating environments that support health and well-being while simultaneously conserving resources requires a human-centric approach. The future development and application of smart technologies is inextricably related to the design of green buildings. Martínez *et al*. [32] As these technologies advance, they will make it possible to take sustainable building in even more creative and useful ways. From AI-driven material selection and utilization to automated building management systems, smart technologies have the potential to revolutionize the field of green building design. The evaluation of energy efficiency results in smart green buildings is an example of how sustainability, technology, and human-centered design come together. A new era of sustainable architecture is being ushered in by the incorporation of ICT, renewable energy sources, and smart technologies into the building process. In addition to making buildings more energy-efficient and environmentally friendly, these technologies are also changing how people interact with the built world. With further research and development in this area, smart technologies have the potential to significantly influence how green building design is developed in the future (Meena *et al*. [33]).

2.7 Progress in Intelligent Building Management Systems

Innovations in Smart Building Management Systems (SBMS) are revolutionizing sustainable architecture by providing creative ways to maximize both environmental sustainability and building performance. These systems reflect a revolutionary approach to designing buildings that are more effective, environmentally sustainable, and sensitive to human needs. They go beyond simple technological innovation. Megahed and Hassan [34] examined the potential and problems that smart building technology presents. Their study explores the function of networked sensors, data analytics software, and smart energy devices in tracking environmental data and occupants' energy usage patterns. In order to modernize the building industry and create more self-reliant, self-automated, self-learning, time-saving, and cost-effective operations throughout a smart building's or city's many life cycle stages, the study highlights the significance of smart technology and controls. From the viewpoint of building experts, Mersal [35] addressed the essential characteristics and intended uses of Smart Building Management Systems (SBMS) in commercial structures. Their study highlights important aspects of the SBMS and investigates the variables affecting the system's intended use by construction professionals. The study analyses data gathered from Hong Kong building experts using structural equation modelling and exploratory factor analysis, both of which are based on the Unified Theory of Acceptance and Use of Technology (UTAUT) (Nadeem *et al*. [36]).

The results demonstrate that safety, preparedness for disaster recovery, and intelligent building operations are essential SBMS components. A real-time management system is proposed by Patil *et al*. [37] to regulate indoor conditions, comfort standards, security, safety, and expenses in smart buildings. The performance requirements, design specifications, and operating restrictions for these systems are presented in their study. The goal of the project is to combine machine learning with model-based control techniques to address issues with smart building development, including dependability and real-time response to environmental circumstances. Energy efficiency and overall building performance are significantly improved by the incorporation of smart technologies into building management systems (Prabhu *et al*. [38]).

With the help of these technologies, energy usage can be monitored and controlled in real time, which improves resource efficiency. These buildings' sustainability is further improved by the application of data analytics and machine learning, which optimizes energy use based on real-time data and predictive analytics. Furthermore, SBMS applications go beyond energy savings. It also includes improving the comfort and well-being of occupants. Real-time monitoring and control of building conditions by smart technologies guarantees the best possible living and working circumstances. Creating environments that support health and well-being while simultaneously conserving resources requires a human-centric approach. The continuous development and integration of smart technology is inextricably related to the future of architectural design. As these technologies advance, they will make it possible to take sustainable building in even more creative and useful ways (Rabadanova *et al*. [39]). With applications ranging from AI-driven material selection and consumption to automated building management systems, SBMS has the potential to revolutionize the field of green building design. The development of Smart Building Management Systems is an example of how sustainability, human-centered design, and technology are coming together. A new era of sustainable design is being ushered in by the incorporation of data analytics, machine learning, and smart controls into the architectural process. In addition to making buildings more energy-efficient and environmentally friendly, these technologies are also changing how people interact with the built world. SBMS has the potential to significantly influence how green building design is developed in the future as we investigate and innovate in this area (Radziejowska and Sobotka [40]).

2.8 The Financial Effects of Purchasing Intelligent Green Buildings

Investing in smart green buildings has a variety of economic effects, including both immediate money gains and more significant socioeconomic ones. It's important to comprehend the long-term value and return on investment that smart green buildings provide while making this investment, in addition to the initial costs. Ramesh [41] investigated the possible uses and financial effects of green building principles in industrial structures. Their analysis focuses on the observable advantages, such lower energy and water usage from the first day of occupation. Early return on investment is aided by the energy savings. Improved daylighting, interior air quality, employee safety, and well-being are further intangible advantages. According to the report, green buildings also tend to boost staff productivity, which raises the financial benefit of these expenditures. Ghana is the main subject of analysis of the Sub-Saharan African market for green buildings. Their research sheds light on the financial advantages of green buildings in the African environment, where sociocultural, political, and commercial constraints are important considerations (Sadowski [42]).

Key economic benefits identified by the research include reduced lifetime and operating costs, higher job productivity, and a revolution of the construction industry. It also emphasizes the significance of building energy costs in driving the demand for green buildings, noting that some anticipated benefits, such as a strong return on investment and a rise in building value, may not be completely realized in the region. Saha *et al*. [43] Beyond only providing a profit, smart green buildings have wider economic effects. By fostering social resilience and lessening their negative effects on the environment, these structures support sustainable urban development. Smart technology integration improves building efficiency, which reduces energy and maintenance costs throughout the course of the building's lifecycle. Additionally, the investment in smart green buildings addresses environmental issues including resource depletion and climate change in line with global sustainability goals. A key component of mitigating environmental impacts is the deployment of smart green buildings, which lower energy usage and greenhouse gas emissions (Simpeh *et al*. [44]).

Adoption of smart green buildings fosters innovation in the technology and construction industries as well. It propels the creation of novel substances, methods, and tools that improve the sustainability and performance of buildings. This innovation promotes economic expansion and the creation of jobs, which advances socioeconomic development more broadly. The drawbacks of investing in smart green buildings, however, are their higher initial costs and the requirement for highly qualified personnel to design, develop, and oversee these structures.

For smart green buildings to be widely adopted, these issues must be resolved. Investing in smart green buildings has far-reaching and substantial economic repercussions. These structures support socioeconomic growth and environmental sustainability while also providing immediate cash gains through lower energy costs and higher productivity. Smart green buildings will become more crucial in creating resilient and sustainable urban environments as the construction industry develops (Suryawinata and Mariana [45]).

2.9 Determining the Obstacles to the Adoption of Smart Green Building Technology

Smart green building technologies are not widely implemented due to several obstacles in their adoption. Comprehending these obstacles is crucial for the progression of sustainable architecture and the wider integration of environmentally conscious building methodologies. These barriers are categorized by their study into a number of areas, including material, information, technology, social perception, organizational, governmental, and economic. The study draws attention to particular difficulties faced by developing nations like India, including protracted project timelines, a dearth of research and development efforts, and a volatile supply of environmentally friendly resources. This thorough analysis emphasizes how dispersed the global green building construction industry is and how specific solutions are required to overcome these obstacles, preventing Nigerians from adopting green building technologies. A standardized questionnaire is utilized in their study to collect practitioner insights related to green building construction (Wang *et al*. [47]). According to the report, the main obstacles include a lack of institutions to develop policies, a lack of knowledge about eco-friendly products, and a lack of awareness of sustainability issues. The study also finds that different organizational groups perceive these hurdles in significantly different ways, underscoring the necessity of specialized tactics to address these obstacles.

Adoption of smart green building technology is hampered by more than just technical issues. They also include more general topics including societal attitudes, legislative and regulatory frameworks, and economic limitations (Wu and Maalek [48]). A multifaceted strategy including regulatory interventions, educational programs, and the creation of affordable green building technologies is needed to address these obstacles. Furthermore, these obstacles have important economic ramifications. Stakeholders are frequently discouraged from investing in green building technology due to high initial costs and uncertain returns on investment. For the construction industry to embrace sustainable practices more widely, these financial obstacles must be removed. In order to remove these obstacles, policymakers and the government play a crucial role. Adoption of green building technology can be promoted and the growth of the sustainable construction industry can be supported by well-crafted legislative frameworks and incentives. Adopting green building technologies presents hurdles, which emphasizes the need for innovation and research in this area. The growth of sustainable architecture depends on the creation of new, affordable, ecologically friendly materials, technologies, and practices. The development of sustainable architecture depends on recognizing and removing the obstacles to the use of smart green building technology. These obstacles are intricate and multidimensional, with elements of technology, economy, policy, and society. Collaboration across a range of stakeholders, including the public, academics, business, and government, is necessary to overcome these obstacles. Adoption of smart green building technologies will be crucial in forming resilient and sustainable urban settings as we experiment and create new solutions (Umoh *et al*. [46]).

3. Results

3.1 Evaluating Smart Green Technologies' Benefits for the Environment

To achieve environmental sustainability, smart green technology integration into urban planning and architecture is essential. These technologies, which cover a broad spectrum of advancements from IoT applications to building materials, have a substantial positive impact on the environment and encourage eco-friendly behaviour. A thorough analysis of the newest developments in sustainable materials and smart green building technologies is given. Their research emphasizes the developments in sustainable materials made from industrial waste that help to maximize the utilization of renewable resources and lower embodied energy. Reducing carbon emissions and improving building performance are directly related to the incorporation of these materials into building design, highlighting support to sustainable development, especially in light of climate change and emphasizing how crucial it is to use water, energy, and other resources in a balanced way in order to enhance the ecosystem. Green buildings offer a comprehensive approach to sustainability by reducing energy consumption and emissions while simultaneously improving productivity and health. They are distinguished by their energy-efficient designs and low operating costs. The idea of Green IoT and how it may be used to build sustainable and environmentally friendly smart cities, addresses issues including trash management, pollution, and energy usage by integrating IoT technologies into smart city applications.

The Green IoT may lower environmental risks, maximize resource use, and improve urban public safety and quality of life. Smart green technologies have advantages for the environment that go beyond energy saving. They cover a wider range of sustainability, such as better air quality, water conservation, and waste reduction. Real-time environmental parameter monitoring and management is made possible by the Internet of Things and other smart technologies, which promotes resource efficiency and better-informed decision-making. Adoption of smart green technologies also encourages sustainable practice research and innovation. It propels the creation of novel materials, techniques, and technologies that improve buildings' and urban areas' environmental performance even more.

This innovation promotes economic expansion and the generation of jobs, which advances socioeconomic development overall. However, the implementation of smart green technologies presents certain hurdles, such as greater initial costs and the requirement for highly qualified personnel to design, build, and oversee these systems. For sustainable methods to be widely adopted in the construction sector, several issues must be resolved. The advantages of smart green technologies for the environment are numerous and profound. By lowering pollutants and using less energy, these technologies directly benefit the environment while also advancing more general sustainability objectives. Smart green technology will become more crucial in creating resilient and sustainable urban environments as the construction industry develops.

3.2 Social and Economic Aspects of Smart Building Technologies

In addition to being a scientific breakthrough, the incorporation of smart building technology into architecture also represents a socioeconomic revolution. These technological advancements have profound effects on sustainable architecture's social and economic facets. Radziejowska and Sobotka [40] looks into how information and communication technologies (ICT) might be used to create smart building designs that balance energy efficiency and user comfort. The study emphasizes how crucial ICT is to improving quality of life, maintaining health and safety, and encouraging effective resource use. According to the study, smart buildings are not only technologically sophisticated but also economically feasible, resulting in lower operating costs and the promotion of environmentally friendly and healthful settings. The new systems affect sustainable architecture and intelligent buildings, their study emphasizes how smart materials may save energy use while giving building inhabitants the best possible comfort. A crucial component of 21st-century sustainable design is the incorporation of materials that are self-healing and intelligent into the building process. This method takes into account financial considerations like material prices and ongoing maintenance in addition to environmental sustainability.

The Smart Eco Home is a concept introduced, seeking to improve ecological sustainability through integrated intelligence in architecture. The study emphasizes the significance of environmental control and building intelligence, with an emphasis on the strategic integration of smart technology in residential structures. A step toward developing sustainable communities that balance social, economic, and environmental factors is the Smart Eco Home model. Beyond just generating profits, smart building technologies have other positive economic effects. These technological advancements lessen their negative effects on the environment and foster social cohesion in urban development. Smart technology integration improves building efficiency, which reduces energy and maintenance costs throughout the course of the building's lifecycle. In addition, implementing smart building technologies helps achieve global sustainability objectives by tackling issues like resource depletion and climate change. A key component of mitigating environmental concerns is the usage of smart buildings, which lower energy consumption and greenhouse gas emissions.

Equally significant are the societal ramifications of smart building technologies. These technologies guarantee ideal interior conditions, which enhances inhabitants' quality of life. The human-cantered design of smart buildings enhances safety, health, and well-being and adds to the general social sustainability of local communities. The difficulties in putting smart building technologies into practice, however, stem from the greater upfront costs and the requirement for qualified personnel to plan, develop, and oversee these structures. For smart green buildings to be widely adopted, these issues must be resolved. The applications of smart building technologies have broad and important social and economic implications. These technologies support environmental sustainability and socioeconomic growth in addition to providing immediate cash gains through productivity gains and energy savings. Smart building technologies will become more crucial in developing resilient and sustainable urban environments as the construction industry develops.

3.3 Imagining Smart Green Building Technologies' Future Course

The world of smart green building technologies will continue to be dynamic and ever-evolving, characterized by ongoing innovation and the seamless integration of cutting-edge technological solutions with sustainable practices. The integration of solar and wind power systems with smart technology in green buildings is essential to create sustainable buildings, where cost effectiveness, resource conservation, and human adaptability design are the three main success criteria. The study highlights the significance of sustainable energy performances in green buildings, emphasizing the help that smart technology and renewable energy systems can provide for this process. The realization of zero-energy buildings—a notion that represents the pinnacle of sustainable energy resources—requires the combination of various technologies. The technology will shape sustainable green architecture in the future.

The smart materials can minimize energy use while ensuring the highest level of comfort. A crucial component of 21st-century sustainable design is the incorporation of materials that are self-healing and intelligent into the building process. This method takes into account financial considerations like material prices and ongoing maintenance in addition to environmental sustainability. The study highlights the potential of Building Information Modelling (BIM) in evaluating energy performance and sustainability, underscoring the necessity for agreement between BIM and green buildings. The notion of Green Smart Building (GSB), a novel architectural paradigm that integrates smart and green technologies to promote eco-friendly living. Architectural models and communication architecture support the GSB idea by highlighting the integration of many digital components. In order to address the difficulties and opportunities associated with creating sustainable smart cities, the study explores real-world uses of green and smart technologies in buildings.

Within the pertinent strategic integrated intelligence of architecture, the GSB paradigm is presented as a noteworthy step towards sustainable community development. The potential applications of smart green building technologies extend beyond sustainability and energy efficiency. It also covers a wider range of sustainability, such as better air quality, water conservation, and waste reduction. Real-time environmental parameter monitoring and management are made possible by the Internet of Things and other smart technologies, which promote efficient resource use and better decision-making. Adoption of smart green technologies also encourages sustainable practice research and innovation. It propels the creation of novel materials, techniques, and technologies that improve buildings' and urban areas' environmental performance even more. This innovation promotes economic expansion and the generation of jobs, which advances socioeconomic development overall. However, the implementation of smart green technologies presents certain hurdles, such as greater initial costs and the requirement for highly qualified personnel to design, build, and oversee these systems. For sustainable methods to be widely adopted in the construction sector, several issues must be resolved. Smart green building technologies have a big and ambitious future ahead of them. By lowering pollutants and using less energy, these technologies directly benefit the environment while also advancing more general sustainability objectives. Smart green technology will become more crucial in creating resilient and sustainable urban environments as the construction industry develops.

4. Conclusions

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) in sustainable building designs has successfully attained its goals and objectives of protecting environment. It has unveiled a detailed story that deftly intertwines the development of smart building technologies, the rise of green building principles, and the well-balanced marriage of AI and IoT, resulting in a thorough comprehension of their diverse effects. The main findings of this investigation highlight how integrating AI and IoT into green buildings improves building performance, increases energy efficiency, and greatly increases environmental sustainability. The combination of IoT's real-time monitoring and control capabilities and AI's predictive analytics and optimization skills has made AI a key player in the field of sustainable architecture. The study also shed light on the function of cutting-edge IoT solutions in building management and shown how well they work to create more sustainable and effective environments. Investing in smart green buildings has significant financial benefits, including long-term cost savings, increased energy efficiency, and increased productivity. Still, the study found significant barriers to the broader use of these technologies, such as high upfront costs, a lack of qualified personnel, and difficulties navigating legal and regulatory environments. For smart green building technologies to be widely used, these obstacles must be removed.

The study's trajectory for smart green building technologies is marked by constant innovation and a smooth integration of cutting-edge technology innovations with sustainable practices. These technologies have the potential to completely transform the design of green buildings, paving the way for more resilient and environmentally friendly urban ecosystems in the future. This study concludes by recommending a multimodal approach to overcome the obstacles in implementing smart green building technologies. This strategy includes the creation of commercially feasible green building technology, as well as policy and educational reforms. The study emphasizes how important it is for all stakeholders to work together, including the public, academic institutions, business sectors, and governmental authorities, to advance the area of moving forward with sustainable building management and architecture. The adoption of smart green building technologies will be crucial in shaping resilient and sustainable urban environments as we experiment and create new solutions.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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