The role of construction project management practices in achieving low-carbon and eco-efficient building delivery in developing economies

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Abstract
The construction sector in developing economies is both an engine of growth and a major source of greenhouse gas emissions and resource consumption. This article reviews how construction project management practices shape the delivery of low-carbon and eco-efficient buildings in these contexts. Drawing on recent international and African literature, it synthesises evidence on planning and scheduling, cost and resource management, quality assurance, risk management, and sustainable procurement, alongside low-carbon construction principles such as life-cycle assessment, green materials, energy-efficient design, circular waste practices and water-sensitive solutions. The review highlights that project managers play a pivotal role in coordinating digital tools like Building Information Modelling, LCA and digital twins, as well as lean construction and prefabrication strategies that can significantly reduce embodied and operational carbon. However, widespread implementation is constrained by skills and knowledge gaps, limited technology adoption, fragmented regulations, and weak green finance ecosystems. Emerging opportunities include rapid urbanisation and housing demand, international climate frameworks, green building certification schemes and public–private partnerships that can mobilise finance and capacity for low-carbon delivery. The paper concludes that aligning project management capabilities, supportive policy, and targeted investment in digital and circular practices is essential for transitioning construction in developing economies toward genuinely low-carbon and eco-efficient pathways.

1. Introduction

The construction sector is a major source of greenhouse gas emissions and resource intensity worldwide: international comparisons show construction among the largest CO2 emitters and growing shares of total emissions, reflecting both production structures and life cycle effects of buildings and infrastructure (Chen et al., 2023; Zhang et al., 2024). Rapid urbanization and expansion of construction land in developing economies amplify demand for building activity and associated energy use, driving higher carbon outputs and spatially heterogeneous emission patterns that complicate mitigation efforts (Sarkodie et al., 2020; Nwamekwe et al., 2024).

Against this backdrop, low-carbon goals and pilot policies underscore the need to integrate sustainability across project stages: improving carbon accounting, adopting low-carbon planning and policy instruments, and aligning regional strategies are essential to curb construction emissions while enabling development (Xiong et al., 2024; Liu, 2023; Huang et al., 2023). Construction project management therefore has a strategic role through procurement, design coordination, digital tools, and market mechanisms to deliver eco-efficient, lower-carbon buildings in developing contexts (Oke et al., 2023; Liu, 2023; Chen et al., 2023).

Low-carbon construction denotes design and delivery strategies that explicitly minimize greenhouse-gas emissions across the entire building lifecycle from material extraction and embodied carbon in structural systems to operational energy use and end-of-life demolition by applying lifecycle assessment, low-carbon material choices, and alternative systems (e.g., mass-timber or other lower-embodied-energy options) and optimizing whole-life energy performance through integrated design tools (Liu, 2023). Approaches such as prefabrication, modular construction, and design-for-manufacture-and-assembly (DfMA) also reduce site emissions and material waste, thereby contributing to measurable lifecycle carbon savings (Abrishami & Martín-Durán, 2021).

Eco-efficient construction extends low-carbon aims by prioritizing resource efficiency, reduced pollution, and circularity for example through material reuse, 3R waste management, supply-chain optimization, and platformed digital tools that enable lifecycle data and circular economy practices thereby improving environmental performance while maintaining functionality and cost-effectiveness (Nwamekwe et al., 2024). Integrating BIM, LCA, and circularity platforms allows project managers to evaluate trade-offs and deliver buildings that meet global sustainability objectives, a critical priority for developing economies facing rapid construction growth (Liu, 2023; Nwamekwe et al., 2024).

Developing economies confront acute socio-economic pressures rapid population growth, persistent housing shortfalls, and constrained infrastructure that amplify construction demand and risk entrenching high-carbon building practices if delivery systems remain unchanged (U-Dominic et al., 2025; Igbokwe et al., 2025). Reviews of carbon emissions in the construction industry emphasize that the sector's material and energy intensity makes urban expansion a potential pathway to long-term environmental lock-in unless project delivery adopts life-cycle and low-carbon interventions early in the planning and construction phases (Igbokwe et al., 2025).

Adopting sustainable, low-carbon construction in these contexts therefore strengthens resilience and operational performance while lowering life-cycle energy costs: case studies report measurable reductions in energy use and operating expenses and demonstrate carbon gains when low-carbon methods and materials are combined with governance and circular-economy measures (Zhang et al., 2024). Economically, aligning project management with low-carbon objectives can catalyse green innovation and market value creation, supporting broader low-carbon development goals in constrained economies (Oke et al., 2023).

This review examines how construction project management practices influence the delivery of low-carbon and eco-efficient buildings in developing economies. It synthesizes existing literature to identify key practices, challenges, and opportunities, and proposes actionable recommendations for industry stakeholders and policymakers.

This paper is organized into five sections: the introduction, the literature review, construction management in developing economies, the role of project management in sustainable building delivery, and the conclusion with recommendations.

2. Method

This study uses a literature review approach with the aim of comprehensively examining the role of construction project management practices in achieving low-carbon and eco-efficient buildings in developing countries. This approach was chosen because it allows the synthesis of knowledge from various previous studies to identify key concepts, key practices, challenges, and opportunities relevant to the topic of study. Data collection is carried out through searching for scientific articles published in reputable national and international journals. The selected articles were then analyzed using a thematic synthesis approach, by grouping findings based on key themes, such as project management practices (planning, cost control, quality, and risk), low-carbon construction principles, eco-efficient approaches, implementation barriers, and development opportunities in developing countries. The results of the synthesis are then used to formulate discussions, draw conclusions, and formulate recommendations for practitioners and policymakers.

3. Results and Discussion

3.1. Overview of Construction Project Management Practices

3.1.1. Planning and Scheduling

Effective planning in construction project management is essential for identifying and selecting low carbon design options, sequencing works to reduce on site rework and waste, and embedding sustainability criteria within the project baseline. Empirical studies indicate that sustainable project planning frameworks and whole-life evaluation at the planning stage can improve decision quality and resource optimization (Nwamekwe et al., 2025). Integrating multi criteria appraisal and Building Information Modelling (BIM)-enabled simulations during planning helps teams evaluate material choices, logistics, and lifecycle trade offs before construction begins, thereby reducing embodied carbon and demolition waste risks (Nwamekwe et al., 2025; Liu, 2023).

Scheduling strategies significantly influence how resources, equipment, and deliveries are utilized over time, directly impacting energy use, idle time, transport emissions, and construction and demolition (C&D) waste. Both classical and advanced scheduling methods such as the Critical Path Method (CPM), Last Planner System (LPS), and Critical Chain Project Management (CCPM), alongside optimization and risk simulation, can reduce clashes, minimize unnecessary activity float, and enhance environmental outcomes. Furthermore, digital controls like 4D/BIM and sensor networks enable dynamic coordination and logistics optimization, thereby reducing time-related environmental impacts in practice (Liu, 2023; Abdullahi et al., 2023).

3.1.2. Cost Management and Resource Optimization

Cost management in construction project practice directly shapes decisions about energy-efficient materials and technologies by exposing life-cycle costs and investment trade-offs. When procurement and budgeting explicitly internalize whole-life energy and replacement costs, project teams are more likely to favour modular, prefabricated, or low-embodied carbon options that subsequently reduce capital and operational burdens (Okpala et al., 2024). Digital tools and Building Information Modelling (BIM) linked to cost planning further enable early-stage trade-off analysis between upfront expenditure and downstream energy savings, strengthening the business case for adopting recycled substitutes (e.g., fly ash blends) and factory-manufactured systems that cut waste and site inefficiencies.

Similarly, resource optimization through accurate waste benchmarking, cut-list optimization, and Industry 4.0 controls lowers material consumption and cost overruns. Quantified waste studies show direct cost impacts of construction and demolition (C&D) waste, while intelligent rebar-cutting and digital waste-management platforms demonstrably reduce off-cuts and disposal volumes. Embedding these optimization practices in cost controls therefore produces both eco-efficiency gains and measurable financial savings, aligning sustainability with project affordability, particularly in developing economies.

3.1.3. Quality Assurance and Compliance

Quality assurance (QA) in construction project management is crucial to ensure buildings meet environmental standards, green certification criteria, and low-carbon codes. QA frameworks and green building rating systems (GBRSs) provide structured metrics and verification procedures that translate sustainability objectives into measurable compliance requirements (Okpala et al., 2025). By embedding QA at project brief and design stages, managers reduce performance gaps between design intent and as-built operation that can undermine low-carbon outcomes. A risk-based environmental safety approach further aligns inspection and audit activities with regulatory and certification priorities (Okpala et al., 2025).

Practical compliance increasingly relies on digital verification and integrated workflows Building Information Modelling (BIM) and green-BIM process models enable automated checks, documentation for third-party certification, and lifecycle evidence for audit trails, while digital twins support operation-stage compliance and continuous performance monitoring. In developing economies, institutionalizing these QA practices requires strengthening project-level quality plans, inspection regimes, and industry self-regulation to sustain certification benefits and enhance market confidence in green building delivery (Abdullahi et al., 2023).

3.1.4. Risk Management in Construction

Risk management in construction systematically identifies environmental risks and quantifies carbon and resource-related uncertainties to help planners prioritize mitigation early in the project lifecycle. Methods such as structured risk registers, scenario analysis, and probabilistic models aid in understanding supply-chain fragility, materials-substitution uncertainty, and site-level environmental hazards that influence both embodied and operational carbon outcomes.

When integrated into project controls, these assessments enable proactive mitigation allocating contingencies, redesigning specifications, and invoking low-carbon procurement or prefabrication pathways while decision tools (e.g., BIM-linked AHP or Monte Carlo frameworks) operationalize trade-offs among carbon, cost, and schedule under uncertainty. These integrated risk management practices, therefore, convert environmental risk insights into concrete, time-sensitive interventions that can significantly reduce emissions and resource waste in developing-economy construction programs.

3.2. Low-Carbon Construction Principles

3.2.1. Carbon Sources in the Building Life Cycle

Major carbon sources across a building's life cycle are conventionally grouped as embodied emissions from material extraction and production, emissions from transportation and logistics, on-site construction activities (fuel use, temporary works, and waste processing), and operational energy during occupancy. Life-cycle assessment (LCA) frameworks and embodied-carbon reviews demonstrate that material production and manufacturing often dominate cradle-to-gate impacts and must be quantified alongside transport and site emissions. Empirical LCAs and benchmarks treat transport and construction-phase fuel use as discrete contributors because long supply chains and energy-intensive on-site processes can significantly increase whole-building GWP (global warming potential) when included in cradle-to-site accounting.

Operational energy (heating, cooling, ventilation, lighting, and services) remains a major life-cycle emitter for conventional buildings; however, multiple reviews note a shifting balance. As operational efficiency and grid decarbonization improve, the relative share of embodied carbon rises, making whole-life accounting essential to avoid shifting burdens between operational and embodied emissions (Onyeka et al., 2024). Recurrent embodied impacts from maintenance, component replacement, and end-of-life treatments further affect total life-cycle carbon. Thus, material choice, service life, and circular-economy strategies are critical levers for low-carbon delivery in developing contexts. Building life-cycle carbon sources in developing-economy contexts can be seen in Figure 1.

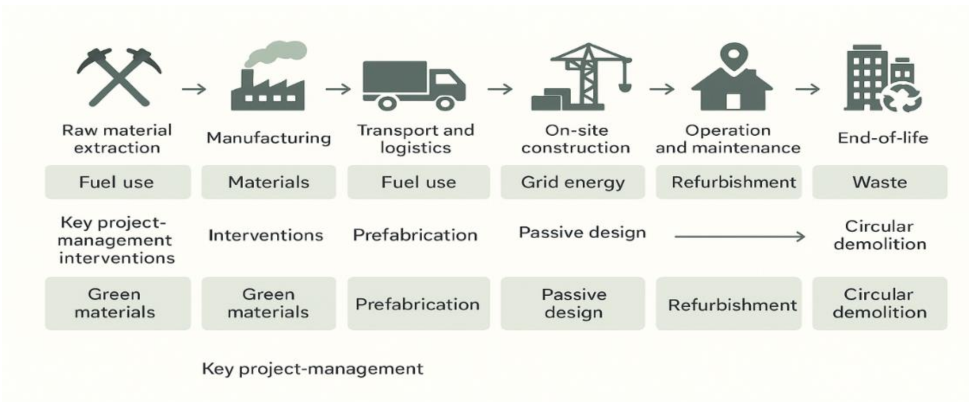


Figure 1. Building Life-Cycle Carbon Sources in Developing-Economy Contexts

Figure 1 illustrates the full building life cycle and highlights where major carbon emissions occur in developing-economy construction systems. It identifies carbon sources fuel use, energy consumption, material production, on-site processes, transport, and waste generation while showing where project-management interventions such as green materials, prefabrication, passive design, efficient logistics, and circular demolition can significantly reduce emissions. The schematic strengthens understanding of carbon hotspots and mitigation opportunities.

3.2.2. Carbon Footprint Measurement Techniques

Life Cycle Assessment (LCA) remains the principal technique for quantifying building carbon across stages, complemented by carbon calculators for rapid project level estimates and Environmental Product Declarations (EPDs) for product level data; together these methods permit cradle to grave accounting and sensitivity testing of boundaries and modules (Nwamekwe et al., 2020; Okpala et al., 2024). Integrating LCA with BIM automates quantity take offs and links EPD data to components, improving early design decision making and enabling comparative scenario appraisal (e.g., material substitutions, prefabrication) that directly informs low carbon choices (Okpala et al., 2024).

In practice, measurement accuracy depends on method selection (attributional vs. consequential LCA), data quality, and localized inventories; sensitivity to transport, end of life assumptions, and EPD variability can markedly shift results, so transparency and stakeholder data responsibilities are critical in developing country projects (Nwamekwe et al., 2020). Emerging automated BIM–LCA workflows and context adapted calculators help overcome data gaps and operationalize carbon measurement within project controls, but require institutional uptake and tool interoperability to be effective.

3.2.3. Strategies for Carbon Reduction in Construction

Strategies to reduce construction carbon emissions focus on material choice, off-site manufacture, and high-performance design. Substituting low-embodied materials such as timber and recycled aggregates, adopting modular/prefabricated systems, and utilizing design for manufacturing and assembly (DfMA) can significantly cut on-site waste, shorten schedules, and ultimately lower whole-life carbon emissions (Chen et al., 2023; Wang et al., 2023; Okpala et al., 2024; Liu, 2023). Integrated design that combines early life cycle assessment (LCA) and performance simulation helps manage these trade-offs and avoids burden-shifting between embodied and operational carbon impacts (Okpala et al., 2024; Liu, 2023).

Complementary strategies include on-site electrification, building-integrated photovoltaics (BIPV), and distributed energy systems, along with circular economy practices like the reuse of materials, employing recycled aggregates, and utilizing biomass residues to close material loops and reduce upstream emissions. Additionally, market instruments and pilots, such as carbon trading and low-carbon trials, along with digital tools, facilitate measurement, procurement, and scale-up, especially in developing contexts (Oke et al., 2023; Zhang et al., 2024).

3.3. Eco-Efficient Building Delivery Approaches

3.3.1. Green Material Selection

Green material selection prioritizing recycled content, renewable timber or bamboo, and low emission cementitious blends is repeatedly shown to cut life cycle environmental burdens by lowering embodied carbon in production and reducing waste at end of life; reviews and LCAs report substantial footprint reductions for mass timber and bamboo systems and for concretes incorporating recycled supplementary cementitious materials (SCMs) relative to conventional steel concrete assemblies (Chen et al., 2023; Zhang et al., 2024; Sarkodie et al., 2020; Nwamekwe et al., 2024). Such material choices therefore address the dominant cradle to gate impacts of buildings and help avoid burden shifting as operational energy falls with efficiency gains (Nwamekwe et al., 2024; Chen et al., 2023; Sarkodie et al., 2020).

Project delivery must translate material strategies into procurement, specification and measurement: integrating EPD linked LCA and early design BIM workflows enables component level comparison and quantifies trade offs, while modular/prefabricated supply chains and green public procurement accelerate uptake of low carbon products in developing contexts (Xiong et al., 2024; Liu, 2023; Huang et al., 2023; Oke et al., 2023). Together, these practices make green material selection actionable within constrained budgets and fragmented supply chains, improving eco efficiency across delivery stages (Liu, 2023; Huang et al., 2023).

3.3.2. Energy-Efficient Building Design

Passive design orientation, shading, daylighting and high-performance envelopes systematically reduces heating/cooling loads and is a first order strategy for eco efficient buildings, while high efficiency HVAC and envelope optimisation deliver deeper operational carbon cuts when combined with whole building simulation and modular detailing (Chen et al., 2023; Zhang et al., 2024). On site electrification, building integrated photovoltaics and low voltage DC distribution further lower net operational emissions and conversion losses, and intelligent environmental controls (EMS/IoT) enable demand side optimisation and storage integration that materially improve yearly energy performance in practice (Zhang et al., 2024; Sarkodie et al., 2020; Nwamekwe et al., 2024).

Realising these technical gains depends on integrated project delivery: early-stage performance modelling, BIM linked LCA and optimisation, and lifecycle-oriented procurement allow trade offs among passive measures, system efficiency and renewables to be evaluated and locked into contracts, turning design strategies into verified operational savings and carbon outcomes in developing contexts (Xiong et al., 2024; Liu, 2023; Huang et al., 2023; Oke et al., 2023).

3.3.3. Waste Minimization and Recycling Practices

Construction waste minimization and recycling are central to reducing landfill burdens and closing material loops in building delivery; circular economy case studies and reviews indicate that redirecting demolition and site residues into reuse, recycling, and value-added products lowers raw material demand and local disposal pressures while creating supply chain opportunities for secondary materials (Nwamekwe & Igbokwe, 2024; Mercader-Moyano et al., 2022). Empirical models and regional pilots highlight that the early incorporation of circular targets in project briefs combined with stakeholder collaboration across designers, contractors, and recyclers is necessary to shift linear disposal practices toward circular waste flows, particularly in developing contexts (Nwamekwe & Igbokwe, 2024; Mercader-Moyano et al., 2022).

Practical approaches reported in the literature include design for deconstruction, on-site segregation and quality sorting, specification of recycled content (e.g., glass-waste gypsum composites, plastic-infused pavers, tyre-based insulation), and institutional mechanisms such as eco-industrial parks and circular design frameworks that valorise by-products and stabilize markets for secondary aggregates (Nwamekwe & Chikwendu, 2025). Together, these measures both reduce emissions associated with virgin production and create resilient local material loops when embedded in project management, procurement, and regulatory incentives.

3.3.4. Water Conservation and Environmental Protection Measures

Green roofs, rainwater harvesting (RWH), and water-efficient fittings reduce runoff, supplement non-potable supply, and lower mains demand thereby easing urban water stress and enhancing building sustainability (Gil-Ozoudeh et al., 2024). Green roofs and similar blue green measures retain stormwater, improve thermal insulation, and reduce cooling loads, delivering co-benefits for energy efficiency and flood mitigation documented in studies focused on low-impact development (LID) and green infrastructure (Carvalho et al., 2020).

Operationalizing these measures in project delivery requires early integration of low-impact development (LID), constructed wetlands, and RWH into design, procurement, and maintenance plans, as well as legal frameworks to secure long-term benefits and stewardship. In developing economies, nature-based solutions, such as decentralized reuse of greywater and RWH, provide cost-effective resilience, but success depends on clear project targets, monitoring, and defined client/contractor responsibilities to ensure performance and upkeep.

3.4. Construction Management Practices Influencing Eco-Efficiency

3.4.1. Lean Construction Techniques

Lean construction applies Toyota-derived waste-reduction and flow principles (such as value-stream mapping, the Last Planner system, and Just-In-Time production) to site processes to reduce material waste, rework, and idle time, thereby lowering the embodied and operational energy associated with inefficiency. Empirical and review studies indicate that integrating lean with information tools (such as Building Information Modelling BIM and Big Data) enhances coordination, minimizes clashes and unnecessary activities, and unlocks measurable eco-efficiency gains in terms of schedule, material use, and energy consumption.

In developing-economy contexts, adapting lean principles can lead to reduced costs and carbon emissions when tailored to local firms and supply chains. However, successful implementation necessitates capacity building, development pathways for small and medium-sized enterprises (SMEs), and supportive competency frameworks to overcome awareness, regulatory, and skills barriers. Integrating lean with circular economy and Construction 4.0 enablers (such as the Internet of Things IoT and prefabrication) enhances waste avoidance and resource productivity, making lean a viable strategy for achieving lower-carbon building delivery when managed by competent project teams.

3.4.2. Building Information Modelling (BIM) for Efficiency

Building Information Modelling (BIM) materially improves sustainability decisions by enabling integrated energy modelling, automated clash detection, and quantity take offs that feed Life Cycle Assessment (LCA) routines, thus linking design choices to quantified carbon outcomes. Early clash detection and prioritization reduce design rework and on-site corrections lowering waste, transport movements, and schedule-related emissions while logistics simulations, such as 4D BIM, and multi objective BIM optimization support trade offs between energy, cost, and embodied carbon across various scenarios.

However, realizing these gains in developing economies depends on clearly defined BIM roles, training, standards, and digital twin interoperability, ensuring that modelled sustainability intent translates into as-built performance data for facilities management and carbon accounting. Contextualized adoption studies demonstrate that tailored BIM–LCA workflows, maturity assessments, and capacity building in policy, procurement, and education are critical to translating BIM's technical potential into routine low-carbon, eco efficient project delivery (Nwamekwe et al., 2024).

3.4.3. Life-Cycle Thinking in Project Management

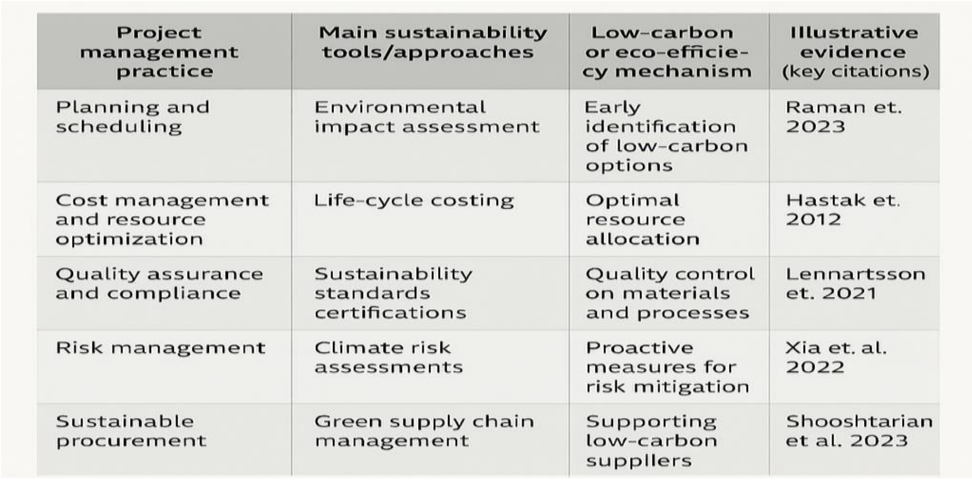
Life-cycle thinking requires that project management assess environmental impacts from concept and design through operation and disposal; life-cycle tools such as life-cycle assessment (LCA) and whole-life cost analysis (LCC/LCCA) provide the analytic foundation and project-level indicators for monitoring sustainability performance across stages (Emeka et al., 2025). Integrating LCA with building information modelling (BIM), geographic information systems (GIS), and digital twin platforms automates quantities, links product environmental product declarations (EPDs) to model elements, and enables continuous verification from design to operation, improving whole-life carbon accounting and enhancing rapid scenario screening with data-driven or artificial neural network (ANN) accelerators for material optimization (Zhang et al., 2024; Nwamekwe et al., 2024).

Operationalizing life-cycle approaches in project management translates assessment into procurement, risk allocation, and maintenance decisions for example via BIM-LCCA workflows, prefabrication LCA, and supply chain risk frameworks thereby reducing both embodied and operational emissions when enforced through contracts and benchmarks (Igbokwe et al., 2025; Nwamekwe et al., 2024). In developing economies, however, limited LCA data, institutional capacity, and standards constrain uptake, making national databases, capacity building, and standardized whole-life benchmarks essential to mainstream life-cycle management for low-carbon delivery (Nwamekwe et al., 2024).

3.4.4. Sustainable Procurement Practices

Sustainable procurement in construction reframes buying decisions to prioritize low-impact materials, socially responsible suppliers, and durable products, thereby aligning purchasing with circularity and whole-life performance objectives. Empirical analyses show that embedding environmental criteria into specifications, tender evaluation, and supplier selection stimulates green supply-chain practices, drives supplier innovation, and leverages institutional pressures (regulatory or market) to improve firm sustainability performance.

In developing economies, sustainable procurement must be operationalized through clear procurement criteria, capacity building for clients and SMEs, and market-shaping instruments (eco-industrial parks, industrial symbiosis, and incentives) to secure secondary materials and resilient green suppliers (Huang et al., 2023). Studies emphasize that without targeted procurement reform and buyer leadership, barriers cost premiums, limited supplier capability, and weak standards will constrain the uptake of environmentally preferable goods and long-lasting construction products (Munir et al., 2025). Construction project management practices and their low-carbon mechanisms can be seen in Figure 2.



Project management practice	Main sustainability tools/approaches	Low-carbon or eco-efficie-cy mechanism	Illustrative evidence (key citations)
Planning and scheduling	Environmental impact assessment	Early identification of low-carbon options	Raman et. 2023
Cost management and resource optimization	Life-cycle costing	Optimal resource allocation	Hastak et. 2012
Quality assurance and compliance	Sustainability standards certifications	Quality control on materials and processes	Lennartsson et. 2021
Risk management	Climate risk assessments	Proactive measures for risk mitigation	Xia et. al. 2022
Sustainable procurement	Green supply chain management	Supporting low-carbon supplIers	Shooshtarian et al. 2023

Figure 2. Construction Project Management Practices and Their Low-Carbon Mechanisms

Figure 2 maps major construction project management practices to the sustainability tools and mechanisms through which they reduce carbon emissions. It highlights how planning, cost control, quality assurance, risk management, and sustainable procurement intersect with tools like BIM, LCA, lean methods, and green procurement. This structure clarifies the pathways through which project managers directly influence low-carbon, eco-efficient construction outcomes in developing economies.

3.5. Characteristics and Challenges of the Construction Sector in Developing Economies

The construction sector in many developing economies is marked by rapid urban expansion, high material wastage, and informal site practices that strain supervision and quality control (Arshad et al., 2018). Technology adoption is uneven: Building Information Modelling (BIM) and advanced cost/production systems show promise but remain confined to niche projects due to limited digital capacity and variable project-management competencies (Nwamekwe et al., 2024). Institutional gaps and regulatory inconsistency further weaken the enforcement of sustainability standards, compounding fragmentation across supply chains and elevating project risk (Al-Otaibi et al., 2025).

These structural features constrain the mainstreaming of low carbon practices: small and medium contractors often lack the skills and incentives to implement prefabrication, lean workflows, or green procurement, while fragmented delivery systems impede circular economy uptake. Addressing this requires targeted capacity building, clearer procurement and regulatory signals, and supply chain coordination to translate project level sustainability intent into routine low carbon delivery (Nwamekwe et al., 2024).

3.6. Constraints to Implementing Low-Carbon Practices

3.6.1. Limited Technology Adoption

Advanced low-carbon technologies (BIM, prefabrication, on-site electrification) face challenges in affordability, availability, and consistency across many developing-economy projects, which hinders their widespread adoption and limits digital tools to specialized applications. Weak local supply chains, the high capital intensity of modular factories, and prevalent material wastage further raise barriers to scaling low-carbon solutions, causing promising methods like off-site manufacturing to struggle to go beyond pilot phases.

Consequently, limited technology uptake exacerbates skills and institutional deficiencies: small and medium-sized enterprises (SMEs) and project teams often lack the capacity, financing, and standards necessary to implement lean, BIM-integrated life cycle assessment (LCA), or prefabricated pathways at scale. This situation slows the mainstream adoption of eco-efficient construction methods and necessitates targeted capacity building, procurement reform, and market development to bridge the existing gaps.

3.6.2. Skills and Knowledge Gaps

Practitioner capacity shortfalls limited training in sustainability tools, carbon accounting, and eco efficient design are repeatedly identified as a primary barrier to low carbon delivery in developing contexts. Empirical studies on Building Information Modelling (BIM) and green construction report poor practitioner readiness, weak BIM and Life Cycle Assessment (LCA) skills, and fragmented knowledge transfer that constrain early-stage low carbon decisions. Surveys of designers and project teams show that unfamiliarity with whole life costing, performance simulation, and green procurement reduces the uptake of prefabrication, LCA, and smart controls that underpin eco efficiency (Wang et al., 2023).

These skills gaps translate into missed opportunities and implementation failures, implying an urgent need for targeted capacity building, certification, and practice-oriented training (e.g., Green Project Management/BIM–LCA curricula), plus institutional support to embed know how across small and medium-sized enterprises (SMEs) and clients (Nwamekwe et al., 2024). Pilot frameworks and BIM training roadmaps demonstrate how structured education and procurement incentives can convert technical potential into routine low carbon outcomes.

3.6.3. Regulatory and Policy Limitations

Regulatory and policy gaps in many developing economies characterised by inconsistent standards, weak permitting and environmental impact assessment (EIA) enforcement, and unclear circular economy rules undermine efforts to mainstream low-carbon construction by creating loopholes, delaying compliance, and raising transaction costs for green projects (Okeagu et al., 2024; Okpala et al., 2025; Nwamekwe et al., 2025; Nkemakonam et al., 2025). Studies of country cases and sectoral reviews report that where environmental regulations are fragmented or poorly implemented, firms default to conventional practices, and informal waste or resource management persists, limiting the uptake of low-emission materials, extended producer responsibility schemes, and recycling initiatives (Okeagu et al., 2024; Song et al., 2021; Okpala et al., 2025).

Consequently, weak enforcement slows the green transformation by reducing investor certainty, constraining market signals for sustainable suppliers, and diminishing the effectiveness of incentives and initiatives intended to scale eco-efficient delivery (Okpala et al., 2025; Nwamekwe et al., 2025). The literature therefore recommends coherent regulatory frameworks, strengthened monitoring and accountability mechanisms, and complementary policy instruments (procurement mandates, financial incentives, capacity building) to unlock low-carbon pathways in construction sectors of developing economies (Okpala et al., 2025; Nwamekwe et al., 2025; Nkemakonam et al., 2025).

3.6.4. Financial and Market Barriers

High upfront capital requirements for low-carbon building measures such as prefabrication, on-site electrification, and renewables raise barriers in developing economies because lenders and buyers perceive lower returns and higher investment risks compared with conventional options. This perception is compounded by household and developer affordability constraints that further limit the uptake of green housing and technologies (Wang et al., 2023). At the market level, underdeveloped green finance ecosystems including thin green bond markets, weak public-private partnership frameworks, and limited concessional instruments, along with deficient institutional frameworks contribute to scarcity in long-term green lending, increasing transaction costs and deterring private investors from financing eco-efficient construction (Amolo, 2024; Nwamekwe & Chikwendu, 2025).

These financial frictions, in conjunction with market resistance to carbon pricing and immature carbon markets, slow the demand for low-carbon building practices and carbon-offset instruments in construction (Oke et al., 2023). The literature advocates for blended finance, green bonds, targeted de-risking instruments, and strengthened public–private mechanisms to mobilize capital and reduce perceived risk. Additionally, policy reforms and capacity-building efforts are necessary to expand green finance access for small and medium-sized enterprises (SMEs) and developers (Nwamekwe & Chikwendu, 2025; Amolo, 2024).

3.7. Opportunities for Eco-Efficient Construction

3.7.1. Growing Urbanization and Housing Demand

Rapid urban expansion and growing housing demand create a strategic opportunity to embed eco-efficient design into new developments. Urban master plans and large-scale housing programs can incorporate prefabrication, mass customization, and circular supply chains to avoid future retrofit lock-ins and reduce whole-life emissions (Vitalis et al., 2024; Song et al., 2021; Larsen et al., 2019). Early adoption of Building Information Modelling (BIM)-enabled design and Life Cycle Assessment (LCA) in these greenfield contexts facilitates material optimization and waste reduction while enabling affordable, high-performance building envelopes and services to be specified at scale (Ezeanyim et al., 2025; Nwamekwe et al., 2024).

Realizing this opportunity requires aligning policy, procurement, and market instruments so developers can deploy scalable low-carbon solutions. Targeted incentives, standards, and supply-chain development can lower barriers for small and medium-sized enterprises (SMEs) and stimulate demand for sustainable materials and prefabricated systems (Song et al., 2021; U-Dominic et al., 2025). When coupled with mass customization and industrialized delivery, these measures can provide affordable, energy-efficient housing that leverages economies of scale and promotes eco-efficient urbanization in developing economies (Larsen et al., 2019; Vitalis et al., 2024; Nwamekwe et al., 2024).

3.7.2. International Sustainability Frameworks

International agreements most notably the Kyoto Protocol and the Paris Agreement establish normative targets and incentives that guide national decarbonization pathways and help mobilize finance for low-carbon transitions in the built environment. These global frameworks have catalysed growth in green finance instruments and multilateral concessional funding that can de-risk investments in low-carbon construction (e.g., through multilateral development bank support and targeted green bond issuance), thereby shaping market signals for eco-efficient building delivery in developing economies.

Complementing treaty drivers, donor-funded programs and multilateral climate funds (Global Environment Facility, Green Climate Fund, Sustainable Energy for All) provide technical assistance, grant finance, and technology-transfer platforms that support capacity building, pilot deployment, and knowledge exchange for sustainable construction practices. Non-state actors and blended finance mechanisms further amplify these flows, but effectiveness depends on coherent national policy, institutional absorption capacity, and aligned procurement to translate international support into routine low-carbon project delivery (Chen et al., 2023).

3.7.3. Green Building Certifications and Standards

Green building rating tools (e.g., LEED, BREEAM, Green Star) translate sustainability goals into verifiable benchmarks and drive compliance by structuring credits, performance metrics, and audit procedures that inform design, procurement, and operations decisions (Zhang et al., 2024; Nwamekwe et al., 2025). Certifications shape project processes: optimisation of energy, materials, and indoor environmental quality through iterative design and simulation is commonly reported in EU case studies. BIM-enabled energy analysis expedites meeting certification criteria by linking modelled performance to rating credits (Nwamekwe & Nwabunwanne, 2025).

In developing economies, certifications can stimulate market change raising occupant satisfaction and asset value and encouraging local adaptation but their effectiveness depends on localisation, cost-benefit alignment, and capacity building for practitioners and certifiers (Nwamekwe & Nwabunwanne, 2025; Gil-Ozoudeh et al., 2024). Hence, certification uptake is most productive when supported by tailored guidance, BIM/LCA workflows, and incentives that reduce green premium barriers while ensuring post-occupancy performance monitoring.

3.7.4. Public Private Partnerships

Public–private partnerships (PPPs) can mobilize finance and implementation capacity for low carbon construction by combining multilateral/development bank de risking, blended finance, and donor technical assistance to improve project bankability and scale pilot interventions into national programs (Adamson & Medeiros, 2023). PPP contracts also provide delivery platforms that channel green bonds, concessional loans, and supplier-development packages into projects, enabling technology transfer and the greening of public building portfolios where governments pair mandates with finance and advisory support (Adamson & Medeiros, 2023).

To convert partnership finance into sustained eco efficient delivery, PPPs must embed whole life procurement criteria, capacity-building for local firms, and robust monitoring so that capital and standards yield measurable emissions and resilience gains. Scholarship emphasizes policy coherence, absorptive capacity, and private-sector engagement as preconditions for success. Blended finance mechanisms and targeted incentives are therefore recommended to align investor risk-return expectations with long-term low carbon outcomes in developing economies. Barriers and opportunities for low-carbon construction in developing economies can be seen in Figure 3.

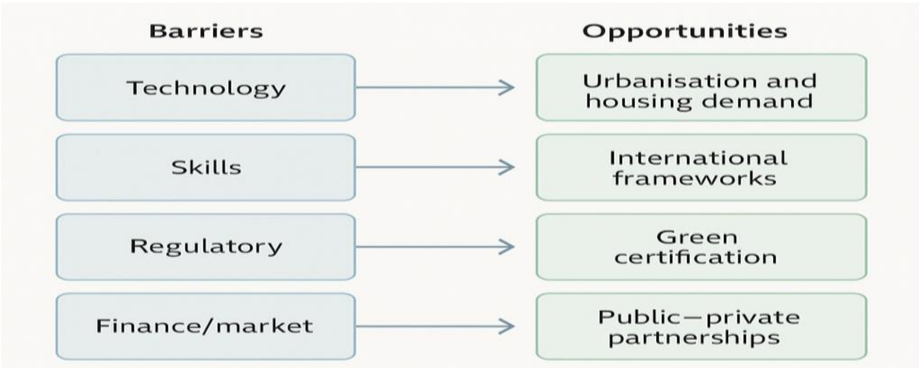


Figure 3. Barriers and Opportunities for Low-Carbon Construction in Developing Economies

Figure 3 presents a clear comparison between the barriers and opportunities influencing low-carbon construction in developing economies. Barriers including technological limitations, skills gaps, regulatory weaknesses, and financial constraints are contrasted with opportunities such as rapid urbanisation, supportive international frameworks, green certification systems, and public–private partnerships. Arrows show how strategic project-management and policy actions can transform existing barriers into enabling conditions for sustainable, low-carbon outcomes.

3.8. The Role of Construction Project Management in Achieving Low-Carbon and Eco-Efficient Buildings

3.8.1. Integrating Sustainability into Project Planning and Design

Integrating sustainability at project inception enables project managers to influence material choices, assembly methods, and performance targets that determine whole-life carbon and operational efficiency. The early adoption of BIM-driven life cycle assessment (LCA) and parametric optimization provides quantified trade-offs between envelope, systems, and embodied carbon. Furthermore, adopting modular and Design for Manufacturing and Assembly (DfMA) approaches can significantly reduce site waste and accelerate delivery, which locks in lower lifecycle impacts when these methods are selected during planning rather than retrofitted later (Okpala et al., 2024).

To operationalize these ambitions, managers must effectively translate design outcomes into procurement, contract, and delivery mechanisms. This includes utilizing low-carbon procurement clauses, Engineering, Procurement, and Construction (EPC) agreements, or relational/Integrated Project Delivery (IPD) arrangements, as well as life-cycle costing to align incentives among clients, designers, and contractors. Capacity building and interdisciplinary frameworks, such as BIM training and sustainable innovation pathways, are essential to ensure that planned low-carbon strategies translate into verifiable performance outcomes and long-term eco-efficiency (Munir et al., 2025).

3.8.2. Project Manager's Role in Promoting Green Technologies

Project managers accelerate the uptake of green technologies from rooftop solar and on-site renewables to energy-efficient plants and low-emission materials by shaping specifications, procurement decisions, and delivery sequencing, which make pilots bankable and operationally effective. They also mainstream smart-building systems and IoT controls (for HVAC, lighting, and asset performance) to harvest operational savings and validate low-carbon claims while leveraging

Building Information Modelling (BIM) and circular economy design tools to compare material and assembly options based on whole-life carbon considerations (Ezeanyim et al., 2025).

In practice, this role combines technical stewardship with leadership: project managers embed green criteria into tendering processes, allocate risk and life-cycle cost incentives, and coordinate training so that contractors and suppliers can reliably deploy new systems. By packaging bankable technical specifications and mobilizing blended finance or venture capital where appropriate, managers translate technology promises into scalable, low-carbon building deliveries in resource-constrained settings.

3.8.3. Monitoring and Evaluating Carbon Reduction Performance

Continuous monitoring translates low-carbon targets into verifiable project actions by combining periodic carbon audits, life cycle assessment (LCA) checks, carbon calculators, and scorecards, enabling managers to track embodied and operational emissions against baselines (Chen et al., 2023; Igbokwe et al., 2024; Wang et al., 2023). BIM-linked LCA frameworks automate quantity take-offs and facilitate model-based verification of design choices, while carbon-tracking approaches, such as the 'CABBAGE' framework, and knowledge-mapping studies illustrate how routine metrics and dashboards enhance decision fidelity and stakeholder reporting (Igbokwe et al., 2024; Wang et al., 2023; Chidiebube et al., 2025).

Effective evaluation necessitates post-occupancy verification, transparent boundary setting, and local emission factors to ensure that monitoring informs corrective procurement, maintenance, and retrofit interventions rather than merely serving symbolic compliance (Chidiebube et al., 2025). Digital integration, including BIM, calculators, and dashboards, combined with periodic audits, helps bridge the gap from planning to operation, making carbon reduction measurable and actionable in developing-economy projects (Igbokwe et al., 2024; Wang et al., 2023; Chidiebube et al., 2025). Digital and data ecosystem for low-carbon project delivery (BIM–LCA–Digital Twin–IoT) can be seen in Figure 4.

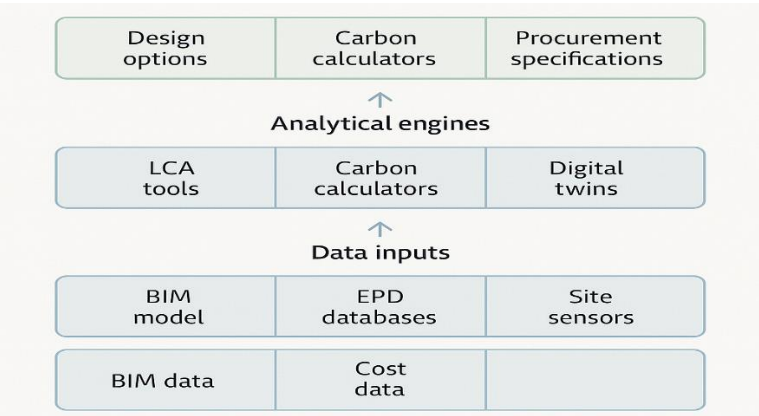


Figure 4. Digital and Data Ecosystem for Low-Carbon Project Delivery (BIM–LCA–Digital Twin–IoT)

Figure 4 illustrates the digital and data ecosystem required for low-carbon project delivery. The bottom layer displays essential data inputs such as BIM models, EPD databases, site sensors, and cost data. These feed into analytical engines LCA tools, carbon calculators, optimisation models, and digital twins. The top layer shows management outputs that guide sustainable decisions, including carbon dashboards, design options, procurement criteria, and operational strategies.

3.8.4. Enhancing Stakeholder Collaboration for Sustainable Outcomes

Project managers are central convenors who coordinate architects, engineers, contractors, and regulators to align technical decisions with sustainability goals, and empirical studies show that active stakeholder engagement and planned team-building improve sustainable project outcomes. Digital collaboration platforms such as cloud-based Building Information Modelling (BIM) and integrated performance tools translate multidisciplinary inputs into shared models and verifiable targets, reducing information asymmetry and enabling coherent delivery of low-carbon measures (Nwamekwe & Chikwendu, 2025).

Effective collaboration requires structured stakeholder integration assessment tools, network mapping, and iterative workshops to surface conflicts, allocate responsibilities, and sustain knowledge transfer across procurement, construction, and operation phases. Public-private and multi-actor initiatives that institutionalize collaboration for circularity, supplier development, and blended finance further convert consensus into scalable eco-efficient outcomes when governance and incentives are aligned.

3.8.5. Case Examples from Developing Countries

Case examples from developing countries illustrate how project management can deliver low carbon outcomes: in South Africa, adaptive public building projects and container unit retrofits have employed passive solar measures and vegetated roofs to improve thermal comfort and reduce cooling loads, demonstrating the value of early planning, site adaptation and maintenance regimes in municipal projects (Chen et al., 2023; Zhang et al., 2024). Such initiatives show that aligning design, procurement and local capacity rather than ad hoc retrofits yields measurable operational and health co benefits in hot urban contexts (Zhang et al., 2024).

In East and West Africa, solar integrated housing pilots and estate developments reveal complementary pathways: PV and off grid systems have been tested across the sub continent to reduce grid reliance and energy costs for households, while circular economy and prefabrication pilots in Nigerian estates point to waste reducing, resource efficient delivery models when coupled with appropriate financing and specification by project teams (Sarkodie et al., 2020; Nwamekwe et al., 2024; , Xiong et al., 2024; , Liu, 2023; Huang et al., 2023). These cases underscore that pragmatic project management linking technology, procurement and finance enables scalable eco efficient delivery in resource constrained settings (Sarkodie et al., 2020; Xiong et al., 2024; Liu, 2023).

3.9. Synthesis of Review Findings

3.9.1. Summary of Key Insights from Literature

The literature converges that construction project management is pivotal for embedding sustainability across project processes: scientometric and review studies highlight managerial control, specification, and procurement as primary levers for green outcomes (Nwamekwe & Nwabunwanne, 2025). Empirical and technological analyses show that integrating lean production with off site prefabrication and deploying Building Information Modelling (BIM) enabled workflows (BIM–LCA) and green procurement criteria measurably reduces embodied and operational carbon while improving resource efficiency and delivery predictability (Wang et al., 2023).

Practically, studies recommend early-stage BIM LCA and parametric optimization, lean–BIM coordination, life cycle costing, and procurement clauses to lock in eco efficiency, though scalability and policy gaps remain constraints noted across reviews (Carvalho et al., 2020; Wang et al., 2023); thus, project managers must combine digital tools, procurement reform, and capacity building to translate technical potential into routine low carbon delivery in developing economies (Liu et al., 2024). Conceptual framework linking construction project management to low-carbon and eco-efficient outcomes can be seen in Figure 5.

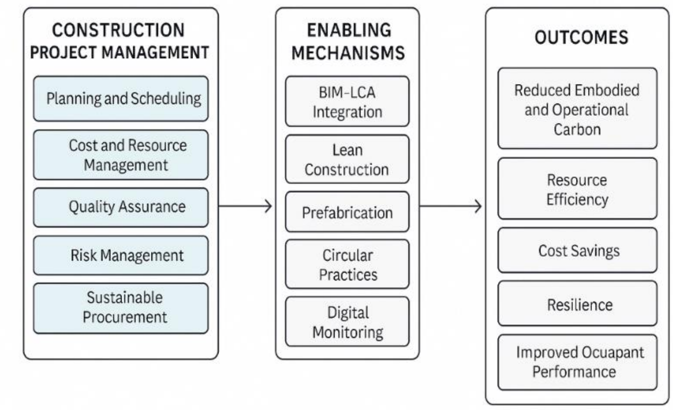


Figure 5. Conceptual Framework Linking Construction Project Management to Low-Carbon and Eco-Efficient Outcomes

Figure 5 presents the conceptual pathway through which construction project management influences low-carbon and eco-efficient outcomes. It highlights core management levers planning, cost control, quality, risk, and procurement before showing how enabling mechanisms such as BIM–LCA integration, lean methods, prefabrication, circular practices, and digital monitoring translate into measurable sustainability outcomes, including reduced carbon, improved efficiency, cost savings, resilience, and better occupant performance.

3.9.2. Gaps in Current Research

Despite a growing corpus on low-carbon construction, reviews and domain studies reveal a geographical bias: much of the scholarship examines technologies, policy mixes, and Building Information Modelling (BIM) / Life Cycle Assessment (LCA) workflows in developed or large emerging economies (e.g., China and EU contexts), leaving empirical evidence from many low- and middle-income countries limited (Nwamekwe et al., 2025; Agyekum et al., 2021). Sectoral reviews and regional case studies therefore call for more context-specific studies that capture informal practices, SME constraints, and local supply chain realities typical of developing economies, so project management interventions can be meaningfully tailored and evaluated (Nwamekwe et al., 2025; Agyekum et al., 2021).

Methodological gaps compound this evidence shortfall: researchers report heterogeneous carbon accounting methods, differing LCA boundaries, and inconsistent policy mix evaluations, which hinder comparability and replication across settings (Igbokwe et al., 2025; Onyeka et al., 2024). The literature highlights an urgent need for standardized, locally calibrated carbon measurement frameworks and shared inventories (Environmental Product Declarations/local factors) alongside longitudinal, field-based studies to validate project management levers for eco-efficient delivery in developing contexts (Onyeka et al., 2024; Igbokwe et al., 2025).

3.9.3. Implications for Construction Practice and Policy

Project stakeholders in developing economies require urgent, targeted capacity-building: empirical syntheses show project managers and teams often lack competencies in sustainability tools such as Building Information Modelling (BIM) and Life Cycle Assessment (LCA), digital stakeholder management, and green procurement, which undermines the effective deployment of low-carbon technologies and circular workflows. Training, accredited competency frameworks, and context-specific guidance (e.g., contractor sustainability indicators and project-level sustainability scales) are therefore necessary to translate technical potential into routine practice across SMEs and public clients (Emeka et al., 2025).

Policymakers must complement capacity measures with coherent regulation, fiscal incentives, and robust monitoring: studies recommend clear regulations regarding waste and carbon emissions, procurement mandates, and policy levers (such as grants and de-risking instruments) to mobilize finance and ensure compliance, while accountability and enforcement strengthen market signals for green suppliers (Nwamekwe & Nwabunwanne, 2025). Together, aligned industry capacity and policy instruments create scalable pathways for project managers to deliver verifiable low-carbon, eco-efficient buildings in resource-constrained settings (Nkemakonam et al., 2025; Nwamekwe & Nwabunwanne, 2025). Policy and practice actions by stakeholder group can be seen in Figure 6.

Stakeholder group	Key responsibilities	Example instruments or tools
Project managers	Embedding carbon targets in projects	LCA, carbon calculators Support design
Contractors/SMEs	Improving on-site practices	Enhanced resource and energy efficiency
Clients and developers	Setting susanability requirements	Low-carbon project choices
Regulators	Defining market standards	Opening markets for sustainable construction
Financial institutions	Supporting green investments	Promoting low-carbon development
Professional bodies	Promoting standards and training	Promoting sustainability competency

Figure 6. Policy and Practice Actions by Stakeholder Group

Figure 6 summarizes the key policy and practical actions required from major stakeholder groups to advance low-carbon construction. It highlights how project managers, contractors, clients, regulators, financial institutions, and professional bodies each play strategic roles through tools such as green procurement, training, regulatory enforcement, and financing mechanisms. The table clarifies responsibilities and shows how coordinated action can accelerate sustainable, low-carbon project delivery.

4. Conclusion

This review reinforces that construction project management is not merely a support function it is the central engine that determines whether developing economies can successfully transition toward low-carbon and eco-efficient built environments. Across the literature, project management consistently emerges as the space where design choices, procurement decisions, technological tools, and site-level practices converge to influence carbon outcomes. As developing countries continue to urbanize rapidly, the construction sector faces increased pressure to deliver higher volumes of projects while minimizing environmental impacts. Without deliberate project management interventions, these pressures risk cementing high-carbon practices for decades. Evidence from the review shows that sustainable outcomes depend on several interconnected factors: early-stage planning that incorporates life-cycle thinking; skilful use of digital tools such as BIM, LCA, and energy modelling; adoption of lean and prefabrication methods to reduce waste; strong quality assurance systems; and transparent stakeholder collaboration. In developing economies, however, these capabilities are often uneven due to constraints in skills, technology adoption, weak regulatory enforcement, and fragmented supply chains. Despite these challenges, the review demonstrates a strong opportunity space. With strategic investment in capacity building, digital integration, circular-economy practices, and coherent regulatory support, project managers can guide the sector toward greener, more resilient construction systems. The conclusion is clear: construction project management holds the potential to reshape building delivery in developing economies, but this transformation requires deliberate, structured, and well-supported actions across industry and government.

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References

Abdullahi, I., Watters, C., Kapogiannis, G., & Lemański, M. (2023). Role of digital strategy in managing the planning complexity of mega construction projects. *Sustainability, 15*(18), 13809. https://doi.org/10.3390/su151813809

Adamson, S. and Medeiros, A. (2023). The greenlight for government buildings: strategies for a low-carbon building portfolio. *Facets, 8,* 1-10. https://doi.org/10.1139/facets-2022-0193

Agyekum, K., Adinyira, E., & Oppon, J. (2021). Factors limiting the adoption of hemp as an alternative sustainable material for green building delivery in ghana. *International Journal of Building Pathology and Adaptation, 40*(2), 202-218. https://doi.org/10.1108/ijbpa-11-2020-0100

Al-Otaibi, A., Bowan, P., Alabdullatief, A., Albaiz, M., & Salah, M. (2025). Barriers to sustainable building project performance in developing countries: a case of ghana and the kingdom of saudi arabia. *Sustainability, 17*(8), 3539. https://doi.org/10.3390/su17083539

Amolo, A. (2024). Green financing for sustainable development in infrastructure projects in kenya. *International Journal of Research and Scientific Innovation, XI*(VIII), 420-426. https://doi.org/10.51244/ijrsi.2024.1108034

Arshad, H., Qasim, M., Thaheem, M., & Gabriel, H. (2018). Quantification of material wastage in construction industry of pakistan: an analytical relationship between building types and waste generation. *Journal of Construction in Developing Countries, 22*(2), 19-34. https://doi.org/10.21315/jcdc2017.22.2.2

Carvalho, J., Alecrim, I., Bragança, L., & Mateus, R. (2020). Integrating bim-based lca and building sustainability assessment. *Sustainability, 12*(18), 7468. https://doi.org/10.3390/su12187468

Chen, L., Huang, L., Hua, J., Chen, Z., Wei, L., Osman, A., … & Yap, P. (2023). Green construction for low-carbon cities: a review. *Environmental Chemistry Letters, 21*(3), 1627-1657. https://doi.org/10.1007/s10311-022-01544-4

Chidiebube, I. N., Nwamekwe, C. O., Chukwuemeka, G. H., & Wilfred, M. (2025). Optimization Of Overall Equipment Effectiveness Factors In A Food Manufacturing Small And Medium Enterprise. *Journal of Research in Engineering and Applied Sciences, 10*(1), 836-845.

Emeka, U. C., Okpala, C., & Nwamekwe, C. O. (2025). Circular Economy Principles'implementation In Electronics Manufacturing: Waste Reduction Strategies In Chemical Management. *International journal of industrial and production engineering, 3*(2), 29-42.

Ezeanyim, O. C., Ewuzie, N. V., Aguh, P. S., Nwabueze, C. V., and Nwamekwe, C. O. (2025). Effective Maintenance of Industrial 5-Stage Compressor: A Machine Learning Approach. *Gazi University Journal of Science Part A: Engineering and Innovation, 12*(1), 96-118. https://dergipark.org.tr/en/pub/gujsa/issue/90827/1646993

Ezeanyim, O. C., Nwabunwanne, E. C., Igbokwe, N. C., & Nwamekwe, C. O. (2025). Patient Flow and Service Efficiency in Public Hospitals: Data-Driven Approaches, Strategies, Challenges, and Future Directions. *Journal Health of Indonesian, 3*(02), 104-124. https://doi.org/10.58471/health.v3i02.228

Gil-Ozoudeh, I., Iwuanyanwu, O., Okwandu, A., & Ike, C. (2024). The impact of green building certifications on market value and occupant satisfaction. *International Journal of Management & Entrepreneurship Research, 6*(8), 2782-2796. https://doi.org/10.51594/ijmer.v6i8.1466

Huang, J., Meng, S., & Yu, J. (2023). The effects of the low-carbon pilot city program on green innovation: evidence from china. *Land, 12*(8), 1639. https://doi.org/10.3390/land12081639

Igbokwe, N. C., Christiana, C., Nweke, C. O. N., & Onyeka, C. (2025). Data-Driven Solutions for Shuttle Bus Travel Time Prediction: Machine Learning Model Evaluation at Nnamdi Azikiwe University. *African Journal of Computing, Data Science and Informatics (AJCDSI), 1*(1), 31-55.

Igbokwe, N. C., Emmanuel, U. N., & Nwamekwe, C. O. (2025). Advances In Post-Harvest Fish Processing: An Appraisal Of Traditional And Modern Smoking Techniques For Improved Quality And Efficiency. *Jurnal Integrasi Dan Harmoni Inovatif Ilmu-Ilmu Sosial 5*(9):1-13. https://philpapers.org/rec/IGBAIP

Igbokwe, N. C., Okeagu, F. N., Onyeka, N. C., Onwuliri, J. B., & Godfrey, O. C. (2024). Machine Learning-Driven Maintenance Cost Optimization: Insights From A Local Industrial Compressor Case Study. *Jurnal Inovasi Teknologi dan Edukasi Teknik, 4*(11), 2.

Larsen, M., Lindhard, S., Brunoe, T., Nielsen, K., & Larsen, J. (2019). Mass customization in the house building industry: literature review and research directions. *Frontiers in Built Environment, 5*. https://doi.org/10.3389/fbuil.2019.00115

Liu, X. (2023). Application of bim in project management in china. *Theoretical and Natural Science, 26*(1), 1-5. https://doi.org/10.54254/2753-8818/26/20241001

Mercader-Moyano, P., López-López, J., & Camporeale, P. (2022). *An environmental construction and demolition waste management model to trigger post-pandemic economic recovery towards a circular economy: the mexican and spanish cases*., 83-135. https://doi.org/10.1007/978-981-16-8426-5_4

Morganti, L., Demutti, M., Fotoglou, I., Coscia, E., Perillo, P., & Pracucci, A. (2023). Integrated platform-based tool to improve life cycle management and circularity of building envelope components. *Buildings, 13*(10), 2630. https://doi.org/10.3390/buildings13102630

Munir, T., Jamal, R., & Watts, S. (2025). Integrating sustainable innovation in the construction projects: a delphi study on corporate social responsibility and business processes. *International Journal of Innovation Science.* https://doi.org/10.1108/ijis-05-2024-0118

Niu, X., Liao, F., Mi, Z., & Wu, G. (2024). The impact of urban construction land expansion on carbon emissions from the perspective of the yangtze river delta integration, china. *Land, 13*(7), 911. https://doi.org/10.3390/land13070911

Nkemakonam Chidiebube Igbokwe, Charles Onyeka Nwamekwe, Patrick Sunday Aguh. Predictive Modeling of Manufacturing Defects using Machine Learning: A Comparative Performance Study in a Manufacturing SME. *African Journal of Advances in Engineering and Technology (AJAET), 2025, 01* (02), pp.93-115. ⟨10.31920/2978-3224/2025/v1n2a5⟩. ⟨hal-05377373⟩

Nwamekwe C. O., and Nwabunwanne E. C. (2025). Circular Economy and Zero-Energy Factories: A Synergistic Approach to Sustainable Manufacturing. *Journal of Research in Engineering and Applied Sciences (JREAS), 10*(1), 829-835. https://qtanalytics.in/journals/index.php/JREAS/article/view/4567

Nwamekwe C. O., Ewuzie Nnamdi Vitalis, Igbokwe Nkemakonam Chidiebube, & Nwabueze Chibuzo Victoria. (2025). Evaluating Advances in Machine Learning Algorithms for Predicting and Preventing Maternal and Foetal Mortality in Nigerian Healthcare: A Systematic Approach. *International Journal of Industrial and Production Engineering, 3*(1), 1-15. https://journals.unizik.edu.ng/ijipe/article/view/5161

Nwamekwe C. O., Ezeanyim O. C., and Igbokwe N. C. (2025). Resilient Supply Chain Engineering in the Era of Disruption: An Appraisal. International Journal of Innovative Engineering, *Technology and Science (IJIETS), 9*(1), 11-23. https://hal.science/hal-05061524/

Nwamekwe, C. O., & Chikwendu, O. C. (2025). Circular economy strategies in industrial engineering: From theory to practice. *International Journal of Multidisciplinary Research and Growth Evaluation, 6*(1): 1773-1782. https://www.allmultidisciplinaryjournal.com/uploads/archives/20250212103754_MGE-2025-1-288.1.pdf

Nwamekwe, C. O., & Chikwendu, O. C. (2025). Machine learning-augmented digital twin systems for predictive maintenance in highspeed rail networks. *International Journal of Multidisciplinary Research and Growth Evaluation, 6*(1), 1783-1795. https://www.allmultidisciplinaryjournal.com/uploads/archives/20250212104201_MGE-2025-1-306.1.pdf

Nwamekwe, C. O., & Nwabunwanne, E. C. (2025). Immersive Digital Twin Integration in the Metaverse for Supply Chain Resilience and Disruption Management. *Journal of Engineering Research and Applied Science, 14*(1), 95-105.

Nwamekwe, C. O., and Igbokwe, N. C. (2024). Supply Chain Risk Management: Leveraging AI for Risk Identification, Mitigation, and Resilience Planning. *International Journal of Industrial Engineering, Technology & Operations Management, 2*(2), 41–51. https://doi.org/10.62157/ijietom.v2i2.38

Nwamekwe, C. O., Chidiebube, I. N., Godfrey, O. C., Celestine, N. E., & Sunday, A. P. (2025). Resilience and Risk Management in Social Robot Systems: An Industrial Engineering Perspective. *Culture education and technology research (Cetera), 2*(2), 1-12.

Nwamekwe, C. O., Chidiebube, I. N., Godfrey, O. C., Celestine, N. E., & Aguh, P. S. (2025). Human-Robot Collaboration in Industrial Engineering: Enhancing Productivity and Safety. *Journal of Industrial Engineering & Management Research, 6*(5), 1-20.

Nwamekwe, C. O., Chinwuko, C. E. & Mgbemena, C. E. (2020). Development and Implementation of a Computerised Production Planning and Control System. *UNIZIK Journal of Engineering and Applied Sciences, 17*(1), 168-187. https://journals.unizik.edu.ng/ujeas/article/view/1771

Nwamekwe, C. O., Ewuzie, N. V., Okpala, C. C., Ezeanyim, C., Nwabueze, C. V., Nwabunwanne, E. C. (2025). Optimizing Machine Learning Models for Soil Fertility Analysis: Insights from Feature Engineering and Data Localization. *Gazi University Journal of Science Part A: Engineering and Innovation, 12*(1), 36-60. https://dergipark.org.tr/en/pub/gujsa/issue/90827/1605587

Nwamekwe, C. O., Ewuzie, N.V., Igbokwe, N. C., Nwabunwanne, E. C., & Ono, C. G. (2025). Digital Twin-Driven Lean Manufacturing: Optimizing Value Stream Flow. *Letters in Information Technology Education (LITE), 8* (1), pp.1-13. https://hal.science/hal-05127340/

Nwamekwe, C. O., Okpala, C. C., & Nwabunwanne, E. C. (2025). Design Principles and Challenges in Achieving Zero-Energy Manufacturing Facilities. *Journal of Engineering Research and Applied Science, 14*(1), 1-21.

Nwamekwe, C. O., Okpala, C. C., and Okpala, S. C., (2024). Machine Learning-Based Prediction Algorithms for the Mitigation of Maternal and Fetal Mortality in the Nigerian Tertiary Hospitals. *International Journal of Engineering Inventions, 13*(7), PP: 132-138. https://www.ijeijournal.com/papers/Vol13-Issue7/1307132138.pdf

Nwamekwe, C., Ewuzie, N., Igbokwe, N., Okpala, C., & U-Dominic, C. (2024). Sustainable Manufacturing Practices in Nigeria: Optimization and Implementation Appraisal. *Journal of Research in Engineering and Applied Sciences, 9*(3). https://qtanalytics.in/journals/index.php/JREAS/article/view/3967

Oke, A., Oyediran, A., Koriko, G., & Tang, L. (2023). Carbon trading practices adoption for sustainable construction: a study of the barriers in a developing country. *Sustainable Development, 32*(1), 1120-1136. https://doi.org/10.1002/sd.2719

Okeagu, F., Nwamekwe, C., & Nnamani, B. (2024). Challenges and Solutions of Industrial Development in Anambra State, Nigeria. *Iconic Research and Engineering Journals, 7*(11), 467-472. https://www.irejournals.com/formatedpaper/1705825.pdf

Okpala C. C., Chukwudi Emeka Udu, & Charles Onyeka Nwamekwe. (2025). Sustainable HVAC Project Management: Strategies for Green Building Certification. *International Journal of Industrial and Production Engineering, 3*(2), 14-28. https://journals.unizik.edu.ng/ijipe/article/view/5595.

Okpala, C. C., Ezeanyim, O. C., & Nwamekwe, C. O. (2024). The Implementation of Kaizen Principles in Manufacturing Processes: A Pathway to Continuous Improvement. *International Journal of Engineering Inventions, 13*(7), 116-124. https://www.ijeijournal.com/papers/Vol13-Issue7/1307116124.pdf

Okpala, C. C., Udu, C. E., & Nwamekwe, C. O. (2025). Artificial Intelligence-Driven Total Productive Maintenance: The Future of Maintenance in Smart Factories. *International Journal of Engineering Research and Development (IJERD), (21*)1, 68-74. https://www.ijerd.com/paper/vol21-issue1/21016874.pdf

Okpala, C. C., Udu, C. E., & Nwamekwe, C. O. (2025). Sustainable HVAC Project Management: Strategies for Green Building Certification. *International Journal Of Industrial And Production Engineering, 3*(2), 14-28. https://journals.unizik.edu.ng/ijipe/article/view/5595

Onyeka, N. C., Vitalis, E. N., Chidiebube, I. N., U-Dominic, C. M., & Chibuzo, N. (2024). Adoption of Smart Factories in Nigeria: Problems, Obstacles, Remedies and Opportunities. *International journal of industrial and production engineering, 2*(2), 68-81. https://journals.unizik.edu.ng/ijipe/article/view/4167

Sarkodie, S., Owusu, P., & Leirvik, T. (2020). Global effect of urban sprawl, industrialization, trade and economic development on carbon dioxide emissions. *Environmental Research Letters, 15*(3), 034049. https://doi.org/10.1088/1748-9326/ab7640

Song, Y., Wang, J., Liu, D., Huangfu, Y., Guo, F., & Liu, Y. (2021). The influence of government's economic management strategies on the prefabricated buildings promoting policies: analysis of quadripartite evolutionary game. *Buildings, 11*(10), 444. https://doi.org/10.3390/buildings11100444

U-Dominic, C. M., Orji, I. J., Nkemakonam, C. I., Onyeka, N. C., & Nwufo, M. A. (2025). A Decision Methodology for Six-Sigma Implementation in the Nigerian Small and Medium Scale Enterprise (SME). Unizik Journal of Technology, *Production and Mechanical Systems, 5*(1), 186-202.

Vitalis, E. N., Nwamekwe, C. O., Chidiebube, I. N., Chibuzo, N., Nwabunwanne, E. C., & Ono, C. G. (2024). Application Of Machine-Learning-Based Hybrid Algorithm For Production Forecast In Textile Company. *Jurnal Inovasi Teknologi dan Edukasi Teknik, 4*(12), 1-9.

Wang, Q., Guo, W., Xu, X., Deng, R., Ding, X., & Chen, T. (2023). Analysis of carbon emission reduction paths for the production of prefabricated building components based on evolutionary game theory. *Buildings, 13*(6), 1557. https://doi.org/10.3390/buildings13061557

Xiong, L., Wang, M., Mao, J., & Huang, B. (2024). A review of building carbon emission accounting methods under low-carbon building background. *Buildings, 14*(3), 777. https://doi.org/10.3390/buildings14030777

Zhang, Z., Wu, Z., Yang, X., Cai, B., & Lin, Z. (2024). The driving factors of spatial differences on the whole life cycle carbon emissions of the construction industry: from the analysis perspective of total factor productivity. *Frontiers in Energy Research, 12.* https://doi.org/10.3389/fenrg.2024.1330614