Overview of the Use of AI in Buildings Sustainability Assessment

Turkay Ersener[1] and Paris A. Fokaides[1,2(✉)]

[1] School of Engineering, Frederick University, Limassol, Cyprus
paris.fokaides@ktu.lt

[2] Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Kaunas, Lithuania

Abstract. This paper presents an overview of how Artificial Intelligence (AI) supports the sustainability assessment of buildings, structured around the main phases of the building lifecycle. The review focuses on four core stages: design and planning, operation and monitoring, assessment and optimization, and compliance and certification support. Within this structure, the study highlights the growing role of AI in enhancing decision-making, improving building performance, and supporting sustainable outcomes across each phase. AI tools are categorized into four main groups: general-purpose platforms, data analytics environments, building-specific tools, and specialized applications. These are then mapped to key application domains such as prediction, simulation, decision support, and system optimization. The study emphasizes the connection between AI functionalities and specific needs in building sustainability, offering a structured approach for understanding the current landscape of tools and methods. By combining a lifecycle-based perspective with a classification of AI technologies and use cases, the paper aims to support researchers and practitioners in navigating the evolving intersection of AI and sustainable built environments. The findings serve as a foundation for further research and tool development, fostering more effective integration of AI in future sustainability assessments.

Keywords: Artificial Intelligence · building sustainability · building lifecycle · smart buildings · energy efficiency · decision support

1 Introduction

The building sector plays a central role in the global sustainability agenda, accounting for a significant share of energy consumption, carbon emissions, and material use. In response to increasing environmental and regulatory pressures, there is growing interest in tools and methodologies that can enhance the design, operation, and assessment of sustainable buildings. Among these, Artificial Intelligence (AI) is emerging as a powerful enabler, offering new possibilities for data-driven insights, predictive modeling, and performance optimization.

Recent advances in AI, including machine learning, pattern recognition, and data analytics, have opened up opportunities to address complex sustainability challenges in

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the built environment. These range from optimizing energy performance and monitoring occupant behavior to supporting certification processes and informing policy compliance. However, while many studies explore AI from a technical standpoint, there remains a need for a structured understanding of how AI tools align with specific phases in the building lifecycle.

This study aims to bridge that gap by providing an overview of AI applications in building sustainability assessment, organized around four key lifecycle phases: design and planning, operation and monitoring, assessment and optimization, and compliance and certification support. Through this lens, the paper identifies tool categories, application domains, and emerging trends relevant to both researchers and practitioners.

2 Methodology

This study follows a systematic literature review approach, structured according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The objective was to identify and analyze recent research exploring the application of Artificial Intelligence in the sustainability assessment of buildings. The literature search was conducted using the Scopus database, covering the period from January 2022 to March 2025. The search string included the keywords “Artificial Intelligence” and “Building Sustainability,” which retrieved a total of 507 documents.

Table 1. Summary of PRISMA Selection Process.

Parameter	Value
Timeframe	January 2022 – March 2025
Database	Scopus
Search Keywords	“Artificial Intelligence” AND “Building Sustainability”
Initial Records Retrieved	507
Final Studies Analyzed	25
Review Framework	PRISMA
Analysis Tool	Biblioshiny (Bibliometrix R package)

A screening process was applied to identify studies specifically addressing the intersection of AI and building sustainability. After reviewing titles, abstracts, and keywords, a targeted subset of 25 studies was selected for detailed analysis. These studies were chosen based on their direct relevance to the topic, their methodological contribution, and their alignment with one or more phases of the building lifecycle. The bibliometric analysis of the selected literature was performed using Biblioshiny, the web-based interface of the Bibliometrix R package. Biblioshiny enabled the exploration of publication trends, identification of the most relevant sources, analysis of citation patterns across countries, and mapping of keyword co-occurrences and international collaborations. The results are presented through a series of visual outputs, including source impact graphs, word clouds, co-occurrence networks, and collaboration maps, offering a comprehensive picture of the research landscape. The key parameters of the review process and bibliometric analysis are summarized in Table 1.

3 Results and Discussion

3.1 Bibliometric Analysis of Literature Resources

Figure 1 presents a word cloud showing the most frequent terms in studies on AI and building sustainability. The word cloud chart visualizes the most frequently occurring terms in the selected literature on Artificial Intelligence and building sustainability. Dominant among them are “energy efficiency” and “artificial intelligence,” reflecting the central focus of the field on using AI techniques to optimize energy performance in buildings. The prominence of related terms such as “energy utilization,” “energy management,” and “optimization” underscores the practical application of AI tools in improving operational performance, reducing consumption, and advancing sustainable development goals. The strong presence of “machine learning,” “deep learning,” and “decision making” indicates a methodological trend in the analyzed studies, suggesting that data-driven, predictive approaches are commonly employed to inform design and operational strategies. Additionally, terms like “forecasting,” “neural networks,” and “intelligent buildings” further point to the integration of AI into real-time systems and smart environments. Notably, keywords such as “sustainable development,” “climate change,” and “Internet of Things” illustrate the broader context in which this research is situated, linking building sustainability with global environmental and technological challenges. This chart thus provides a snapshot of the conceptual landscape and thematic emphasis within the field, highlighting the convergence of AI, energy-focused objectives, and the digital transformation of the built environment.

Fig. 1. Word cloud showing the most frequent terms in studies on AI and building sustainability (2022–2025).

The co-occurrence network chart (Fig. 2) maps the thematic relationships between keywords in the selected literature on Artificial Intelligence and building sustainability. Two distinct clusters are visible: the red cluster, which centers around “energy efficiency” and “artificial intelligence,” and the blue cluster, which gravitates around terms related to smart energy infrastructure and digital technologies, such as "smart grid," "deep learning," and "internet of things." The prominence of "energy efficiency" and "artificial intelligence" as central nodes reflects their foundational role in this research domain. Closely linked keywords in the red cluster—such as "optimization," "decision making," "machine learning," and "sustainable development"—highlight the breadth of AI's applications in improving building performance, informing policy, and supporting climate-related goals. In contrast, the blue cluster reflects a more infrastructure- and systems-oriented focus, with strong links among terms like "energy management systems," "smart power grids," and "intelligent buildings." The connections between the two clusters suggest an interdisciplinary convergence, where AI-driven optimization and control strategies are increasingly integrated with smart energy systems and urban infrastructure. This network provides insight into the evolving structure of research topics, revealing how sustainability goals in buildings are being addressed through a combination of intelligent technologies and system-wide innovations.

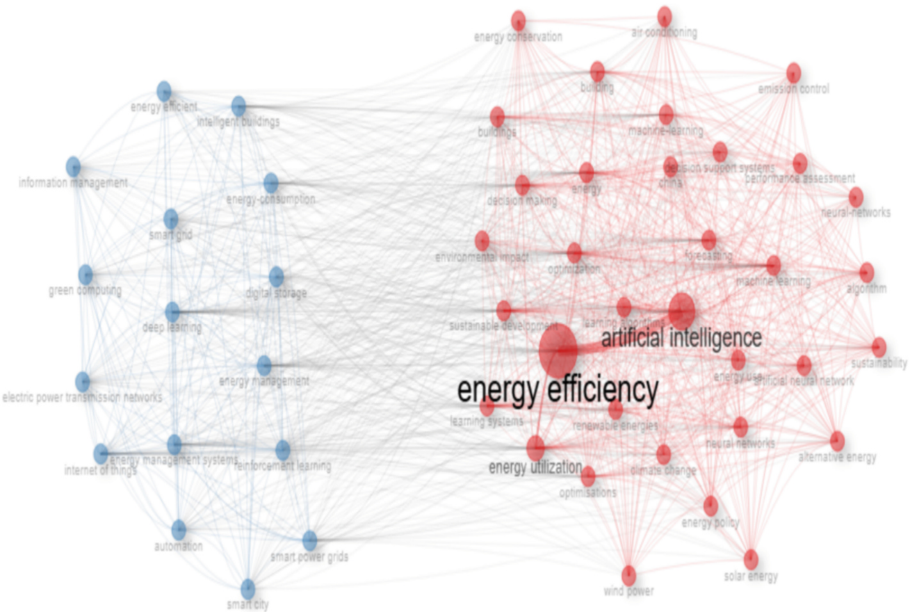

Fig. 2. Keyword co-occurrence network showing thematic clusters in AI and building sustainability research (2022–2025).

The analysis of the 26 selected studies revealed distinct patterns in how Artificial Intelligence (AI) technologies are applied to support sustainability in the built environment. The results are discussed in three interrelated subsections. The first outlines the integration of AI across building lifecycle phases, the second categorizes the types of tools encountered in the literature, and the third reflects on the main purposes these tools serve in promoting sustainable outcomes.

3.2 Integration of AI Across the Building Lifecycle

A core finding of this review is that the application of AI in the context of building sustainability is closely aligned with key phases of the building lifecycle. Most studies demonstrate that AI offers added value not as a standalone digital solution, but as a process-oriented enabler embedded within specific lifecycle stages.

In the Design and Planning phase, AI is frequently used for early-stage performance predictions and optimization [1]. Studies report the deployment of machine learning algorithms to estimate future energy consumption based on material choices, building orientation, and architectural layout [2]. Tools like AI-driven generative design platforms and spatial analysis engines support decision-making by simulating multiple scenarios under constrained parameters, thus allowing for more sustainable design configurations [3]. In several reviewed papers, neural networks and support vector machines were applied to predict heating and cooling loads in the conceptual design stage, improving accuracy and allowing for data-driven material selection and layout adjustments before construction [4].

During the Operation and Monitoring phase, the role of AI shifts toward real-time data analytics and system control [5]. AI models trained on historical building performance data are used to detect anomalies in HVAC systems, predict occupancy patterns, and adjust lighting and temperature settings for optimal comfort and energy efficiency [6]. Smart building platforms integrating reinforcement learning and sensor fusion techniques are gaining ground in this phase. In the literature, operational strategies supported by AI were often cited for enabling proactive maintenance, reducing energy waste, and adjusting building systems based on dynamic environmental inputs or user behavior (Tables 2, 3 and 4).

Table 2. AI Applications Across Building Lifecycle Phases

Lifecycle Phase	AI Applications	Insights from Literature
Design and Planning	Energy forecasting, material selection, generative design, spatial optimization	AI used for early-stage simulation and decision support; neural networks improve accuracy
Operation and Monitoring	Real-time control, anomaly detection, occupant behavior prediction	AI enables dynamic building responses, smart control of HVAC/lighting, and preventive actions
Assessment and Optimization	Retrofit planning, scenario comparison, performance evaluation	AI assists in identifying optimal renovation paths based on energy, cost, and emissions
Compliance and Certification Support	Automated reporting, design validation, regulatory alignment	Tools help meet LEED/BREEAM/EPBD targets; an emerging trend in policy compliance

The Assessment and Optimization phase includes studies where AI supports performance evaluation and renovation planning. Several tools in this domain are designed to model retrofit scenarios by combining building simulation outputs with AI-generated predictions on cost, energy use, and potential emissions reduction [7]. This allows stakeholders to compare multiple renovation pathways and select the most cost- and carbon-efficient option. While life cycle assessment (LCA) was referenced in some studies, it was typically linked to broader performance assessments rather than in-depth LCA automation, as this was not a dominant theme in the final selection of studies [8].

In the final phase, Compliance and Certification Support, AI is applied to streamline the generation of sustainability documentation and facilitate decision-making aligned with certification requirements such as LEED, BREEAM, and EPBD-compliant energy performance certificates. The reviewed studies highlight AI's contribution in cross-referencing design or operational data with certification benchmarks, producing automated compliance reports, or recommending design adjustments to meet minimum energy performance criteria. Although less prevalent than the other phases, this area showed promising growth, particularly in studies targeting policy support and smart regulation compliance tools.

3.3 Typologies of AI Tools in Building Sustainability

A second layer of analysis involved classifying AI tools used in the selected studies into four broad categories: general-purpose AI/ML platforms, data analytics platforms, building-specific AI tools, and applied or niche tools tailored to sustainability contexts.

General AI/ML platforms were widely referenced, especially in studies focused on model training and algorithm development [9]. These tools typically serve as a foundation for building custom solutions and include environments such as TensorFlow, PyTorch, and Scikit-learn. Researchers used these platforms to develop tailored models for energy forecasting, optimization, and anomaly detection.

Table 3. Types of AI Tools in Sustainable Building Research

Tool Category	Examples	Primary Use Cases
General AI/ML Platforms	TensorFlow, Scikit-learn, PyTorch	Model development for prediction, classification, control
Data Analytics Platforms	Power BI, KNIME	Workflow-based visualization, exploratory data analysis
Building-Specific AI Tools	Digital twins, BIM-integrated AI modules	Real-time performance feedback, intelligent control
Applied/Niche Tools	Daylighting optimizers, thermal comfort models	Highly specific applications; support comfort and passive strategies

Data analytics platforms like KNIME or Power BI were noted for their low-code or no-code capabilities [10]. These were primarily used in studies that emphasized accessibility and visualization rather than algorithm development. Their workflow-based interfaces made them suitable for stakeholders without advanced programming expertise, providing intuitive means to track energy performance or conduct exploratory data analysis[11]. Building-specific AI tools represent a growing category that includes digital twins, simulation-coupled AI engines, and intelligent building management systems. These tools are often integrated with Building Information Modeling (BIM) platforms or sensor-based monitoring frameworks, offering real-time AI insights within the operational layer of the building [12]. Examples include AI modules embedded within energy management platforms and smart grid-aware control systems [13]. Applied or niche tools emerged in highly focused sustainability areas such as daylighting optimization, indoor environmental quality assessment, or occupancy-driven thermal control [14]. While these tools tend to be narrower in scope, their targeted nature allows for high precision and relevance [15]. For instance, AI-based daylight prediction models were employed to optimize window placement and shading strategies for improved energy use and comfort [16].

3.4 Application Domains and Functional Roles of AI

The final dimension of analysis concerns the specific purposes AI tools serve in building sustainability. These functions fall into five major domains: prediction and modeling, data analysis and decision support, building performance simulation, sustainability assessment, and operational optimization. Prediction and modeling were the most dominant application domains across the reviewed studies. AI was frequently used to forecast energy consumption, predict occupant behavior, or estimate environmental impacts under future use scenarios. Machine learning algorithms such as random forests, gradient boosting machines, and neural networks were prevalent in this space, offering substantial improvements over traditional statistical methods.

Data analysis and decision support was the second most frequently addressed domain. AI-enabled platforms supported multi-criteria decision-making processes by evaluating trade-offs between environmental, economic, and functional parameters [17]. These tools facilitated design-stage assessments where multiple material or layout options were assessed in parallel, providing actionable insights through visual dashboards or ranking systems [18]. Building performance simulation involved the integration of AI with existing simulation engines like EnergyPlus or TRNSYS. These hybrid tools helped reduce computational time, improve result accuracy, or introduce learning-based adaptability into otherwise static simulation environments [19]. In many cases, simulation data served as training inputs for AI models used in performance optimization or control feedback loops [20]. Sustainability assessment, although referenced in fewer studies, featured in applications that involved system-wide sustainability scoring, material impact estimation, or scenario comparison for retrofitting [21]. While full LCA integration was not a major theme, AI was instrumental in supporting simplified assessments or linking design choices with environmental metrics [22]. Finally, operational optimization and fault detection was a strong area of focus in the Operation and Monitoring phase [23]. AI was used to improve HVAC scheduling, detect faults in

Table 4. Functional Roles of AI in Sustainability Applications

Application Domain	AI Functionality	Benefits Identified in Literature
Prediction and Modeling	Energy use, occupant behavior, cost forecasting	Increases accuracy, enables scenario testing
Data Analysis and Decision Support	Multi-criteria assessment, trade-off analysis	Supports designers and planners in sustainable decision-making
Building Performance Simulation	Hybrid AI-simulation environments	Reduces computation time, adds adaptability to simulation tools
Sustainability Assessment	Impact scoring, simplified evaluations	Facilitates comparison of sustainable alternatives
Operational Optimization and Fault Detection	HVAC control, anomaly detection, energy saving strategies	Improves comfort, reduces operational costs and energy consumption

mechanical systems, and adapt energy management strategies in real time [24]. Studies showed that reinforcement learning and predictive control strategies could reduce energy consumption while maintaining or enhancing occupant comfort levels [25].

4 Conclusions

This study examined how Artificial Intelligence (AI) contributes to the sustainability assessment of buildings, using the building lifecycle as a guiding framework. Through a systematic literature review, it was found that AI applications are increasingly aligned with the four key phases: design and planning, operation and monitoring, assessment and optimization, and compliance and certification support. In the design phase, AI supports early decision-making through energy forecasting and spatial optimization. During operation, AI facilitates real-time monitoring, anomaly detection, and adaptive control of systems. For performance assessment, AI enables scenario modeling and supports renovation planning, while in the compliance phase, it assists in aligning building data with certification requirements such as LEED and EPBD. The review also revealed four main types of AI tools—general-purpose machine learning platforms, data analytics environments, building-specific tools, and niche applications—each contributing uniquely across functional domains, including prediction, decision support, simulation, and optimization. Importantly, AI is not a standalone solution but acts as an enabling layer integrated into broader decision and control systems within the built environment. While this review captured the current landscape of AI-driven sustainability assessment, future work should focus on the validation of AI models in real-world settings and their long-term impact on building performance.

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