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Innovative Strategies for Energy Efficiency in the Construction Industry

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Abstract
The construction industry has consistently been among the largest consumers of energy globally. Construction uses between 20–40% of the total energy demand in many developed countries. Additionally, the construction industry is responsible for 36% of the world's energy-related greenhouse gas emissions. As we move further into a period of urbanization, coupled with rapid growth in emerging economies, the imperative for energy-efficient, sustainable construction is even greater. This research engages with the relevant literature posing a systematic review and synthesis of recent advances in energy-efficient strategies in the construction sector, with a focus on emerging materials, passive and active design strategies, smart technologies, and renewable energy technologies or schemes for policy enabling. This study employs systematic review methods, screening 560 academic records from 2015–2024, devoted to energy efficient strategies within construction contexts, arriving at 35 quality studies in different contexts around the world. The study indicated, in its findings, the transformative advantages in energy reduction that can accrue from AI driven smart building systems, Digital Twins, new advanced materials such as phase-change products, and hybrid renewable energy systems that can reduce operational energy and embodied energy. Emerging challenges were noted around safety on green construction deliveries, high front-end investment costs, legacy skills shortages, and slow transition to integrated digital technologies. The research concludes with recommendations targeted at a variety of stakeholders and a SWOT analysis prepared to aid policymakers, designers, engineers, and project leaders in addressing barriers and scaling sustainable energy-efficient buildings. This paper contributes to the growing discourse on resilient, future-ready construction models that balance environmental, economic, and social sustainability imperatives.

Keyword: Energy-Efficient Construction, Smart Building Technologies, Sustainable Building Materials, Renewable Energy Integration, Green Construction Safety.

I. Introduction

The construction industry continues to be one of the largest energy consuming industries in the world as it is responsible for a significant share of total energy consumption and the emissions of greenhouse gases. For example, in many developed countries, the energy consumption of buildings is between 20% and 40% of total energy demand, which exceeds transportation and manufacturing industries. As energy consumption increases, especially due to continuing urbanization and infrastructure development in developing economies, enhancing energy efficiency in the built environment will continue to be a global focus. To address this challenge, governments and stakeholders across the world have enacted legislative restrictions, regulations and various certifications to promote energy-efficiency in construction or renovations of buildings. These include minimum energy performance standards, financial incentives that allow for a green building certification, and targets to achieve aggressive building renovation targets that achieve a sustainable, cost-effective and environmentally sensitive construction industry. Energy-efficient and sustainable design, construction and maintenance is important not only for cost savings and reduced environmental impact, but also for the health and productivity of occupants, as well as the long-term sustainability and performance of a building. This is accomplished by creating environments with minimal energy consumption throughout the building life-cycle—from design and construction to operations and deconstruction—through the innovative use of materials, intelligent products and systems, and renewable energy/energy efficiency systems.

There are four key aspects when discussing energy efficiency in a building. First, employing passive building design principles prior to construction reduces the dependency to artificial heating, cooling, and lighting, using passive building strategies like solar orientation, natural ventilation, and daylighting. Second, a producer of low-embodied energy materials during construction reduced the environmental footprint of building materials at a very minimal impact from extraction through installation. Third, operational energy conservation occurs through operational energy-efficient equipment and systems that reduced ongoing energy consumption while providing for occupant comfort. Finally, renewable energy technologies, such as solar photovoltaic systems and solar heating systems, allow for decentralized, clean energy development and reduce dependency on conventional fossil fuels.

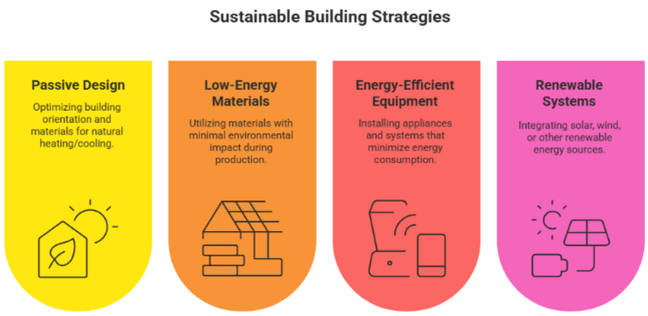

Fig 1: Key Sustainable Building Strategies for Enhancing Energy Efficiency: An Overview of Passive Design, Low-Energy Materials, Energy-Efficient Equipment, and Renewable Energy Systems.

To help facilitate the transition towards sustainable and energy-resilient construction, Fig. 1 shows a number of strategies are beginning to come together that approach the energy concerns comprehensively addressing the operational energy and embodied energy of buildings. The image above highlights four primary strategies that support this transition: passive design, low-energy materials, energy-efficient equipment, and renewable systems Passive design seeks to reduce artificial energy use through the use of optimized building orientation, ventilation and daylighting. Using low-energy, sustainable materials mitigates damage to the environment in the construction process. Using energy-efficient appliances and operational systems reduces energy consumption. Renewable systems like solar or wind power reduce dependency on fossil fuels. Together, these approaches provide a comprehensive approach to optimizing energy performance in new construction and existing buildings.

This research aims to systematically investigate and synthesize recent advancements in innovative energy-efficient strategies across building materials, construction technologies, passive and active design practices, and supportive policy mechanisms. Through a comprehensive literature review and analysis of global case studies, this study intends to identify key drivers, challenges, and outcomes associated with these strategies. The findings are expected to offer practical recommendations for architects, engineers, policymakers, and construction industry stakeholders to enhance the resilience, sustainability, and efficiency of future buildings.

II. Literature Review

The global construction sector has been under increasing pressure to improve energy efficiency due to rising energy demand, climate change, and operational cost increases. Conventional construction, which is often based on fossil-fuel energy systems, also contributes considerably to greenhouse gas (GHG) emissions and unsustainable levels of resource use; according to the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), buildings are responsible for approximately 39% of global CO_2 emissions, more than either industry or transportation (Asadi et al., 2017).

A. **Traditional Approaches vs. Innovative Energy-Efficient Strategies**: For a long time, building design was typically done for functional and aesthetic reasons but not necessarily energy performance. This resulted in inefficient thermal envelopes with little natural light and high operational expenses. New studies have shown that the building industry must embrace sustainable building practices that incorporate new energy technologies and new materials (Elgendy & Shaaban, 2017). The most important distinction is that it is possible for the built environment to embrace passive design strategies that optimize for orientation, shading, and ventilation to regulate indoor conditions without relying on energy (Asadi et al., 2017). The change to energy-efficient technologies (EETs), which includes programmable thermostats, quality insulation, and low-emissivity windows, has produced real energy savings in operational energy use. Buildings that are designed sustainably are assumed to use 26% to 50% less energy than traditionally designed buildings (Alyami & Rezgui, 2012). Solar photovoltaic (PV), wind turbines, and geothermal heating systems all provide evidence of a carbon-neutral future for buildings and construction (Ibrahim et al., 2017).

B. **Role of Smart Technologies and AI-Driven Solutions:** With the incorporation of Artificial Intelligence (AI), Internet of Things (IoT), and Building Information Modelling (BIM), building management systems are growing rapidly in scope and sophistication. Smart buildings, enabled with Digital Twins (DTs), can monitor buildings in real time, automatically detect faults, and enable predictive maintenance, while improving the energy efficiency of systems and occupant comfort (Yildiz et al., 2023). Recently, a study showed how AI-based DT applications can improve indoor environmental quality (IEQ) while also augmenting operational performance in smart building systems (Abu-Hijleh et al., 2023).Furthermore, big data analytics for lighting, HVAC, and security systems have become important for evaluating energy consumption patterns and developing data-informed decisions in both new building or retrofitting exercises (Di Noia et al., 2021). Using smart control systems that leverage AI and IoT can show significant energy savings and reduced operational costs (Cavalcante et al., 2023).

C. **Regional Case Studies and Context-Specific Innovations:** Energy efficiency remains a critical issue in developing nations, where rapid urbanization and unreliable electricity grids exacerbate energy challenges. In Nigeria, Unegbu et al. (2024) proposed a framework combining passive design, renewable energy systems, and local material use to enhance building performance in resource-constrained settings. Similar context-specific studies highlight the importance of tailoring energy solutions to local climates, socio-economic factors, and infrastructure limitations (Ahmed et al., 2017).

D. **Circular Economy and Hybrid Energy Systems:** The construction industry's contribution to environmental degradation has encouraged the adoption of circular economy principles, emphasizing resource reuse and closed-loop energy systems. Recent literature stresses the importance of integrating net-zero energy building practices with circular design frameworks to minimize lifecycle emissions (Wuni et al., 2022). Hybrid renewable energy systems, combining solar, wind, and biomass energy sources, have demonstrated potential for enhancing energy reliability and reducing dependence on centralized grids (Ben-Fares et al., 2023).

E. **Policy Measures, ESCO Models, and Economic Incentives:** Government policies and financial strategies can be essential to facilitate the uptake of energy-efficient technologies. Examples of government policies that have improved the uptake of energy-efficient technologies include regulatory building codes, issuing energy performance certifications, and tax incentives to encourage sustainable construction (Fan et al., 2022). The ESCO model started to gain traction, especially in China, where performance-based energy management contracts fund energy-saving retrofits (Zhou et al., 2023).

F. **Summary of Key Literature Trends:** In conclusion, the literature portrays a consensus about the need for holistic energy-efficient approaches that incorporate passive design, sophisticated materials, smart technologies, renewable energy systems, and enabling policies. Of particular note, energy conservation focused on user behavior and lifestyle changes remains an underexplored, but all-important aspect of reaching carbon neutrality in the long-term (Santoyo-Castelazo & Azapagic, 2014). Table I presents a structured summary of key contemporary research studies addressing energy-efficient strategies in the construction industry. It highlights the diverse methodologies employed — from systematic literature reviews and surveys to case studies and technical reviews — and outlines their core findings, strengths, and limitations. The table reflects a wide spectrum of focus areas, including passive design strategies, renewable energy technologies, digital twin applications, stakeholder decision-making, and circular economy practices. It serves as a consolidated overview to compare existing approaches, identify research gaps, and guide future innovations in sustainable construction and energy management.

Table I. Summary of Key Research Studies on Energy-Efficient Strategies in the Construction Industry, Highlighting Methodologies, Core Findings, Strengths, and Limitations.

S.NO	Title	Methodology	Key Findings	Strengths	Limitations
1	A systematic review of strategies for overcoming the barriers to energy-efficient technologies in buildings	Systematic review methodology, involving a structured search, selection, data extraction, and qualitative synthesis of existing literature.	Demonstration projects & best practice advice effectively address uptake barriers.	Comprehensive taxonomy of barriers and strategies.	Dependent on existing literature, lacks new empirical insight.

2	Innovative Energy-Efficient Solutions for Sustainable Development in Nigeria's Construction Industry	Case studies and solution framework via ResearchGate PDF	Identified renewable-energy, passive-design, and material strategies suitable for Nigeria.	Context-specific recommendations, practical focus.	Nigeria-specific; findings may not generalize globally.
3	Modern Energy Sources for Sustainable Buildings: Innovations and Energy Efficiency in Green Construction (Energies, MDPI)	Quantitative review and bibliometric analysis of energy sources	Emerging green technologies gaining traction; energy-source trends identified.	Data-driven, trend-focused.	Bibliometrics only; lacks depth in tech evaluation.
4	Energy Efficiency in Buildings and Innovative Materials for Building Construction (Applied Sciences, MDPI)	Literature review of passive designs & materials	Low-embodied materials and passive strategies boost lifecycle efficiency.	Integrates design & material tech.	Lacks real-world performance validation.
5	Renewable energy technologies for sustainable development of energy efficient building (Alexandria Engineering Journal)	Review of passive strategies	Passive design (orientation, shading) critical to energy reduction.	Solid passive-tech overview.	Narrow scope—no active systems or retrofits.
6	Adopting green construction practices: health and safety implications (JEDT)	Survey of 168 Nigerian contractors; PLS-SEM	Energy & waste practices positively affect safety; stormwater ≤ no effect.	Empirical, statistical rigor.	Self-reported data; Nigerian context limits wider applicability.
7	AI-Driven Digital Twins for Enhancing Indoor Environmental Quality and Energy Efficiency in Smart Building Systems (Buildings, MDPI)	Conceptual/technical review of DT applications	Digital twins improve IEQ monitoring and operational efficiency.	Tech-forward, covers modern data tools.	Mostly conceptual; needs deployment case studies.
8	Big Data in the construction industry: A review of present status, opportunities, and future trends	Systematic review of digital data use (BIM, sensors)	Big data supports circularity, building performance optimization.	Cross-disciplinary perspective.	High-level only; lacks specific actionable insights.
9	Key decision factors of professional stakeholders when deciding for	Stakeholder survey + qualitative analysis (MDPI? research aggregator)	Quality, resource-use, regulation rank high for design decisions.	Multi-stakeholder focus.	Limited to survey data; may omit emerging drivers.

	sustainable construction				
10	Investigating key factors influencing decision-making in the design of buildings and places: A survey of stakeholders' perception	Survey-based stakeholder analysis	Perception-driven factors like cost, health, environment influence design.	Highlights perception vs. policy gaps.	Self-report bias; regional constraints.
11	Stakeholder studies of green buildings: A literature review	Systematic review of stakeholders in green building projects	Architects, engineers, constructors vary in awareness/priorities.	Holistic stakeholder mapping.	Limited analysis of evolving roles and data frameworks.
12	A systematic literature review on Circular Economy implementation in the construction industry: a policy-making perspective	Systematic review of CE studies and policies	CE adoption depends on standards, data-sharing, market rules.	Strong policy lens, global scope.	Lacks quantifiable impact measures.
13	Policies for energy conservation and sufficiency: Review of existing policies and recommendations for OECD countries	Review of OECD-level policy frameworks	Incentives, codes, info programs crucial to energy efficiency uptake.	Policy-relevant and multi-national.	OECD-focused; excludes non-OECD contexts; no quantitative outcomes.

Figure 2 depicts the phased development of the construction industry's energy efficiency approaches beginning with obsolete construction practices that, while informative, included the use of natural elements and, transitioning through conventional design and implementation methods, towards newer modern practices such as high-performance insulation, HVAC, and integrating renewable energies as well as green-certified builds, to new, emerging technologies that include smart buildings that incorporate AI and IoT and BIM and to applying circular economy principles focused on best acheivable systems toward net-zero energy. This visualization begins to highlight the transformation of sustainable construction to a multi-faceted and multilayered technology-intensive sector addressing not just environmental issues but also operational issues.

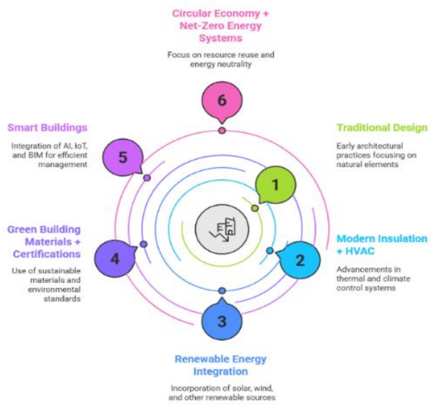

Fig 2: Evolution of energy-efficient strategies in construction

Research Objectives

This study aims to critically evaluate and advance innovative strategies for energy efficiency in the construction industry by investigating the integration of advanced materials, smart technologies, and renewable energy systems in both new builds and retrofits. The research will focus on assessing the effectiveness of emerging solutions such as phase-change materials, AI-driven energy optimization, solar-integrated building components, and circular construction practices in reducing energy consumption and carbon emissions, while also addressing economic and operational feasibility for widespread industry adoption.

Research Questions:

1.What are the most effective innovative strategies currently available for enhancing energy efficiency in the construction industry?

2.How do advanced materials (e.g., phase-change materials, insulated concrete forms) and smart technologies (e.g., building automation systems, AI-driven optimization) impact overall energy consumption and operational costs in buildings?

3.To what extent can renewable energy integration (e.g., solar shingles, solar windows, biogas systems) and circular construction practices contribute to achieving net-zero energy targets in new and existing buildings?

4.What are the primary barriers and enablers for the large-scale adoption of these innovative strategies in diverse construction contexts?

Hypothesis

1. Integration of Smart Building Technologies and AI Will Significantly Reduce Operational Energy Consumption in New and Existing Structures: The adoption of smart building technologies, including IoT sensors and AI-driven systems, optimizes energy use by enabling real-time monitoring, predictive maintenance, and adaptive control of HVAC, lighting, and other building systems. This integration is expected to reduce operational energy consumption by 20–40% in both new constructions and retrofits, particularly in energy-intensive facilities such as data centres
2. Circular Construction Practices and Advanced Materials Will Lower the Embodied Energy and Carbon Footprint of Buildings: Implementing circular economy principles—such as modular construction, on-site waste recycling, and the use of carbon-negative or recycled materials—will substantially decrease the embodied energy of buildings. Innovations like prefabricated treatment plants, waste-to-aggregate solutions, and phase-change materials for insulation are projected to reduce lifecycle energy use and emissions by up to 30% compared to conventional methods
3. On-Site Renewable Energy Systems and Energy Storage Innovations Will Enable Net-Zero or Energy-Positive Building Performance: The deployment of on-site renewable energy technologies (e.g., solar shingles, solar windows, small wind turbines, and hydrogen fuel cells), combined with advanced energy storage solutions such as sand batteries, will make it feasible for buildings to achieve net-zero or even energy-positive status. This integrated approach can reduce reliance on grid electricity by 40–60%, enhancing both energy efficiency and resilience in the built environment.

III.Research Methodology

This research paper is using a systematic literature review (SLR) methodology, this study critically evaluated and synthesized recent literature related to innovative energy efficient approaches in the construction industry. The key research aim was to identify the best approaches related to advanced materials, smart technologies, sustainable design strategies, and supportive policy programmatic approaches. A systematic approach was appropriate because it is a robust process to ensure comprehensive coverage and minimize bias while also ensuring replicability of the research methodology. The literature search identified multiple electronic academic databases: IEEE Xplore, ScienceDirect, Scopus, Web of Science, and Google Scholar. The researchers reviewed publications from 2015 to 2024. The 10-year time frame was selected to cover the most contemporary developments with respect to energy efficiency and construction (given the rapid advancements with modern technological innovations and policies), and options for energy efficiency have invariably grown in the past decade. The database produces demonstrated a mix of search strings and careful application of Boolean operators ("energy efficiency" AND "construction industry", "green building" OR "sustainable construction materials", "passive cooling" AND "smart building systems", and "low energy architecture" AND "urban energy policy").

Zotero software was used to manage the references and identify duplicates. The first search yielded 560 records, which were screened further. During the screening process, 130 duplicate records were removed, and the remaining 430 titles and abstracts were screened for inclusion and exclusion based on existing criteria. The inclusion criteria allowed only peer-reviewed journal articles and conference papers to ensure quality and trustworthiness of data. Articles focusing on energy-efficient technologies, design strategies, or policy interventions within the construction industry were retained for inclusion, while publications in languages other than English, and studies that pertained only to stand-alone electrical appliances were excluded. Following screening, 75 articles were put through to full-text review. Each study was analysed against the study aims, the use of either innovative or comparison strategies, or the study design quality empirical, experimental, or systematic review. Ultimately there were 35 high-quality papers included in the final review, which obviously, were focused on material, construction, integrated renewable energy systems, or policy mechanisms contributing to energy utilization efficiency improvements in buildings.

Key data points extracted from these studies included the type of innovation (whether material-based, technological, design-oriented, or policy-driven), the regional or national context of the research, and measurable outcomes such as energy savings achieved, reductions in greenhouse gas emissions, or economic returns on investment. This structured process provided a solid foundation for analyzing trends, identifying gaps, and evaluating the practical implications of the identified energy-efficient strategies.

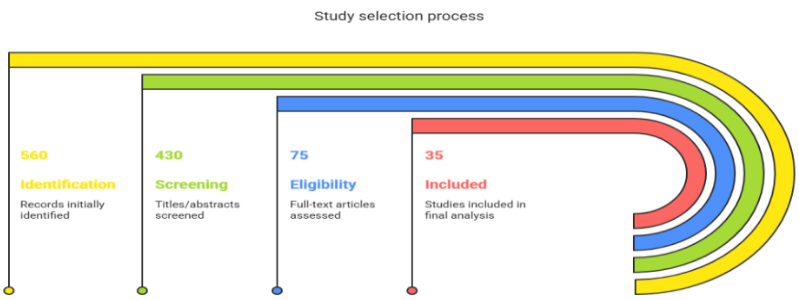

Fig. 3: Study selection process for the literature review on energy-efficient construction strategies.

To visually represent the research workflow, a **PRISMA-style flowchart** summarizing the stages of identification, screening, eligibility assessment, and final inclusion has been prepared (which you can include as Figure 1 in your paper). This structured, replicable process ensures that the review comprehensively captures contemporary research developments while maintaining methodological transparency and academic rigor.

IV. Discussion and Findings

The research outputs of this study highlight the continuing growth importance of developing energy-efficient and green construction practices in the construction sector worldwide. The construction industry is increasingly considering adopting sustainable practices as climate change, resource depletion, and energy costs escalate globally. Sustainable construction (also known as green construction) captures those practices that provide sustainable environmental, economic, and social outcomes. The literature review confirms that changing practices in green construction initiatives - through innovation in building materials, energy systems, and operational practices - can lead to energy conservation and emission reduction while also affecting workplace safety and working conditions with variable outcomes.

The implications for modern-day construction practices are immense. Green construction has been characterized as a continuous, dynamic process with a desire to protect the natural environment through enhancing public health, and worker health, and improving resource efficiency (Marjaba & Chidiac, 2016; Onubi et al., 2019). Incorporating green design principles, renewable energy technologies, and low impact materials in building projects helps achieve this ambition. However, part of this transition includes unforeseen safety issues on construction sites. As Mogensen (2006) and Karakhan (2016) highlighted, worker health and safety must be recognized as a fundamental aspect of social sustainability, and therefore, moving toward greener practices must not put worker health and safety at risk to help address environmental outcomes. In some areas (e.g., in Nigeria), concerns regarding health and safety regulations in construction are more pronounced due to an overall lack of uniformity and enforcement of regulations (Nnedinma, 2016; Idoro, 2011). Nationally, regulated environments are informed by a mixture of international standards and codes of practice, many of which stem from voluntary commitments and usage at the discretion of the contractor. Going forward, although the multinational companies may adopt robust systems of protection such as the Occupational Safety and Health Convention (ILO No. 155) standards, this is not true of local companies who lack structured systems of health and safety management. In this context, it will complicate the site level for attaining both sustainability and occupational safety goals.

In addition, there are strong safety measures in place and best practice strategies for global site safety that have become embedded in health and safety conscious green construction projects (e.g, proactive alerts systems - Mohammadfam et al., 2017; Zhu et al., 2016, fall protection - Zhang et al., 2015, and scheduled safety training - Shen et al., 2015) - were intended to also lessen the types of risks which had been introduced by the increasingly complex and new processes relating to sustainable building behaviours such as using unfamiliar design and construction materials and the presence of unique on site power systems (i.e. renewable). Engineering controls, safer machinery, greater number of labor inspections, and ultimately, increased levels of observance with safe work practices have also been useful in reducing the rates of workplace injury and illness (Kim et al., 2016).

However, despite these mitigations to prevent worker safety incidents, the literature shows conflicting evidence about the net effect of green construction on site safety. Some authors, such as Ghasemi et al. (2015), and Jamil and Fathi (2016), have indicated positive health and safety outcomes from the use of green construction practices, while others indicate that green practices raise safety risk. Karakhan and Gambatese (2017b) identified that increased safety risk was imposed on site workers for a green construction project as compared to a conventional construction project, while Hwang et al. (2018) indicated green construction projects had greater safety risks relative to conventional construction projects. The increased risks of injury from using green construction practices often stem from the use of complex systems or unfamiliar technologies for workers, or, workers using special processes to manipulate advanced building components, which can lead to unexpected hazards if not properly controlled. While this duality prompts many questions about how to define and measure sustainability performance objectives of construction projects, an immediate question is, is it fair to call a project sustainable if it meets energy efficiencies and carbon emissions considerations but recorded increased rates of workplace accidents during construction? This dilemma calls into question the value of the traditional notion of the holistic approach to sustainability which considers environmental, economic and social facets, inclusive of worker safety. If one pillar of sustainability is undermined, then would it be fair to then characterize the construction project sustainably or ethically?

The shift toward green and energy-efficient construction processes has substantial ramifications for how the construction industry understands themselves in the operational, economic, and the environment. This research has highlighted the benefits of sustainable construction by identifying the benefits including energy savings, reduced greenhouse gas emissions, and improved health and wellbeing for occupants. This is consistent with prior research evaluating sustainable construction that also showed sustainably designed buildings perform roughly 26% better than traditional building practices in terms of energy use, and occupants tend to be more satisfied and deliver operational savings (General Service Administration, 2008; Rifkin, 2011; Oti et al., 2017).
Nevertheless, the findings also reflect consideration of a broader context of occupational health and safety for workers on green projects. As reflected by the research of Karakhan and Gambatese (2017b) and Hwang et al. (2018), while the environmental strategy of a project is improved through the use of green practices, it is not without site-specific hazards that may present themselves through the use of new sustainable materials, unfamiliar methods, and emerging technologies. These new risks associated with the green construction site call for an array of health and safety management strategies to properly deal with the social aspect of sustainability while also considering the environmental aspect of sustainability, as well. This paper's findings align with those of Chong et al. (2017) and their observation that, while the construction industry is accumulating massive amounts of data, the adoption of constructed advanced technologies such as Big Data back-end analytics is not evolving as fast as in other sectors. As a result, this has resulted in a missed opportunity, especially with technologies such as AI, IoT, and Digital Twins, which are identified by Shahzad et al. (2023), having substantial potential to improve indoor environmental quality (IEQ), energy efficiency (EE), and predictive maintenance to name a few. Moreover, this paper's review of decision-making factors, as noted above, is consistent with the findings of Tomaževič et al. (2022), which also established a focus in the project decisions made by various professional stakeholders (i.e., architects, engineers, and constructors) on occupant health, energy-efficiency, and environmental considerations. However, ongoing constraints of up-front cost relative to construction cost and lack of awareness continue to restrict the broader adoption of paths to sustainable construction solutions.

A primary strength of this research is its systematic, multi-database literature review design, which reviewed over 560 initial records and narrowed them down to 35 papers that were carefully assessed during the period of 2015-2024. This inclusive approach has allowed the research to provide insights across a wide range of global approaches in multiple innovation contexts – advanced materials, renewable energy systems, AI-interfaced process controls and policy approaches. Nevertheless, limiting the research to peer-reviewed-English language publications has potentially meant losing sight of more relevant regional studies or grey literature from non-English speaking contexts. Furthermore, while the research assessed evidence of use in practice, it did not conduct primary data collection through interviews or case studies on-site which would have provided more of the contextual rich plurality from practice. The analyzed strategies show a clear, scalable opportunity to increase the energy performance and sustainability profile for new and existing buildings. Specifically, smart building technologies and controls from AI-enabled Digital Twins and IoT technologies are reported to reduce operational energy use by 20–40% while indicated in programs such as smart buildings (based on a specific study by Shahzad et al., 2023 and more), energy use will be reduced in large energy-intensive buildings such as data centers or hospitals.

Therefore, the integration with phase-change materials, solar-integrated window products and modular and prefabricated solutions will be able to reduce embodied energy in buildings in the future (up to -30%) and further reduce emissions in the future but also lifecycle costs (anti-ratios). In the future, we can certainly utilize Big Data and AI-enabled analytics for real-time management and energy forecasting in buildings when used in practice can achieve high-intake value and carbon reduction value and opportunities (similar to research findings from Chong et al., 2017). This technology opportunity needs to be sustained through sectorial investment, training, skill development and proactive investments by sectors to serve the greatest impact.
Based on the literature review and findings, we make a variety of suggestions for a range of stakeholders:

- Architects and Designers: Incorporate energy modeling and smart material specifications in the early design phase focusing on passive cooling of buildings, renewable integration, and occupant health and well-being.

- Engineers and Contractors: Use advanced safety management systems and risk management plans, especially in green projects involving complex technologies, like 3D printing. Use predictive maintenance and sensor-based monitoring for optimizing performance and building operational effectiveness.

- Policymakers: Implement regulatory standards to provide green certifications, have health and safety standards developed based on international best practices, and encourage funding for AI, Big Data and other forms of renewable technologies.

- Industry Associations and Educators: Conduct awareness initiatives and training programs on sustainable construction practices, safety management and new digital technologies. Develop an understanding of sustainability standards as new practitioners often go into education through associations.

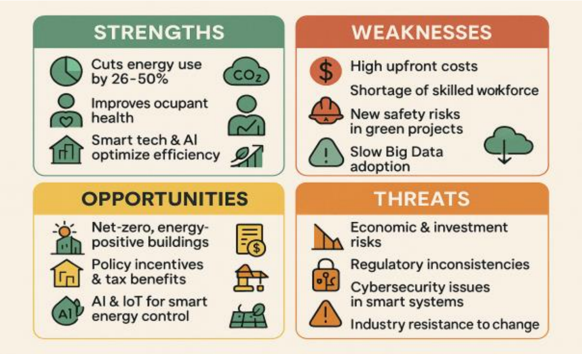

Fig. 3: SWOT analysis highlighting the strengths, weaknesses, opportunities, and threats in adopting energy-efficient strategies in the construction sector.

In order to further position the findings of this report in context, we did a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to map out the current state of energy-efficient approaches across the construction industry. As shown in the figure, the biggest Strengths in energy-efficient approaches are that they reduce energy usage by 26–50%, improve occupant health, and create efficiency in operations in smart technologies and AI-based systems. However, although the weaknesses include a high capital investment, a lack of qualified people, new safety risks with green projects, and slow adoption of Big Data analytics. There are opportunities to make net-zero and energy-positive buildings more and more feasible, opportunities for incentives and tax benefits, and forcing AI and IoT to implement smarter energy management. But with that said there are also many external threats -willingness to adopt change, economic fluctuations, regulatory barriers, cybersecurity implications. which are major drawbacks to the ability to scale energy-efficient and advanced renewable energy approaches. The SWOT stretches any significant barriers to action as well for all stakeholders interest in actions that lead to sustainable construction.

V. Conclusion and Future Scope

This research attempted to investigate and critically assess innovative approaches to improve energy efficiency in the building sector concentrating on advanced materials, smart technologies, renewable energy, and sustainable design practices. It has revealed that there is considerable potential to reduce carbon emissions and operational costs through the use of green construction practices and energy-efficient technologies that have been proven to improve occupant health and wellbeing. Nevertheless, the introduction of buildings utilizing these processes and technologies are still limited by high costs, complexity regarding the regulatory process, potential safety impacts, and the need for a trained workforce. A key contribution of this study is the formation of a structured and evidenced synthesis of the energy-saving strategies that have the greatest effect today and a detailed analysis of decision-making factors that are impacting sustainable construction practices. This study has further established the relevance of AI, IoT, and Big Data Analytics for informing building performance optimization and the need to consider a larger variety of stakeholders in their decision making to improve outcomes on green building projects. From a practical perspective, the data shows that circular construction practices, smart energy management systems, and on-site renewables can facilitate either a new development, or existing buildings, to achieve a net-zero energy performance. However, successful implementation depends on policy support, motivations, increased awareness among stakeholders, and cooperation across regulatory, technical, and management levels.

There is a need for future studies to examine the behavioural and lifestyle factors relating to energy demand in residential and commercial buildings. Energy-efficient technologies are vital not only to meet climate targets but to achieve the goal of limiting energy usage and responsible consumption will require policies and programs that cultivate energy sufficiency. Future studies may also want to develop integrated policy frameworks for circular economy practices in construction, extrapolate long-term socio-economic benefits of sustainable building developments, and explore the digitalization issues related to the proliferation of smart systems used to implement energy management.

Moreover, future studies should identify how decision-making tools, and methodologies can be further enhanced in the context of changing human-machine interactions, in order to optimize the benefits associated with these emerging technologies while limiting the risks. Future research is vital for creating a more sustainable, resilient, and inclusive built environment in the next decades.

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