ER Environmental Review Journal

Volume 10 No. 1, 2025.
ISSN:1118-7190

Sustainable Built Environment Features Towards Climate Change Mitigation: Systematic Review.

[*]Emmanuel, Uchenna Ezeani, Danjuma, David, Chinomso Ukah
Department of Environmental Management, Nnamdi Azikiwe University, Awka
*Corresponding Author: Ezeani, Emmanuel Uchenna. Kcuche2000@yahoo.com

Abstract
Climate change represents one of the most urgent global challenges, threatening environmental stability and human well-being worldwide. The built environment, which encompasses infrastructure such as buildings, transportation systems, drainage networks, power grids, and communication facilities, plays a pivotal role in contributing to this crisis through its significant greenhouse gas (GHG) emissions and resource consumption. This paper presented a comprehensive qualitative systematic literature review (SLR) which studied recent research on how built environment features and sustainable practices such as the use of green building materials, biophilic design principles, integration of renewable energy technologies, efficient waste management systems, and the deployment of smart and intelligent technologies can effectively mitigate climate change impacts. Drawing from authoritative peer-reviewed journals indexed in major academic databases, including Scopus, Google Scholar, ScienceDirect, Springer, and Web of Science, the study highlighted potentials of these strategies to reduce GHG emissions, promote low-carbon development, and foster resilient, climate-adaptive communities. Moreover, the study underscored the critical importance of transition toward a sustainable built environment to advance the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). To realize this transformative shift, this paper advocated for targeted investments in material science and construction innovation, the integration of climate-responsive design principles in planning and development processes, the provision of incentives or tax benefits to stakeholders, adopting renewable energy systems and recycled or low-carbon building materials, the implementation of robust awareness programs, promotion of energy efficiency and sustainable resource utilization. Collectively, these measures are vital for fostering a built environment capable of supporting global climate action and sustainable development goals.

Keywords: Built Environment, Green Building Materials, Biophilic Design, Renewable Energy Integration, Smart and Intelligent Technology, Waste Management System, Climate Change Mitigation

1.0 Introduction

The environment comprises two interrelated components: the natural environment and the built environment. The natural environment encompasses all ecological elements formed without human intervention, including climate, mountains, rivers, soils, vegetation, and other biophysical features. In contrast, the built environment refers to human-made surroundings that facilitate daily activities. These

include buildings, transportation networks, drainage and water supply systems, energy infrastructure, and communication networks. Importantly, the built environment extends beyond physical structures to encompass open spaces, parks, and the interconnected infrastructure (UNEP, 2022). A sustainable built environment is one that is consciously designed, constructed, and operated to minimize negative environmental impacts throughout its lifecycle. These include the selection of building materials, energy consumption patterns, waste management strategies, and reduction of the overall ecological footprint (UNEP, 2022). However, conventional built environments have significantly contributed to environmental degradation and climate-related challenges. These include extreme weather events, such as flooding, erosion, and heatwaves, which in turn drive deforestation, loss of biodiversity, degradation of ecosystems, and reduced ecosystem services. These disruptions are intricately linked to the emission of greenhouse gases (GHGs), which are primary drivers of global warming and climate change (IPCC, 2023).

As urbanization and infrastructural development accelerate globally, the built environment has emerged as a critical factor influencing environmental sustainability. The built environment plays a vital role in shaping microclimates. Different parts of the same built environment (rooftops, parapets, and facades) experience varied exposure to sunlight, wind, and rainfall, all of which influence building temperature, lifespan, and surrounding vegetation (Kolawole & Okonkwo, 2022). Also, a built environment is a notable contributor to climate change due to its dependence on fossil fuel-based energy, and the removal of non-renewable resources. The increasing global population and escalating demand for infrastructure have placed unprecedented pressure on the environment. Both urban centers and rural areas are undergoing rapid infrastructural expansion, often progressing at a geometric rate. This accelerated development, while essential for socioeconomic growth, has led to significant environmental degradation. One critical issue is the limited attention given to the lifecycle of buildings, particularly the end-of-life phase. Factors such as structural aging, changing architectural trends, and evolving user preferences often result in the premature demolition of buildings without sustainable deconstruction strategies (Ghosh & Neogi, 2018). The built environment remains a substantial contributor to climate change, despite increasing awareness and technological advancements in sustainable construction, the transition to environmentally responsible infrastructure remains hindered by several interconnected challenges. These include inefficient resource use, low integration of renewable energy systems, high embodied carbon in materials, and fragmented or poorly enforced policy frameworks. Furthermore, many conventional buildings are not designed to withstand or mitigate the adverse effects of climate change. This vulnerability heightens risks related to extreme weather events, energy inefficiency, and environmental pollution.

This study aims to showcase the climate change mitigation potential of the built environment features. It explores how various structural designs, and emerging technologies reduce GHG emissions, improve energy efficiency, and support the climate resilience of the built environment. The mitigation of these impacts requires a shift toward low-carbon, energy-efficient, and ecologically sensitive design strategies. Climate change mitigation in the built environment encompasses the reduction of GHG

emissions through renewable energy adoption (solar, wind, biofuels), energy-efficient appliances, green roofs, and resource recovery initiatives (Hamin & Gurran, 2009; IPCC, 2007). To ensure long-term environmental sustainability, built environments must integrate climate-responsive designs, zero-waste systems, and intelligent infrastructure (Kolawole & Okonkwo, 2022). This study seeks to assist Architects, Planners, Engineers, and Policymakers to take an informed decision on the transition from a conventional built environment to a sustainable built environment for effective climate change mitigation.

1.1 Aim and Objectives

The aim of this study is to unveil practices and features within built environments that have the capability to prevent or mitigate climate change. Specifically, the study will investigate:

i. Green building materials and their role in reducing carbon emissions and lowering the environmental footprint of construction activities.
ii. Biophic design that can mitigate climate change.
    Renewable energy within the built environment that can promote energy efficiency and Decarbonization.
iii. Sustainable waste management systems that can promote climate change mitigation.
iv. Application of smart and intelligent technologies within built environment for energy optimization.

2.0 Methodology

This study employed a qualitative systematic literature review (SLR) methodology to critically examine the climate change mitigation features inherent within built environment. Comprehensive literature searches were conducted across major academic databases, including Scopus, Web of Science, Springer, and Google Scholar. Peer-reviewed articles relevant to the topic were meticulously selected based on established inclusion criteria and subsequently categorized according to specific climate change mitigation practices or features identified within the built environment context. Searches focused on literature published between 2016 and 2025. This rigorous approach ensures a broad synthesis of the most salient strategies and interventions that contribute to the reduction of built environment's carbon footprint and enhancement in its resilience to climate impacts.

3.0 Literature Review

This section recorded the findings of scholarly articles, each addressing various features and practices within the built environment that contribute to climate change mitigation. The study focuses on a range of innovative approaches such as the use of green and sustainable building materials, the incorporation of biophilic design principles, and the integration of renewable energy resources into building systems. In addition, the study explored advancements in waste management strategies and the deployment of smart and intelligent technologies designed to enhance resource efficiency and reduce environmental impacts.

3.1 Green building materials

The targeted literature studied was searched with the keywords "Green building materials and Climate Change Mitigation" across leading academic databases: Google Scholar, Springer, and ScienceDirect. The search specifically focused on features in the built environment with proven or potential ability to mitigate climate change. While numerous articles were identified, four were selected for study based on full-text accessibility and relevance to the research scope. Green building materials are eco-friendly, sustainable products carefully chosen to reduce the environmental footprint of the built environment throughout their entire lifecycle. Key attributes include Low embodied energy, Sustainable sourcing, Renewability and recyclability, Durability and longevity (Aslam & Rana, 2022)

Lemkalli et al. (2025) conducted a comprehensive study that investigated the potential of clay-based metaBricks for the enhancement of both thermal and acoustic insulation in building applications. The study, published in The Journal of the Acoustical Society of America and indexed in Google Scholar, addressed the growing interest in acoustic metamaterials as innovative solutions for energy efficiency and noise control within built environment. In their experimental setup, the researchers evaluated walls constructed from clay metaBricks, focusing on both their sound attenuation capabilities and thermal resistance. The findings revealed that metaBricks provided a substantial improvement in acoustic insulation, achieving an average sound attenuation of 20 dB across a wide frequency band (500–2500 Hz). This range effectively encompasses typical noise frequencies encountered in residential and commercial buildings, underscoring metaBricks' practicality for real-world noise mitigation. Thermally, the metaBrick walls demonstrated an 8% increase in thermal resistance compared to conventional clay bricks, signifying better insulation and potential energy savings for heating and cooling. Interestingly, while the incorporation of metamaterial structures led to a 33% reduction in compressive strength, the metaBricks still outperformed the minimum compressive strength standards required for construction purposes, ensuring their structural viability. Moreover, the study highlighted the promise of clay metaBricks as multifunctional building materials that can significantly reduce noise transmission and enhance thermal insulation without compromising essential structural integrity. These positions clay metaBricks as a forward-looking solution for sustainable, comfortable, and energy-efficient buildings.

Aketouane (2018) conducted an in-depth investigation into the energy-saving potential of incorporating Phase Change Materials (PCMs) into hollow bricks for building applications. This research, published in Building Simulation and indexed in Springer, addressed the significant energy demand posed by the building sector in Morocco, which accounts for approximately 25% of the nation's total energy consumption. The study specifically assessed the performance of hollow bricks integrated with PCMs with different melting temperatures, evaluating their capacity to enhance thermal inertia and reduce energy loads across Morocco's diverse climate zones. The results highlighted that PCM-infused bricks regardless of climate zone effectively diminished the peak heat flux entering buildings. More notably, bricks containing PCM with an average melting temperature of 32 °C were

found to significantly suppress heat flux peaks, contributing to improved indoor thermal comfort and reduced cooling loads.

Furthermore, the research demonstrated substantial energy savings associated with PCMs featuring a 27 °C average melting temperature; energy consumption was reduced by up to 25% in the Saharan climatic region and by an impressive 40% in the oceanic climate. These findings illustrate the adaptive potential of PCM-modified bricks to reduce energy demands in both extreme heat, moderate, and humid environments. Supporting these findings, Tyagi et al. (2007) presented a comprehensive review of various PCM applications for building thermal management ranging from PCM Trombe walls and wallboards to shutters, building blocks, air-based heating systems, as well as floor and ceiling heating components. Their findings confirmed that phase change materials offer considerable benefits for both heating and cooling purposes, significantly lowering the overall energy demand of buildings and promoting energy-efficient design. Collectively, these studies underscored the promise of phase change materials, not only for reducing energy consumption and enhancing indoor comfort across diverse climates, but also for advancing sustainable construction practices in regions with significant building-related energy demands.

Diego et al. (2016) conducted a comprehensive study on the climate impact of bio-based materials in building construction, with their findings published in Construction and Building Materials Journal and indexed on ScienceDirect. The primary focus of the investigation was to assess the potential of bio-based materials for reducing greenhouse gas emissions associated with the built environment. The researchers systematically tested building components incorporated with varying proportions of bio-based materials, such as timber, wood fiber, and advanced bio-composites, substituting them for conventional materials like concrete and steel. Their results demonstrated that increasing the percentage of bio-based materials in building assemblies led to a significant reduction in embodied carbon by 20–50%; the energy savings is directly correlated to the level of material substitution. This underscored the transformative potential of shifting away from traditional, high-carbon materials toward renewable alternatives. Beyond emissions reduction during construction, the study highlighted an additional climate benefit unique to bio-based materials: carbon sequestration. As these materials derive from plant matter, they capture and store atmospheric CO_2 during their growth phase, effectively acting as carbon sinks throughout their lifecycle, provided they are sourced and managed sustainably. In light of these findings, Diego et al. advocated for the development and implementation of supportive policy and design frameworks that actively incentivize the adoption of renewable bio-based materials in the construction industry. The authors emphasized the importance of material selection for achieving low-carbon construction pathways and meeting ambitious emission reduction targets. They recommended that decision-makers prioritize materials with a proven capacity to minimize building-related emissions, thereby promoting a sustainable built environment and contributing meaningfully to global climate change mitigation efforts.

Jay et al. (2021) investigated the role of carbon sequestration and storage within the built environment, with their work published in Sustainable Production and Consumption and indexed in ScienceDirect. The authors noted the growing enthusiasm for bio-based construction materials which

has given rise to the concept that building is carbon sink; buildings not only reduce emissions but actively store carbon over time. To address this concept, Jay et al. conducted a comprehensive review of 180 scholarly articles from the past decade, critically assessing methodologies and outcomes. The study examined the various accounting methodologies adopted nationwide and globally to quantify buildings' contribution to global warming potential.

The authors emphasized the heterogeneous and sometimes conflicting nature of existing research, highlighting the need for further validation of the "buildings as a carbon sink" theory before it can be reliably positioned as a climate change mitigation strategy. Critically, the study pointed out that the net carbon gains achieved through sequestration and storage in buildings could be counterbalanced or even negated by net carbon losses in forest ecosystems, particularly if sustainable harvesting and forest management practices are not ensured. Moreover, the often-cited benefits of substituting traditional construction materials with wood may be overstated without careful lifecycle analysis and contextual consideration. Jay et al. concluded that while the increased use of bio-based materials in construction holds promise, its true potential to contribute substantially to climate change mitigation depends on broader, rapid progress in global decarbonization efforts. They advocated for integrated approaches recognizing the interdependencies of ecological preservation, technological innovation, and economic policies to realize the full climate benefits of bio-based building materials within sustainable development frameworks.

3.1.1 Summary and contributions from other scholars

The construction industry is one of the largest consumers of raw materials and energy, contributing significantly to global greenhouse gas (GHG) emissions. According to the Global Alliance for Buildings and Construction the sector accounts for over 34% of energy demand and 37% of CO_2 emissions globally (IEA & UNEP, 2022). Also, sustainable construction practices are increasingly adopting green building materials and energy-efficient technologies to mitigate their environmental footprint. The built environment exists as a subset of the natural environment, and the materials for build environment are derived from ecosystem. Building materials significantly influence the design, development, and resilience of built environments (Aslam & Rana, 2022). Built environments are inherently resource-intensive, it involves significant land use, energy consumption, and waste generation. Materials such as fiberglass quilts, aerated concrete, reflective foils, and expanded polystyrene are widely used for their insulating properties. Effective insulation also reduces surface condensation and associated risks such as mold growth and material degradation (Chinda & Ikiroma, 2022). Material selection also plays a crucial role in climate change mitigation. The use of low-carbon, recycled, or bio-based materials can significantly reduce embodied carbon emissions. Sustainable materials such as reclaimed timber, recycled concrete, and low-emission finishes reduce embodied carbon in buildings. Emerging materials like "metabrick" offer enhanced insulation and acoustic properties, contributing to energy efficiency and user comfort (Lemkalli et al., 2023; Vijayan et al., 2021). In a recent comparative life-cycle assessment study, Liu et al. (2021) found that buildings

constructed using bio-based materials can achieve 30% to 50% lower embodied carbon emissions compared to those constructed with traditional materials. This makes them a crucial component of climate-resilient and net-zero building strategies.

3.2 Biophilic design/ Passive design

The targeted literature studied was searched with the keywords "Biophilic design and Climate Change Mitigation" across leading academic databases: ScienceDirect and Scopus. The search specifically focused on biophilic designs within the built environment with proven or potential ability to mitigate climate change. While numerous articles were identified, four were selected for study based on full-text accessibility and relevance to the research scope. Biophilic design is about integrating natural elements into built environments, and this practice is for improving energy efficiency, indoor environmental quality, and occupant health (Ochedi, 2023). The works of some authors on biophilic design within built environment were studied and their findings recorded.

Ochedi, E. T. (2023) conducted an influential study on the integration of biophilic design in sustainable building practices, the work was published in the Journal, Sustainable Cities and Society, indexed in ScienceDirect. The author adopted a **c**omprehensive literature review and conceptual analysis. Data were sourced from Peer-reviewed articles, Sustainability Reports, and Case Studies relevant to biophilic design and sustainable construction. The objective was to theoretically explore how biophilic design can contribute to climate-responsive and sustainable built environments.

Key Findings stated:

i. Biophilic design is characterized by integrating natural elements such as vegetation, daylight, water features, and organic materials into building architecture. This approach fosters a harmonious relationship between people and nature within urban contexts.

ii. The analysis highlighted biophilic design's potential to reduce urban heat effects, improve air quality, and enhance building energy efficiency. Such features contribute significantly to climate change mitigation within the built environment.

iii. Biophilc design aligns with Sustainable Development Goals (SDGs):

- SDG 11 (Sustainable Cities and Communities): Promotes inclusive, safe, and sustainable urban spaces by improving occupant well-being and ecological performance.
- SDG 13 (Climate Action): Supports proactive measures to address climate change through resilient, adaptive building strategies rooted in nature.

iv. The study advocates firmly for positioning biophilic design as a core sustainability strategy rather than as a peripheral or decorative addition to new construction and urban renovation projects.

The authors proposed:

i. Adoption of biophilic principles in the early stages of planning to maximize environmental and health benefits.
ii. Integration of biophilic design standards into sustainability-driven building codes and urban development policies.
iii. Incorporation of biophilic design in global sustainability targets

Ochedi's (2023) research emphasized that biophilic design is not only an aesthetic or wellness trend but also a crucial, evidence-based approach to sustainable urban development. By directly supporting key UN Sustainable Development Goals, biophilic design stands out as a core strategy for the future of climate-responsive, sustainable cities.

Oleiwi & Mohamed (2022) conducted a comprehensive investigation into passive design strategies aimed at enhancing energy efficiency in buildings located in hot climate regions. Published in the Journal of Building Engineering and indexed in ScienceDirect, their study employed a systematic literature review coupled with a comparative analysis of various passive techniques. The research identified several key passive design strategies namely, optimized building orientation, strategic shading, enhanced natural ventilation, utilization of thermal mass, and the application of cool roofs as highly effective in minimizing cooling energy requirements. By reducing dependency on mechanical cooling systems, these methods help to lower operational energy consumption significantly. The authors emphasized that adopting passive design strategies not only curtails energy use and associated costs but also contributes meaningfully to climate change mitigation efforts. Through decreased greenhouse gas emissions and improved indoor environmental quality, passive design ultimately enhances the sustainability and resilience of the built environment. Oleiwi & Mohamed advocated for the integration of passive design principles as foundational in architectural practice, particularly in regions facing intense heat and growing energy demands. Their findings reinforced passive design as an essential pathway toward achieving more sustainable, climate-adaptive buildings.

Zhang et al. (2018) studied biophilic design and climate change adaptation in urban environments. The work was published by the Journal of Cleaner Production, and indexed in Scopus. The study examined how biophilic design strategies can contribute to heat effect mitigation, and thermal resilience of the built environment. The key findings from the study included:

i. Vegetation, green roofs, and vertical greenery reduce surface temperatures, thereby enhancing thermal comfort and reducing cooling loads.
ii. Biophilic elements like rain gardens, permeable pavements, and bioswales improve water absorption and reduce runoff.
iii. The integration of nature improves mental health, productivity, and overall well-being of urban residents.
iv. The integration of biophilic design with urban planning enhances ecological resilience and the adaptive capacity of cities.

Amirhosein et al. (2022) studied the influence of biophilic design on building sustainability and occupant well-being. The work was published by the Journal of Building Engineering, indexed in Scopus. The authors adopted a systematic review and over 60 peer-reviewed articles on biophilic design's impact on building sustainability and occupant well-being were studied. The key findings are:

i. The incorporation of biophilic elements such as green roofs, living walls, and natural ventilation reduces heating, cooling and lighting demands, thereby saving energy by between 10 – 25%.
ii. Building with biophilic features improves indoor air quality, daylight access, thermal comfort, and acoustic performance.
iii. Biophilic design integrates ecosystem services into the urban environment, thereby promoting climate adaptation strategies.
iv. Biophilic design supports building sustainability.

3.2.1. Summary and contributions from other scholars

Biophilic architecture emphasizes nature-based integration within the built environment, enhancing psychological well-being, biodiversity, and environmental quality. Green roofs, living walls, natural ventilation, and visual connections to nature all serve to regulate indoor temperatures and reduce energy use. Biophilic design also promotes improved indoor air quality and microclimate regulation (Ochedi, 2023). The design utilizes natural energy flows such as solar radiation, air movement, and thermal mass to maintain indoor comfort without mechanical heating or cooling. This approach includes orientation optimization, natural ventilation, daylighting, shading devices, and thermal insulation. Such strategies reduce operational energy demand and subsequently lower greenhouse gas emissions (Oleiwi & Mohamed, 2022). Thermal insulation minimizes heat exchange between indoor and outdoor environments, thus stabilizing internal temperatures. Ventilation enhances indoor air quality and prevents the buildup of pollutants and excess humidity. It also controls air movement and temperature, thereby contributing to indoor thermal comfort while requiring efficient energy use. Lighting also plays a crucial role in energy conservation. Building orientation and reflective materials also support daylight harvesting and indoor lighting efficiency. Passive design strategies can reduce operational energy consumption by 20–40% in temperate climates (Zang et al., 2018).

3.3 Integration of renewable energy sources

The targeted literature studied was searched with the keywords "Renewable Energy Integration and Climate Change Mitigation" across leading academic databases: Scopus and Elsevier. The search specifically focused on renewable energy integration in the built environment with proven or potential ability to mitigate climate change. While numerous articles were identified, four articles were selected for study based on full-text accessibility and relevance to the research scope.

Attia et al. (2018) presented a thorough evaluation and comparative analysis of Net Zero Energy Building (NZEB) initiatives implemented throughout Europe. Their work, published in the Journal of

Energy and Buildings and indexed in both Scopus and Elsevier, provided deep insights into the regional variations and performance dynamics of NZEBs in the European context. The study introduced two comprehensive benchmark models, meticulously developed to assess and compare NZEB projects across diverse European settings. These models were distinguished by their integration of:

i. **Climate Zone Variations**: Recognizing the heterogeneity of Europe's climates, the models account for site-specific external conditions, ranging from Nordic to Mediterranean environments.
ii. **Building Envelope Characteristics**: Detailed parameters include insulation levels, glazing performance, airtightness, and thermal bridging, all of which critically impact heating and cooling loads.
ii. **HVAC (Heating, Ventilation, and Air Conditioning) System Efficiencies**: The models closely examined how diverse heating, cooling, and ventilation strategies shape overall energy use, tailoring energy solutions to local requirements.
iii. **Renewable Energy Systems**: Various renewable technologies, such as photovoltaics, solar thermal systems, and ground-source heat pumps, are considered for their ability to offset building energy demand and achieve NZEB targets.

Key Findings:

i. The analysis revealed pronounced disparities in energy performance among NZEB initiatives across Europe, underscoring the influence of both regional climate differences and national building practice traditions.
ii. The results attributed much of the observed performance variance to the selection and optimization of HVAC systems and renewable energy technologies, both of which must be carefully matched to local climatic and operational contexts.
ii. NZEB projects succeed when solutions are tailored not only to policy requirements but also to the specific climatic, technical, and regulatory environment of each location.
iii. The dual benchmark approach offers policymakers and practitioners a valuable framework for performance assessment, supporting the refinement of NZEB standards and the transfer of best practices across European countries.

The authors suggested the following:

i. Climate-responsive and context-specific approaches to building envelope design, HVAC selection, and renewables integration.
ii. Enhanced benchmarking and knowledge-sharing to harmonize NZEB principles while respecting unique regional challenges.
iii. Ongoing revision of standards to reflect emerging technologies and lessons learned from real-world implementations.

The International Energy Agency (IEA), in its flagship 2021 report: Net Zero by 2050. A Roadmap for the Global Energy Sector presented a comprehensive, science-based strategy to align the global energy system with the 1.5 °C limit on global temperature rise. Sourced directly from the IEA, this roadmap provides a milestone-filled pathway for decarbonizing the energy sector, which accounts for approximately 75% of global greenhouse gas emissions.

Key Findings and Strategic Pillars

i. A complete transformation of existing energy systems is essential to meet net-zero by 2050.
ii. Immediate and sustained reductions in fossil fuel use are critical. The roadmap calls for no new oil, gas, or coal exploration or supply projects beyond 2021.
iii. By 2040, unabated coal-fired power plants must be retired or retrofitted with carbon capture, utilization, and storage (CCUS).
iv. Annual clean energy investments must triple by 2030. This includes aggressive scaling of renewable energy infrastructure, especially solar PV and wind power to displace fossil fuel-based electricity.
v. Rapid deployment of these technologies is at the heart of the net-zero pathway.
vi. Electrification is identified as a primary lever; the widespread adoption of electric vehicles (EVs) and heat pumps is vital to reduce oil and gas consumption and decarbonize end-use sectors.
vii. The advancement and commercialization of emerging technologies (e.g., advanced batteries, low-carbon hydrogen production, and CCUS) are pivotal to achieving residual emission reductions by mid-century.
viii. Significant R&D and targeted policy support are needed to accelerate the maturation and global adoption of these innovations.
ix. Global progress hinges on robust international collaboration, with developed economies supporting developing and emerging nations through finance, technology transfer, and capacity-building to facilitate their transitions.
x. Sustainable buildings should be at the forefront of the energy transition, integrating renewable energy technologies, deep energy efficiency measures, and electrification wherever possible.
xi. Adoption of emerging digital solutions such as the Internet of Things (IoT), smart controls, and building automation is recommended to maximize efficiency gains and support real-time energy management. The roadmap emphasizes the need for all new buildings to be highly energy-efficient, fossil-fuel-free, and equipped for renewable generation by 2030.

The IEA's Net Zero by 2050 roadmap provides a clear, actionable blueprint for the global energy transition, underscoring the scale, speed, and systemic change required to keep the 1.5 °C goal within reach. Success will demand coordinated action across governments, industries, and civil society, with the built environment playing an integral role in driving emissions reductions, fostering innovation, and realizing a sustainable, resilient future.

Gou et al. (2018), in their comprehensive review published in Renewable and Sustainable Energy Reviews (ScienceDirect), examined the adoption of renewable energy technologies specifically in the building sector. They analyzed key drivers**,** barriers**, and** policy implications associated with technologies such as Solar Photovoltaic (PV) systems, Solar Thermal, Wind energy integration at building scale, and Hybrid renewable systems. Their main findings are:

i. Drivers include ongoing technological advancements, heightened environmental concerns, economic incentives, and climate change mitigation targets aimed at sustainable development.
ii. Barriers consist of high upfront installation and integration costs, particularly for retrofitting existing buildings, lack of awareness or expertise among building owners and developers, policy gaps, fragmented regulations, and insufficient government commitment in certain regions.
iii. They emphasized the need for consistent, long-term government policy frameworks to build market confidence and stabilize investments.
iv. The study advocated for the incorporation of renewable energy mandates into building codes and certification systems such as LEED and BREEAM to standardize and incentivize sustainable practices.
v. Promoting public-private partnerships is highlighted as critical to scaling renewable energy adoption within urban environments.

The study underscored renewable energy integration in buildings as a vital strategy to achieve low-carbon, climate-resilient built environments, aligning with UN Sustainable Development Goals (SDG) 7 (Affordable and Clean Energy) and 13 (Climate Action).

Zhao et al. (2019) conducted a critical review of green building assessment tools, focusing on their effectiveness in evaluating lifecycle energy use and carbon emissions with the aim of identifying gaps and recommending improvements for climate change mitigation in the built environment. Their review, published in Environmental Impact Assessment Review and indexed on ScienceDirect, highlighted several key findings:

i. Most green building tools such as LEED, BREEAM, and CASBEE concentrate primarily on operational energy and emissions, with relatively few incorporating comprehensive assessments of embodied energy and carbon associated with construction materials and processes.
ii. The inclusion of a full LCA is crucial to accurately capturing the environmental impact of buildings. However, significant variation in the methodological assumptions including system boundaries and data sources exists among tools, causing inconsistencies in outcomes.
iii. There is no widely accepted metric for embodied carbon assessment. Additionally, demolition, recycling, and end-of-life stages are often neglected in assessments. Many regionally focused tools do not align well with global climate impact frameworks.

Zhao et al. recommended the following to strengthen green building assessment tools:

i. All green building assessments should incorporate embodied energy and the impacts associated with building demolition, recycling, and disposal.

ii. Harmonized and standardized approaches to lifecycle assessment should be developed to improve the comparability and reliability of results across different tools.
iii. Policies mandating full lifecycle carbon evaluations are essential to support the achievement of low-carbon building targets.
iv. The authors assert that achieving net-zero carbon buildings requires assessment frameworks capable of comprehensively evaluating both operational and embodied emissions. Enhancing these tools will empower more informed design, construction, and policymaking decisions geared toward climate change mitigation and sustainable development.

Thus, Zhao et al.'s review underscored fundamental limitations in existing green building assessment tools and charts a clear path forward emphasizing lifecycle inclusivity, standardization, and policy support to drive impactful climate action in the built environment.

3.3.1 Summary and Contributions from Other Scholars

Integrating renewable energy systems into building design is a fundamental strategy for climate change mitigation, significantly reducing the carbon footprint associated with energy consumption within the built environment. On-site generation of clean energy such as photovoltaic (PV) panels, solar thermal systems, and small-scale wind turbines contribute directly to achieving carbon neutrality in buildings. These technologies help in displacing the demand for grid-supplied electricity, which is often generated from fossil fuels. According to Zhao et al. (2019), buildings equipped with solar energy systems can offset up to 70% of their annual electricity demand, thus playing a crucial role in decarbonization efforts. Advancements in battery energy storage systems (BESS), when integrated with smart grid technologies, further enhance the effectiveness of these renewable systems by optimizing energy usage patterns and providing backup during peak demand or grid outages. These developments support the widespread adoption of net-zero energy buildings (NZEBs); buildings designed to produce as much renewable energy on-site as they consume over a year, thereby aligning the built environment with long-term climate action goals (Attia et al., 2018; IEA, 2021).

3.4 Waste Management Systems in Sustainable Buildings

The targeted literature studied was searched with the keywords "Waste Management System and Climate Change Mitigation" across leading academic databases: Scopus, Web of Science, and Google Scholar. The search specifically focused on renewable energy integration in the built environment with proven or potential ability to mitigate climate change. While numerous articles were identified, four articles were selected for study based on full-text accessibility and relevance to the research scope.

The International Energy Agency (2023) report on Global waste outlook for construction and demolition was sourced from the IEA website and is accessible through institutional subscriptions and aggregated in research libraries. The key insights revealed that nearly 2 billion tonnes of construction and demolition (C&D) waste is generated annually, making it one of the largest single waste streams. C&D activities contribute significantly to the embodied carbon footprint of buildings. The productions of construction materials such as cement, steel, and aluminum are responsible for approximately 7% of global energy system emissions. To align with net-zero energy goals under the IEA building roadmap, C&D waste must be managed through circular economy strategies which include material reuse, recycling, and recovery, and embedded in whole-life carbon accounting. Hence, buildings and operations account for 33% of total energy system emissions. Improvements in energy efficiency and emissions reduction can be achieved by policy and global collaboration, especially in emerging and developing economies. Enhanced deconstruction, recycling, and reuse systems are needed to manage C&D waste sustainably. To achieve Sustainable Built Environment Projects, the following roadmap is needed:

i. Reduction of embodied emissions through proactive C&D waste management for achieving net-zero energy buildings.
ii. ii Promotion of alignment with SDG 11 (Sustainable Cities) and SDG 12 (Responsible Consumption & Production); by embedding circular economy strategies into policy and practice.
iii. The adoption of Integrated Environmental Design (IED) and lifecycle assessment frameworks in green building protocols and urban development plans.

Boukherroub et al (2024) designed a sustainable deconstruction model for minimizing environmental impacts in the construction industry. The work was published in the Journal of Cleaner Production, indexed in Scopus and the Web of Science. The authors designed a multi-objective optimisation model for deconstruction. This model was applied to five real case studies across Brazil, Canada, China, Nigeria, and Switzerland, and the evaluation was based on environmental impact, economic costs and recovered material volume and resale revenue. The model maximizes recovery of materials while keeping environmental and financial costs within acceptable bounds. Effectiveness varies by context. The highest recovery/revenue was achieved in Switzerland and Canada due to supportive regulations and infrastructure. The highlights of deconstruction strategies include logistics optimization, recycling center, transport planning, and material selection. The study emphasized that large components like doors and beams offer higher value than numerous small items. The study suggested that the strategies should be based on local regulation, labor cost structures, and market demand for reclaimed materials. The project was designed to achieve: Quantitative framework for sustainable deconstruction aligned with circular economy principles, and effective policy advocacy for design-for-deconstruction, material recovery incentives, and multidimensional evaluation. Also, scalability across diverse regions; this is relevant for global best practices in climate-resilient built environments.

Sakcharoen et al (2021) carried out an assessment of green building waste management strategies in construction practices. The work was published in the Journal of Waste Management & Research, indexed in Scopus, Web of Science, Google Scholar. The study assessed the effectiveness of green building waste management strategies within construction practices for the promotion of sustainable waste reduction. The study engaged in qualitative and quantitative assessment of waste management practices within certified green building projects, reviewed construction waste management plans (CWMPs) and also conducted surveys with site managers and waste management professionals. The key findings showed that:

i. Green building projects had higher rates of material recovery (e.g. concrete, steel, timber) than conventional projects.
ii. Integration of waste management into the design stage significantly reduced overall waste generation.
iii. The challenges of green building projects include few skilled personnel, inadequate recycling facilities, and low market demand for recycled materials.

The authors emphasized the need for stricter enforcement of construction waste management policies, incentives for recycling, and investment in waste-processing infrastructure. The benefits of green building projects for a Sustainable Built Environment are:

i. Provision of Sustainable Materials Management (SMM) and circular economy approaches inconstruction.
ii. Reinforcement of the critical role of waste segregation, design for deconstruction, and inculcation of the benefits in achieving zero-waste.
iii. Boosting climate change mitigation through reduction of greenhouse gas emissions from C&D waste

Lee (2024) conducted a comprehensive global assessment of construction and demolition (C&D) waste management practices, providing critical insights into current generation rates, environmental and human health impacts, and the effectiveness of various waste mitigation strategies. The study meticulously evaluated recycling, reuse, and circular economy frameworks as pivotal solutions to the escalating C&D waste challenge. The work was published in Journal of Cleaner Production, indexed in ScienceDirect.

Key findings highlighted that:

i. Recycling and reuse play a crucial role in significantly reducing landfill volumes, thereby mitigating associated environmental hazards such as soil contamination, groundwater pollution, and greenhouse gas emissions.
ii. Circular economy approaches including design for disassembly, enhanced material recovery, and closed-loop recycling systems have substantial potential to minimize embodied carbon emissions embedded in construction materials, fostering sustainable resource utilization.

iii. The research underscored the urgent need for integrated policy frameworks that promote innovation in recycling technologies, alongside comprehensive stakeholder education and engagement, to effectively facilitate the transition from traditional linear waste management models to sustainable circular systems.

iv. Ultimately, the study concluded that widespread adoption of these strategies not only advances climate change mitigation and environmental protection efforts but also aligns closely with the United Nations Sustainable Development Goals, particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).

This work sets a robust foundation for policymakers, industry practitioners, and researchers to collaboratively drive the evolution toward more sustainable and resilient C&D waste management paradigms worldwide.

3.4.1 Summary and Contributions from Other Scholars

Construction and demolition (C&D) activities contribute significantly to global waste streams, often comprising more than one-third of total solid waste generated worldwide (IEA, 2023). As part of climate change mitigation strategies, green building frameworks increasingly emphasize the adoption of waste reduction techniques through material recovery, reuse, and recycling. The zero-waste concept aligns with Sustainable Materials Management (SMM)**,** which promotes a circular economy approach by encouraging lifecycle designed buildings for adaptability, disassembly, and material recovery rather than linear consumption (Sakcharoen et al., 2021). One of the core practices under this paradigm is deconstruction, a strategic alternative to conventional demolition. Deconstruction involves the systematic dismantling of buildings to maximize material reuse and recycling, thereby minimizing C&D waste and reducing the demand for virgin materials (Boukherroub et al., 2024). This process not only limits resource extraction but also significantly lowers greenhouse gas (GHG) emissions associated with material manufacturing and landfill disposal. Additionally, effective sewage systems**,** organic waste management**,** and anaerobic digestion technologies are increasingly integrated into green building practices to tackle methane emissions (greenhouse gas). Anaerobic digestion processes convert biodegradable waste into biogas, which can be used as a renewable energy source, thus contributing to energy efficiency and emission reductions (Wu et al., 2016). Furthermore, green buildings are designed to optimize energy and resource consumption while minimizing environmental impact, fostering high-performance environments that prioritize occupant well-being and ecological sustainability..

3.5 Smart and Intelligent Technology

The targeted literature studied was searched with the keywords "Smart and Intelligent Technology and Climate Change Mitigation" across leading academic databases: Scopus and Web of Science. The search specifically focused on renewable energy integration in the built environment with proven or potential ability to mitigate climate change. While numerous articles were identified, four articles were selected for study based on full-text accessibility and relevance to the research scope.

Randall, T. (2022) delivered an in-depth exploration of how digital twin technology is transforming smart infrastructure management, elevating operational efficiency, and driving energy optimization across the built environment. This pivotal work, published in Smart Cities and indexed in both Scopus and Web of Science, synthesizes extensive literature and offers conceptual analysis on the adoption and impact of digital twins in both buildings and urban infrastructure. A digital twin is defined as a dynamic, virtual replica of physical assets such as buildings or entire urban systems synchronized in real time with the physical counterpart via integrated sensor data streams. This enables ongoing monitoring, advanced simulation, and predictive analytics, all of which profoundly enhance decision-making capabilities in facility and infrastructure management.

Key Findings:

i. Digital twin frameworks enable real-time monitoring and adaptive management of building systems.
ii. Through integration with HVAC and other subsystems, digital twins facilitate dynamic energy management, predictive maintenance, and operational fault detection, resulting in substantial energy savings and improved facility performance.
iii. The technology supports adaptive control of energy and resource use, leading to reductions in operational costs and optimization of utilities.
iv. It further underpins enhanced climate resilience, empowering cities and building operators to proactively manage demand, reduce emissions, and swiftly respond to evolving environmental and operational challenges.
v. Randall identifies challenges such as data interoperability, high implementation costs, cybersecurity vulnerabilities, lack of standardized frameworks and protocols.

Randall concluded that digital twins are the cornerstone technology for achieving a sustainable built environment, offering a high-impact pathway toward net-zero carbon goals and efficient resources management at both building and city scales. The review underscored digital twins' potential in supporting smart city initiatives, urban resilience planning, and proactive facility management. These advancements directly align with Sustainable Development Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action), reinforcing digital twins' role in global sustainability and climate mitigation strategies.

Prusak et al. (2021) conducted a rigorous investigation into the synergistic integration of real-time control systems (RTCS) with intelligent building envelope technologies: a promising trajectory towards achieving zero energy buildings. Their comprehensive review, published in the Energy and Buildings Journal and indexed in both Scopus and Web of Science, systematically analyzed contemporary literature and real-world case studies to uncover the dynamic potential of these technologies for optimizing building energy performance.

Core Insights

i. Significant energy savings are achieved through the deployment of RTCS, which enables continuous monitoring and adaptive adjustment of HVAC systems, lighting, and other building components.
ii. These systems respond instantly to changes in occupancy patterns, external weather conditions, and indoor environmental factors, ensuring that operational parameters are always optimized for current needs.
iii. Utilizing smart materials such as electrochromic (tintable) glass, advanced dynamic insulation, and responsive shading devices allows for precise control over thermal loads.
iv. These adaptive systems help regulate heat gain and loss, reducing the reliance on mechanical heating and cooling and leading directly to lower energy consumption.
v. Combining RTCS with adaptive envelopes amplifies benefits such as improved thermal comfort for occupants, decreased energy use due to real-time optimization and dynamic responsiveness.

The research highlighted that integrated RTCS and intelligent envelopes are essential for closing the gap between theoretical building performance (design intent) and actual operational outcomes. These technologies make it realistic to achieve net-zero operational energy consumption in practice, moving the building sector closer to long-term sustainability goals.

Farid Shahsavar's 2025 study, published in the Journal of Design Studio (indexed in Google Scholar, ScienceDirect, and Scopus), presented a holistic approach to green hospital architecture that integrated sustainable design principles, cutting-edge smart technologies, and green certification systems tailored specifically for healthcare environments.

The key contributions of Shahsavar's work included:

i. The article emphasized the use of passive design techniques, renewable materials, and water conservation measures adapted for healthcare settings. These approaches not only reduce ecological impact but also enhance patient well-being by improving indoor environmental quality factors such as air quality, lighting, and acoustics, which are critical for recovery and staff performance.
ii. Advanced building management systems (BMS), IoT-enabled occupancy monitoring, AI-driven energy optimization, and adaptive control of ventilation and lighting are identified as essential tools for achieving operational efficiency while maximizing environmental performance. For example, using IoT data to adjust HVAC systems in real time according to occupancy patterns helps minimize energy waste without compromising comfort or safety.
iii. The study reviewed certifications such as LEED, WELL, and Green Globes, demonstrating their role in setting performance benchmarks and steering design decisions during hospital construction and renovations. These certifications also promote integrated design processes that involve multidisciplinary collaboration, essential for complex hospital projects.

Shahsavar further provided case examples of hospitals successfully merged sustainable design with smart technologies. The study concluded that embedding smart technologies within sustainable hospital designs boosts energy savings and ecological performance, while also fostering resilience and higher healthcare infrastructure standards especially critical given hospitals' need to function continuously during emergencies and disasters.

Cosimo Magazzino (2025), examined the critical role of Smart Active Buildings (SABs) enhanced by Artificial Intelligence (AI) in mitigating greenhouse gas emissions caused by rising energy use in buildings worldwide. SABs integrate AI algorithms with sensor networks embedded in building infrastructure to dynamically optimize energy consumption related to heating, cooling, lighting, and other systems based on real-time occupancy and environmental conditions. The article appears in the Journal of Sustainability, an open-access interdisciplinary journal indexed in Google Scholar and other academic databases focused on sustainability research.

The key features and Technologies of SABs highlighted by the author included:

i. AI-enabled sensor data analysis for adaptive building system control.
ii. Real-time occupancy and external condition monitoring.
iii. Predictive energy demand forecasting models.
iv. Integration and intelligent management of renewable energy resources.
v. Alignment with environmental standards and sustainable development imperatives

The key findings:

i. SABs dynamically optimize energy consumption related to heating, cooling, lighting, and other systems based on real-time occupancy and environmental conditions.
ii. SABs reduce energy waste by intelligently managing systems for optimal indoor thermal comfort while minimizing energy input. They can forecast energy demand through predictive analytics, enabling proactive adjustments that reduce reliance on carbon-intensive power sources during peak load times.
iii. SABs facilitate seamless integration of renewable energy sources (solar panels, wind turbines) into the building's energy grid. AI controls maximize the use of clean energy and manage energy storage efficiently.
iv. SABs contribute to achieving the United Nations' Sustainable Development Goals (SDGs) by improving energy efficiency, lowering carbon footprints, and promoting environmental sustainability in the built environment.

This work provided a blueprint for future building designs where structures actively participate in carbon footprint reduction by blending AI intelligence with renewable energy and advanced building management systems, positioning smart active buildings as pivotal for climate change mitigation in the built environment

3.5.1 **Summary and contributions from other scholars**

Emerging energy-efficient technologies are playing an increasingly significant role in reducing the operational energy demand of buildings and enhancing climate resilience. A wide range of innovative systems are now integrated into building design to optimize performance and reduce environmental impacts. For instance, thermoelectric systems, smart heating controls, and real-time monitoring tools allow for continuous adjustments based on usage and climate patterns, leading to significant reductions in energy consumption (Irshad et al., 2019; Prusak et al., 2021). Double or triple glazing, reflective roofs, and airtight envelopes reduce thermal losses, while improved insulation in walls and roofs minimizes heating and cooling loads (Attia et al., 2019). Advanced heating, ventilation, and air conditioning (HVAC) systems such as variable refrigerant flow (VRF) units, geothermal heat pumps, and energy recovery ventilators are essential components of modern energy-efficient buildings. These systems maintain indoor air quality while consuming significantly less energy. Buildings can adapt to energy using national systems (Jradi et al., 2018). When integrated with smart technologies such as occupancy sensors dynamically based on actual occupancy and environmental conditions, smart or intelligent buildings incorporate Internet of Things (IoT) technologies, artificial intelligence (AI), machine learning, and digital twin frameworks to enable proactive energy management and real-time operational optimization (Randall, 2022). Adaptive building envelopes respond to external conditions such as solar gain and humidity, while centralized building automation systems (BAS) integrate data from sensors to manage lighting, HVAC, and water usage efficiently. These technologies not only reduce operational costs and emissions but also enhance occupant comfort and productivity (Prusak et al., 2021). Ultimately, intelligent building technologies are the cornerstone of climate-responsive architecture. They enhance resilience, reduce greenhouse gas emissions, and align building operations with global sustainability and net-zero energy goals.

4.0 Discussion

Studies carried out consistently affirmed that integrating green building materials within built environments effectively reduces a structure's embodied carbon footprint, thereby, underscores their vital role in climate change mitigation. These materials not only lower carbon emissions but also maintain or enhance construction performance. Insulation materials such as reclaimed wood, recycled aggregates, low-emission finishes, Metabrick, fly ash, and ground granulated blast-furnace slag demonstrated strong potential in reducing embodied carbon. In additional, the studies assured that fiberglass quilts, aerated concrete, reflective foils, and expanded polystyrene significantly enhance thermal insulation, decrease energy requirement for heating and cooling, thereby reducing greenhouse gas emissions. The integration of renewable energy technologies such as solar photovoltaics and wind turbines directly into building design markedly reduces reliance on fossil fuels and grid electricity. The result is a substantial decrease in the operational carbon footprint and the realization of net-zero energy objectives. Such integrations are recognized not just as environmental imperatives, but as viable technical and economic strategies that foster energy security. Also, it helps to decarbonize the construction sector and supports national and international climate commitments.

The studies affirmed that circular waste management models, green building standards, and advanced waste treatment technologies present effective climate change mitigation routes. Embracing these measures supports the development of resilient, low-carbon cities, while also addressing broader environmental goals and facilitating sustainable urban growth.

The studies supported the report that Intelligent systems such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning, and Digital Twins have the capability to optimize building operations, achieve net-zero energy outcomes, and tangibly lower operational emissions. Moreover, Advanced HVAC systems further contribute to sustainability by harnessing renewable energy sources, improving energy efficiency, and, in some cases, capturing waste heat for recovery and reuse. The literature assessed agreed that these innovations simultaneously enhance indoor environmental quality and occupant health, therefore, driving both climate and human-wellbeing benefits.

Collectively, these advances underpin a new era of sustainable design and construction, positioning the built environment as a powerful lever in addressing climate change, realizing international agreements, and building a resilient, low-carbon future.

5. **Conclusion and Recommendations**

In conclusion, the built environment remains a critical sector in the campaign against climate change, given its substantial operational energy demands, resource consumption, and greenhouse gas emissions. Integrating sustainable construction practices such as the use of low-carbon and recycled materials, bio-based components, and renewable energy systems can markedly diminish the environmental footprint of buildings. Furthermore, the adoption of advanced energy-efficient technologies and intelligent building management systems presents a transformative opportunity to optimize operational performance, cut emissions, and enhance resilience to climatic shifts. Embracing circular economy principles in construction and demolition waste management further advances sustainability by encouraging material reuse, minimizing landfill waste, and reducing embodied carbon. Innovations in high-performance insulation, emerging HVAC systems, and smart control mechanisms underscore the importance of designing buildings that are not only energy-efficient but are also responsive to occupant needs and adaptable to dynamic climate conditions.

i. Ultimately, the shift toward climate-responsive architecture through integrating green materials, smart technologies, and renewable energy solutions represents a comprehensive strategy for decarbonizing the built environment. This paradigm shift supports international sustainability Prioritize investment in Material Science and Construction Innovation**:** Policymakers and industry leaders should actively invest in material science research and construction innovation to accelerate the development of next-generation low-carbon, biodegradable, and bio-based building materials. Support should also extend to the advancement of cutting-edge energy-efficient technologies, fostering an ecosystem of sustainable construction practices.

ii. Implement incentives and tax waivers:
Governments and regulatory bodies should introduce robust incentive schemes and tax waivers for individuals and organizations that adopt on-site renewable energy systems and utilize recycled or low-carbon construction materials. Such financial support will help stimulate wider adoption, reduce initial investment barriers, and drive market transformation toward greener built environments.

iii. Promote Integration of Climate-Responsive and Passive Design Strategies**:**
The integration of climate-responsive architecture, including passive design strategies that optimize natural ventilation, daylighting, and thermal performance, should be actively encouraged. Building codes and standards should be updated to reward or mandate passive design approaches that reduce energy demand while enhancing occupant comfort.

iv. Enhance Public Awareness and Education Campaigns:
Comprehensive public awareness programs are needed to sensitize communities, industry professionals, and stakeholders about the benefits of energy efficiency and the sustainable use of resources in the built environment. Educational initiatives, workshops, and outreach campaigns can foster a culture of sustainability and empower informed decision-making at all.

References

Aketouane, Z., Malha, M., Bruneau, D., Bah, A., Michel, B., Asbik, M., & Ansari, O. (2018). Energy savings potential by integrating Phase Change Material into hollow bricks: The case of Moroccan buildings. *Building Simulation* 11(6), 1109 - 1122.

Amirhosein, S., Mahdavinejad, M., & Ostovar, A. (2022). The influence of biophilic design on building sustainability and occupant well-being: A systematic review. Journal of Building Engineering, 46, 103765. https://doi.org/10.1016/j.jobe.2021.103765

Aslam, M., & Rana, I. A. (2022). Climate change and the built environment: A review of impacts and adaptations. *Journal of Environmental Management*, *304*, 114234 https://doi.org/10.1016/j.jenvman.2021.114234

Attia, S., Evrard, A., & Gratia, E. (2018). Developing two benchmark models for the comparison of NZEB initiatives in Europe. *Energy and Buildings, 45*(1), *16–26*. https://doi.org/10.1016/j.enbuild.2018.03.003

Boukherroub, T., Ait-Kadi, D., & Chatelet, E. (2024). A sustainable deconstruction model for minimizing environmental impacts in the construction industry. Journal of Cleaner Production, *419*, 139711. https://doi.org/10.1016/j.jclepro.2023.139711

Chinda, T., & Ikiroma, A. (2022). Green roof performance for building energy efficiency:A review. Renewable and Sustainable Energy Reviews, 160, 112302. https://doi.org/10.1016/j.rser.2022.112302

Diego Peñaloza, Martin Erlandsson, Andreas Falk (2016). Exploring the climate impact effects of increased use of bio-based materials in buildings, Construction and Building Materials, 125, 219 - 226, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2016.08.041

Gou, Z., Xie, X., & Lu, Y. (2018). Renewable energy in the building sector: drivers, barriers, and policy implications. Renewable and Sustainable Energy Reviews, 81, 1276 – 1285. https://doi.org/10.1016/j.rser.2017.05.240

Hamin, E. M., & Gurran, N. (2009). Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. *Habitat International, 33*(*3*), *238–245*. https://doi.org/10.1016/j.habitatint.2008.10.005

IEA & UNEP. (2022). *2022 Global Status Report for Buildings and Construction: Towards a* zero-emission, efficient and resilient buildings and construction sector. International Energy Agency & United Nations Environment Programme.

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate change 2007: Mitigation of climate change. *Cambridge University Press.*

Internal Panel Climate Change (2023). Climate Change 2023*:* Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

International Energy Agency (IEA). (2021). *Net zero by 2050: A roadmap for the global energy sector*. https://www.iea.org/reports/net-zero-by-2050

International Energy Agency (IEA). (2023). Global waste outlook for construction and demolition. https://www.iea.org/reports/global-cd-waste

Irshad, K., Khan, Z. A., & Tariq, M. (2019). Smart energy-efficient building systems: Integration of building automation system with renewable energy and storage systems. *Sustainable Cities and Society*, *45*, *116-123*. https://doi.org/10.1016/j.scs.2018.11.030 technologies for waste heat recovery in buildings. Renewable and Sustainable Energy Reviews, 107, 473–484. https://doi.org/10.1016/j.rser.2019.03.029

Jradi, M., Veje, C., & Jørgensen, B. N. (2018). Deep energy renovation of the Danish residential building stock: A multi-level cost-benefit analysis. *Energy and Buildings, 158, 173–188.* https://doi.org/10.1016/j.enbuild.2017.10.031

Jay H. Arehart, Jim Hart, Francesco Pomponi, Bernardino D'Amico (2021). Carbon sequestration and storage in the built environment, Sustainable Production and Consumption, 27, 1047 - 1063, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2021.02.028.

Kolawole, A., & Okonkwo, F. (2022). Microclimates in urban settings: A study of environmental performance in tropical cities. Journal of Environmental Management, 315, *115–126.* https://doi.org/10.1016/j.jenvman.2022.115126

Lee, S. (2024). Construction and demolition waste management and its impacts on the environment and human health: Moving towards sustainability enhancement. *Journal of Cleaner Production*. Advance online publication. 16, 2014

Lemkalli, H., Elhaddadi, B., & Aït Ahsaine, H. (2023). Metabrick: A novel sustainable building material with enhanced thermal and acoustic performance. Construction and Building Materials, 376, 131081. https://doi.org/10.1016/j.conbuildmat.2023.131081

Liu, Z., Osburg, V. S., & Lange, J. (2021). Reducing embodied carbon through bio-based construction materials: A literature review and future research agenda. Sustainable Cities and Society, 64*(*10) 25 - 56. https://doi.org/10.1016/j.scs.2020.102556

Magazzino, C. (2025). Towards Smart Active Buildings for Reducing Carbon Footprint and Achieving Sustainable Development Through Artificial Intelligence. Journal of Sustainability. Available via the Journal of Sustainability website

Ochedi, E. T. (2023). The role of biophilic design in enhancing sustainable building practices. Sustainable Cities and Society, 89, 104285. https://doi.org/10.1016/j.scs.2022.104285

Oleiwi, S. M., & Mohamed, Y. A. (2022). Passive design strategies for energy-efficient buildings in hot climates. Journal of Building Engineering, 45, 103453. https://doi.org/10.1016/j.jobe.2021.103453

Prusak, A., Kobyliński, A., & Dziadosz, A. (2021). Real-time control systems and intelligent building envelopes: A path toward zero energy buildings. Energy and Buildings, 236, 110784. https://doi.org/10.1016/j.enbuild.2021.110784

Ramage, M. H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D. U., ... & Scherman, O. (2017). The wood from the trees: The use of timber in construction. Renewable and Sustainable Energy Reviews, 68*(1), 333–359.* https://doi.org/10.1016/j.rser.2016.09.107

Randall, T. (2022). Digital twins in the built environment: Smart infrastructure and energy efficiency. Smart Cities, *5*(3*), 477–493*. https://doi.org/10.3390/smartcities5030025

Sakcharoen, W., Charoenkit, S., & Kongboon, R. (2021). Assessment of green building waste management strategies in construction practices. Waste Management & Research, 39(12), 1482–1495. https://doi.org/10.1177/0734242X211039228

Shahsavar, F. (2025). Integrating Sustainable Design, Smart Technologies, Certification in Green Hospital Architecture. Journal of Design Studio, 7(1), 207–216.

Tyagi, V. V., & Buddhi, D. P. C. M. (2007). PCM thermal storage in buildings: A state of art. Renewable and sustainable energy reviews, 11(6), 1146 – 1166

United Nations Environment Programme (UNEP). (2022). Building resilience: The role of buildings in addressing climate change. https://www.unep.org

Vijayan, R., Sharma, S., & Prasad, S. (2021). Emerging building materials for sustainable construction: The case of metabricks. Journal of Building Performance, *12*(3), 127–138.

Wu, P., Low, S. P., & Xia, B. (2016). Examining the determinants of green building waste reduction: A framework for developing sustainable construction practices. Resources, Conservation and Recycling, 107, 122–132. https://doi.org/10.1016/j.resconrec.2015.11.007

Zhang, Y., Lahr, M. L., & Kleinschmit, D. (2018). Biophilic design and climate change adaptation in urban environments. Journal of Cleaner Production, 172, 3711–3719

Zhao, D., Zuo, J., Wu, G., & Huang, C. (2019). A critical review of lifecycle energy use and carbon emissions of green building assessment tools. Environmental Impact Assessment Review, 72, 85–93.