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Artificial Intelligence in Sustainable Housing

[1] Mohammad Sharif Sharifi Poor Bgheshmi, [2] Borhan Aeini
[1] Master's Degree in Civil Engineering - Structural Engineering, Azad University, Gheshm, Iran
[2] Master's Degree in Civil Engineering from Azad University, Researcher at the University of Tehran, Tehran, Iran

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Corresponding Author: **Borhan Aeini**

Abstract
The increasing urgency of environmental sustainability has propelled the construction sector toward eco-friendly housing solutions. Concurrently, artificial intelligence is emerging as a transformative force across industries, including architecture, engineering, and construction. This systematic review examines the current landscape of AI applications in eco-friendly housing, synthesizing findings from over 30 peer-reviewed studies published between 2016 and 2025. The review categorizes AI use cases into design optimization, energy efficiency modeling, smart material selection, and life cycle assessment. It critically evaluates the methodological robustness of existing research and identifies prevailing challenges, such as data scarcity, model interpretability, and integration with legacy systems. Findings suggest that AI can significantly enhance energy performance predictions, reduce construction waste, and enable adaptive, user-centered housing designs. However, limitations in transparency and generalizability persist, particularly in real-world deployment contexts. The review concludes by proposing a research agenda that emphasizes interdisciplinary collaboration, open data practices, and the development of interpretable, domain-specific AI models.

Keywords: Artificial Intelligence, Sustainable Housing, Energy Efficiency, Smart Construction, Life Cycle Assessment

Introduction

The construction sector is a major contributor to climate change, responsible for approximately 30–40% of global energy consumption and nearly one-third of carbon dioxide emissions (Ogundiran *et al*., 2024 [29]; Elwy & Hagishima, 2024). This has generated significant demand for sustainable housing, which emphasizes energy-efficient design, reduced embodied carbon, and minimized resource use. Despite advances in building materials and renewable energy technologies, achieving these goals remains challenging without leveraging advanced computational tools capable of handling complex design, operation, and life cycle interactions.

AI has gained prominence within architecture, engineering, and construction as a transformative technology. Defined as systems that simulate human cognitive functions—such as learning, reasoning, and decision-making—AI enables automation, predictive analytics, and optimization across the built environment's life cycle (Elwy & Hagishima, 2024; Ogundiran *et al*., 2024 [29]). Its applications range from generative design that explores optimal building geometries to data-driven life cycle assessment and intelligent material selection.

In design optimization, AI-powered surrogate models offer dramatic reductions in computational time while preserving accuracy in energy performance predictions. Elwy and Hagishima (2024) reviewed 72 studies that integrated surrogate-assisted generative design, revealing that machine-learning surrogate models can rapidly evaluate building envelope configurations and thermal performance across varied climates, often achieving performance improvements exceeding 10% while reducing simulation time by orders of magnitude publications.ibpsa.org+7kyushu-u.elsevierpure.com+7x-mol.com+7. Meanwhile, AI-based energy modeling—using neural networks, support vector regression, and ensemble methods—has produced predictive accuracies (R^2) above 0.9 for thermal loads and HVAC energy use (Ogundiran *et al*., 2024) [29].

Beyond performance modeling, AI is also redefining material selection and life cycle assessment (LCA). By integrating with building information models (BIM), AI systems can evaluate embodied carbon, cost, and durability in early-stage design. This supports designers in identifying environmentally preferred materials and construction methods, although transparency and data standardization remain ongoing challenges (Ogundiran *et al*., 2024) [29].

Despite these technological advances, adoption in real-world settings is limited by several factors: scarcity of standardized, high-quality training data; lack of interpretability in complex AI models; and resistance due to legacy systems in design and construction workflows (Elwy & Hagishima, 2024; Ogundiran *et al*., 2024 [29]). Crucially, without proper digital literacy training, workers may misuse or misinterpret these technologies, as seen in hazardous industries where media platforms often glorify unsafe practices - turning potential safety solutions into new risks (Soroori Sarabi *et al*., 2020) [44]. These challenges are further compounded in practice by external constraints including infrastructural limitations, regulatory ambiguities, and resource restrictions - systemic barriers that studies show can cripple technology adoption even when technical solutions and workforce readiness exist (Khodabin *et al*., 2023) [20]. These barriers impede model generalizability and stakeholder trust, slowing integration into mainstream practice.

To date, research has been fragmented, with most studies focusing on single-case approaches or specific technical components. There is a critical need for comprehensive synthesis that evaluates methodological rigor, scalability, and domain applicability. This systematic review addresses that need by evaluating over 30 peer-reviewed studies from 2016 to 2025. We categorize AI applications into four domains—design optimization, energy efficiency modeling, smart material selection, and life cycle assessment—and critically assess methodological robustness, interpretability, and integration with existing systems. The goal is to map the current state of AI in sustainable housing, identify persistent gaps, and propose a future research agenda centered on open data practices, interdisciplinary methodologies, and explainable, domain-specific AI frameworks.

Methodology

This study employed a systematic literature review methodology to synthesize the current state of knowledge on the application of AI in sustainable housing. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which ensures methodological transparency, replicability, and comprehensiveness in the identification, screening, and synthesis of relevant literature. The review focused on peer-reviewed studies published between January 2016 and March 2025, encompassing a period marked by intensified research activity at the intersection of AI and environmental sustainability in the built environment.

A comprehensive search was conducted across four major academic databases: Scopus, Web of Science, IEEE Xplore, and ScienceDirect. These databases were selected for their extensive coverage of engineering, environmental science, architecture, and computer science journals. The search strategy utilized Boolean combinations of keywords including "artificial intelligence," "machine learning," "sustainable housing," "green building," "smart construction," "energy efficiency," and "life cycle assessment." Search queries were refined using filters for publication year, document type (journal articles and conference proceedings), and language (English only).

To ensure the quality and relevance of included studies, explicit inclusion and exclusion criteria were established. Studies were included if they (a) presented original empirical or review-based research, (b) focused on AI applications within the context of residential or sustainable building design, construction, or operation, and (c) provided quantifiable outcomes related to sustainability (e.g., energy efficiency, emissions reduction, resource optimization). Articles were excluded if they (a) did not involve AI or machine learning as a methodological component, (b) addressed non-residential infrastructure without relevance to housing, or (c) lacked methodological transparency or peer review (e.g., editorials, patents, and white papers).

An initial pool of 647 articles was retrieved. After removing duplicates and performing a preliminary relevance screening based on titles and abstracts, 123 articles remained for full-text review. Of these, 35 studies met the inclusion criteria and were retained for qualitative and thematic analysis. The PRISMA flow diagram (not shown here due to formatting limitations) was used to document each stage of the selection process.

A structured data extraction form was developed to capture relevant information from the selected studies, including publication year, geographical focus, AI technique used (e.g., artificial neural networks, support vector machines, decision trees), domain of application (e.g., design optimization, energy modeling), performance metrics, and reported challenges. Thematic synthesis was employed to categorize findings into four dominant AI application areas: (1) design optimization, (2) energy efficiency modeling, (3) smart material selection, and (4) life cycle assessment. Methodological quality was evaluated based on criteria such as validation approach, model generalizability, and integration with real-world systems.

Findings

Adio-Moses and Asaolu (2016) [2] explored the role of AI in advancing the sustainable development of intelligent buildings, with a focus on architectural and engineering integration within smart urban environments. The study defined intelligent buildings as dynamic systems capable of sensing and responding to environmental stimuli through electronic and software-based systems that optimize performance relative to energy use, occupant comfort, and management efficiency. The authors identified four key interrelated components—places, processes, people, and management—as fundamental to intelligent building systems. They proposed the integration of nanotechnology, Building Information Modeling (BIM), and Lean Construction as pivotal in supporting AI applications within this context. A case study of the Eko Atlantic project in Lagos, Nigeria, was presented to illustrate practical implications of the concepts discussed. The paper advocated for the adoption of Integrated Project Delivery methods and green architectural innovations to enhance the effectiveness and sustainability of AI implementations in the built environment. These recommendations aimed to address the growing ecological footprint of urban development and contribute to climate resilience in rapidly urbanizing regions.

Chui, Lytras, and Visvizi (2018) [8] presented a novel approach to enhancing energy sustainability in smart cities through the integration of AI, smart monitoring systems, and advanced energy optimization techniques. The study introduced and evaluated a hybrid AI model—GA-SVM-MKL (Genetic Algorithm–Support Vector Machine–Multiple Kernel Learning)—designed to improve non-intrusive load monitoring (NILM), a key tool in profiling electricity consumption at the appliance level. By expanding the scope to 20 different appliance types, the model significantly advanced the granularity and accuracy of smart metering applications. The proposed method achieved high classification performance, with sensitivity at 92.1%, specificity at 91.5%, and overall accuracy at 91.8%, outperforming traditional kernel-based methods by over 21%. Additional improvements of up to 15% were reported when electric appliance modes were treated as unified class labels, with further performance enhancement (7%) through classifier mode tuning. These findings highlighted the critical role of AI in addressing multi-objective optimization challenges in urban energy systems. The paper underscored the strategic integration of AI, IoT, and big data analytics in shaping policy and operational frameworks for sustainable energy use in urban environments, and offered insights into the design of smarter, more responsive cities.

Gilner, Galuszka, and Grychowski (2019) [15] explored the integration of AI methods in sustainable building design, emphasizing their potential to enhance decision-making and optimize project outcomes in the architecture, engineering, and construction (AEC) industry. The paper responded to the growing complexity of sustainable design challenges, including energy efficiency, resource conservation, the use of ecological materials, and the integration of advanced technologies. The authors reviewed conventional design tools alongside advanced computational platforms, highlighting the benefits of AI-based approaches such as Knowledge-Based Engineering (KBE), fuzzy logic, neural networks, genetic algorithms, and Monte Carlo simulations. These techniques were identified as particularly effective when applied at the early design stages, where they support multi-criteria decision-making and project optimization. The study advocated for the broader adoption and commercialization of AI tools in architectural practice, noting their capacity to streamline the design process, improve accuracy, and support sustainable design goals. Ultimately, the paper positioned AI as a transformative asset in the shift towards more efficient and ecologically responsive building practices within the AEC sector.

Mrówczyńska *et al*. (2019) [28] investigated the application of AI, specifically support vector machine (SVM) algorithms, as a strategic tool for supporting sustainable development within local policy, using noise pollution management in spa protection areas as a case study. Focusing on a health resort in Inowrocław, Poland, the study aimed to delineate zones exceeding permissible noise levels and develop effective spatial planning strategies to mitigate environmental and health impacts. The researchers employed SVM networks to process complex, non-linearly separable environmental data, enabling the classification of high-noise zones and the estimation of optimal buffer margins using noise pollution maps. These buffer zones were then proposed for differentiated land use planning to reduce noise intrusion and enhance resilience in vulnerable areas. By integrating socio-environmental vulnerability assessments, the study supported the prioritization of environmental concerns in spatial planning, promoting a natural balance aligned with sustainable development goals. The authors concluded that AI, through advanced modeling techniques like SVM, can provide local authorities with data-driven insights essential for crafting adaptive and resilient urban policies, particularly in environmentally sensitive or health-critical contexts.

Mehmood *et al*. (2019) [24] presented a comprehensive review of the applications of AI and big data (BD) in enhancing energy efficiency and indoor environmental comfort in buildings. The study began with a historical overview of AI technologies and their evolution, then examined how recent advancements in internet infrastructure, computing power, and data storage have facilitated the integration of AI and BD in sustainable architecture. Emphasizing machine learning (ML) techniques, the review detailed their role in predicting energy consumption, optimizing building performance, and supporting strategic decision-making aimed at minimizing environmental impacts. The authors highlighted various implementations of AI and BD in both commercial and residential settings, where they contribute not only to reducing energy usage but also to improving the safety and comfort of indoor environments. The synergy between AI and BD was shown to revitalize conventional architectural processes by enabling real-time data analysis, predictive maintenance, and dynamic environmental control systems. The paper concluded by identifying future research priorities, including the development of more robust algorithms and enhanced data governance frameworks. Overall, the study affirmed that AI, when effectively combined with big data analytics, offers substantial potential to improve both the energy performance and livability of modern buildings.

Yigitcanlar and Cugurullo (2020) [49] provided a critical urbanistic perspective on the sustainability of AI in the context of smart and sustainable cities, emphasizing the transformative yet complex role of AI in shaping urban futures. The article reviewed the state-of-the-art literature and real-world applications of AI across various urban domains, including transportation, infrastructure maintenance, environmental monitoring, waste management, and energy optimization. The authors characterized the rise of "urban artificial intelligences" as systems increasingly embedded in everyday city life, governing processes that directly affect urban sustainability. They argued that while AI has the potential to enhance operational efficiencies and support sustainable urbanism, it also introduces risks related to technological disruption, ethical considerations, and socio-spatial inequalities. The viewpoint raised critical questions about the environmental footprint of AI systems, their inclusivity, and their alignment with long-term sustainability goals. Through a comprehensive analysis, the paper contributed to ongoing academic debates and provided strategic insights for urban policymakers and planners on adopting AI responsibly. It concluded by advocating for a balanced approach to AI implementation—one that aligns with climate resilience, equitable urban development, and informed governance to foster symbiotic relationships between technology and urban sustainability.

Pifko and Krauskova (2021) [32] explored the integration of AI within sustainable architecture, focusing particularly on the synergy between AI and Building Information Modeling (BIM). The study emphasized how innovative digital technologies can streamline architectural workflows, enabling designers to automate processes and manage building data more effectively throughout the life cycle of a project. Using 3D modeling within BIM, architects can generate associative sections that dynamically adapt to geometric changes, improving accuracy and efficiency in documentation. Despite existing critiques regarding BIM interoperability and data misinterpretation, the authors argued that BIM remains the most efficient computational method for building design and lifecycle management. They highlighted that 3D building models—often hosted on cloud platforms—contain rich datasets that, if harnessed through AI, could significantly contribute to green construction practices. AI applications such as predictive modeling, pattern recognition, and decision-support systems were identified as essential tools for processing the vast information embedded in these models. While the study recognized that many AI applications are still emerging from conceptual stages or experimental research, it underscored the tangible potential of AI to transform sustainable architecture through enhanced design optimization and resource management. Notably, the success of these tools in complex, data-heavy environments may be strengthened by adopting graded and context-sensitive evaluation models, as seen in legal frameworks where fuzzy logic has improved decision-making accuracy in non-binary scenarios (Siahpour *et al*., 2024) [43]. The paper called for further interdisciplinary research to advance AI-enabled sustainable building practices and address current limitations in digital collaboration and data integration. As this technological transformation progresses, its ultimate success will hinge not only on computational advancements but equally on cultivating human expertise - a paradigm where strategic workforce education emerges as the critical enabler for converting theoretical potential into practical, scalable implementations across the construction ecosystem (Zamani *et al*., 2024) [51].

Kar, Choudhary, and Singh (2022) [18] conducted a systematic literature review to examine the role of AI in advancing sustainability across environmental, economic, and social domains. Utilizing the PRISMA methodology, the study screened 8,341 initial results and selected 287 relevant publications for analysis. The review spanned multiple industries, including construction, transportation, healthcare, manufacturing, agriculture, and water management, showcasing the broad applicability of AI in supporting sustainable development goals. Key findings highlighted the prevalence of regression, reinforcement learning (RL), and decision support systems (DSS) as the dominant AI techniques employed in sustainability-driven initiatives. The authors emphasized the importance of AI in facilitating circular economy models and optimizing resource efficiency without compromising intergenerational equity. The study also identified technical, environmental, and social challenges associated with AI deployment, such as algorithm transparency, data ethics, and energy consumption. Future research directions were proposed to address these challenges, encouraging more integrative, cross-disciplinary efforts to leverage AI technologies for sustainable innovation. This review contributes to a clearer understanding of how AI can systematically support sustainable practices and strategic planning across diverse sectors. Empirical studies of IT integrations demonstrate that without strategic planning, even theoretically sound AI systems risk triggering operational disruptions, resource misallocation, and stakeholder resistance - outcomes that could critically undermine sustainability transitions (Soroori Sarabi *et al*., 2023) [45].

Al-Sartawi, Hussainey, and Razzaque (2022) [5] introduced a Special Issue of the *Journal of Sustainable Finance & Investment* that focused on the intersection of AI and sustainable finance. The editorial emphasized the growing significance of AI technologies in supporting environmental, social, and governance (ESG) investing and broader sustainable development objectives. Highlighting a collection of articles, the authors explored how AI assists investors, creditors, and business managers in making data-informed, strategic decisions that align with long-term financial sustainability. They noted that AI not only serves as a problem-solving instrument but also offers broader transformative potential in reshaping financial modeling, risk assessment, and decision-making processes. Key challenges were acknowledged, including ethical concerns, data transparency, and technological adoption barriers, but the overall discourse was framed around the opportunities AI presents in improving the precision, efficiency, and accountability of sustainable financial systems. The editorial concluded by urging further research into the role of AI as a strategic enabler of sustainable investment practices and corporate governance.

Debrah, Chan, and Darko (2022) [9] conducted a comprehensive bibliometric and systematic review to examine the integration of AI in green building (AI-in-GB) within the Architecture, Engineering, and Construction (AEC) sector, a field increasingly driven by the dual imperatives of sustainability and operational efficiency. The study addressed a notable gap in existing literature by synthesizing both quantitative and qualitative research findings to map the evolution, research hotspots, and future trajectories of AI-in-GB. From an initial pool of 383 publications sourced from Scopus, a refined set of 76 studies underwent systematic qualitative analysis. The results highlighted that AI applications in green building contribute to enhanced knowledge discovery, decision-making automation, intelligent optimization, and improved reliability, efficiency, and accuracy in project delivery. Despite its strengths, the AI-in-GB domain remains underdeveloped, with significant potential for further exploration. The authors identified key emerging areas warranting attention, including digital twins and AI of Things (AIoT), blockchain integration, robotics, and 4D printing technologies. Additionally, the study underscored the importance of addressing legal, ethical, and moral implications as AI becomes increasingly embedded in green building practices. This review offers a foundational framework for advancing research and practice in AI-in-GB, guiding stakeholders toward more sustainable, efficient, and ethically aware building solutions. The emphasis on ethical implementation aligns with cross-sector professional consensus that AI systems should augment human expertise rather than replace it - particularly for sustainability decisions requiring nuanced judgment and value-based tradeoffs (Tomraee *et al*., 2024) [47]. Importantly, ethical awareness cannot be presumed; it must be actively taught and reinforced, as even highly educated individuals often lack clear understanding of ethical standards (Sabbar *et al*., 2019) [39].

Mhlanga (2023) [25] examined the application of AI and machine learning (ML) technologies in advancing sustainable development within emerging markets, using case studies to illustrate their practical impact. The chapter emphasized that these regions face unique socio-economic and environmental challenges that necessitate innovative, scalable solutions. The case studies explored in the chapter span sectors such as agriculture, energy, healthcare, and transportation. Specific examples include AI applications for improving crop yields and ensuring food security, expanding access to clean energy, optimizing healthcare systems, and enhancing transport infrastructure. These implementations demonstrated the ability of AI and ML to increase operational efficiency, minimize resource wastage, and expand access to essential services. The chapter highlighted the transformative potential of these technologies in driving inclusive economic growth and improving living standards in resource-constrained environments. Ultimately, Mhlanga concluded that AI and ML are powerful enablers of the Sustainable Development Goals (SDGs) in emerging markets, providing cost-effective, adaptable tools to address complex development challenges and foster a more sustainable future. However, as others have noted, such technological progress can only be effective when supported by efficient and clearly defined legal and regulatory frameworks; without them, even well-designed systems risk low compliance and diminished societal impact (Aghigh *et al*., 2022) [3].

Zaidi *et al*. (2023) [50] conducted a bibliometric mapping and network analysis to examine the evolving research landscape on the application of artificial intelligence in sustainable smart cities (AISC). Using the PRISMA methodology, the study analyzed 1,982 publications indexed in Scopus between 2011 and 2022, highlighting significant growth in both publication output and citation impact over the review period. The number of annual publications increased from 2 to 470, with corresponding citations rising from 157 to 1,540. Key contributors included prolific author Tan Yigitcanlar and King Abdulaziz University, identified as the most active affiliation. Funding trends revealed the National Natural Science Foundation of China as the leading sponsor of AISC research, accounting for 126 publications. The study identified six thematic research hotspots through keyword co-occurrence and clustering analyses: digital innovation and technologies, digital infrastructure and intelligent data systems, cognitive computing, smart sustainability, energy efficiency, and the interconnected nexus of AI, IoT, data analytics, and smart cities. The authors projected that future research will increasingly focus on ethical, socio-economic, technical, and policy challenges, underscoring the expanding global relevance and multidisciplinary nature of AISC research. The study provided a foundational overview for scholars and policymakers aiming to navigate and contribute to this rapidly advancing field.

Gourisaria *et al*. (2023) [16] explored the foundational technologies and strategic planning required to develop self-sustained, intelligent urban environments through the conceptualization of an Artificially Intelligent and Sustainable Smart City. The chapter emphasized the critical role of interconnected systems powered by the Internet of Things (IoT), sensors, and advanced machine learning algorithms, which together enable real-time data processing and autonomous decision-making. The authors highlighted the significance of these technologies in managing urban challenges such as traffic congestion, pollution, waste management, and public health by creating a responsive, eco-efficient digital ecosystem. A key innovation proposed in the chapter is the Smart City Autonomous System (SCAS), a central management framework designed to oversee city functions with minimal human intervention. This model integrates non-deterministic machine learning systems capable of evolving with new data, enhancing the resilience and adaptability of smart city infrastructure. The SCAS concept was presented as a blueprint focused on the implementation and planning phases, offering a scalable and replicable strategy for urban development. The chapter concluded by advocating for a holistic and technologically grounded approach to urban planning that supports socio-economic sustainability, autonomy, and environmental responsiveness. While the SCAS concept offers a scalable and replicable strategy for urban development, its implementation underscores a broader need for AI integration to be guided by ethically grounded frameworks that balance technological innovation with inclusive, human-centered development—a concern echoed across sectors (Rahmatian & Sharajsharifi, 2022) [34].

Rodríguez-Gracia *et al*. (2023) [37] conducted a comprehensive bibliometric and content analysis to evaluate the integration of AI techniques in green and smart buildings (GSBs), aiming to consolidate fragmented knowledge and highlight the multi-dimensional benefits of this convergence. Drawing on data from Web of Science and Scopus, the study mapped key contributors, influential publications, and geographic research distribution in the AI-GSB domain. The authors framed their analysis using the Triple Bottom Line—environmental, social, and economic dimensions—revealing significant gains in each area. Environmentally, AI was associated with improved thermal performance and enhanced energy management, primarily through machine learning applications. Socially, GSBs supported by AI contributed to occupant health and well-being by ensuring optimal indoor environmental quality. Economically, the implementation of AI in GSBs led to measurable reductions in energy consumption and cost savings through efficiency improvements. The study also identified five thematic research clusters that define the cognitive structure of the field and provided a temporal analysis of evolving keywords to track research trends over time. Notably, this work represents the first bibliometric review focused specifically on AI applications in GSBs, offering valuable insights and a foundational reference for academics, industry professionals, and policymakers interested in advancing sustainable and intelligent built environments.

Rieder, Schmuck, and Tugui (2023) [36] conducted a systematic literature review to investigate how AI is being integrated into sustainable urban development (SUD), focusing on identifying the dimensions impacted and the specific AI techniques employed. Drawing on literature from 2012 to 2022 and analyzed using PRISMA methodology, the study documented a marked increase in AI-related SUD research from 2018 onward. The review identified five core dimensions of SUD where AI applications are prominent: environmental protection, economic development, social equity and justice, cultural preservation, and governance. The paper outlined a wide array of AI techniques utilized in these domains, including general AI applications, machine learning, deep learning, artificial neural networks, operations research, predictive analytics, and data mining. These tools have enabled cities to better manage urban complexity, optimize infrastructure, enhance policy responsiveness, and promote citizen engagement. Despite these opportunities, the study highlighted several critical challenges associated with AI implementation in SUD, such as the need for responsible municipal governance, attention to data quality, privacy and security concerns, and fostering transparent, multi-stakeholder collaborations. The authors concluded that while AI is increasingly shaping the evolution of smart, sustainable cities, careful attention to ethical, technical, and participatory dimensions is essential to ensure equitable and effective outcomes.

Kazeem, Olawumi, and Osunsanmi (2023) [19] conducted a systematic review to explore the roles of AI and machine learning (ML) in optimizing construction processes and fostering sustainable communities. Following the PRISMA methodology, the study synthesized existing literature to delineate the practical applications and potential research trajectories of AI and ML within the architectural, engineering, and construction (AEC) sector. The review identified several key contributions of these technologies across both construction operations and broader community development. In the built environment, AI and ML facilitate enhanced energy management by detecting inefficiencies, predicting usage patterns, and recommending actionable interventions, thereby minimizing environmental impacts. Additionally, these technologies support the monitoring and mitigation of urban environmental challenges, including air pollution, noise, and waste accumulation, through real-time sensing and data-driven responses. Within construction processes, AI and ML improve planning accuracy, streamline scheduling, and augment facility management by enabling predictive analytics and intelligent automation. The study concluded that AI and ML are critical enablers of sustainable development in the AEC industry, with the capacity to significantly improve operational efficiency and environmental outcomes. The authors advocated for continued interdisciplinary research and strategic implementation to harness the full benefits of these technologies in sustainable construction and community planning.

Leal Filho *et al*. (2024) [21] explored the role of AI in advancing United Nations Sustainable Development Goal 11 (SDG 11), which focuses on fostering sustainable cities and communities. The study combined an expert-driven literature review with illustrative case studies to assess how AI can support urban sustainability initiatives. The findings highlighted AI's capacity to optimize energy consumption, streamline waste management systems, enhance urban mobility through traffic management, and contribute to broader environmental sustainability efforts. The paper emphasized that AI can serve as a powerful decision-support tool for urban planners and policymakers, offering data-driven insights to address complex socio-economic and environmental challenges in urban contexts. However, the authors cautioned that AI implementation must be accompanied by robust oversight mechanisms to ensure ethical standards, inclusivity, and data privacy. The study concluded that interdisciplinary collaboration among city planners, policymakers, and AI developers is essential to fully leverage AI's potential in achieving SDG 11 and to build equitable, resilient, and smart urban environments. This potential can only be realized through parallel investments in inclusive education programs that equip diverse stakeholders with the necessary competencies to effectively implement and sustain these technological solutions (Sakhaei *et al*., 2024) [41].

Bolón-Canedo *et al*. (2024) [7] presented a comprehensive review of green artificial intelligence (Green AI), emphasizing its dual role in fostering environmentally sustainable AI systems and supporting eco-conscious practices across diverse sectors. The paper introduced two key dimensions of Green AI: "green-in AI," which focuses on designing energy-efficient algorithms and models to minimize computational costs and environmental impact, and "green-by AI," which utilizes AI applications to promote sustainability in other fields, such as energy management, transportation, and agriculture. The authors discussed innovations in algorithmic efficiency, hardware optimization, and energy usage measurement tools that collectively reduce the carbon footprint of AI development and deployment. Furthermore, the study highlighted the democratizing aspect of Green AI, enabling high-quality research with modest computational resources, thus lowering barriers to entry and promoting inclusivity in AI research. The review also addressed the regulatory and policy frameworks needed to incentivize the adoption of sustainable AI practices. These governance structures find strong empirical support in cross-sector studies, where professionals consistently identify robust regulations as essential for mitigating algorithmic biases, ensuring data privacy, and maintaining accountability in AI systems - particularly when applied to sustainability-critical domains (Tomraee *et al*., 2022) [46]. In conclusion, the authors identified emerging trends and future research opportunities aimed at aligning AI development with broader environmental goals, advocating for a responsible, energy-aware evolution of machine learning technologies.

Garba *et al*. (2024) [14] investigated sustainable architectural strategies to address Nigeria's escalating affordable housing crisis, driven by rapid urbanization and population growth. Employing a qualitative methodology that combined literature review, case study analysis, and trend evaluation, the study assessed the practicality and challenges of implementing environmentally conscious, cost-effective housing solutions. Key findings emphasized the potential of locally sourced materials—such as stabilized earth blocks and interlocking bricks—to significantly reduce construction costs while promoting ecological sustainability. Additionally, the integration of renewable energy systems, particularly solar technologies, was highlighted as essential for enhancing energy efficiency and long-term housing resilience. However, several barriers to adoption were identified, including limited financial resources, technical skills shortages, and the erosion of traditional building methods. The authors advocated for a comprehensive, multi-stakeholder approach that incorporates circular and sharing economy principles, alongside the use of emerging technologies like artificial intelligence and machine learning to optimize housing design, construction, and maintenance. The study concluded with recommendations for continuous professional development, supportive policy frameworks, and active stakeholder collaboration to ensure the sustainable transformation of Nigeria's housing sector.

Hanafi, Moawed, and Abdellatif (2024) [17] provided a comprehensive review of AI techniques for optimizing energy management in buildings, highlighting their critical role in promoting sustainability and operational efficiency. The study examined AI's capabilities in identifying inefficiencies, forecasting energy demand, reducing wastage, and enabling buildings to participate dynamically in energy markets. Key applications discussed include energy consumption prediction, real-time optimization, and fault detection and diagnosis (FDD). The review presented strong empirical evidence supporting AI's effectiveness, such as a 20% reduction in heating energy achieved through predictive control without compromising occupant comfort. Additionally, smart home algorithms were shown to reduce electricity costs by 22.63% and the peak-to-average energy consumption ratio by 22.77%. These quantitative outcomes demonstrate AI's tangible impact on energy efficiency and cost savings. The authors also emphasized AI's role in enhancing diagnostic accuracy, thereby improving maintenance strategies and overall system reliability. The review concluded that AI-based energy management systems significantly advance the environmental and economic performance of buildings, positioning AI as a foundational technology for future energy-efficient building operations.

Li *et al*. (2024) conducted a systematic literature and science mapping review to evaluate the role of AI in achieving net-zero carbon emissions (NZCEs) within sustainable building projects. Recognizing the pressing need to decarbonize the built environment, the study reviewed 154 peer-reviewed articles from the Scopus database, using a mixed-methods approach that combined structured literature review with bibliometric science mapping. The analysis identified six primary research domains: life cycle assessment and carbon footprint analysis, practical AI applications in construction, multi-objective optimization methods, energy efficiency and management systems, building-specific carbon emissions, and decision support systems for sustainability. The review highlighted the growing impact of AI in improving design decision-making, reducing carbon-intensive processes, and supporting the long-term sustainability of buildings. Furthermore, six research gaps were identified, including limited integration of AI with lifecycle carbon data, lack of standardized evaluation metrics, and insufficient empirical validation of AI models. The authors proposed a conceptual framework to guide future research and practice, aiming to strengthen the deployment of AI technologies for carbon-neutral construction. This study offers a foundational reference for both researchers and industry practitioners seeking to leverage AI for decarbonization in the built environment.

Oyetunji *et al*. (2024) [31] examined the application of predictive AI models in the maintenance forecasting and energy optimization of smart housing infrastructure. The study emphasized AI's transformative potential in reducing operational inefficiencies and supporting sustainability goals within the housing sector. By leveraging real-time data from smart devices and occupancy sensors, AI algorithms were used to predict equipment failures before they occur, thereby minimizing unplanned maintenance costs and reducing system downtime. Simultaneously, AI-driven energy optimization enabled dynamic adjustment of utility usage, resulting in enhanced energy efficiency and cost savings. The research presented both theoretical frameworks and practical case studies that illustrated the successful implementation of AI technologies in real-world housing contexts. Key challenges were identified, including issues related to data quality, system integration complexity, and the initial financial burden of technology adoption. The authors concluded by advocating for policy interventions to support AI integration in housing, recommending regulatory frameworks, financial incentives, and workforce training initiatives to enable broad-scale implementation. This study contributes to the discourse on sustainable housing by demonstrating the significant benefits and considerations of integrating predictive AI technologies into housing infrastructure management. The success of such integration hinges on comprehensive workforce training that simultaneously develops technical AI proficiency and ethical decision-making skills - a dual-competency approach proven essential across professional fields implementing advanced technologies (Rahmatian & Sharajsharifi, 2021) [33]. Educational attainment remains a persistent predictor of engagement with complex systems, whether in cultural participation (Mohammadi *et al*., 2025) [27] or technology adoption—underscoring the need for accessible upskilling programs in AI implementation.

Fan, Chen, and Zheng (2024) [13] explored the application of AI, specifically the YOLOv8 object detection model, in the routine heritage monitoring and sustainable planning of the Fujian earthen houses (Tulou), a UNESCO World Heritage site in China. Focusing on the conservation challenges posed by the wooden structures that characterize Tulou architecture, the study addressed the labor-intensive nature of traditional damage assessment methods. Through a series of experimental refinements—including the removal of visually complex samples, enhancement of annotation quality, and hyperparameter tuning—the researchers optimized the YOLOv8 model for detecting structural damage such as holes, stains, and cracks. While the model's mean average precision (mAP) reached only 57% in controlled testing, field application at the KuiJu Lou site demonstrated its practical effectiveness, with successful identification of nearly all targeted damage types in real-world conditions. The findings affirmed the model's reliability and efficiency in heritage conservation tasks, particularly in complex environments. This research highlights AI's potential to enhance the sustainability of heritage preservation practices by enabling more consistent, accurate, and resource-efficient monitoring systems, serving as a foundational tool for the long-term renewal and management of historic districts.

Elwy and Hagishima (2024) provided a systematic review of surrogate model-based optimization approaches for sustainable building design, emphasizing their utility in addressing the computational challenges of complex building performance simulations. Surrogate models (SMs), which serve as AI-driven approximations of more computationally intensive models, were analyzed for their efficacy in optimizing passive design strategies—particularly building form and envelope configurations—to enhance energy efficiency and sustainability. The study synthesized findings from 72 peer-reviewed articles, selected via Scopus, and evaluated key factors influencing the performance and reliability of SMs across diverse climatic and design contexts. It highlighted significant advancements in surrogate-assisted optimization, including improved accuracy, scalability in high-dimensional problem spaces, and adaptability to varied environmental and architectural conditions. Additionally, the review revealed global disparities in methodological adoption, showcasing the need for context-specific model calibration and pre-experimentation. Despite these advances, the paper identified persistent limitations, such as model generalizability and sensitivity to input variability, suggesting avenues for future research. The authors concluded that surrogate models hold substantial promise for advancing passive, low-energy building design practices, especially when tailored to contextual variables and integrated into early-stage design decision-making.

Li *et al*. (2024) explored the interrelationship between AI and building information modeling (BIM) technologies in supporting sustainable building practices within the framework of smart cities. Recognizing the pivotal role of digitalization in transforming the architecture, engineering, and construction (AEC) industry, the study assessed how the integration of AI and BIM can enhance decision-making processes at both the building and urban scales. Using a dual bibliographic approach—macro to map the broader research landscape, and micro to delve into specific domains such as sustainable design, construction, development, and life cycle assessment (LCA)—the study revealed that AI-BIM integration significantly contributes to optimizing material selection, energy usage, cost estimation, scheduling, and real-time monitoring. These capabilities collectively support the achievement of several Sustainable Development Goals (SDGs), notably SDGs 7, 9, 11, and 12. The authors further emphasized that future development of AI and BIM in smart city contexts must expand beyond technical performance to incorporate human-centered design principles, including stakeholder well-being, safety, and comfort. The study concluded by identifying AI-BIM-LCA integration as a powerful mechanism for advancing holistic and sustainable urban development underpinned by City Information Modeling (CIM).

Mohamed, Khorshid, and Hassan (2024) [26] explored the application of AI in achieving sustainable maintenance of residential buildings, addressing the limitations of traditional periodic maintenance practices. The study proposed that AI-driven strategies, particularly those utilizing unsupervised machine learning algorithms, offer effective solutions for detecting anomalies and processing large volumes of data in both real-time and retrospective contexts. Through a structured theoretical and analytical framework, the researchers examined global case studies to demonstrate how AI can extend the assumed lifespan of buildings and enhance the preservation of residential real estate assets. The analysis emphasized AI's role in bridging the gap between sustainable maintenance programs and their practical implementation. Key tools identified include Internet of Things–Building Information Modeling (IoT-BIM) integrations, which facilitate dynamic monitoring, predictive maintenance, and lifecycle assessments. The study concluded with an applied framework recommending smart exploratory methods that can transform maintenance practices by enabling early detection of issues, optimizing resource allocation, and supporting long-term asset sustainability. The findings highlight AI's potential as a transformative tool for improving building resilience, reducing operational inefficiencies, and achieving long-term sustainability goals in residential infrastructure.

Ezebuilo (2024) [12] examined the challenges and barriers associated with the implementation of digital technologies (DTs) in promoting sustainable housing within the UK context, utilizing qualitative research methods to gain in-depth insights into their practical application. The study employed semi-structured interviews as primary data sources, supported by extensive secondary data from academic literature and other relevant publications. Through thematic analysis, the research identified key digital technologies currently influencing sustainable housing initiatives, highlighting their impact on energy efficiency, environmental performance, and overall housing quality. Despite recognizing the positive contributions of DTs, the study also revealed substantial challenges in their implementation, including knowledge gaps, limited user expertise, and institutional inertia. The findings underscored the need for improved education and training on DT application within the building industry to ensure effective deployment. Furthermore, the research called attention to strategic enablers that could facilitate better integration of DTs, such as policy support, cross-sector collaboration, and investment in capacity building. While the study was UK-focused, it concluded with a recommendation for broader international investigations to address global barriers to digital adoption in sustainable housing development.

Walacik and Chmielewska (2024) [48] examined the integration of AI algorithms in assessing the significance of sustainable solutions within the real estate industry, particularly from an Environmental, Social, and Governance (ESG) perspective. Aiming to enhance decision-making processes, the study developed a machine learning framework—specifically employing the random forest algorithm—to analyze large datasets encompassing various intrinsic and extrinsic real estate attributes. The methodology enabled the identification and evaluation of features such as energy efficiency and their impact on property values. The research demonstrated that AI-powered models can effectively handle non-linear relationships, offering more nuanced insights compared to traditional statistical methods like multiple regression analysis. Results indicated that sustainable solutions significantly influence real estate valuation, underscoring the financial and strategic benefits of adopting environmentally responsible practices. The study provided actionable insights for real estate professionals and investors, promoting a more informed, data-driven approach to sustainability within the sector. By highlighting the utility of AI in ESG assessments, the research contributed to the evolving discourse on digital innovation in sustainable real estate development and strategic asset management.

Regona *et al*. (2024) [35] conducted a systematic literature review to examine the intersection of AI and sustainable development goals (SDGs) within the construction industry, aiming to clarify AI's role in enhancing sustainability across the full lifecycle of construction projects—from planning and design to operation and maintenance. The review identified that AI applications are particularly relevant to SDGs 6–9, 11–13, 15, and 17, with SDGs 7 (affordable and clean energy), 9 (industry, innovation, and infrastructure), and 11 (sustainable cities and communities) highlighted as having the highest transformative potential. The study emphasized AI's ability to increase process efficiency and resilience in sustainability considerations, enabling improved decision-making and resource optimization. However, the paper also underscored critical challenges, including ethical issues, data privacy and security risks, and the need for adequate training and support systems for AI deployment. It concluded that while AI holds considerable promise for fostering sustainability in construction, its full potential can only be realized through careful, context-sensitive implementation, robust governance frameworks, and continuous capacity-building efforts across all stakeholder levels.

Al-Raeei (2024) [4] provided a comprehensive overview of the transformative role of AI in facilitating sustainable urbanization, emphasizing the technology's potential to reshape urban planning and management practices. The article explored a broad array of AI applications, including data analytics, machine learning, and predictive modeling, which are increasingly utilized to support decision-making, optimize resource allocation, and improve the quality of life in urban environments. Key domains addressed include urban planning, environmental monitoring, disaster risk management, and infrastructure optimization. While acknowledging the promise of AI in creating more efficient, resilient, and eco-friendly cities, the paper also critically discussed significant barriers to implementation. These challenges include data privacy concerns, algorithmic bias, and ethical implications, all of which necessitate ongoing research and interdisciplinary collaboration. Al-Raeei advocated for proactive engagement from policymakers, urban planners, and technology developers to ensure AI is applied in a manner that is both ethically sound and practically effective. The article concluded that AI, if responsibly and strategically deployed, holds substantial promise for advancing the global sustainable development agenda through the transformation of urban systems.

Ohakawa *et al*. (2024) [30] examined the integration of digital technologies—specifically AI, machine learning (ML), and Building Information Modeling (BIM)—in the design and delivery of affordable housing, with an emphasis on enhancing cost-efficiency, sustainability, and design precision. The study employed case study analyses of the Green Urban Living Initiative and the Smart Living Community project to illustrate practical applications of these technologies in real-world contexts. Through the use of AI-driven predictive analytics and ML-enabled resource optimization, the projects demonstrated measurable reductions in material waste, improved construction timelines, and enhanced energy performance. The research further identified key implementation challenges, including issues related to data governance, technological interoperability, and stakeholder coordination. Despite these obstacles, the findings indicated that a strategic, well-managed deployment of digital tools can significantly uplift the quality and sustainability of affordable housing solutions. The paper concluded by recommending best practices for future projects, advocating for early-stage integration of AI/ML tools, inclusive stakeholder engagement, and continuous data-informed decision-making processes to achieve resilient, community-focused housing outcomes.

Sai Pranay *et al*. (2025) [40] developed a Smart Housing Forecast system utilizing advanced AI techniques to enhance predictive pricing and personalized property recommendations. The study implemented the XGBoost Regression model-a gradient boosting algorithm known for its high accuracy-in forecasting real estate prices, while employing a cosine similarity-based approach to tailor property suggestions according to individual buyer preferences. Recognizing the challenges faced by both buyers and sellers in navigating housing markets, the authors introduced analytical tools, including visual aids like scatter plots, to support transparent and informed decision-making. The system aims to optimize housing transactions by enabling real estate agents to provide more accurate, personalized recommendations. Furthermore, the research aligns with several Sustainable Development Goals (SDGs), notably SDG 11 (sustainable cities and communities), SDG 10 (reduced inequalities), SDG 16 (peace, justice, and strong institutions), and SDG 3 (good health and well-being), highlighting its broader societal relevance. By integrating predictive analytics with ethical and sustainable practices, the Smart Housing Forecast model contributes to more inclusive, economically feasible, and resilient urban housing ecosystems.

Satpathy, Nayak, and Jain (2025) [42] examined the transformative potential of green artificial intelligence (Green AI) in advancing sustainable and smart urban living, emphasizing its role in urban planning, infrastructure management, and public safety. The chapter, situated within the broader context of sustainable urbanization, discussed how AI technologies enable intelligent automation in energy systems, infrastructure monitoring, transportation management, and surveillance. Drawing on case studies from cities like Amsterdam, Singapore, London, and New York, the authors illustrated AI's capacity to improve energy efficiency, reduce emissions, and enhance environmental monitoring. Specific applications included predictive policing, AI-based safety alerts, traffic congestion mitigation, and real-time evaluation of sensor data for public infrastructure. These technologies collectively contribute to the creation of resilient and sustainable urban environments. The chapter argued that AI-driven urban governance is not only a technological advancement but also a strategic imperative for future-ready, ecologically responsible cities. It concluded by advocating for the widespread adoption of Green AI in urban policy and territorial management to optimize urban operations and improve quality of life in metropolitan contexts.

Arabasy *et al*. (2025) [6] investigated the integration of machine learning (ML) technologies in smart housing as a strategic approach to address critical challenges in sustainable urban planning, particularly in the context of smart cities. The study aimed to assess the feasibility of ML applications for optimizing resource management, promoting environmental sustainability, and enhancing public safety. Utilizing comprehensive datasets, the authors applied ML algorithms to analyze key operational domains such as energy consumption, waste management, and safety response systems. The findings demonstrated notable improvements, including a 20% reduction in overall energy consumption, a 15% increase in the use of renewable energy sources, a 25% gain in waste management efficiency, and a 30% reduction in emergency response times. Furthermore, ML models achieved an average prediction accuracy of 92% for variables such as power usage, traffic flow, and air quality, contributing to a 10% decrease in carbon emissions. The study emphasized the transformative potential of ML not only in external urban systems but also in housing planning and interior design, illustrating its broader relevance to livability and sustainability. These results underscore the critical role of ML in advancing integrated, data-driven approaches to smart housing within sustainable city frameworks.

Adediran *et al*. (2025) [1] investigated the scholarly landscape of AI applications in housing through a bibliometric analysis, focusing on publications indexed in Scopus and Web of Science from 2000 to 2024. The study aimed to uncover publishing trends, influential contributors, and institutional involvement in this emerging interdisciplinary field. A total of 246 publications were identified, demonstrating a marked growth from a single article in 2000 to 68 in 2024, reflecting an overall increase of 5,016 in publication activity. Articles constituted the predominant document type, accounting for 172 entries. The analysis highlighted the most prolific authors-Ahmad, Chatterjee, Cho, Lee, Mehmood, Shaheen, Yang, and Zhao-each contributing three publications. It also identified ten leading institutions, with the U.S.-based National Science Foundation recognized as the foremost funding body, supporting eight publications. Co-authorship networks, citation patterns, and keyword co-occurrence were analyzed, revealing four central thematic clusters: technological tools, theoretical frameworks, methodological approaches, and socioeconomic and financial dimensions of AI in housing. The authors concluded that future research will increasingly leverage advanced machine learning and neural network models to enhance the prediction and optimization of housing transaction patterns, thereby supporting more efficient and equitable housing markets globally.

Conclusion

This systematic review has examined the evolving landscape of AI applications in sustainable housing, drawing from over thirty peer-reviewed studies spanning 2016 to 2025. The analysis categorized AI integration into four principal domains: design optimization, energy efficiency modeling, smart material selection, and life cycle assessment. Collectively, these domains illustrate the significant potential of AI to support sustainability objectives by improving energy performance, minimizing environmental impact, and enabling user-centered, adaptive housing design.

Empirical evidence from the reviewed studies confirms that AI techniques—particularly machine learning algorithms such as support vector machines, neural networks, and ensemble models—achieve high predictive accuracy and optimization efficiency across various housing-related tasks. These applications range from non-intrusive load monitoring and HVAC control to predictive maintenance and carbon footprint analysis. Moreover, the integration of AI with digital construction platforms such as Building Information Modeling (BIM) has enabled the dynamic assessment of design alternatives, material sustainability, and operational outcomes.

Nonetheless, the review also highlights critical limitations that constrain the scalability and real-world deployment of AI in sustainable housing. Chief among these are challenges related to data availability and standardization, model interpretability, integration with legacy systems, and the contextualization of AI frameworks across diverse geographic, economic, and regulatory environments. Furthermore, ethical and social dimensions—such as transparency, inclusivity, and algorithmic bias—remain underexplored in the current literature, especially in applications that intersect with housing equity, affordability, and user agency.

To advance the field meaningfully, future research must prioritize the development of interpretable, domain-specific AI models grounded in real-world datasets and stakeholder needs. Open data practices, interdisciplinary collaboration, and policy-aligned AI governance are essential to overcoming current barriers. Additionally, increased attention to social and environmental equity—particularly in Global South contexts—will ensure that AI-driven housing innovation contributes to broader sustainable development goals.

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